THE MONITORING OF POWER SYSTEM EVENTS ON TRANSMISSION AND DISTRIBUTION LEVEL BY THE USE OF PHASOR MEASUREMENT UNITS (PMU)

Josef TLUSTY
CTU FEE – Czech Republic
tlusty@fel.cvut.cz

Andrew KASEMBE
CEPS – Czech Republic
kasembe@ceps.cz

Zdenek MULLER
CTU FEE – Czech Republic
mullez1@fel.cvut.cz

Jan SVEC
CTU FEE – Czech Republic
svecj3@fel.cvut.cz

Tomas SYKORA
CTU FEE – Czech Republic
sykorat1@fel.cvut.cz

Antonin POPELKA
AIS - Czech Republic
popelka@ais-brno.cz

Erick V. MGAYA
DIT - Tanzania
emgaya@yahoo.com

Oumar DIALLO
CTU FEE – Czech Republic
diallo1@fel.cvut.cz

ABSTRACT

Large power system disturbances and their consequences, represent a challenging problem for the power industry and especially for the network system operators, the ones who are responsible for the network operation at large, its security and reliability. This fact has reinforced interest in the new generation of monitoring systems with the aim to gain if possible a precise and maximum knowledge about those disturbances and their impact. Most of these severe events with impact on the entire system typically occur in or near the transmission network and are therefore best monitored at transmission system level. This puts great demands on the equipments and in general restricts the use of the data since it becomes property of the transmission system operator.

Synchronized Phasor Measurement System has emerged as a powerful tool to improve power systems performance and reliability and fault localization possibility. Typical example of fault event that occurred in the transmission system and which was well registered by Phasor Measurement Units (PMU) that are installed in the distribution system will be shown in this paper.

INTRODUCTION

The deregulation of the electric power industry, the demands for better energy quality and restrictions on the expansion of the transmission and distribution system have increased the complexity of the power system operation [1]. While the power system is continuously exposed to different disturbances that range from small ones with little impact on operation to large ones with severe consequences, including blackouts, secure and reliable operation remains to be a fundamental requirement for a power network system. Only to mention, the following issues from power industry deregulation point of view have heighten need for more rigorous security assessment:

- Aging transmission and distribution infrastructures, usually means potential components failures
- Increasing number of small and distributed generators brings uncertainty in dispatch patterns
- Cutbacks in system maintenance that means potential for failures such as flashovers to trees
- Dependence on information technology may leave operators blind
- Expansion of interconnection network system may lead to exposure to cascading disturbances.
- Insufficient and/or improper generation/transmission resources which may result from the lack of integrated system planning

In addition to those facts mentioned above (which can be classified as long term and development planning factors), unpredicted events can stress even the best-planned system beyond the acceptable limits. Some of the reasons for less than complete system reliability are:

- Unpredicted changes in power systems, which may differ dramatically from the forecasts (one of the fault events that will be discussed later happened due this reason)
- A very large number of possible operating contingencies
- A combination of unusual and undesired events (for example, human error combined with heavy weather or other combination of events that would be considered very improbable in the earlier times of power system evolution
- Reliability design philosophy that is pushing the system close to the limits, imposed by both economic and environmental pressures

Upon capturing and acquiring a precise knowledge, a power system disturbance is mitigated via protection and control actions, required to stop the power system degradation, restore the normal state and minimize the impact of disturbance.

OVERVIEW OF MONITORING SYSTEMS

The disturbance aspects mentioned above have required better tools for monitoring and control for power system in real time operation. Conventional operating guides derived by conducting off-line studies have become inadequate because number of possible conditions and contingencies becomes unmanageable as system complexity increases, exact system state is never accurately captured by forecast, most study results are never used and some conditions which usually cause problems have never studied off-line (such as N-1 event evolving into an N-3 event).

As a promising solution is an On-line security monitoring and assessment system which can be based for example on measurements from Phasor Measurements Units. This system provides a possibility for a network topology and operating conditions to be modelled in real time as seen by the operator in the control room.

A variety of methods of monitoring, detecting and locating faults on power transmission and distribution system exist. Most of these methods utilize measurements from voltage and current transformers at substations or switching stations to perform their analyses. To gain knowledge about the disturbances and their impact, it is necessary to monitor the system at sufficiently many geographical locations using measurement equipments with sufficient bandwidth. The collected data must also be condensed into useful information and properly analyzed.

