USING DIGITAL FAULT RECORDER DATA TO CREATE REPORTS COMPLYING TO NATIONAL STANDARDS

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Abstract

The significance of digital fault recorders in the Philippines had further been enhanced, beyond transient fault data analysis, due to the restructuring of the country's electric power industry, resulting in the establishment of power quality standards. The Philippine Grid Code had specified the required quality of the voltage, including its frequency and the resulting current that are measured in the grid during normal conditions. Significant power quality standards considered include frequency variations, voltage variations, harmonics, and voltage unbalance. Due to the sheer volume of information needed to define good power quality, it is a cumbersome and tedious manual process to analyze these data. The analysis software of digital fault recorders used in the evaluation of these power quality parameters based on the guidelines of the Philippine Grid Code can be made to tailor-fit to the said standards. This paper will describe the required recorder data for power quality evaluation and will propose modifications in the analysis software toward the end-result of automating the creation of reports suitable to the power quality standards defined in the Philippine Grid Code.

Introduction

In the past, the power industry in the Philippines was virtually a monopoly where the generation and transmission of electricity were ran solely by the government-owned National Power Corporation (Napocor). The energy crisis in the early 1990's led to the emergence of Independent Power Producers (IPP's), which generated electricity to cope up with demand that Napocor could not fill.

Nonetheless, power quality was not a very big issue and there were no established standards. Customer complaints were largely restricted to voltage dips, which were mostly due to occurrence of faults along transmission lines and feeders. The voltage dips were captured by fault recorders installed in most substations of the grid since the late 1980's. These records were used to determine the frequency, magnitude and duration of the dips.

What do we mean then when we say "power quality"? A perfect power supply would be one that is always available, always within voltage and frequency tolerances, and has a pure sinusoidal waveform. Apparently, there is no such thing as a perfect power supply. There are always deviations from perfection, and for power quality, there are harmonic distortion, under or over voltage, voltage dips or swells, and transients.

It was not until the late 1990's during heated deliberations on the enactment of the Electric Power Industry Reform Act or EPIRA, otherwise known as the Power Bill, that power quality was given more emphasis. The EPIRA would pave the way for the restructuring of the electric industry in the Philippines and the privatization of the Napocor. With that in mind, Napocor began procuring digital fault recorders that could not only record faults but could also capture power quality data.

It would later turn out that monitoring power quality is not as simple as reporting transmission line faults. The number of power quality parameters considered and the sheer volume of information needed to define good power quality has made analyzing these data a cumbersome and tedious manual process.

History of Transco

As the Philippine electric grid continued to expand, so did its requirements for resources to sustain this growth. Long-term electricity requirements needed massive financial support. The Napocor did not have the funds to finance the construction of power plants and transmission lines to meet the increasing demand for power. The infusion of needed capital was so great that the national government eventually decided to relieve itself of this burden.

The Electric Power Industry Reform Act (EPIRA) of 2001, also known as Republic Act No. 9136, became effective on June 2001 and established the necessary legal framework to enable full restructuring and privatization of the power industry in the Philippines. This would involve the sale of Napocor's generation and transmission assets, among others, to private investors. Under the new structure, the electricity industry was officially segregated for regulatory purposes into the separate functional areas of Generation, Transmission, Distribution and Supply.

The National Transmission Corporation (Transco) was created independent of Generation and Distribution and Supply, as a regulated natural monopoly. The transmission and sub-transmission facilities of the Napocor would be transferred to the Transco. A new focus for Transco has been established to become a self-financing business that is complying with a set of transmission service standards established by the Energy Regulatory Commission (ERC) and documented in the Philippine Grid Code.

As the monopoly electricity transmission service provider in the Philippines, Transco has the authority and responsibility for planning, construction, centralized operation and maintenance of the high voltage transmission facilities (including, as the system operator, grid interconnections and ancillary services) in the Philippines.

Part of the key functions and responsibilities of Transco as defined in the EPIRA include:

1. to provide open and non-discriminatory access to its system to all electricity users; and
2. to ensure and maintain the reliability, adequacy, security, stability and integrity of the Grid.

Transco's network covers around 21,000 circuit-kilometers, with some 13,000 circuit-kilometers of transmission facilities linked by about 110 substations, throughout the Philippine grid.

Table I. Transco Transmission Facilities
(As of end December 2003)

Transmission Lines	CKT-KMS
500 KV	1,126
350 KV HVDC	954
230 KV	5,183
138 KV	4,882
115 KV & BELOW	8,628
TOTAL	**20,773**
Substation Capacity	MVA
	24,254

This covers facilities in the Luzon, Visayas, and Mindanao (three main islands in the Philippine archipelago) grids.

Government-Enacted National Standards

The two reforms under the Power Bill aim to promote competition and attract private investments in the industry. A more competitive electric power industry will, in turn, ensure the provision of quality, reliable, and affordable power to all consumers.

Thus, the Energy Regulatory Commission established national standards contained in the Philippine Grid Code (Grid Code) and the Philippine Distribution Code, where the quality of electric power in the grid was also emphasized. These two documents, which underwent several deliberations among various players of the power sector, the government and representatives from the public sector, took several revisions before the official version was released.

