SYNCHRONOUS MEASUREMENT IN ELECTRICAL NETWORKS

Václav BÖHM,
ZČE, a.s. – Czech Republic
bohm@zce.cz

Antonín POPELKA
AIS spol. s r.o. – Czech Republic
popelka@ais-brno.cz

Bohumil SADECKÝ
EGÚ Praha Engineering, a.s. - CR
sadecky@egu-prg.cz

Development of electricity market forces the power engineering companies to apply more emphasis to effectiveness of operation by cost reduction. On the other hand, there is a significant demand to increase security and reliability of transfer and distribution of electricity. This can be demonstrated by blackouts in Europe and North America. Monitoring of network status is focused and better quality of input information is required, than the traditional SCADA systems can provide. Widespread measurement of synchronous phasors can provide such information.

The need of reliable electricity supply poses high claims to modern systems of network control, to support systems and to software tools for secure, effective and cost optimal network control. The control is based on status vector of electric network. Available redundant measurements are used for estimation of this vector, i.e. voltages, currents, active and reactive power. However, the calculation algorithms are valid only for simultaneously measured data.

The uncertainty of measured quantities comes from errors of individual parts of measuring chain in the switching station control system, i.e. measuring transformers, A/D converters or delta criterion algorithm. Another source of errors is asynchronous measurement of measured quantities and data delay in communication lines. All these errors mean aggravation of exactness of calculations. Synchronous measurements of all quantities (V, I, P, Q) can reasonable improve control and management in distribution network.

Relative phasors between network nodes are specific variables. Methods of their measurement are synchronous by principle and they are less dependent on the error of amplitude. Demands on their quality, especially exactness and periodicity, differ according to the way of their utilization.

SIGNIFICANCE OF PHASOR MEASUREMENT

The wide spread measurement of synchronous phasors of voltages and currents is important both for steady operation and for dynamic changes during unstable states and failures. Synchronous measurement is also important for various operational domains, protections and network control.

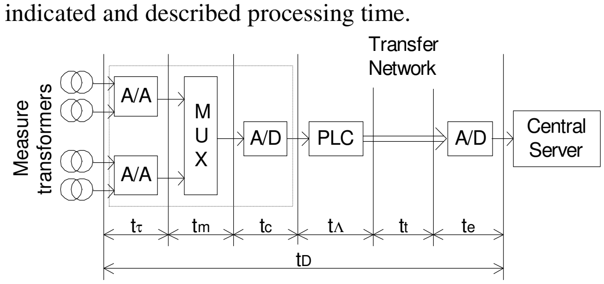
- **State estimation** - synchronous measurement plays key role in the state estimation of high voltage power systems. Practical experience shows that delay of information can seriously damage the result of estimation. The benefit of completing the set of measured quantities by synchronous phasors can be demonstrated by comparative calculation of estimation criterion. Adding a vast volume of phasor measurements can significantly reduce consequences of non-synchronous measurement of active and reactive power.

Error of phase measurement has to be very small for successful application. Acceptable error of measurement belongs to the range of tenths of angle degree.

- **Switching conditions** – the problems of switching in medium and high voltage distribution systems are very significant from the security and reliability point of view. These problems arise especially on the occasion of work preparation in the network or restoration of power supply after failure. Optimization of switching sequences directly affects the quality of power supply and value of network availability indicator. Technical limitations must not be exceeded during the switching sequence. Protection systems activation and consequent failures must not appear. Phase relations in the system represent very important parameters for the dispatcher decisions. This applies namely to the phase differences in the switched points of network.
- It is possible to **increase the transfer capacity of lines** by evaluation of dynamic monitoring of phasors.
- Dynamic wide spread phase monitoring of phasors enables dynamic **evaluation of network stability** and anticipation of failures and blackouts.
- Recording of phasor trends enables exact **analysis of failure**.
- Wide spread phasors measurement can significantly improve the **localization of failures**.

