New Efficiency Monitoring and Control Technology Using Synchrophasors

Antonín Popelka [1], František Vybíralík [2] and Daniel Juřík [3]

[1] AIS, Brno, Czech Republic, e-mail: *popelka@ais.cz*

[2] EEC, Podebrady, Czech Republic, e-mail: *vybiralifra@gmail.com*

[3] AIS, Brno, Czech Republic, e-mail: *jurik@ais.brno*

***Abstract* — In this paper we describe the synchrophasor-based WAM technology particularly with regard to usage in distribution networks. The information contained here comes out from experience with deployment and operation of the WAM system in distribution companies in the Czech Republic.**

Keywords — Wide Area Monitoring, PMU, Synchrophasor.

I. Introduction

The current method of transmission and distribution network operation leads to their full use up to overloading. As a result of this congestion, critical conditions appear more frequently at all voltage levels and also outages can appear in a worst case.

The causes of this are multiple, from economic reasons (reduction of investment, separation of power generation, transmission and distribution etc.) to technical (extensive transmission system, lower behavior predictability of large number of small sources).

Systems based on monitoring of large networks using synchrophasor measurement are known as the Wide Area Monitoring Systems (WAMS – WAM). WAMS together with other bound systems (Wide Area Control - WAC and Wide Area Protection – WAP) allow monitoring and evaluation of operation of interconnected systems in real time and provide global view of the monitored systems. Sometime abbreviation WAMPAC combinating all is used.

II. PHASORS

The definition of phasors, mathematic formalization of the vector error, recommendations for the phasor measurement and definition of communication protocol suitable for transfer of phasor data are defined in IEEE standard C37.118 and in older standard IEEE 1344.

The electric quantities (1. harmonics of voltage and current) are defined by the equation:

$$x(t) = X * \cos(\omega * t + \varphi), \qquad (1)$$

where φ is the angle – rotation of vector in the time $t = 0$. The phasor is vector characterized by amplitude X and angle φ.

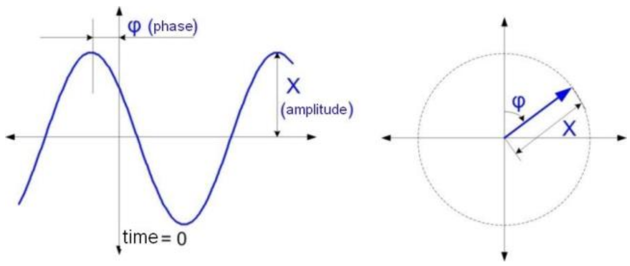

Fig. 1 Phasor representation

Phasors in various network nodes can be measured exactly at the same time using precise time synchronization of the measurement. The set of the phasor data measured synchronously in various places and completed by the time information represents set of absolute synchrophasors.

Using the set of the synchrophasor data, we can analyze the angle between the synchrophasors measured at the same time and change of the synchrophasor angle at a time. It is also possible to select one of the available synchrophasors as the reference measurement with $\varphi_r = 0$ and to relate other measurements to the reference value. In such case we shall get set of the relative synchrophasors with the reference value of a selected measurement.

