Automatic Network Power Quality Analyzing System

M. Freres, Dr. L. Philippot, B. Wartmann and A. L. P. de Oliveira

***Abstract*--The worldwide deregulation of the energy market has created growing concern regarding power system reliability and quality. This calls for more efficient disturbance recording instrumentation and software tools to reduce the analysis time and to keep the down time as short as possible. The goal is to minimize the lost revenue of utilities and the manufacturing loss of industrial customers. Power quality problems like voltage sags and swells, long term voltage deviations, flicker, voltage and current harmonics may cause additional monetary losses in facilities with sensitive electronic equipment such as factories and data centers. The reason for these problems has to be analyzed using a large amount of collected data by various Intelligent Electronic Devices (IED´s) like Protection Relays, Digital Fault Recorders (DFR), and Power Quality Recorders. In this paper, results of a successfully tested automatic disturbance recording, fault and power quality analysis and information distribution system is presented. The distributed system includes IED´s in several major and small substations. Focus of the application is the quick and reliable analysis of any abnormal behavior of a metropolitan power system. The power system consists of different sections in various locations and includes voltage levels from 400V up to 380kV. The target of the maintenance group is "to know what has happened and what we have to do before the customer calls".**

***Index Terms*--Digital Fault Recorder, Power System Disturbance Recording, Power Quality Recording, Power System Monitoring, Preventive Maintenance.**

I. INTRODUCTION

To achieve the challenging goal described above and to keep the investment costs at a minimum, all possibilities of numerical intelligent electronic devices, communication network structures and modern computer systems have to be deployed in an economical and effective way.

The heart of the system is a computer server station with management software collecting all data gathered by IED´s in the field using Ethernet or ISDN communication channels. The server manages a database with all data coming from protective relays, disturbance recorders and power quality monitoring units. Some of these units are directly connected to the server system; some are connected in a first level to a substation automation system computer which is connected to the managing server system.

Using international communication protocols, the system is widely independent of the different equipment suppliers. In parallel to the management software, various application software tasks are processing the data in the database. These applications include automatic distance to fault location, comprehensive fault analysis, power quality analysis and registration of power quality deviations from defined limits.

The focus of the automatic fault analysis is to find out the principle reason of a power system fault in case of trip decision of more then one protection unit. After a detailed analysis of the disturbance records and the generation of a report, the system is able to send "the right information to the right person". For this purpose, information channels like sms (short message system), e-mail, WEB pages and fax are used. After receiving a message from the system, the responsible person has the option to log via the intranet of the company and read the disturbance report. This quick information system enables the key person to deploy other maintenance personnel and keep the repair time at a minimum.

II. TECHNICAL WORK PREPARATION

A. Importance of Power System Quality Analysis

Maintenance personnel face new challenges with increasing installation of electronic components in industrial sites. These systems are sensitive to voltage fluctuations, voltage dips and to voltage harmonics caused by nonlinear loads. Data centers, Programmable Logical Controllers (PLC), field bus systems in factories, and wide area communication network require a high level of power quality.

For this reason, European and international standards like EN50160 and IEC 61000-2-2 were defined. This is the major reason why power system disturbances and quality problems should be monitored. In case of problems, measures can be implemented, but their effectiveness should also be observed.

M. Freres is with Siemens AG, Humboldtstr 59, NE 90459, Nuremberg, Germany (e-mail: marco.freres@siemens.com).

Dr. L. Philippot is with NetCeler, Les Peyrons, F - 05400, Veynes, France (e-mail: lphilippot@netceler.com).

B. Wartmann is with EWZ, Aubruggweg 21, CH – 8050, Zûrich, Switzerland (e-mail: bruno.wartmann@ewz.ch).

A. L. P. de Oliveira is with SIEMENS Ltda. - PTD H - Power Transmission and Distribution – High Voltage Department, Av. Mutinga, 3.800, 2o Floor – Pirituba – São Paulo/SP – ZIP CODE 05110-901 Brazil (e-mail: andreluiz.oliveira@siemens.com).