DELAY IN THE MEASUREMENT CHAIN

The following figure shows components of usual measurement chain of dispatcher control system with indicated and described processing time.



t_τ - τ is time constant of stabilization of A/D converters. This constant eliminates quick changes of input quantities and thus brings undefined delay,

t_m – time needed for input multiplex switching is defined by order of measured quantity in the input card terminals and by number of measured inputs,

t_c – time of A/D conversion is constant and very small,

t_Δ - time of processing the quantity in PLC of control system with Δ-criterion is very changeable. It depends on Δ-criterion parameters and variability of measured quantity.

t_t – communication time needed to transfer data to central station depends on the speed of communication channels and on load of communication channels by changes of signals.

Changes of signals have usually higher transfer priority and thus the delay of measurement transfer is very changeable. Some values are even not transferred at all.

t_e – processing time for evaluation in front-end depends on the front-end load and cannot be precisely defined,

t_D – entire time for preprocessing of analog measured quantities is defined s as sum:

$$t_D = t_\tau + t_m + t_c + t_\Delta + t_t + t_e$$

and is indefinably changeable in range of tens of seconds.

Δ-criterion and various time interval needed to transfer data from terminal to central computer have biggest influence to the quality of measurement synchronicity. The delay time for various quantities is uncertain in the range between ones and tens of seconds.

MEASUREMENT OF PHASORS

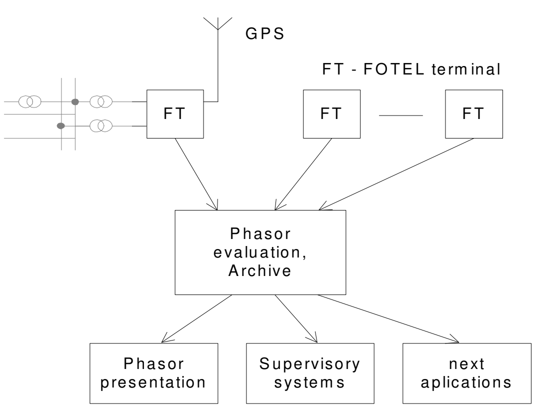
Wide spread monitoring of large transmission and distribution networks are based on new technology – measurement with the utilization of time synchronization by GPS system. The existing SCADA systems measure effective values of voltages and currents while the phasor measurements inform about the voltage and current amplitude and angle between measured quantities in the entire area. Set of phasors measured exactly in the same time represents snap of status of monitored area in all monitored nodes.

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.

- Phasor is complex number associated with the sine wave.
- Utilization of phasors require constant parameters of network
- There is no need to use time trends in the calculation. Time dimension is already contained in the phasor snap.

Structure of measurement system



Terminals for the phasor measurement (FT) are placed in switching stations and measurement nodes. The terminals measure voltage and optionally current in all operational states. Bus bars, selected lines and generator outputs are usual places of measurement. Measured data are transferred to the central computer by 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 another applications for user processing. Examples of consequent applications can be e.g. dispatcher system, estimation and network status calculation programs, network stability analysis etc. Archive data for analysis of network behavior are also available.

Properties of phasor systems

Properties of phasors measurements are dependent on the character of data consuming applications. Differences consist above all in frequency of measurement, where frequency of 1 measurement per 1 – 10 s is suitable for steady state of network while analysis of network dynamics requires 10 – 60 measurements per second.

Samples measured in "time window" are used for evaluation of phasors in terminals. The window size is set to 1 or more periods. Thus the measured phasor represents the measured quantity during the time of the window.

Power network consists of large amount of inertia elements (rotating parts of engines), thus the time window enlargement can improve exactness of measurement. This, on contrary, reduces the ability to capture quick dynamic processes. The window size is usually set to 1 – 2 periods of nominal frequency.

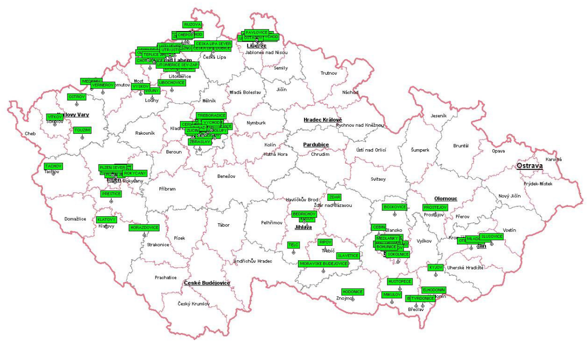
Exactness of entire measurement is affected by exactness of synchronization (GPS), measuring method (algorithm, window, sampling), measuring current transformers, analog inputs of terminal. Average exactness of 0.1° between individual measurements can be achieved by matching of individual influences.