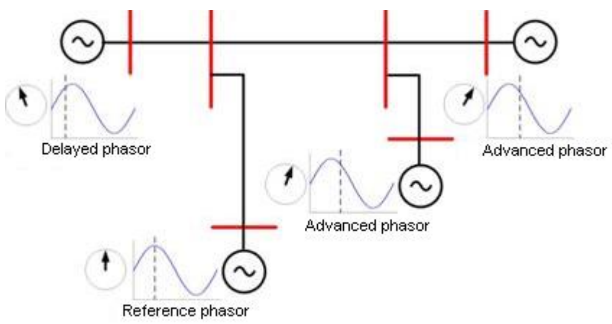

Fig. 2. Snap of relative phasors with reference measurement

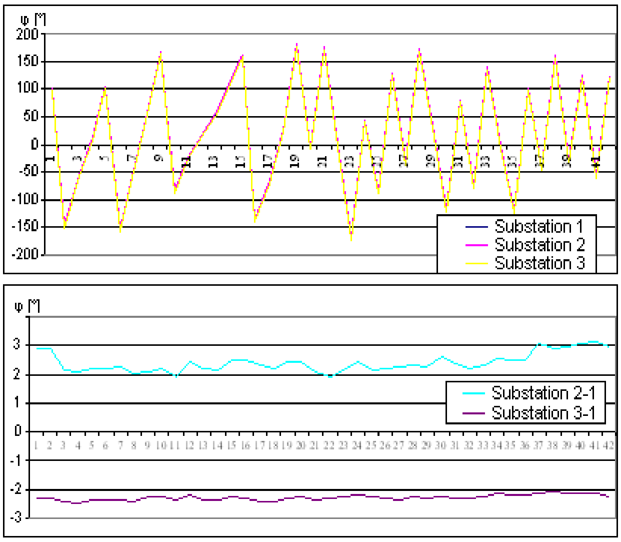

Fig. 1. Sample of synchronous and relative phasors (Substation 1 is selected as reference measurement)

III. MEASUREMENT SYSTEM

The voltage synchrophasors are mostly measured in bus bars or in selected outlets in the electric substation. The current synchrophasors are measured in the outlets.

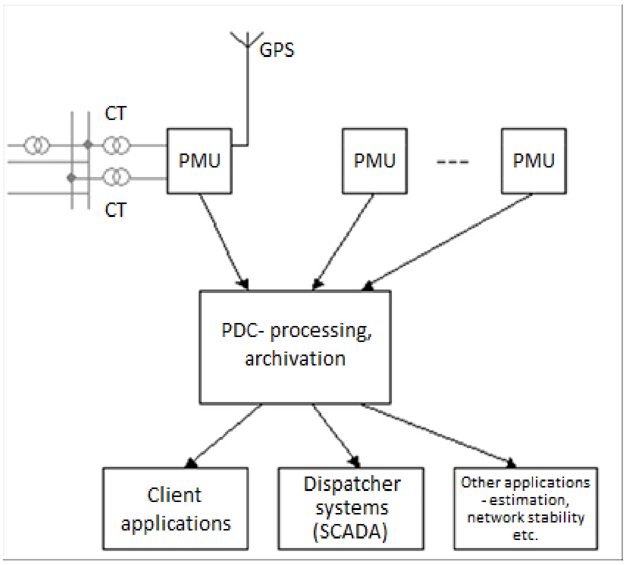

Fig. 2. Structural diagram of synchrophasor system

The synchrophasor systems consist of:

Measurement devices

The phasor measurement devices are in the English literature called Phasor Measurement Units (PMU). The PMU functionality is defined by the IEEE standard.

The measurement of voltage is used in most cases because measurement of current shows a bigger angle error caused by the error of current instrument transformers. Parameters of measurement are defined by the IEEE standard in a wide range what leads to difficulties in comparing results between devices from different manufacturers. The reporting rate ranges from 50 (60) samples per second to 1 sample per second.

Communication infrastructure

Communication between PMU and PDC (Phasor Data Concentrator) significantly affects possibilities and usability of the system. There are very different requirements for various applications namely in the following parameters:

- Delay during data transfer, i.e. time required to get available data for applications (latency)
- Reporting rate
- Amount of data transferred from PMU to PDC

E.g. the delay of data transfer for the application related to protection of wide networks in the real time is required in the range up to tens of milliseconds. The delay of data transfer for the purpose of estimation applications can be in the range of ones of seconds.

