International Power Quality Conference 2002: Singapore
21-25 October 2002
Singapore International Convention Centre
Singapore

ON-LINE POWER QUALITY MONITORING OF A COMMERCIAL BUILDING IN SINGAPORE

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ABSTRACT: This paper is the valuable result of a joint effort between a large facility management organization – PREMAS International Limited and Quality Power Management Pte Ltd (QPM), a service provider in the power and electrical sectors. It highlights the important reasons for on-line power quality (PQ) monitoring for a commercial building in Singapore.

The paper highlights the pioneering applications of internet-enabled energy meters and softwares to support real-time energy monitoring of distributed power generation and shows how this can be utilized as a diagnostics tool for performance benchmarking and predictive maintenance in the future. The subject system comprises more than 500 metering network utilizing meters from various manufacturers including Cutler-Hammer.

The paper will give a general description of the installed system and its capability. Enhanced data from this site will be presented. The paper also illustrates how the building benefited from the analysis and recommendations from the data collected.

1. GENERAL INFORMATION

The field of PQ diagnostics and monitoring has matured drastically over the past years. This is attributed largely to the way PQ is perceived in commercial facilities. Monitoring power quality in an electrical distribution system is becoming increasingly important with the growing use of electronic loads such as computer electronic ballasts and variable frequency drives. It is now possible to verify that the quality of purchased power meets the contractual obligations.

New lower cost monitoring systems can integrate standard electrical energy monitoring information with high-speed PQ data capture to provide proactive electrical system information. PQ meters track critical electrical parameters such as voltage or current waveforms and harmonics to help identify PQ degradation and potential equipment failure characterized by overheating and breaker trips.

Other less obvious consequences of PQ degradation include : reduction in energy efficiency, overloading of the installation causing premature ageing leading to over sizing of distribution equipment.

The subject system utilizing the Quality Power Management (QPM) Remote-On-Line Monitoring (ROLM) system describes the interfacing and integration of components with an existing building's connections, customization of the requirements and how these components are very useful to the operators and building owner. Some site usage data is presented to back-up the case study and to highlight the reliability and usefulness of the system in monitoring and verifying PQ.

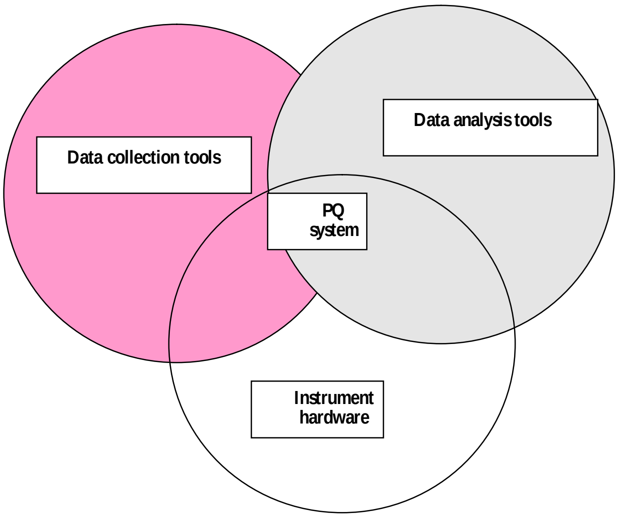


Figure 1: Comprehensive PQ system

2. THE NEED

The proliferation of mission-critical computer equipment and the increasing instability of public utilities continue to boost the demand for reliable power. Equipment demand high-quality power to guarantee against surges, outages, sags, transients or harmonics that could result in equipment breakdown and lost revenues.

Electricity quality has become a great concern for energy suppliers and their customers. The increasing use of sensitive measuring devices and diagnostic tools has unveiled the ill effects of poor PQ and its impact on the competitiveness of companies not only in the high-tech industries but also in commercial complexes.

The value of on-line monitoring lies in the premise that it can help the building operators to maintain the level of disturbances within the limits defined by the contracts and utilities

set-up rules. End users are moving towards predictive maintenance and this trend is expected to drive the demand for remote on-line monitoring systems.
With liberalization of the Singapore electricity market, the rules governing the electricity supply landscape will change radically. Consumers can now have the opportunity to choose their supplier. In addition, the search for competitiveness now means that quality has and will become a differentiating factor for the supplier, the market service support companies and the consumer.