The Standards establish the baseline of performance to ensure that the delivery of power from generators to consumers is continuous, on time and within the prescribed amount without jeopardizing the integrity of the transmission system. They are, in essence, measures of reliability and quality of performance of the system.

The EPIRA mandates the ERC to enforce compliance to the Grid Code and to impose fines and penalties for any violations of the provisions set therein.

The Philippine Grid Code

The Philippine Grid Code establishes and documents the basic rules, requirements, procedures and standards that govern the operation, maintenance and development of the high voltage backbone transmission system in the Philippines.

The Grid Code was prepared using a functional rather than an organizational format so that it will remain robust and require minimum changes as the Philippine electric power industry is transformed to its new organizational structure.

Power Quality Standards

Electricity could be the most vital raw material being utilized by modern industry and commerce. Electrical power is an unusual commodity since it is continuously needed and can not be stored, and more significantly, it cannot be subjected to quality check/assurance before it is delivered. Assuring power quality is a very difficult task but acceptable quality levels have already been established.

As earlier mentioned, the Power Quality Standards are laid down in the Philippine Grid Code produced by the ERC. These are in the main related to the purity of the voltage (its sinusoidal waveform) and relate to harmonics, dips and sag. These parameters are influenced in the main by disturbing loads and by the impact of HVDC links. A transmission company has very little control of these factors other than by policing and mitigating against the connection of "dirty loads" when they are requested.

The power quality standard is defined as the quality of the voltage, including its frequency and resulting current, that are measured in the grid during normal conditions. A power quality problem exists when at least one of the following conditions is present that significantly affects the normal operations of the system:

- The system frequency has deviated from the nominal value of 60 Hz;
- Voltage magnitudes are outside their allowable range of variation;
- Harmonic frequencies are present in the system;
- There is imbalance in the magnitude of the phase voltages;
- The phase displacement between the voltages is not equal to 120 degrees;
- Voltages fluctuations cause flicker that is outside the allowable flicker severity limits; or
- High-frequency over-voltages are present in the grid.

Performance Standards for Transmission

The Performance Standards for Transmission (PSFT) indicated in the Grid Code is aimed at:

- Ensuring the quality of electric power in the grid;
- Ensuring that the grid will be operated in a safe and efficient manner and with a high degree of reliability; and
- Specifying safety standards for the protection of personnel in the work environment.

Being foremost, the following define the conditions, as specified in the Grid Code, that will be met to ensure power quality standards are met:

Frequency Variations

The nominal fundamental frequency shall be 60 Hz and this shall be maintained within the limits of 59.7 Hz and 60.3 Hz during normal condition, which are +/- 0.5 percent of nominal value.

Voltage Variations

The voltage variations are the deviation of root-mean-square (RMS) value of the voltage from its nominal value, expressed in percent. Voltage variation will either be short duration or long duration.

A Short Duration Voltage Variation (SDVV) is a variation of the RMS value of the voltage from nominal voltage for a time greater than one-half cycle of the power frequency but not exceeding one minute. A SDVV is a "Voltage Swell" if the RMS value of the voltage increases to between 110 percent and 180 percent of nominal value. A SDVV is a Voltage Sag" (or "Voltage Dip") if the RMS value of the voltage decreases to between 10 percent and 90 percent of the nominal value.

A Long Duration Voltage Variation (LDVV) is a variation of the RMS value of the voltage from nominal voltage for a time greater than one minute. A LDVV is an "Undervoltage" if the RMS value of the voltage is less than or equal to 90 percent of the nominal voltage. A LDVV is an "Overvoltage" if the RMS value of the voltage is greater than or equal to 110 percent of the nominal value.

It shall be ensured that LDVV result in RMS values of the voltages that are greater than 95 percent but less than 105 percent of the nominal voltage at any Connection Point during normal conditions.

Harmonics

Harmonics are sinusoidal voltages and currents having frequencies that are integral multiples of the fundamental frequency. These are caused by non-linear loads, which virtually all modern electrical and electronic equipment are.

The Total Harmonic Distortion (THD) is the ratio of the RMS value of the harmonic content to the RMS value of the fundamental quantity, expressed in percent.

The Total Demand Distortion (TDD) is the ratio of the RMS value of the harmonic content to the RMS value of the rated or maximum, expressed in percent.

The THD of the voltage and the TDD of the current at any Connection Pointshall not exceed the limits as shown below.

Table II. Maximum Harmonic Voltage Distortion Factors

Harmonic Voltage Distortion			
Voltage Level	THD	Individual	
		Odd	Even
500kV	1.5%	1.0%	0.5%
115kV – 230kV	2.5%	1.5%	1.0%
69kV	3.0%	2.0%	1.0%

Table III. Maximum Harmonic Current Distortion Factors

Harmonic Current Distortion			
Voltage Level	TDD	Individual	
		Odd	Even
500kV	1.5%	1.0%	0.5%
115kV – 230kV	2.5%	2.0%	0.5%
69kV	5.0%	4.0%	1.0%

Voltage Unbalance/Imbalance

The voltage of a three-phase power system is said to be unbalanced if the voltages do not have the same amplitude and/or are not phase shifted 120^0 apart with respect to one another.