Monitoring of events in the power system itself provides a great deal of insight into the behavior of the system. Due to the interconnection and mutual interaction between transmission and distribution systems, and in case of absence of the monitoring units in the transmission system, such monitoring units in the distribution system can be used to locate, forecast danger or even fault events in the near point of transmission system. Most of these severe events with impact on the entire power system typically occur in or near the transmission network and are therefore best monitored at transmission system substations. This puts great demands on equipments and in general restricts the use of the data since it becomes property of the transmission system operator. An alternative is measurement at lower voltage levels.

This paper documents the close agreement between frequency measurements at low and high voltage levels during fault in the transmission network. The very high quality of the data suggests that valuable information about the transmission system can be obtained at lower voltages. This aspect is documented by typical example of fault events that occurred in the transmission system and were well captured by PMU in the distribution system.

Here, a point can be made that, application of PMUs has been rising as one of the new tools to improve the power system monitoring and performance. A more complex system comprising of PMUs is usually referred as Wide Area Measurement System (WAMS). These systems are basically composed by PMUs connected to a Phasor Data Concentrator (PDC) and applications for monitoring and control of power system real time operation [2].

Synchronous phasors

Phasor represents information about the magnitude of measured quantity and about its rotation – angle with respect to reference vector. Synchronous phasor is characterized by position – angle in selected time point. Set of synchronous phasors of electric quantities in distribution network is denoted as phasor snap of network.

- All phasors in one snap are obtained exactly in the same time
- Reference vector has zero angle
- Phasor is complex number associated with the cosine wave
- Time dimension is already contained in the phasor snap

Fundamentals for synchronous measurement and communication are described in IEEE Standard C37.118 – 2005

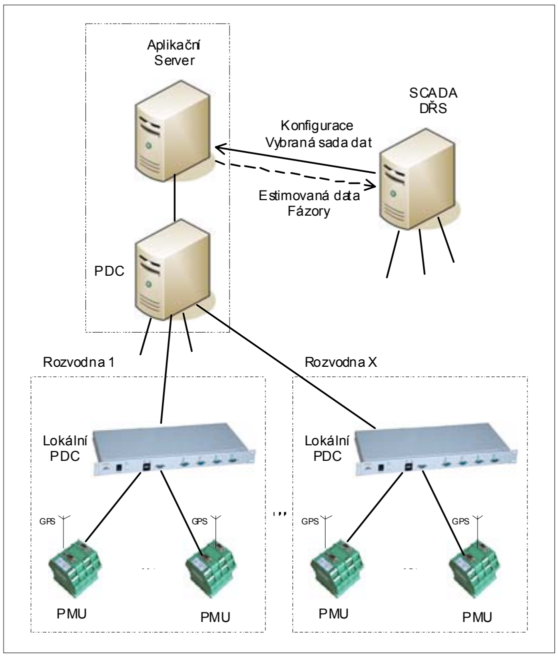

Fig. 1: Typical structure of system WAM

PHASOR MEASUREMENT

System for synchronous phasors measurement is used in certain distribution regions in Czech Republic. Phasor measurements in 128 switching stations with the total of 475 nodes are available at the end of 2008. The map shows location of terminals in distribution network.

Terminals for the phasor measurement (PMU) are placed in switching stations. The terminals measure voltage phasors in 10, 22, 35 and 110 kV levels. Selected busbars, lines and generator outlets are fitted with PMU. Measured data are transferred to the central phasor concentrator (PDC) via reserved communication channels. Consequently, the data are processed and network phasor snaps are created from data measured in the same time point.

The network phasor snap is presented to the users in suitable format and it is also continuously transferred to other applications for user processing. Examples of consequent applications can be e.g. dispatcher system, state estimation and network status calculation programs, network stability analysis etc. Archive data for analysis of network behavior are also available.

Some data from 110kV was used for presented study.