B. Environmental Structure

Worldwide there are very few substations completely equipped with numerical relays of one vendor, and with a Substation Integration and Monitoring System collecting all relay information. In this case the retrieved information is generally limited to one substation. More commonly experts have to cope with the signals of electromechanical relays and use different software packages of numerical relays for the analysis of a breaker trip even in one single substation. In case of a wide range blackout, the fault analysis will be more complicated due to the fact that detailed information from several substations must be compared to understand the cause of the initial fault and evolving faults. Today, this process takes obviously a long time and leads to high economic losses.

To overcome some of these problems, utilities are also installing Digital Fault Recorders (DFR). This step leads to a quick analysis of faults especially in substations mainly equipped with electromechanical relays. Even if a substation is equipped with numerical relays, the installation of fault recorders brings some major benefits for a quick fault analysis. One major advantage is the use of a single software package, if the DFR software can also process the data from protective relays and use all data for disturbance analysis. Another important item is the usually significantly higher sampling rate of a DFR, which allows the analysis of signals in a frequency range from 50Hz to 3 kHz during a power system disturbance.

C. Structure of the Monitoring System in Zurich

The municipality of Zurich (EWZ) has installed a comprehensive Power System Quality Monitoring System. This includes the Power Plants in Graubünden and Bergell, the City of Zurich and the area up to Wettingen in Aargau.

All installed protective relays, digital fault recorders and power quality monitoring units are locally connected to station data collectors with adequate communication channels. To achieve a vendor independent system, protective relays with IEC 60870-5-103 protocol are used to retrieve the fault records and signaling information. These station data collectors collect all the data of the mentioned units in automatic mode and store the data locally.

To keep the transmission time short, data reduction algorithms are applied. Precise time synchronization of the units in the field is done by station data collectors which are synchronized by GPS receivers. Thus, all recordings in the whole area of the monitoring system have time synchronization accuracy better than 0.5ms. A LAN/WAN network with a data transfer rate of 2MBit/s is used for the communication between the station data collectors and the centralized Server system. A redundant communication network based on analogue telephone network with adequate modems is also in service. Data transferred to the central office Server systems (NQS1 and NQS2 in Figure 1) is then used for power system disturbance and power quality analysis.

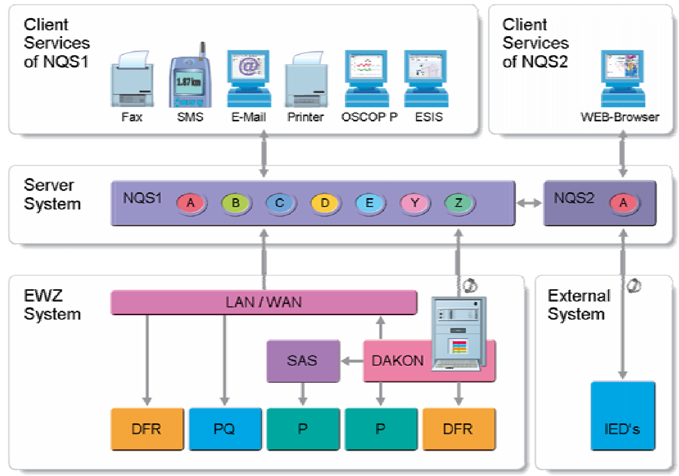

Fig. 1. Structure of ewz NQS System

Additionally, at station level, the grouping of all local data sets belonging to a network event and the data analysis is done. The purpose is to provide the local users at station level fast and reliable information without the necessity of specialized tools.

The office communication network with a data transfer rate of 100 MBit/s is used for data exchange between Server system and Client PCs for the company internal distribution of analysis results.

The complete power system of the city Zurich between the voltage levels 400V up to 380kV is connected to the monitoring system. The system also monitors nodes where power system sections under the responsibility of different utilities are connected together. A major advantage of the system is the very short disturbance analysis time of 15 to 30 minutes and automatic sending of reports to the customers of the utility EWZ. This can be in form of E-Mail, sms or Fax. Also, some customers can retrieve the information through internet. To achieve this, the intranet system of EWZ offers access rights to customers to log in through internet. To avoid misuse, a firewall is installed at the intranet / internet interface. Disturbance records, disturbance analysis results and power quality reports are saved in a data base including data since 1995. This enables the maintenance personnel to compare older disturbances at one location with new ones. This can lead to useful additional information, for example the change of breaker behavior during opening.