The Negative Sequence Unbalance factor shall be defined as the ratio of the magnitude of the negative sequence component of the voltages to the magnitude of the positive sequence component of the voltages, expressed in percent.

The Zero Sequence Unbalance Factor is the ratio of the magnitude of the zero sequence component of the voltage to the magnitude of the positive sequence component of the voltage, expressed in percent.

The maximum Negative or Zero Sequence Unbalance Factor at the connection point of any user shall not exceed one percent (1%) during normal operating conditions.

Voltage Fluctuation and Flicker Severity (VFFS)

Voltage fluctuation is the systematic variation of voltage envelope or random amplitude changes where the RMS of the voltage is between 90 percent and 110 percent of the nominal voltage. Flicker is the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

The Voltage Fluctuation at any point of connection with fluctuating demand shall not exceed one percent (1%) of the nominal voltage for every step change, which may occur repetitively. Any large Voltage Fluctuation other than a step change may be allowed up to a level of three (3%) provided that this does not constitute a risk to the Grid or to the system of any user.

The short and long-term flicker severity for any Connection Point in the grid shall not exceed the values given below.

Table IV. Maximum Flicker Severity

Voltage Level	Short Term	Long Term
115kV and Above	0.8 unit	0.6 unit
Below 115kV	1.0 unit	0.8 unit

Transient Voltage Variations

Transient Voltages are the high frequency over-voltages that are generally shorter in duration compared to the Short Duration Voltage Variations (SDVV). Infrequent short-duration peaks may be permitted to exceed the levels specified for harmonic distortion provided that such increases do not compromise service to other end-users or cause damage to any grid equipment. Infrequent short-duration peaks with a maximum value of two percent (2%) of nominal voltage may be permitted for Voltage Unbalance, subject to certain terms of a Connection Agreement.

Use of Multi-Function Recorders (MFR)

Digital fault recorders in the Philippine transmission system have been available for many years. Early equipment were, however, limited in their capabilities, recording only transient voltages and currents, particularly during faults in the system. Modern equipment, such as the Multi-Function Recorder (MFR), performs many more measurements and store huge volume of data for detailed analysis.

The MFR was recently introduced in the Philippine electrical grid, and the first unit was installed by Transco in 2003 in its 230kV transmission system. At present, there are ten MFR's installed in four 230kV substations in the Luzon grid. The mode of data retrieval is through the use of LAN/network modems via dial-up connection (thru Transco's communication system).

The multi-function recorder is the term used for a digital fault recorder that has capabilities other than transient/fault recording, such as disturbance recording and trend recording. This device is being used to gather information/data that serve as basis for determining power quality in the transmission system. Hence, Transco is gradually tapping more MFR's to upgrade its recording system.

The focus of the new applications has been the trend data. The following graphs show how this information is useful in determining the power quality in the transmission system.