ADVANCED FAULT LOCALIZATION

The data measured in PMUs and transferred to a central unit can be processed using advanced methods for fault localization. The use of new methods is suitable for example in case of a multiple long lines or two long parallel lines, where the classical approach always cannot lead to the correct determination of the fault distance.
The description of Z and Y parameters are used for the network calculations at present for historical reasons. The suggested use of H parameters shows the possibility of more accurate fault localization and at the same time it works thoroughly with wave description of the line.
Let's consider the equivalent diagram of the single-phase line section as the T-network. It can be described by means of H-matrix (H = hybrid parameters). Its elements are known as Blondel constants:

$$\begin{pmatrix} \hat{U}_2 \\ \hat{I}_2 \end{pmatrix} = \hat{H} \begin{pmatrix} \hat{U}_1 \\ \hat{I}_1 \end{pmatrix}$$

Advantage of using **H** description consists in an easy describing of cascading elements. For example cascading of two sections of the line with the same parameters:

$$\begin{pmatrix} \hat{U}_3 \\ \hat{I}_3 \end{pmatrix} = \hat{H} \begin{pmatrix} \hat{U}_2 \\ \hat{I}_2 \end{pmatrix} = \hat{H}^2 \begin{pmatrix} \hat{U}_1 \\ \hat{I}_1 \end{pmatrix}$$

Likewise, the nth power of H-matrix gives the same meaning as sorting n circuits of the same sections consecutively. Limiting the transition by considering partitioning into infinite small differential sections will lead the description into the telegraphic equation.
Now, consider the situation where the line is imaginarily divided into n sections, whereas the first m sections is unfaulted, (m+1)th section is faulted and the remaining n-m-1 sections is also unfaulted. Then the system can be described by:

$$\begin{pmatrix} \hat{U}_n \\ \hat{I}_n \end{pmatrix} = \hat{H}_{\Sigma} \cdot \begin{pmatrix} \hat{U}_1 \\ \hat{I}_1 \end{pmatrix} = \hat{H}^m \cdot \hat{H}_{\downarrow} \cdot \hat{H}^{n-m-1} \cdot \begin{pmatrix} \hat{U}_1 \\ \hat{I}_1 \end{pmatrix}$$

Using this method for a known fault character requires the use of the method for determination of the function minimum.

Fig. 2 shows the error course for the faulted conductor. The error failure values for the non-faulted conductors were about hundred times or much higher than for the faulted conductor. Therefore the assessment of the right affected conductor was simple. Also the assessment of the right failure place on the affected conductor was clear because the error value in that point is much lower than in the neighboring points.

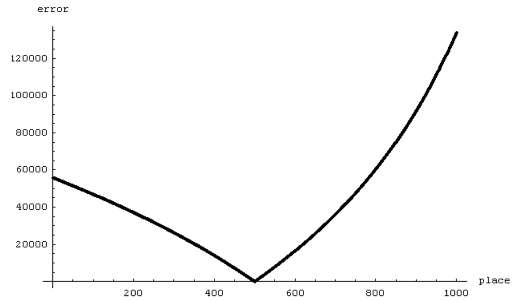

Fig. 2: Fault localization

FAULT EVENT IN THE STUDIED SYSTEM

This section will be dedicated to the description of the fault event that occurred in the transmission network system of the Czech Republic (CZ) and were captured by PMUs which are installed in some parts of the distribution network system. At that time no PMUs were installed in the transmission network.

The fault event on July 25th 2006

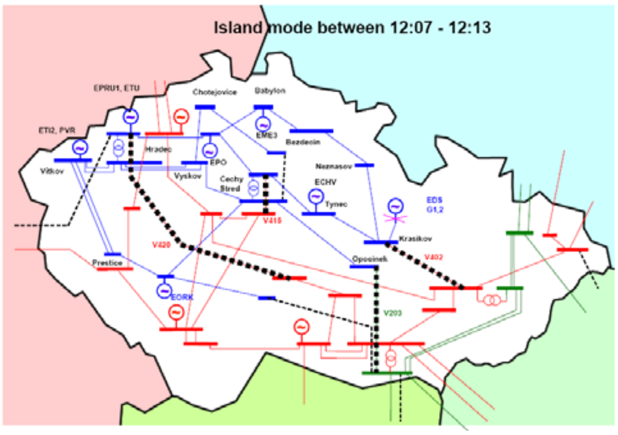

Fig. 3: Division of the network into two island areas, blue and red respectively

The 25th July 2006 was a very hot day almost with tropical temperatures. The actual day energy consumption was much higher than its forecasts. This increase of energy consumption was registered not only in the CZ but also in other parts of Europe. Day energy market, planned energy exchange and real-time network operation in most countries like CZ found to be in crisis. In the CZ network about 5 of its lines were on planned maintenance (i.e. were off-line). A combination of unusual events (line disconnections due to short circuits together with the decision of the dispatching center to trip the one line because of overload triggered other cascading disturbances (see Fig. 3).
It is assumed that this was related to the oscillation phenomenon which was registered at this hour. Because of these outages the CZ network system broke into two islanding operations (see Fig. 3), blue and red color respectively. Part of the system with blue color experienced