All TCP/IP nodes of the LAN/WAN network are permanently monitored by dedicated software that also checks the operation of the main applications. This allows quickly detecting a failure in the data stream and restoring the faulty component. The software also computes Quality of Service (QoS) figures that help improving the recording system.

D. Functions of the Power Monitoring and Quality Analysis System

The user interface of the power monitoring and quality analysis system is simple but very effective. Selecting the modules “Disturbance Recording”, “Complex Disturbance” and “Power Quality”, the user can get immediate information about the status of the power system. With a few mouse clicks, the maintenance personnel and also the customer of the utility can receive detailed information about power quality problems or power system disturbances.

E. Function “Disturbance Recording”

With the function “Disturbance Recording” the user can display each recording of disturbance recorders and numerical protective relays separately. All current and voltage data; start and stop time of the recording is shown. Each record is separated in “before, during and after” time segments in regard to the disturbance. These records can also be displayed in RMS values; a calculation of the minimum/maximum positions of the recorded data and a precise calculation of the distance to fault location is possible. Figure 2 depicts the result of a record after a trip of one relay in a substation. The event diagnosis algorithm marks the importance of relay or DFR records in different colors. All data are prepared for representation with spreadsheet programs, like EXCEL.

Station	Feeder	State Time (s) Duration (s)	7 0,1537 0,0347	8 0,1884 0,0082	9 0,1966 0,0085	10 0,2051 0,0309	11 0,236 0,1807	12 0,6167 0,0595
		ZL3-L1	7.87 Ohm, -7.8°			16.94 Ohm, 17.7°	29.64 Ohm, 26.9°	21.70 Ohm, 31.9°
UW Aubrugg 150 kV	+H03, 150kV LFE Fällanden	ZL1-Erde	66.61 Ohm, 139.2°			343.78 Ohm, 151.8°	579.63 Ohm, 155.3°	577.26 Ohm, 154.9°
		ZL2-Erde	133.19 Ohm, 0.6°			935.50 Ohm, 162.4°	666.02 Ohm, 162.5°	660.55 Ohm, 162.0°
		ZL3-Erde	85.46 Ohm, 117.8°			445.30 Ohm, -174.1°	599.21 Ohm, 161.2°	600.42 Ohm, 160.3°
		ZL1-L2	238.10 Ohm, 167.1°			469.14 Ohm, 168.9°	598.64 Ohm, 160.9°	595.51 Ohm, 160.4°
		ZL2-L3	108.45 Ohm, 42.1°			552.70 Ohm, 166.7°	634.79 Ohm, 160.1°	634.46 Ohm, 159.5°
		ZL3-L1	***65.21 Ohm, 130.9° (R=-42.72,X=49.27)***			483.08 Ohm, 160.1°	608.05 Ohm, 157.6°	605.31 Ohm, 156.9°
UW Auwiesen 220 kV	+F24, 220kV TFE Transformator 1							
	+F26, 220kV TFE Transformator 3							
	+F28, 220kV LFE Fällanden Ost	ZL1-Erde	[illegible]			88.78 Ohm, -43.5°	531.36 Ohm, 175.2°	484.34 Ohm, 174.1°
		ZL2-Erde	[illegible]			65.41 Ohm, -155.9°	564.27 Ohm, 172.5°	541.75 Ohm, 169.3°
		ZL3-Erde	[illegible]			60.67 Ohm, 92.1°	663.46 Ohm, -179.1°	624.90 Ohm, -177.5°
		ZL1-L2	[illegible]			406.79 Ohm, -169.4°	554.87 Ohm, 174.9°	524.14 Ohm, 173.7°
		ZL2-L3	[illegible]			***727.80 Ohm, 157.9° (R=-674.10,X=274.39)***	586.03 Ohm, 179.0°	547.24 Ohm, 177.6°
		ZL3-L1	[illegible]			340.83 Ohm, 160.0°	606.66 Ohm, 174.0°	569.13 Ohm, 173.3°
	+F29, 220kV LFE Regensdorf	ZL1-Erde	106.98 Ohm, 139.0°			424.17 Ohm, 149.0°	3558.73 Ohm, 177.4°	4316.82 Ohm, 179.7°
		ZL2-Erde	95.89 Ohm, 15.3°			467.50 Ohm, 19.8°	4307.62 Ohm, -158.1°	4845.88 Ohm, -159.2°
		ZL3-Erde	***6.67 Ohm, -109.2° (R=-2.20,X=-6.30)***			***228.20 Ohm, -103.5° (R=-53.22,X=-221.91)***	3467.08 Ohm, -170.6°	4565.63 Ohm, -175.6°
		ZL1-L2	1627.34 Ohm, -53.3°			3681.06 Ohm, -124.4°	3542.17 Ohm, -168.6°	4192.21 Ohm, -168.6°