Communication subsystem represents important part of the entire system. Communication subsystem has to transfer data from terminals to central computer in reasonable time even in case of dynamic measurements to ensure early data availability.

Mobile measuring terminals are also available. Mobile terminals can be used for analysis of actual problems. Data from mobile terminals can be used stand-alone or together with the data from fixed terminals.

Phasor measurement in Czech Republic

System FOTEL for measurement of synchronous phasors is used in certain distribution companies in Czech Republic. Phasor measurements in 89 switching stations with the total of 297 nodes are available at the end of 2004. The map shows location of terminals in distribution network:



The system is synchronized by exact time stamp obtained from GPS (Global Positioning System). Measured voltage samples are processed with the result of voltage amplitude and phase in the node. The central computer FOTEL-C (server FOTEL) enables to compare phases from arbitrary nodes and to show difference related to selected reference measurement.

Results can be seen in computers with client software connected to LAN network. Results can be also used for presentation and other computations in consequent information systems, e.g. network analysis system NETAN, estimation and dispatcher systems.

The system consists of:

Measuring terminals FOTEL,

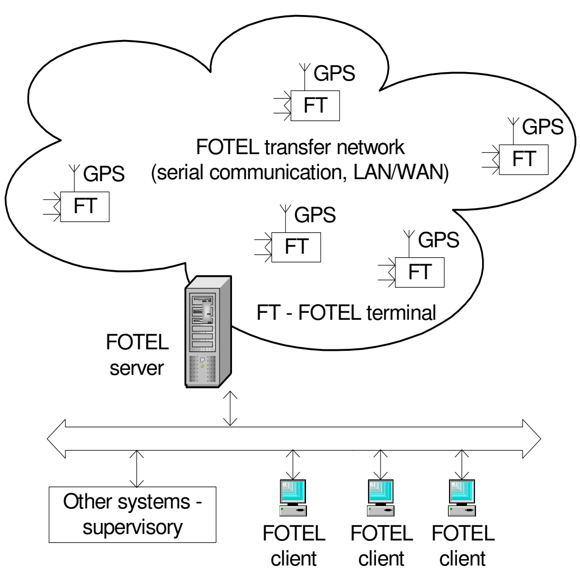
Communication subsystem for data transfer to central computer,

Server FOTEL for data processing and transfer to another systems,

User software for client workstations

Interface for cooperation with other information systems.

FOTEL - system structure

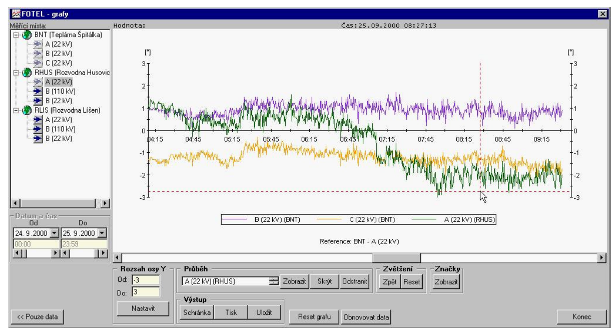


Data presentation in system FOTEL

User software of system FOTEL enables to display and analyze the voltage phase differences between one reference measurement place and one or more other places. Values are arranged in time cuts – 10 sec. phasor snaps. Results can be shown either in tabular form or in form of graphical trends. The measured voltage and number of GPS satellites in the individual place (available and used) can be shown in the same way without selecting the reference place.

User can select the reference place. List of compared measurement places, number of displayed time cuts or time interval of archive data are also user-selectable. Server FOTEL then sends requested data to client workstation according to the preset parameters. Thus various instances of client software in various client workstations can show different sets of data related to different reference places.