3. **OBJECTIVES OF POWER QUALITY**

The objectives can be summarized into three key areas:

a. Contractual fulfillment
Within the context of the de-regulated market, PQ must be defined within the performance values decided in the contractual agreement. Contractual relations may therefore exist not only between the electricity supplier and the end-user but also between the transmission company, distribution company and market service support companies.

b. Corrective maintenance
Even with best practices or best of breed solutions, malfunctions can occur during operation. To mitigate against malfunctions caused during operations due to oversight, under-estimation or changes in the installation, portable measurement systems may be used (for limited period) or fixed apparatus (for continuous monitoring).

c. Optimising operational parameters of electrical installation
To increase productive gains, ensure operational economies and reduction of operating cost, effective correction of processes and energy management are required. These factors are dependent on PQ monitoring.

Performance benchmarking concept

Contrary to traditional thinking, a building may be likened to a human patient with vital signs that requires monitoring on a regular basis. In the human context, blood samples are taken from patients to determine their blood sugar level, cholesterol level, white blood cell composition and ascertain whether the blood has been infected with HIV.

Similarly, samples can be taken of a building to determine its “state of health”. A sample in the form of a PQ *blood test sample* can tell a lot about the building condition and allow detection of *symptoms* such as harmonic distortion, voltage dips and interruptions, overvoltages and other anomalies. The sampling result thus becomes a Benchmark for succeeding samples.

Benchmarking allows comparisons to be made of the “state of health” of the building relative to its original condition. By extrapolating the information available, predictive analysis can be performed to forecast specific breakdown conditions like overheating of switchboards, current surges, overvoltages, voltage dips and fluctuations or to detect deterioration and PQ degradation.

Through early detection, steps can be taken to rectify or retrofit the situation. This leads onto a whole new concept of building operation – maximizing the operating parameters to minimize costs and improve operating efficiency.

In recent years, predictive maintenance has become more of an industry buzzword. Widely accepted in North America, it is relatively new in the Asian market. Its acceptance in this region is somewhat being hampered by lack of awareness and knowledge of its long-term transient benefits.

Predictive maintenance

Preventive maintenance was a common jargon from the 70's to the 90's. In the same light, the catchphrase at the beginning of the 21st century is predictive maintenance, a term synonymous with most if not almost all facility managers.

In commercial facilities, PQ forms a critical and integral part of the predictive maintenance programme. Proactive electrical system information is possible due to a new generation of low-cost PQ monitoring equipment available from many different suppliers. This has spawned a whole new breed of PQ engineers who have positioned themselves to serve this market sector.

Armed like highly specialised building "doctors" with a wide array of PQ software tools, diagnostics devices and high-end computing equipment, they are able to interpret data collected, identify problems and make recommendations and also solve/rectify the problems.

The flags and alert parameters programmed into these softwares alert the electrical maintenance personnel once any anomaly is detected. It is a norm for critical operation centres to demand 100% system availability. To increase system availability, it is important to monitor the electrical system parameters. Predictive maintenance provides a means through which early detection can be initiated and preventive actions taken to correct equipment failure.

Table 1: The reliability in power delivery

Number of 9's	Reliability	Expected disruptions per year	Satisfactory for
3	99.9%	9 hours	Homes
4	99.99%	59 minutes	Factories
5	99.999%	5 minutes	Hospitals/Airports
6	99.9999%	32 seconds	Banks
7	99.99999%	30 milliseconds	On-Line marketplaces

Source: Monitoring power for the future by Afroz K. Khan, Power Engineering Journal April 2001

4. SITE DESCRIPTION

The subject site is a highly prestigious and certainly one of the most intelligent buildings in Singapore with state-of-the-art automation systems performing mission-critical functions. It is a class “A” high rise building with a built-in area of about 120,000m^2 and tenants are high-profile financial institutions and multi-national companies.

The approved electrical load for the building is 7,000kW. The power provision per floor is 200A and emergency supply per floor is 20kVA. There are three 1500kVA, one 1,000kVA and two 600kVA standby generators. To meet the increasing sophistication of modern office systems, 200 Amperes 3 phase Alternating Current (A.C.) averaging out to around 60 watts/m^2 is provided for each floor (est. floor area of 1800 m^2) which exceeds the normal commercial provision of 40 watts/m^2.

The higher power provision, coupled with sourcing the power from PowerGrid Ring-Main stations with two feeders coming from different direction, would be comforting for institutions intolerant of power failures. The reliability of the power supply is enhanced by the Intelligent Building Management System (IBMS) which can monitor critical power currents and generate alarm messages to appropriate personnel, both on and off site, for immediate attention.

For tenants with critical services and an intolerance to power failures, an average 20kVA of power per floor has been set-aside**.** Generators and several Uninterrupted Power Supply (UPS) have also been deployed within the building premises for this purpose.

Intelligent features

To meet the design vision for an intelligent and friendly building that supports the business needs and processes of its tenants, sophisticated automation systems were incorporated into the design and construction phases.