Figure 1. Frequency variations for 60Hz system recorded over one-week period

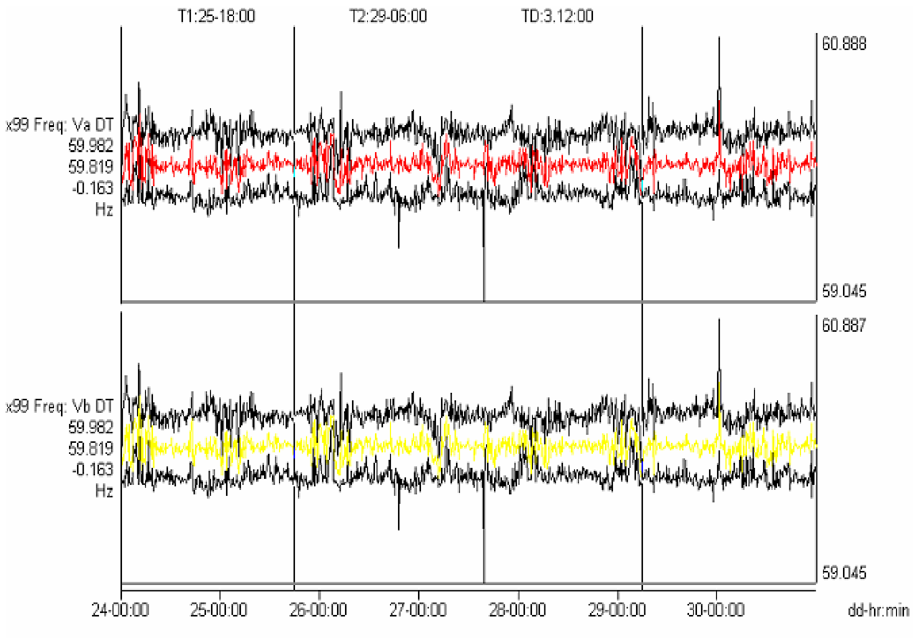


Figure 2. Voltage variations for 230kV system recorded over one-week period

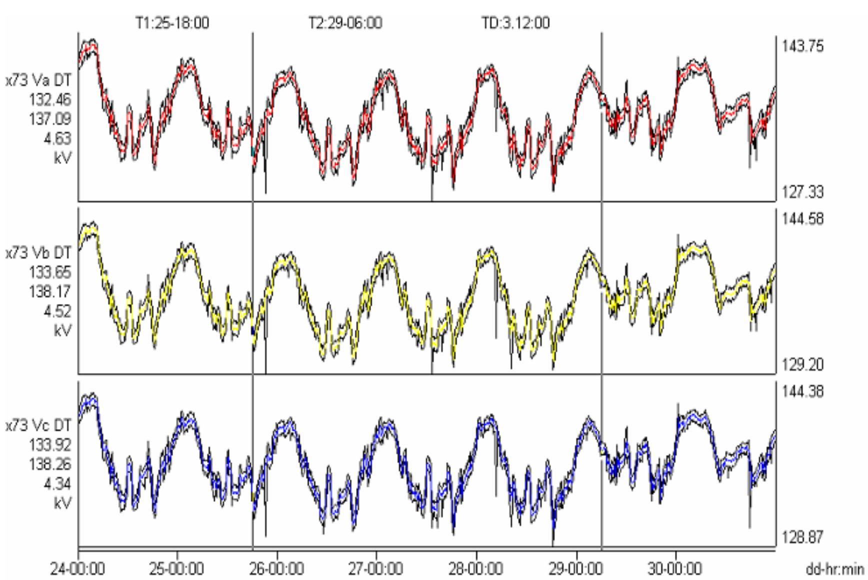


Figure 3. Voltage unbalance in 230kV system recorded over one-week period

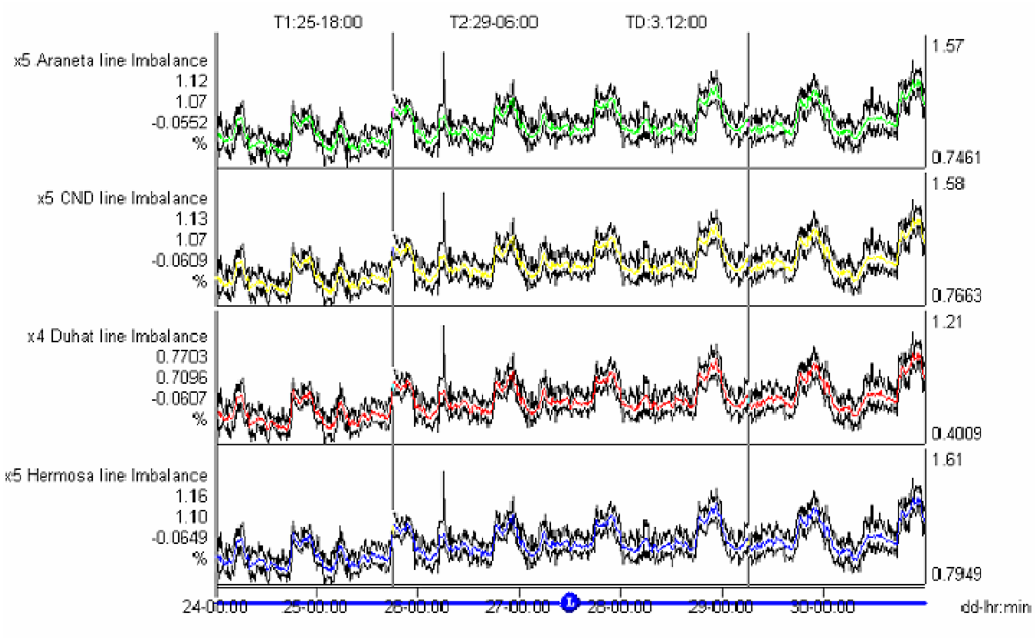
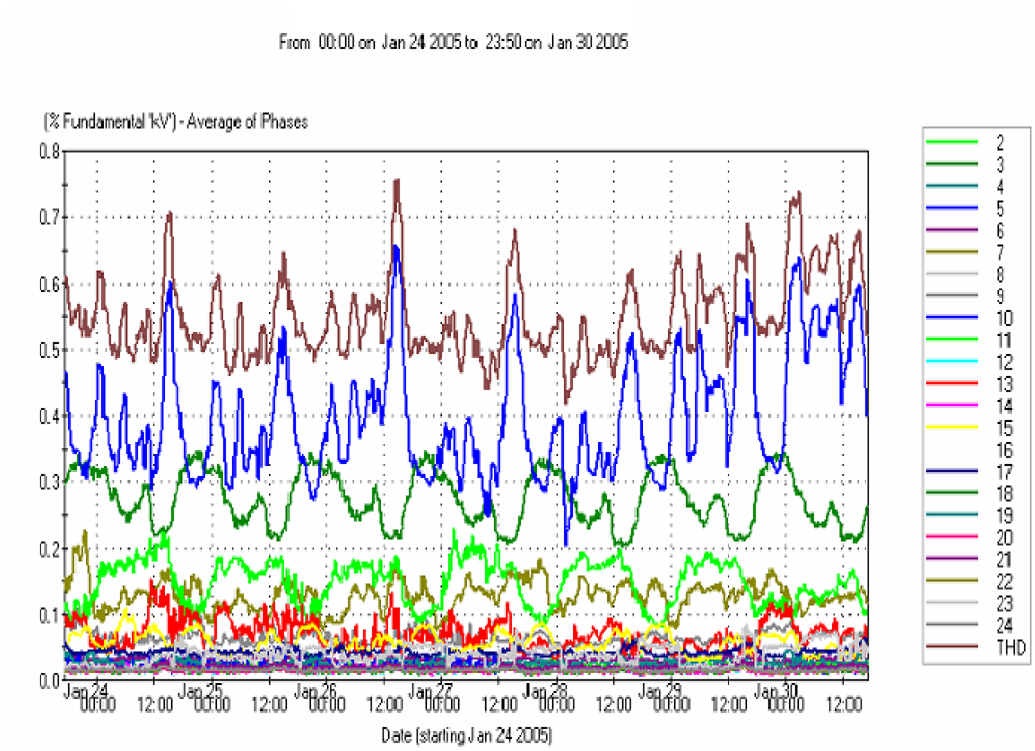