Example of graphical trends:



PHASORS APPLICATION IN DISPATCH CONTROL

Check of switching conditions in supply areas

Security of switching in distribution systems is very important for work preparation in power networks or for power restoration after failure. Optimization of switching sequences directly affects reliability of power supply. Phase angle differences in switched nodes represent important parameters for dispatcher decision. System FOTEL enables real time measurement and transfer of these quantities for acceptable cost.

Check of switching conditions represents basic application of phasor measurements. Switching conditions together with estimation enable to determine phase difference between arbitrary nodes of network.

Calculated angles of voltage phasors in all network nodes represent one of estimation results. As the estimation of high voltage network is done according to supply areas, the calculated angles are always related to a reference node of supply area. Phase angles between arbitrary nodes of various supply areas can be obtained by measurement of phasors in supply nodes of the supply areas. These angles are then deducted and result is added to the estimated phase differences.

Estimation of steady state of electrical network

Estimation of steady state requires synchronous measurement. Synchronous phasors represent significant addition to the estimation measurement data set. They can be also used as first iteration of corresponding components of state vector instead of usual zero voltage angles. If the phasors are added then the static estimation of steady state of electrical network requires only small modification of the algorithm of least squares while the estimation results are more exact and reliable.
Phase angle can replace existing power measurement in the estimation algorithm, thus data transfer and communication channel can be saved. However, measurements of power are important for identifications of measurement errors. That's why it is not possible to measure only phasors and to calculate all other quantities, although it would be enough for the entire system description if there were no big measurement errors.
First experience shows that positive effect of phasor measurements to the estimation results increases if number of these measurements is increased.

Extension of estimation to adjacent parts of medium voltage network

If extension of estimation to adjacent parts of medium voltage network is required then the usage of voltage and current phasor measurement seems to be economic solution. Phase measurement can replace expensive measurement of active and reactive power, which can be calculated according to the network equations. It also means saving of telecommunication paths because of reduced requirements to data transfer.
Phase measurement terminals have to be placed so that newly measured part of system can be estimated. Method is known how to determine minimum set of measurements suitable for state description of system objects and for acquiring the rest of quantities by calculation.
This procedure can be used in parts of system where usual measurement system of active power, reactive power and currents was not still applied.

Dynamic estimation of system state in real time

Application of synchronous phasors with high sample rate (fractions of second) and consequent new algorithms for dynamic estimation of transient process is very promising. Dynamic estimation of voltage phasor reliably enables to monitor transient processes in real time. Consequent algorithms quickly and effectively enable to react to advancing failure and to perform a corrective action.
Main aim is to prevent the failure from spreading, prevent protection from excessive actions and prevent unwanted dropouts.
Application of phasors in transient process requires more sophisticated data processing because network frequency changes during the process. Synchronous phasors with quick sample rate can provide reliable information about the transient processes in network unlike the common measurements that apply when steady state was achieved.

SPECIFICATION OF ECONOMIC CONTRIBUTIONS

An investment to installation of system of phasor measurements brings benefit to the distribution company. The benefit has to be economically evaluated and compared to the required costs. It's well known that economic evaluation of investments to information and control system is difficult to figure out because of indirect effects. Nevertheless these investments affect the economic results of distribution companies.
Expected effects can be divided in several groups:

- Possibility to reduce power losses and to increase usage of power transfer capacity by more exact knowledge of system obtained by estimations, calculations and effective optimization.
- Increased reliability, decreased time and volume of non-delivered power because of reduced danger of incorrect manipulation, consequent protection actions and outages.
- Decreased time needed to solve a failure because of better knowledge of the system state during manipulations and corrective actions.
- Better possibility to plan and control work in system and better work effectiveness because dispatcher has more information about the system state that are needed for switching in network. Planned outages can be decreased and thus delivered power increased.
- Savings in installation of traditional systems for measurement of active and reactive power. Cheaper terminals for phase measurement can replace these systems.

Unfavorable cases of blackouts or postponed switching can be significantly reduced if dispatcher has information about phase differences in switched nodes and can actively affect them by dispatcher control. Thus, indication of network availability can be increased.

For any questions about referred problems please send an email to authors or at **ais@ais-brno.cz.**

More information is available using the web-page
www.ais-brno.cz.