The Intelligent Building Management System (IBMS) is a highly functional Intelligent Building with integrated systems. This interface through IBMS, networks with most of the Building Services Control Systems and physical operating environment including Information Systems, Telecommunication, Security Systems, Lift Systems, Air Condition Mechanical Ventilation (ACMV), Fire Protection Systems, Electrical Monitoring Control Systems, Car Park Systems and the Management Services.

IBMS is a truly integrated intelligent building management tool capable of pulling in real-time information from M&E sub-systems, Car Park Guidance System, Lift Car Intelligent Information Display as well as Management application systems. It is an invaluable building management system that delivers information to the operator allowing him to work smarter in a well-informed environment and hence more efficiently.

5. SITE CONSIDERATIONS AND REQUIREMENTS

Throughout our evaluation, the following issues were critical in developing a workable monitoring system for this site.

Monitoring parameters

The building operator was concerned with these key concerns :

- How to effectively manage the contracted capacity (a unique power supply characteristic in Singapore);
- Maximise the diagnostics observations derived from the load profile trending of the electrical equipment installed by the landlord and the tenants and most importantly;
- How to operate building efficiently and cost-effectively.

To obtain the required data, it was important that the monitoring system be practical and capable of interfacing with the existing building management system. Data from the system had to be portable to allow interchange between the collection units and the application units.

Staff technical expertise

The site staff was highly experienced and knowledgeable in the day to day management of the building and displayed competence in operating with the usual building control systems such as HVAC, fire, alarms, chillers, lighting, mechanical and electrical utilities.

However, they were not PQ monitoring experts but were interested in the performance characteristics of the building. They had been monitoring “snap-shot” load profiles of the power characteristics and through this rudimentary monitoring framework, they were able to appreciate the value of an on-line PQ monitoring service which they liken to a 24 X 7 “blood sampling” of the building.

The building manager sought a system whereby the operator could monitor the building’s load profile, improve specific operational efficiencies, apply diagnostic tools for predictive maintenance, identify harmonics distortion at its source(s) and predict other potential problem areas.

The monitoring system

The following considerations were key to our implementation strategies:

PQ monitoring – parameters

To meet building operations expectation on the electrical system, the following parameters were continuously monitored by the Electrical Monitoring and Control System (EMCS).

1. Voltage sags and surges
2. Voltage and current distortion in percentage (%) Total Harmonic Distortion (THD) or Total Demand Distortion (TDD) of fundamental plus individual harmonic frequencies up to the 50^{th} harmonic (IEEE 519 standard)

3. K Factor to indicate the harmonic load versus the non-harmonic loading and the percentage (%) the transformer should be devoted to avoid potential overheating of the transformers
4. Neutral current to indicate the level of triplen harmonics in the transformer
5. Profiling of power factor, KW and KVA Demand on the system
6. Demand load profile
7. Voltage and current demand

The monitoring system was also geared towards collating vital information on the current and harmonic, leaking current and voltage distortion, voltage and current unbalance, neutral current readings in real-time.

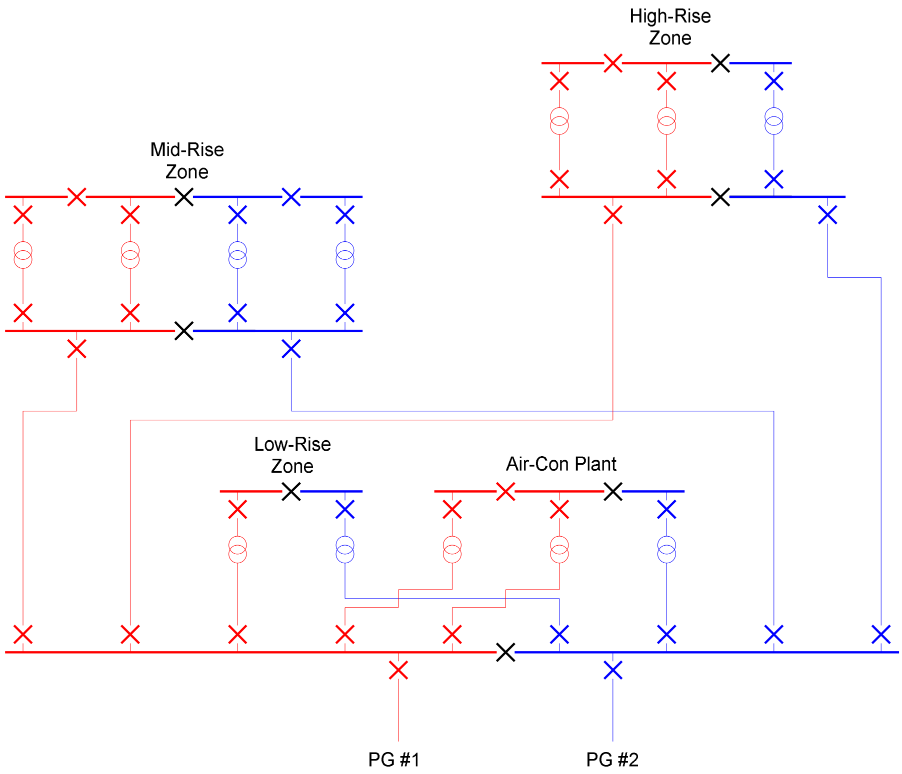
Data was gathered from the following sources:

- 2 numbers 22KV incoming feeders
- 10 numbers of 22KV/433 V transformers
- All the main Low Tension (LT) switchboards
- All the sub-switchboards

The EMCS system with more than 500 points is capable of interfacing with the existing building automation system. Combined with the specially customized Quality Power Management (QPM) software, the system is able to provide transient, sag and swell and waveform deviation graphs and statistics including histograms.

The presentation of the PQ data is simplified so that the reporting format can be easily understood even by the lay-man without any formal electrical engineering training. Data from the system is portable enough to allow for remote monitoring in the near future.

Figure 2: Building single line diagram (High Tension)



Configuration and installation

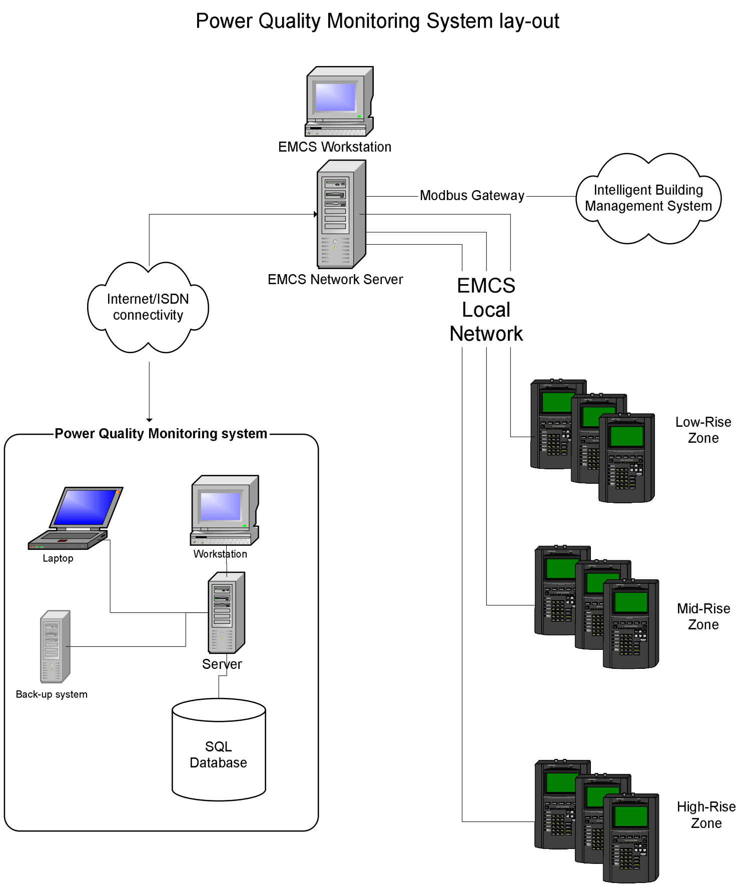
The two basic components are the hardware installation and application softwares. This project requires a rare combination of skills, knowledge and a mixture of computer networking knowledge and lots of expertise in electrical power system knowledge.

Some of the issues associated with the hardware include:

- Back-up of data collected when the power fails
- Enclosure –depends on portable or permanent application
- Sampling rate – is it fast enough?
- Ease of use – user friendliness?
- Processing power
- Communications – current state-of-the-art technology

Database tracking for quality control and commissioning

The system requires the advance collection of electrical distribution information and metering data. This data is tracked and stored in a basic database at the rate of 2MB per day. Archival and storage issues require the data to be stores in a secured and isolated environment. The database also includes a series of checklist such as nominal voltage, CT ratios, reactive power, THD and communication parameters.



QPM on-line monitoring system

After a few months in operation, the data collected exceeded 200 MB. Data collected by the EMCS PowerNet system would be backed up on-line to QPM office via the ISDN connection. To ensure data integrity, daily archival practice and storing techniques were practiced.

ODBC linked to the PowerNet database system would enable real-time on-line monitoring of the system parameters for the building's EMCS. The data was also stored and archived locally on QPM SQL Database Server as off-site backup.