Fig. 2. All recorded data involved in network fault shown in one spreadsheet, subdivided into electrical states (for each state, diagnostic results are available)

F. Function “Complex Disturbance”

Usually more than one Disturbance Recorder or Protection Device records a short circuit after a power system disturbance. The software function “Complex Disturbance” first sorts all records belonging to one specific disturbance and starts with each record the calculation of the distance to fault location, if possible. As a next step, all available information like recording time, start and trip information of protective relays, and fault location are used to generate a “Comprehensive disturbance report” (Figure 3).

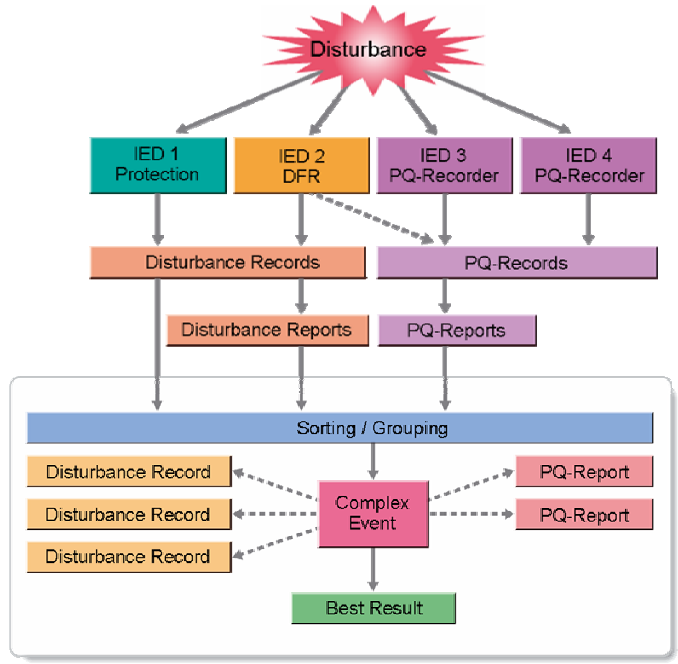

Fig. 3. Complex Disturbance analysis and reporting

Maintenance personnel can then get detailed information like first trip location, evolving faults, in some cases wrong trip of protective relays with inadequate settings, maximum short circuit current, duration of the fault etc. One should not underestimate the importance of power quality recorders for further analysis. Although protective devices clear the faults correctly, disturbances cause voltage dips in bus systems resulting in power quality problems on lines adjacent to the lines affected by the short circuit. These types of problems can cause additional economic losses, but will not be recorded by protective devices. By processing the corresponding information, production losses of utility customers can be identified.

G. Function “Power System Quality”

Power Quality reports are generated using the power quality related data registered by Digital Fault Recorders and Power Quality Recorders. Daily, weekly and monthly power quality reports are automatically created using standard predefined limits according to EN50160 or IEC 61000-2-2, and also with company specific limits.

