INTRODUCTION

With the ongoing deregulation on the energy market, utilities are looking for cost savings like outsourcing of engineering services, delayed investments and downsizing of not fully utilized power system regions to reduce maintenance costs. To avoid a significant loss of the energy supply and voltage quality, governments established regulation authorities to monitor the changes and define countermeasures. With the growing number of installations of decentralized power generation systems like wind and solar generators, fuel cells and small private power plants, the structure of power distribution is also changing. Voltage regulation is getting complicated due to the energy generation at low voltage level and supply into the medium voltage system. These small decentralized power plants change the behavior of the power system in case of disturbances; adjustment of the existing protection schemes is challenging the utility personnel. The above listed changes in the power distribution system lead in many cases to voltage harmonics and flicker and with the increased breaker operations to a reduced power quality. On the other hand, increasing use of sensitive electronics and high speed production machines in manufacturing plants lead to severe production losses caused by voltage sags and short term voltage fluctuations. Therefore, managers of industrial facilities demand from utilities to eliminate these power quality problems and are ready to pay a premium for reliable power with adequate quality. As a result of these structural changes on power distribution system, the importance of monitoring, recording and reporting of power quality related problems is growing. In this paper, results with a power quality monitoring and disturbance analysis system will be presented and discussed.

STRUCTURAL CHANGES ON POWER SYSTEMS

Since 1990, wind energy installations in Germany have grown rapidly, achieving an installed base of 15.688 MW in September 2004, covering 16.017 wind generator systems. With a real energy supply of 18.92 TWh, wind energy had a contribution of 3.7% to the total national energy consumption in the year 2003; the estimated contribution for the year 2004 is over 6.00%. Although the installed base of hydro power generation systems is significantly smaller (4.620 MW in June 2003), the contribution of hydro power is over 24 TWh. A comparison with the numbers of wind energy indicates the reliable continuity of hydro energy and the strongly weather dependent character of the wind energy. As a result, a very important feature of the wind energy is the high number of breaker operations, i.e. wind power system is frequently changing the status “on line” and “off line”. A similar change in the power generation structure of the European Union is under way, including the installation of micro generators, bio–gas power plants, small hydro generators, solar generation systems etc. These new small power plants influence the structure and the operation of power distribution systems, in some cases also the power transmission lines. Therefore, some utilities have started to measure and monitor the voltage quality of the own grid. The first goal for this action is to understand the influences of the structural changes and to work out countermeasures if necessary. In the meantime, regulation authorities in some European countries require from utilities power quality reports according to EN 50160, like in Netherlands and Denmark. The main goal of these activities is to keep the quality of the energy supply in Europe on a high level and avoid wide area blackouts. Similar activities will start soon all countries of the EU.

On the other hand, an increasing number of industrial customers are expecting a quick and reliable analysis of power quality problems like voltage sags and swells, flicker, short and long interruptions etc. For example, a utility must be able to find out if specific voltage sags were “injected” by the transmission system or caused by breaker operations in small generation plants or in an industrial site by starting motors. Managers of industrial plants have understood that the electrical energy is a “manageable” resource, where “risk” can be calculated and the economical loss of a manufacturing plant can be minimized with reasonable measures.

Figure 1: Wind Energy installations in Germany
The utility Pfalzwerke in Germany is running a high and medium voltage grid comprising approximately 130km of 220kV lines, 1100km of 110kV lines and 4500km of 20kV in rural and urban areas.

To meet the requirements and expectations of the customers today and in the future, Pfalzwerke has started a program for an extended analysis of all power system disturbances and to monitor the quality of the voltage according to EN 50160 on the own transmission and distribution lines.

The utilization of this monitoring system can be subdivided into an active and a passive use.

Passive use is the mandatory reaction to all system faults like short circuits, equipment malfunctions and power quality violations using the recorded events.

Active use means to find out detailed information about the status of the power system, which is then used by the system planning department to increase the system reliability and availability.

The system described below is running for approximately one year and comprises 23 recording devices, three data acquisition servers and five workstations for data evaluation. Independent from the number and type of the recording devices, the Power Quality Monitoring System structure reflects the organizational structure: Two servers collect event and disturbance recordings from devices assigned to 110kV or 20kV equipment and are under the responsibility of the system operators. A third server is used as a data base for power quality recordings for the system planning department. The ‘passive’ use has been available immediately after the installation of the Monitoring System. The recorded data is used to create reports after disturbances on the power system or after an equipment failure. The reports usually include the fault location, the cause of the fault etc.

Examples for successful passive use are the analysis and reporting after disconnection of wind power facilities, monitoring, recording of unsymmetrical voltages after reactive power compensation regulator failure and the early detection of a slow circuit breaker drive in a single phase. After approximately one year of operation, extensive statistical data, mostly of line-to-ground disturbances has been collected and analyzed. In control system applications with compensated power lines it is common to suppress transient messages of the single line-to-ground short circuit unless the failure persists a certain time. Since recording devices are independent from the control system, it is possible to alter suppression periods and collect more detailed information. Currently this data is being correlated with possible influence factors like cable/overhead line ratio, environmental data, seasonal effects such as bird flocks, etc. to gain additional information in order to support scheduling of maintenance measures.