Additional back-up storage included writing to CD-ROMs. This was utilized for any external analytical work.

In the longer-term, this system will serve as a features-rich functional PQ tool that can be integrated with a messaging host located on-site which will alert the building operator of any discrepancy in the operational profile.

Through the intricate design of PQ profile, various alert profiles can be integrated into the software to track the performance profile. The host will be alerted and be informed of the severity of any PQ disturbance or anomaly from within the parameters of the categories and past historical data.

The system will then automatically notify key personnel through a combination of email, paging, SMS and any alert tools.

Report parameters

The QPM report provided the building operator with strategic information on selected monitoring points. These are as follows:

1. Monthly Load Profile of PG Main Incomer Feeders and also aggregated load profiles of both.

2. Monthly System Voltage Performance with :

    a. Monthly histogram of Phase RMS Voltage of individual feeder.
    b. Monthly histogram of Phase Voltage Negative-Sequence Unbalance of individual feeders.

3. Monthly Harmonic Distortion Report with :

    a. Histogram of Phase Voltages Total Harmonic Distortion.
    b. Histogram of Phase Current Total Demand Distortion.

4. Monthly Summary of Voltage Sags and Interruption (if any).

5. Monthly Summary of Transient Over-voltages (if any).

6. Monthly Summary of Major Events.

The on-line PQ monitoring allows any changes in the electrical system to be detected before it escalates into a critical issue. With monthly reporting, analysis and benchmarking, potential problems could be identified and addressed quickly. The resolution period is critical to commercial premises as clients need problems to be fixed as soon as possible to minimize disruption to their business operations.

6. POWER MONITORING OBSERVATIONS

PQ monitoring observations were based on a study of the current waveforms and neutral current profile of the main incomers and PowerGrid main incomers.

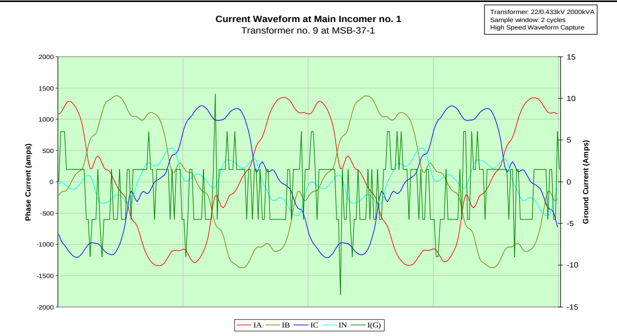


Figure 4 : Current waveform at Main Incomer No. 1 Transformer No. 9

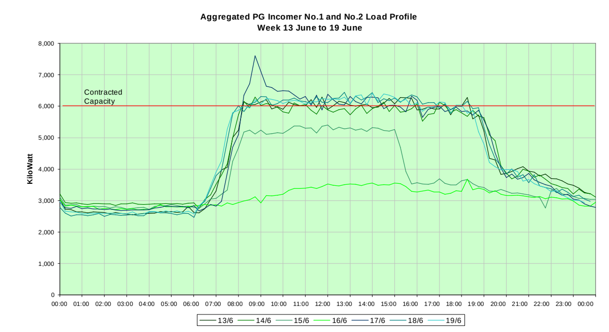


Figure 5 : Superimposed daily aggregated load profiles (one week period) for PowerGrid incomer no.1 and no. 2

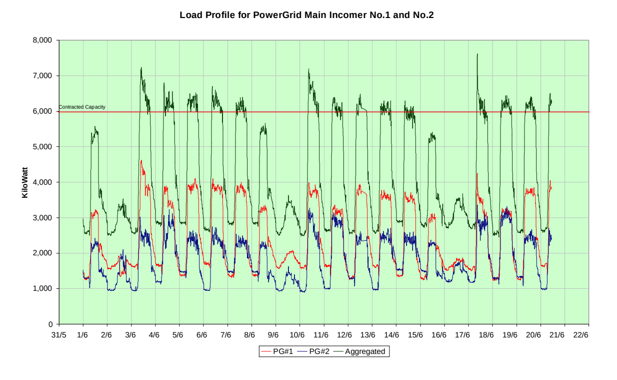


Figure 6 : Load profile for Power Grid Main incomer no.1 and no. 2

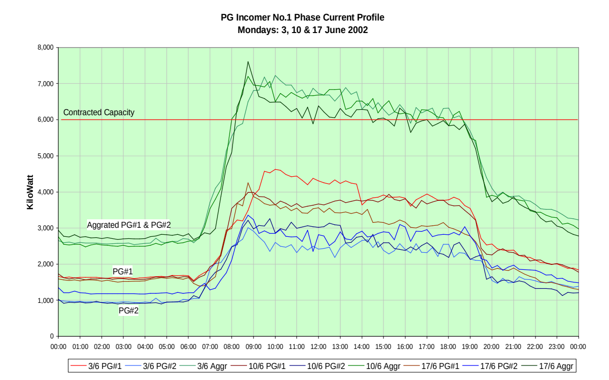


Figure 7 : Superimposed load profile of PowerGrid incomer no.1 and no.2 for 3 Mondays