Figure 4. Harmonics in 230kV system recorded over one-week period



Preparation of Power Quality Report

The information contained in the graphs mentioned above serve as basis in the generation of a power quality report called "Performance Standards for Transmission Report", which was derived from a Section in the Grid Code identifying the power quality standards.

Based on experience, generation of this report is anything but easy. The number of power quality parameters being monitored in the four stations over seven days has made data retrieval very tedious considering the mode of communication used. Dial-up connection usually operates around 9600 baud, which is quite slow for today's volume of information. Hence, remote retrieval of a week's worth of data from an MFR in one substation usually takes about two hours to complete. Then, this data is analyzed and the violations from the prescribed limits are determined manually. The daily high and low values for the monitored parameters are tabulated in MS Excel format and from these, graphs are generated showing the limits and the actual values read from the MFR's of each substation. Known causes, as well as possible grounds of violations from the Grid Code standards are also indicated.

With this much work, the Performance Standards for Transmission (PSFT) report for a particular week is normally submitted to management after about one week following the reported period covered. Since its inception in May 2004, the PSFT report has been modified a number of times to accommodate the increasing amount of data as more MFR's are becoming operational.

Table V. Part of early generation PSFT report

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3.0 Harmonics (PGC 3.2.4)

3.1 Total Harmonic Distortion (THD)

115 kV-230kV = 2.50%

LINE	Mon 12/27	Tue 12/28	Wed 12/29	Thurs 12/30	Fri 12/31	Sat 1/1	Sun 1/2
ARANETA LINE	1.40	1.40	1.50	1.60	1.40	1.40	1.40
CND LINE	0.95	0.98	0.95	1.03	0.95	1.00	1.05
DUHAT LINE	0.65	0.68	0.71	0.68	0.68	0.85	0.89
HERMOSA LINE	1.65	1.50	1.50	1.60	1.50	1.70	1.70

3.2 Total Demand Distortion (TDD)

115 kV-230kV = 2.50%

LINE	Mon 12/27	Tue 12/28	Wed 12/29	Thurs 12/30	Fri 12/31	Sat 1/1	Sun 1/2
ARANETA LINE	1.90	1.60	1.60	1.70	1.30	1.70	1.60
CND LINE	2.50	2.30	2.50	2.50	2.40	**2.75**	**3.30**
DUHAT LINE	0.90	1.00	0.85	0.80	0.90	1.15	1.03
HERMOSA LINE	**4.20**	**3.50**	**4.00**	**4.00**	**4.30**	**5.00**	**5.50**

4.0 Voltage Unbalance (PGC 3.2.5)

Negative Seq. Unbalance Factor

$$\frac{\text{Neg. Seq.}_{(V)}}{\text{Pos. Seq.}_{(V)}} \times (100\%) \leq 1\%$$

LINE	Mon 12/27	Tue 12/28	Wed 12/29	Thurs 12/30	Fri 12/31	Sat 1/1	Sun 1/2
ARANETA LINE	**1.28**	**1.30**	**1.80**	**1.32**	**2.30**	**1.31**	**1.27**
CND LINE	**1.27**	**1.28**	**1.86**	**1.37**	**2.29**	**1.30**	**1.33**
DUHAT LINE	0.92	0.94	**1.52**	0.96	**1.94**	0.95	0.99
HERMOSA LINE	**1.29**	**1.31**	**1.90**	**1.33**	**2.31**	**1.32**	**1.36**