![Disturbance and Power Quality Recording System](image)
SYSTEM OVERVIEW

Figure 2 shows an overview of the equipment currently installed. The relevant data is recorded and buffered by the remote devices like DFR (Digital Fault Recorder with Power Quality recording features) and PQM (Power Quality Monitoring Unit) located in different substations. The 12 DFR and 11 PQMU are connected to a wide area network (WAN) and acquire both disturbance records and long term power quality related data. In a time interval of 10 min RMS values of operational parameters such as voltages, currents, frequency, active/reactive power, flicker and voltage/current harmonics are recorded. In addition voltage sags are registered according to customized thresholds. The wide area network mentioned above integrates all measurement information of all IED’s (Intelligent Electronic Devices) in approximately 50 substations at 110kV level. The devices transmit disturbance records immediately to the server they are assigned to (i.e. 110kV or 20kV server). These servers are located in the control centre to provide disturbance records for the network operators.

In addition, power quality data and event records are periodically polled by a third server which also collects data from the PQMU’s. These devices do not support disturbance records and are generally assigned to crucial nodes in the 20kV grid or to special customers respectively. The incoming data of both device types is periodically analyzed according to EN 50160 and customized profiles. The results are summarized in a report which is generated once a week for each device. Analysis results, captured events, etc. can be accessed via a client software from ‘evaluation PCs’ in the corporate network.

Since accessing data via client PCs requires user activity, an automated generation and distribution of relevant data has been implemented. Figure 3 illustrates the data flow and implemented components. The server system evaluates incoming data and forwards the results (DR: Disturbance Report, PQ: Power Quality Report) automatically to evaluation PCs or printers. Since the servers are installed in a protected communication network, all output generated by the server system's evaluation components is redirected to automated printer queues which generate ‘PDF’ output files, following appropriate name conventions. In addition, incoming raw data is checked and a monitoring report (MR) is generated in case of communication problems with the connected IED’s, or if the devices report a specific operation problem. All files are stored in directories which are periodically checked by an automated SMTP manager that distributes this information according to distribution lists via e-Mail.

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The system offers triggered fault and event records which allow analyzing transients, and long term average values like 10 minute averages according to EN 50160. Triggered events represent an immediate benefit of the system. Although disturbance records do not represent a new development, it is worth mentioning because some very specific problems could be located and solved avoiding further damage. Compared with the older recorder systems, the new system offers a large variety of triggering criteria and allows picking up nearly all abnormal system situations. In addition, these fault records have been made accessible to the appropriate group of persons very quickly by an automated distribution system as shown in Figure 2.

As an example, Figure 4 depicts a disturbance record with an asymmetric voltage rise after the connection of a 110/20kV transformer. The disturbance recorder is triggered at each transformer connection or disconnection to monitor the behavior of the breaker and the transformer. Usually, only records with RMS-data are distributed, which give a quick
overview of each operation. Whenever a graph shows an abnormal behavior, detailed information can be extracted from one of the evaluation workstations. The example in Figure 4 shows the line-to-ground and line-to-line voltages of the transformer bay. During the connection of the transformer, the circuit breaker pole of phase L2 on the 110kV side was approx. 12ms slower, as shown in the voltage curve in Figure 4. In this particular case, an abnormally worn part of the breaker mechanism was found and could be replaced.

Monitoring of the 110kV switchgear is costly and therefore not very common. The availability of recorded data can offer benefits which would otherwise require more complex monitoring equipment and has in this particular case offered an immediate return of investment.

A typical use of the recorded power quality data is shown in Figure 5. The graph was retrieved after a cut-off of a 3.6MW wind power facility due to a significant rise of the voltage, thus exceeding the allowed band (which is not shown in the plot). The facility’s regulator was set to a power factor of 1.0, where the terminal conditions allowed only a value of 0.95 due to voltage stability requirements. This information is very helpful in case of legal disputes, for example if the owner of the wind power facility requires compensation for lost revenue.

LONG TERM BENEFIT

Figure 6 shows the annual history of all line-to-ground faults of eight 110kV substations (SS_1 to SS_8), recorded in the year 2004. The data available for compensated medium voltage grids usually does not include the transient faults with a short duration – usually up to 10s – because the RTU’s (Remote Terminal Units) in the system are programmed to ignore them, unless they persist for a certain time interval. The problem is that especially imminent faults on overhead lines are indicated by an increase of transient events which are not registered by the system due to fault suppression. Collecting data with an independent monitoring system is considered as very helpful since it allows to apply own rules concerning the relevance of the data. It is expected that the correlation of fault and equipment data with environmental data like weather conditions, seasonal influences will help to optimize maintenance efforts and maintenance scheduling. In order to make use of this data in respect to system planning or maintenance scheduling, currently correlations with various influence factors like clearing in timbered areas, etc. are checked and an automated generation of geographically referenced data is prepared.

CONCLUSION

The disturbance recording and power quality monitoring system described above is running for approximately one year and has brought an immediate benefit to the system operators. Disturbance records and power quality reports according EN50160 are automatically distributed by an SMTP Server. The collected data will be used for long term statistics in order to support the power system planning department and asset managers.

In addition the system has been helpful to react upon events very quickly, e.g. to compare calculated and measured values, after voltage drops on important nodes due to faults on adjacent lines.

Since power quality data and reports according to EN 50160 are archived, the expectations and requirements of the power system regulation authority will be met, for example in case of quality audits.

REFERENCES