H. Power Quality Recording versus Disturbance Recording

Although the data acquisition principle is similar, there is a significant difference between power quality recording and fault recording. The result of a PQ recording is calculated data like RMS values of voltages and currents, power system fundamental frequency, current and voltage harmonics, voltage sags and swells etc. The typical sampling frequency for PQ data recorders is usually 64 to 128 times the nominal power system frequency (3,2kHz - 6,4kHz@50Hz). Averaging time for the calculated PQ data is typical 1s to 2h, depending on the type of information and the applicable standard. On the other hand, registered data for fault recording is purely sampled data, transmitted with a high degree of compression and a sampling frequency of 256 times the fundamental frequency (12,8kHz@50Hz). This high sampling rate is important for detailed visualization of all harmonics in a range of 50Hz up to 3 kHz. The typical recording time for a power system disturbance is 10s to 30s, depending on retriggering. The fault records of numerical relays are usually created with rather low sampling frequencies in a range of 1 kHz, which is acceptable for the calculation of fault location. But to be able to visualize the effects of higher frequencies, for example during breaker opening or resonant frequencies caused by voltage transformers, the high sampling rate of the DFR's is required. On the bottom line, the focus of the installed monitoring system is the optimal use of all available information retrieved from numerical protection relays, digital fault recorders and power quality registration units. Under this consideration, each of the mentioned registration units is an important part of the whole system.

I. Summary of the Experience with the Monitoring System

The feasibility and justification of a quality monitoring system depends on the requirements of a specific area. Metropolitan areas with a high population including important industrial areas, data centers and power quality sensitive manufacturing facilities require a high degree of power system reliability. Today, the power quality norm EN50160 is specified in many European countries, and the power supply quality is on average better than required. But for several facilities, even the conformity with EN50160 is not sufficient. Using additional information about fault probability and results of fault statistics, the definition of additional measures to increase the reliability of the power supply is possible.

On the other hand, the use of detailed statistical data and its analysis shows the results of implemented measures like the installation of reactive power compensation systems, uninterruptible power supplies etc. In some cases it was possible to show that some of these led to a worse power quality than it was originally planned. To achieve the defined goals for the increase of power quality and reliability, not only the implementation of the measures are important, but also the installation of an adequate controlling system. In this case, the presented monitoring system can be the right answer. With such a system, power system operation and maintenance personnel can receive the right answers to questions like: Why did the UPS System not start? Why did the protection unit trip although the fault was on an adjacent line? What is the reason for the resonant effects after connecting the own power system with the neighbor utility system?

The presented monitoring system locates the weak points of the power system quickly and reliably. Thus, long discussions and expensive research work after a big disturbance or even after a blackout can be avoided. Instead of asking for "who is guilty and responsible", all manpower can be deployed to reactivate the power supply in a short time. Also, a significant increase of the investment quality for higher power quality and reliability can be achieved. In many cases, an adjustment of protective relay settings brings better results then the installation of several UPS systems in various locations. The major goal for the installation of a monitoring system is the early recognition of the weak points of the power system, quick understanding of what has happened and professional implementation of adequate measures. In summary, the goal is the implementation of preventive measures and achievement of shortest possible down times. Such a system can be very useful for all companies with high energy consumption and / or power quality sensitive production or operation processes.

J. Examples for Preventive Problem Solution

Figure 4 shows the recorded signal of a defective voltage transformer on a distribution line without load (Ferro resonance).

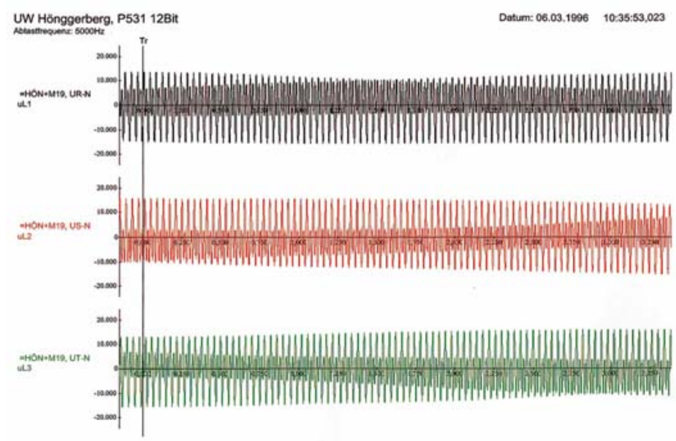

Fig. 4. Ferro resonance caused by an 11 kV voltage transformer

After data analysis, the voltage transformer was replaced, and stable behavior was restored with a load resistor.