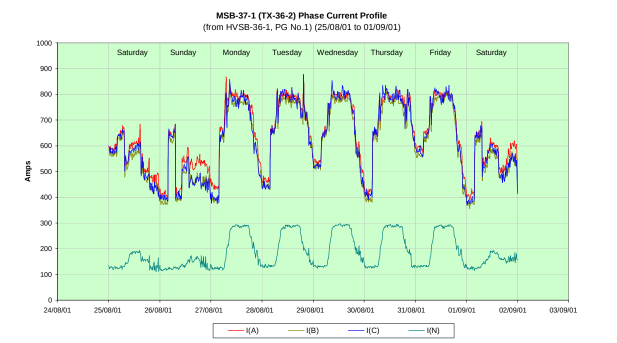


Figure 8 : Office tenant phase current profile (from tenant switchboard) (August 2001)

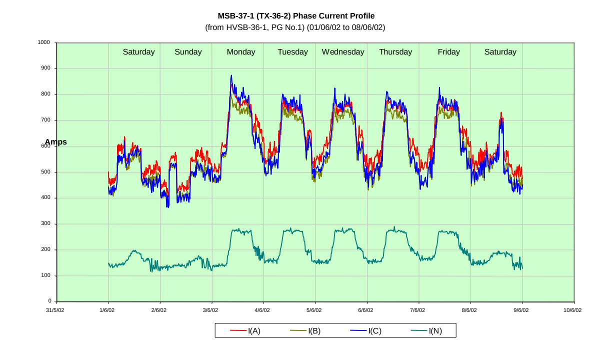
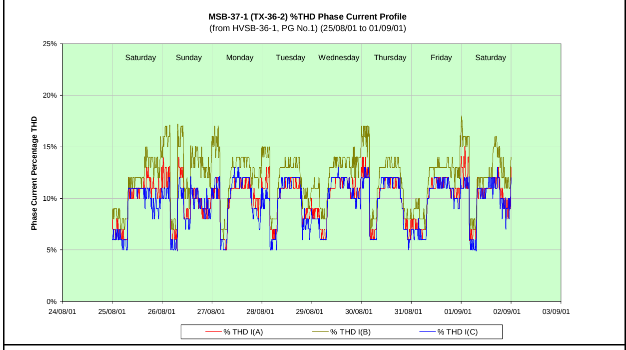


Figure 9 : Office tenant phase current profile (from tenant switchboard) (June 2002)



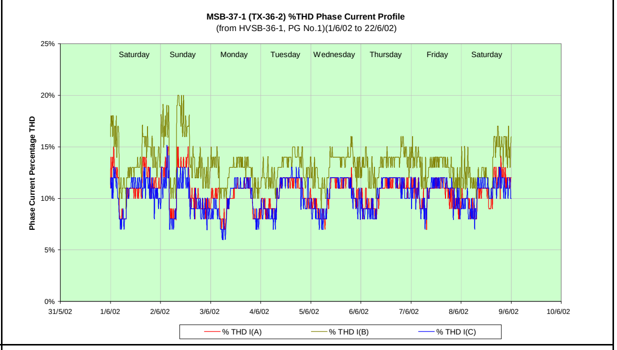


Figure 10a : %THD phase current profile (from tenant switchboard) (August 2001)

Figure 10b : %THD phase current profile (from tenant switchboard) (June 2002)

Harmonics

Harmonics current travel from the load through the electrical system and into the power source. The amount of harmonic voltage and current that a system can tolerate is dependent upon the load and the source. The continuing proliferation of single-phase non-linear power electronic loads guarantees that damaging harmonic disturbances will only increase as equipment operation becomes faster and more sophisticated.

The best known harmonic problems are related to performance, safety and over-heating. Overheating is a common harmonic disturbance resulting from large quantities of single-phase non-linear loads.