excess power production than its consumption, frequency of this part of the system exceeded predefined upper limit, i.e. 50.2 Hz. In contrary, the red part experienced power deficiency of about 1500 MW and frequency went down the lower limit 49.8 Hz. The resulted power unbalance affected the CZ planned power exchange.
The described phenomenon which resulted into islanding operation was precisely captured by PMUs which at that time were only installed in the distribution system. Frequency deviation which was computed from the PMU measurements located at 110 kV sides (see Fig. 3), of the substations of Vitkov (green color) and Chrast (red color) indicates how the system frequency gradually changed before the whole system broke into islands (see Fig. 4).
The island occurrences can be also depicted from the computed frequency deviation of the mentioned monitored substations as can be seen from Fig. 5.
This picture demonstrates a very good visibility of dynamic process in transmission grid from distribution level. The graph shows the critical value of relative angle between referred nodes. The angle about 54° starts network splitting to islands repeatedly in this case.

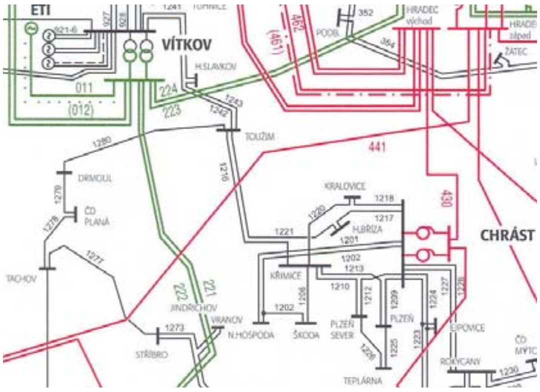

Fig. 4: Case study of PMU application in DS

CONCLUSION

The paper deals with two basic tasks: advanced approaches to the fault localization and correspondence of phenomena in the transmission and distribution systems.
The big advantage of calculation using H parameters is the possibility to describe line like a product of H matrices, which enables to include all discreteness of the line in the calculation, which must be usually neglected for the reason of calculation while using other methods. Consideration of all partial special influences and their inclusion in H matrices of the system approaches the mathematical model more closely to the physical reality.
This paper suggests that the effect of switching operations and fault events in the transmission network will be visible in low-voltage measurements in the interacted distribution system. Access to measurements from several distribution networks makes it straightforward to classify events as occurring on transmission or lower levels.

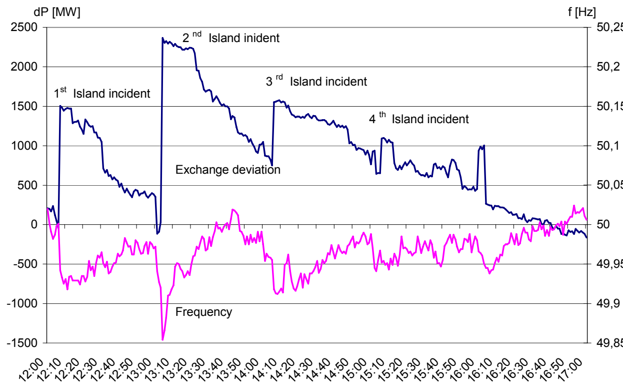

Fig. 5: Frequency deviation and angle computed from PMUs at Vitkov and Chrast.

It can also be deducted that the use of PMU data from 110 kV network provides specific knowledge and information about transmission system dynamic behavior that can be registered and obtained at lower voltage levels. From the case study above only part of information is available, it is not for instance obvious the extension of the island area, therefore the obtained information is not complete and should be used with care but suggests that a network of phasor measurement units at a lower voltage level may deliver high-quality system-wide data sets, where the phase angle information makes it possible to pinpoint the location of transmission system events. Information of islanding occurrence is provided in our case study. Future work can be dedicated at setting up a reasonable PMU system at transmission level, collect and analyze data. This process has been launched by CEPS.

ACKNOWLEDGEMENT

Financial support of the Ministry of Education, Youth and Sports, through grant number MSM 6840770017, is highly acknowledged.

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