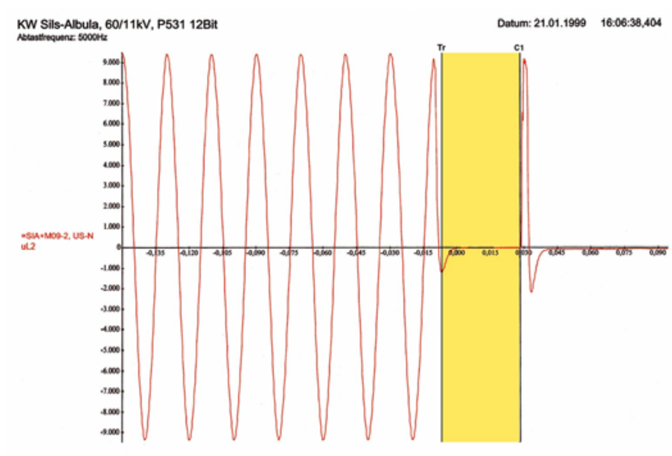

Fig. 5. Restriking of an 11 kV breaker

In Figure 5, a record of a breaker restriking is shown. It is possible to observe aging effects after analysis of breaker behavior by comparison of records registered at different times. This may be the increase of breaking time, or unsymmetrical pole opening.

III. Conclusions

A quality monitoring system is not a replacement for an energy management or substation automation system. The major intention is to observe and monitor the power system, and also the performance of the protective relays and substation automation systems. Also, continuous recording of the performance of various compensation systems installed in the power system is possible.

Due to the passive behavior, the focus of this system is collection and processing of power system fault and power quality related data. In case of disturbances in a "grey zone", where protection devices do not detect any fault but industrial customers complain about production loss, trigger levels of the disturbance recorder units can be set relatively low for detailed analysis.

The investment in such a power quality monitoring system depends on the long term strategy of a utility. In case of severe power loss, immediate investments into the power system are required by all affected parties. To plan such investments reliably, a quality monitoring system can help in an efficient way.

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V. Biographies

Marco Freres was born in Ettelbruck, Grand Duchy of Luxembourg, on October 20, 1963. He graduated from the Institut Supérieur de Technologie, Luxembourg, in 1986.

His employment experience includes commissioning of power plants, commissioning of fault recording and Power Quality devices world wide, training for Power quality products; business development for protection systems and Power Quality solutions. Today, he is responsible for marketing and Sales of SAFIR solutions (web based power system fault analysis, equipment monitoring and power quality monitoring) within the Power Transmission and Distribution organisation of Siemens AG.

Luc Philippot (M'1994) was born in Rome, Italy, on December 25th, 1965.

He studied electrical engineering and received his M.Sc. and Ph.D. degrees from Brussels University (ULB), Belgium, in 1988 and 1996, respectively.

His professional experience started with 5 years of research work at ULB on phasor estimation, line fault location, sensitive earth fault detection and power system event classification. He also taught power systems protection and computer science at the University of Rwanda in Butare.

He joined the Energy Automation department of Siemens Power Transmission and Distribution in 1996 and designed a two-ended fault locator and a line differential protection relay, working as a project leader and product manager in Stuttgart, Berlin and Nuremberg, Germany. He has been working for NetCeler, a software company in Veynes, France, since 2002, designing web-based applications for power system fault analysis, equipment monitoring and power quality monitoring.

Bruno Wartmann was born in Luzern, Switzerland, on October 27, 1958. He graduated from the Technical Highschool, Luzern, in 1985.

His employment experience includes construction engineering at several small companies. Actually, he is head of the maintenance department of ewz. He is responsible for the installation, maintenance and commissioning of the installed protection systems, sub station control systems and power quality monitoring systems in the high voltage systems and power generation plants.

André Luiz Pereira de Oliveira was born in 1978 (Brazil). He received his BSEE degree in electrical engineering from the Itajubá Federal School of Engineering (EFEI), Brazil, in 2001.

Obtained Specialist's title in Power Systems Protection and MSc in electrical engineering, in 2004 and 2006, respectively, from Itajubá Federal University (UNIFEI), Brazil.

Project Management Professional (PMP®) certified by the Project Management Institute® - PMI® (USA) since 2004.

He works at SIEMENS Ltda. as a Project Manager (PM) since 2001 at PTD H (Power Transmission and Distribution - High Voltage Department). Responsible for the supplying of "turn-key" High Voltage Substations and Power Compensation Systems, managing contracts with industrial sector and Brazilian Electrical Power System utilities.