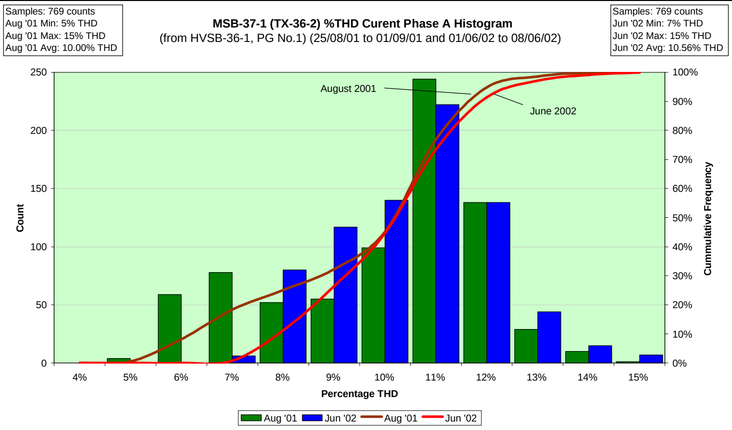


Figure 11: Red-Phase Current %THD Histogram for Tenants switchboard (August 2001 and Jun 2002)

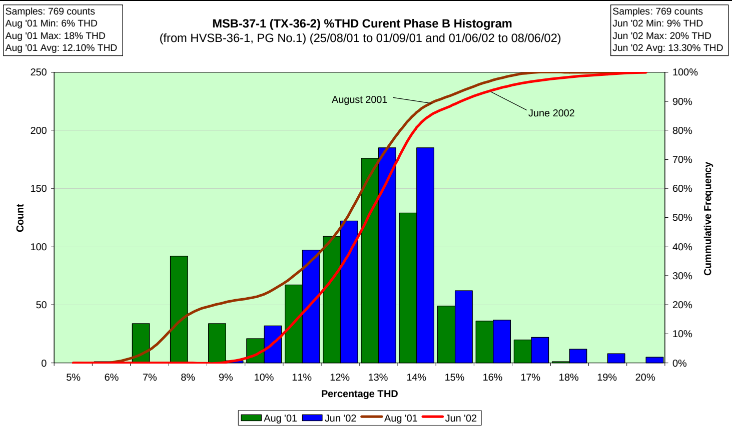


Figure 12 : Yellow-phase Current % THD histogram from tenant switchboard (August 2001 and June 2002)

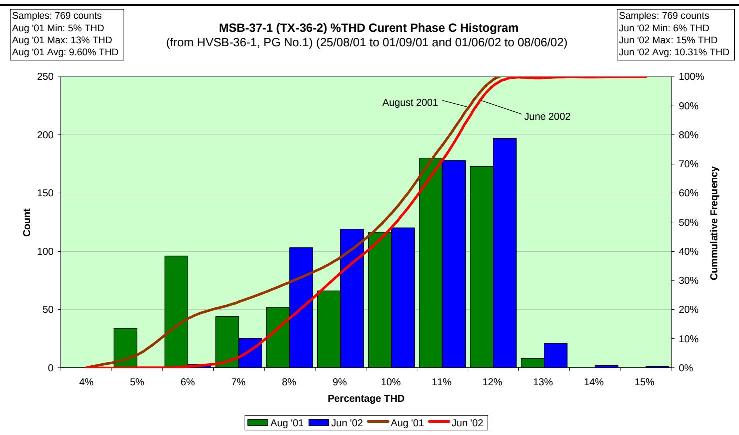


Figure 13 : Blue phase Current % THD current histogram from tenant switchboard (August 2001 and June 2002)

Statistical Surveys

Many papers have been written on the subject of recommended practice for monitoring of PQ based on international standards. But to have predictive maintenance, benchmarking of system performance from statistical surveys is a must. Benchmarking helps to monitor and identify critical information such as:

Harmonics and inter-harmonics

Histograms of harmonics level plotted over a period of time will give a performance curve of each transformer in the complex. We are able to identify which transformers are under stress and at what level. After plotting a series of curves over a period of time, we were able to predict (based on international standards) when the harmonics would reach a critical level that would affect the operations.

If harmonics mitigation is carried out, the histograms will confirm whether this has been successfully performed since we will able to compare the before and after mitigation profile. Extrapolating the application further, histograms can be used to ensure that the harmonics level affected by the landlord and tenants services generated into the electrical system is kept to an acceptable level or vice-versa.

This capability can help to solve the enforcement issue since the data of the harmonic level is readily available to the building operator.

Contracted Capacity

In Singapore, customers with high tension (HT) intake need to enter a supply agreement called ‘Contracted Capacity’ with their electricity retailers. Customer must pay contracted capacity charges whether energy consumed or not. There will be a penalty charge if the customer exceeds the contracted demand.

It is therefore quite critical for the customer to be able to determine his contracted capacity profile and declare this value as close as possible to the anticipated demand to avoid paying penalty or paying unutilized capacity. Through PQ, benchmarking of the load profile can be used to decide the most appropriate value to be declared.