IDMS/ PSFT/ 15-Feb-2005

Figure 5. Part of latest generation PSFT report showing frequency variations

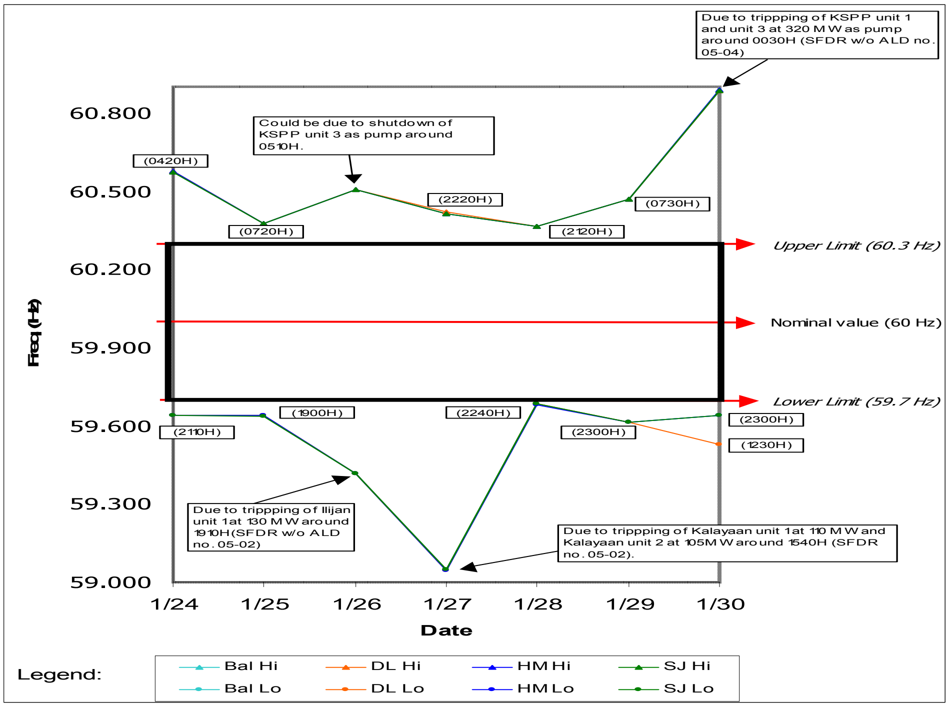


Figure 6. Part of latest generation PSFT report showing voltage variations

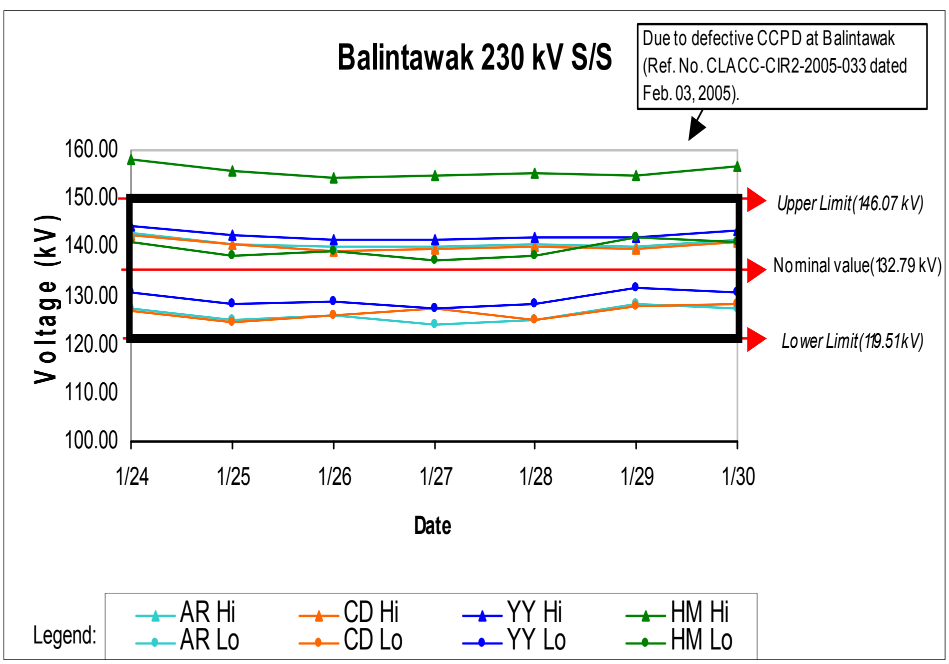


Figure 7. Part of latest generation PSFT report showing harmonics

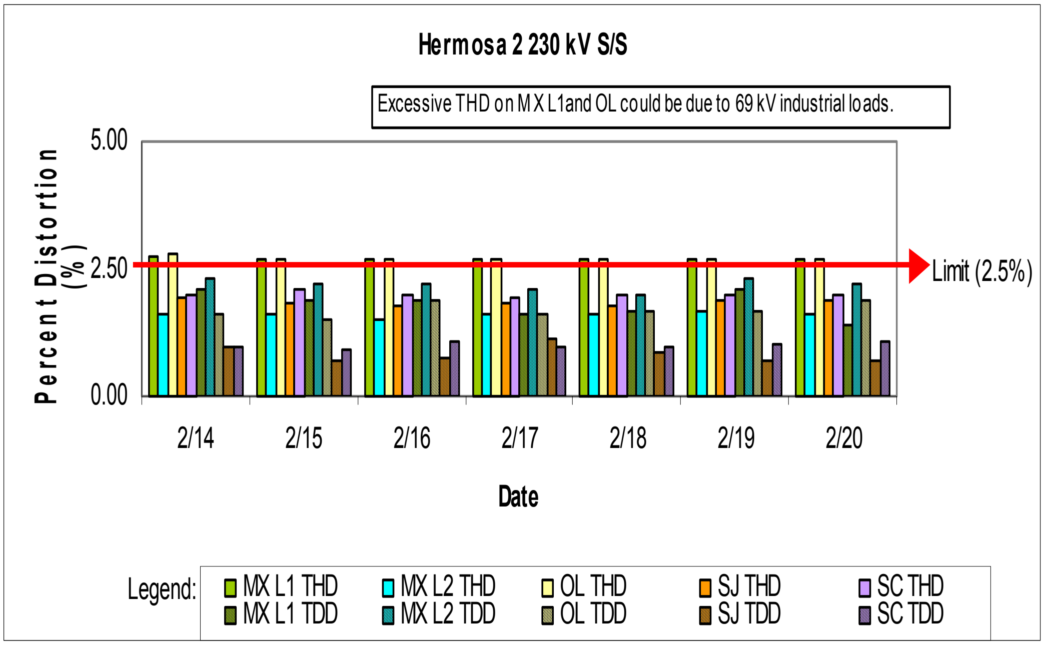
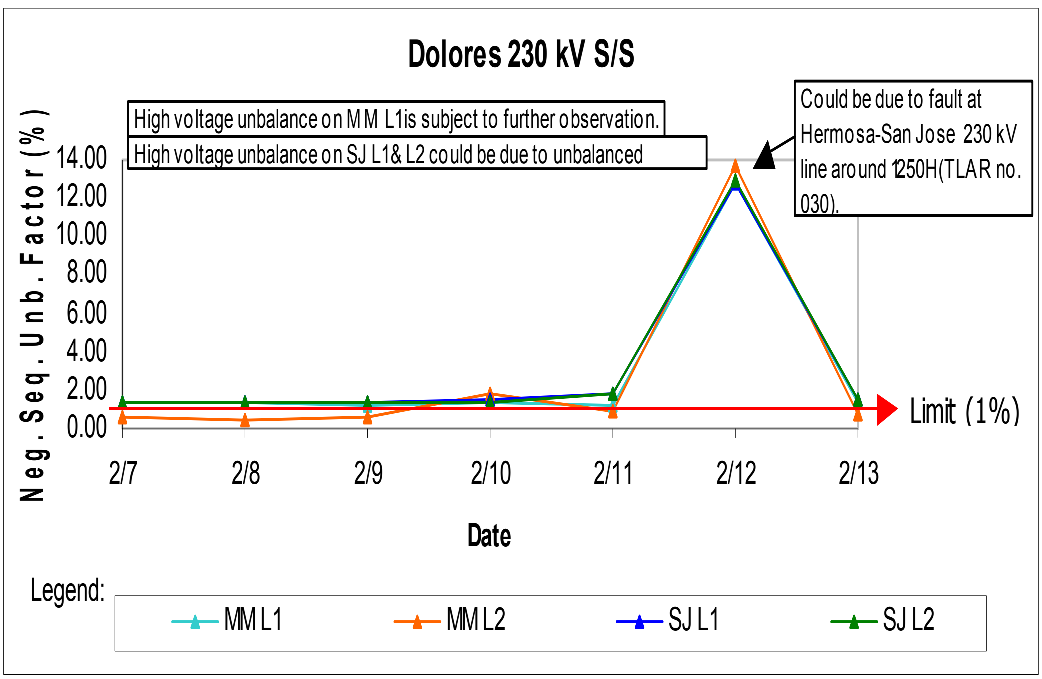


Figure 8. Part of latest generation PSFT report showing voltage unbalance



Benefits of the Power Quality Report

Power quality problems have been known to cause detrimental effects to generating units and loads alike. It is therefore the objective of the PSFT report to identify the violations to the Grid Code standards so that these problems could be eliminated, or at least mitigated.

The PSFT report has already been useful in identifying equipment problems in the transmission system. These problems were appropriately addressed before further damage could happen. Abnormalities are commonly discovered from the Voltage Variations and Voltage Unbalance aspect of the report, where the specified limits for these power quality parameters were observed to have been continuously violated in some substations. These were traced to voltage circuit problems, where the culprits were defective coupling capacitor potential devices (CCPD), often found to have leaks. The consequences were incorrect meter readings and inaccurate fault locator calculations, but more significantly, this could have caused misoperation or maloperation of protective relays/devices.

Another positive effect of the PSFT report was facilitating the installation of new electronic revenue meters with power quality measuring features at industrial loads/customers. This would ascertain the degree/amount of harmonics being produced by each industrial customer; hence, giving Transco more solid basis to compel the customer to adhere to the required standards. The unusually high level of harmonics being captured by the MFRs can only be seen at the transmission line level leading to the industrial customer/s.

With these developments, the value of the PSFT report had been further enhanced. However, Transco management wants fresh information and not the current practice of reading reports with two-week old data.