Building load balancing

Although the building is less than two years old, the data collected from the PQ equipment indicates that there is potentially a great amount of phase current unbalancing. This could be due to the fact that some distribution boards are higher than others. It was also observed that load movements within the building were not always coordinated with the building operator.

It is possible that due to business process requirements, load concentration may develop in specific operational areas of the building where not previously identified. These developments usually occur without regard to the harmonic loading requirements of the source transformer. A programme is being set-up to ensure that new equipment is systematically loaded into the system for a more balanced result. Improvements in the current unbalancing also inadvertently improves the voltage balancing.

Unbalancing of current is a critical problem if the building is heavily loaded. All it takes is just one high unbalance phase current to trip out the whole system. Therefore, by improving the balancing, we are indirectly increasing the capacity of the system.

Future Trends

The building operator is now looking at the possibility of remote on-line monitoring of the system and to have the system web-enabled so that the outsource company will provide all the data analysis tasks, domain expertise and all reports can be made available on-line 24X7 via the internet.

7. RECOMMENDATIONS

This project has helped reinforce the potential of PQ as a strategic parameter for consumers. In reviewing the present economic situation, it has become apparent that electrical disturbances are becoming more serious. Fortunately, these problems are not impossible to rectify or correct with early detection.

Ironically, this situation is similar to cancer detection in humans. If the symptoms are detected early while still benign, a simple operation and follow-up treatment may usually rectify the situation. However, if the condition goes undetected to the malignant stage, then it may be too late and drastic measures may have to be taken.

Benefits of conducting PQ analysis

PQ analysis allows early detection by:

- Listing and explaining the main causes of PQ problems
- Detect the sensitivity of electronic equipment to PQ events
- Monitor PQ at the source
- Predict the performance of electronic equipment
- Use circuit analysis techniques to predict PQ levels for specific circuits
- Apply a holistic approach to solving power quality problems

Through PQ analysis, consultants are able to improve:

• Sags in voltage
• Interruptions in supplied voltage
• Distortion of supplied voltage due to harmonic currents

Building operators, with the assistance of PQ consultants will learn to make rational decisions on how to improve the performance of electronic equipment in a cost effective manner.

Through the analysis, consultants will be able to trace and identify the causes of PQ problems. They will also be able to highlight the effect on sensitive electronic equipment and provide building operators with informed decisions on the predictive impact on PCs, network servers, computer workstations, machine tool electronic controllers, and other micro processor-based equipment used in commercial and industrial applications.

8. CONCLUSION

This site's exposure and experience with the monitoring equipment has provided greater insight into the building characteristics and performance. The benefits of monitoring are:

- Data and reports have provided the building operators and management with new insights into equipment utilization and operations;
- Information can be made available at all times and can be downloaded for analysis on a 24 X 7 basis, and;
- Reporting can be simplified using the QPM format to show the shape, size and duration of any power quality anomalies

In sophisticated commercial and high-tech complexes, where harmonics may affect the power supply, the building owner or operator could (in the near future) ensure that the building harmonics are maintained within the guidelines or regulations stipulated by the Institution of Electronics and Electrical Engineering (IEEE) 519.

Monitoring provides a basis to detect the source of harmonics distortion and if so, the owner in mutual agreement with his tenant can then ensure that the level is kept within acceptable limits either through regular maintenance or through rectification.

Through our case study, the building operator is now looking into new strategies on how to operate the building to lower the contracted capacity further with the help of the continuous load profiling. This is one form of energy management unique to the Singapore environment where PQ information is utilized for value-added services.

With liberalization of the electricity markets, PQ monitoring services may become a pre-requisite for commercial, industrial and high-tech complexes. PQ monitoring functions have the potential to be outsourced to external PQ specialists. Live monitoring data can be web-enabled to allow these specialists to monitor, audit, analyse and make recommendations on the building performance from remote locations.

Future applications

In the near future, it is envisaged that remote monitoring and web-enabled tools will be the norm for PQ monitoring. With internet and wireless accessibility, reports can be streamed on-line and web-enabled so as to be accessible to the operator on a 24 X 7 basis, anywhere and anytime.

Among QPM's research and development programme is a web-based e-licensing and management tool codenamed – Elisapower. Elisapower is the acronym for Electrical Licensing System Administrator. It serves the needs of the electrical engineering and electricity sectors.

Through this platform, members can manage their licensing activities productively, organize their time and resource allocation, improve customer satisfaction and utilize value-added applications such as PQ monitoring, auditing, analysis and reporting functions on internet, mobile computing tools and wireless platforms. End-users will receive value-added reports packed with valuable information allowing them to make effective and well-informed decisions on operational and business levels.

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