There is thus a need to speed up the preparation of the power quality report, and in order to meet this objective, the generation of the report would have to be automated.

Recommended Improvements

Automating the generation of reports showing transmission power quality compliance to the national standards would require a recorder evaluation/analysis software that would allow the user to do the following:

- Define list of files to automatically retrieve and compression ratio;
- Define the interval for retrieving data, i.e., daily or weekly;
- Define the interval for creating reports and summaries;
- Consolidate reports, i.e., for weekly reports into monthly, quarterly, and annual summaries;
- Define limits on a per parameter and voltage level basis;
- Create tabular reports showing percentage of interval where the parameters are beyond the defined limits and the min/max values;
- Create graphical of data with limits highlighted on plot;
- Create and store reports in text editor programs such as MS Word format;

- Enter a time frame to exclude from the report records due to extreme weather condition or other reason/s;
- Retrieve un-compressed data if a more detailed report or analysis is needed;
- Optionally include the ability to re-start retrieval at/or near point of any communications interruption/s.

Considering that most of the substations in the transmission system have no network connection yet, which should have been helpful in speeding up retrieval of recorder information, the automation of report generation is the immediate solution.

Besides the applicable standards in the Grid Code, reference should also be made on EN 50160 Regulation on Power Quality as follows:

<u>Frequency variations</u>

A ten-second time averaging interval with an acceptance percentage of 95% of the measurement interval falling within acceptable limits sampled in a week's time of monitoring shall be considered.

<u>Voltage variations (LDVV)</u>

A ten-minute time averaging interval with an acceptance percentage of 95% of the measurement interval falling within acceptable limits sampled in a week's time of monitoring shall be considered.

<u>Harmonics</u>

A ten-minute time averaging interval with an acceptance percentage of 95% of the measurement interval falling within acceptable limits sampled in a week's time of monitoring shall be considered. Harmonic values specified up to order 25 only is recommended.

<u>Voltage unbalance</u>

A ten-minute time averaging interval with an acceptance percentage of 95% of the measurement interval falling within acceptable limits sampled in a week's time of monitoring shall be considered.

<u>Flicker</u>

Short-term flicker shall be averaged over ten minutes. Long-term flicker shall be averaged using short-term flicker values.

Proactive Approach

Since the ultimate objective of this paper is to immediately generate the power quality reports, retrieval of data from the recorders should be done daily and automatically. From the data compiled daily, a weekly report and summary should also be automatically-generated.

Considering that the supply of electricity is a 24-hour a day business, continuous monitoring of the power supply is an essential proactive approach. By doing this, we are able to compile historic record of power quality that would allow us to analyze and identify the trending of say, behavior of harmonics, as well as the frequency and severity of voltage dips. This would also provide us with data for detailed analysis of system disturbances, in order to determine root causes and how to avoid their recurrence or mitigate their effects. Also, continuous monitoring of harmonics is vital to ensure that the addition of loads would not cause undue heating that could lead to early problems on transformers and other high voltage equipment.

Inasmuch as the monitoring of power quality in the Philippine transmission system is relatively new, the weekly reports should be regularly submitted to management for review, who will also forward the same to the Grid Management Committee (GMC). The GMC, which is responsible for monitoring the day-to-day operations of the grid, ultimately refers any finding/s to the Energy Regulatory Commission for final decision.

Summary

The electric power industry has of late become very dynamic, with most countries having undergone restructuring in this sector. The Philippines is no exception where the recent change in setup has led to the creation of a national grid code where power quality standards were established. And it has been evident that, just like in any other power system around the world, power quality problems exist in the Philippine transmission system.

In order to determine compliance with the Philippine grid Code standards for quality of power supply, Transco has utilized the capabilities of new digital fault recorders to compile needed data. In effect, the significance of recorders had been further enhanced beyond transient fault data analysis.

However, due to the sheer volume of information needed to define good power quality, it has been a cumbersome and tedious manual process to analyze these data. And while retrieving data is one thing, creating reports to show this information is another. The generation of these reports is being done manually, which has proved to be time-consuming and making the final power quality report too long to complete.

Inasmuch as automating the process of creating reports complying to the Philippine Grid Code standards is the practical solution, it is therefore necessary that Transco work with the vendors of digital fault recorders in order to achieve this objective.

Biographical Information

Patrick M. Donato is a Registered Electrical Engineer in the Philippines who received his BSEE from the Mapua Institute of Technology in 1985. He entered the National Power Corporation (Napocor) in 1988, having gained experiences in substation engineering and power system protection. He joined the National Transmission Corporation (Transco) upon its formation and eventual separation from the Napocor in 2003 by virtue of R.A. 9136 creating the Transco. He is currently the head of the Integrated Disturbance Monitoring Section of the Protection Services Division under System Operations, which operates and maintains the fault recording system in the Luzon grid.

John Sperr is an active member of IEEE – Power System Relaying Committee who received his BS-ChemE from Clarkson University in 1984. He has been working for Ametek Power Instruments (formerly Rochester Instrument Systems) in various sales-support and marketing roles focusing on their power monitoring products since 1985.

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