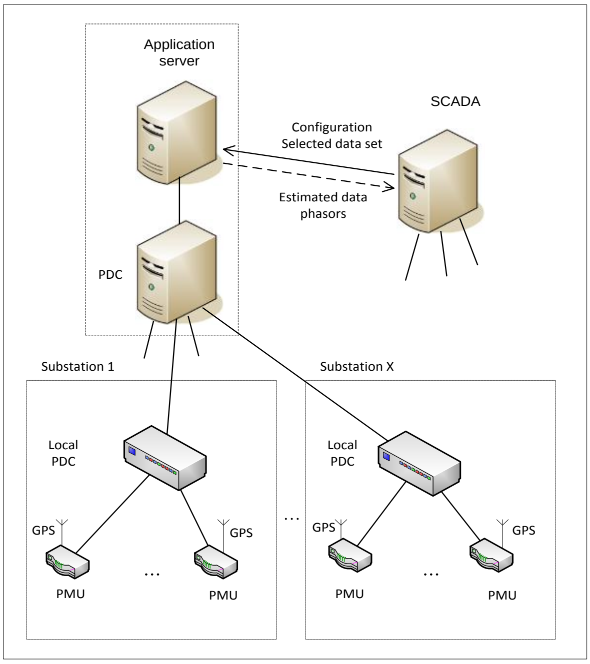

Fig. 3. System with the local PDC

Phasor servers

PDC (Phasor Data Concentrator, phasor server) is represented by a server organizing collection of the data from PMU, data pre-processing and data storage in the database available for related applications.

Suitable structure of the PDC servers (layered and multiplied organization) can assure:

- Integration character of the implemented system, i.e. possibility to integrate various PMU types from different manufacturers

- Distribution of the computing power according to the requirements of various applications (e.g. applications requiring data transfer with a low delay and at the same time no data from other sources can be hosted in the local PDC)
- Possibility to provide data with different quality to various users (e.g. various departments of one company)

- Cooperation (data sharing) with other information systems e.g. SCADA (Supervisory Control And Data Acquisition) or other application programs or systems.

Various requirements for the data processing and amount can be also solved by usage of the local PDC placed directly in the electric substation. The local PDC servers can pre-process and aggregate data and also run selected applications.

IV. PRECISION OF ANGLE MEASUREMENT

Precision of the phasor (precision of the time synchronization, precision of the angle and amplitude) affects possibilities of the phasor usage.

Today PMU achieve accuracy in the angle measuring of about 0.1 degrees. Precision of the measurement is affected by all parts of the measurement chain. The following influences have to be taken into consideration when user requirements are analyzed:

- Voltage and current instrument transformers. The measurement error depends on the accuracy class and transformer load (25 – 100 % of load results in error 2˚ - 0.08˚). Error of the current instrument transformers is significant because measurement is done within the entire transformer range.
- Input circuits with isolation and anti-aliasing filter causes the measurement shift. The shift can be the same for all devices from the same producer in an ideal case and can be compensated in the data processing. Stability of the input circuits has to be ensured.
- The precision of the GPS time synchronization is 20 ns to 500 ns according to the manufacturer's data. Another error can be caused by the transfer and processing of the synchronization pulse. The error of 5.5 µs in time synchronization represents error of 0.1˚ in the phasor measurement.
- The method of analysis affects the quality of measurement mostly for the purposes of comparison with systems from various PMU producers. It represents the sampling frequency, length of measurement window and frequency of processing and data transfer. Algorithms used for calculation of the synchrophasors affect the quality of results from the point of view of dynamics (speed and accuracy of the response time).
- Further parts of the measurement chain (communication subsystem, data processing in PDC, transfer of data to the user) do not affect the quality of data but the delay of data usability. Parameters of these parts of measurement chain affect usability of data in various applications.

The following table shows estimated contribution of the individual components to the overall error:

TABLE I.
CONTRIBUTION TO OVERALL ERROR

Source of error	Angle error	Time error
Time synchronization	± 0,02°	± 1 µs
Primary instrument transformers (accuracy class 0.3)	± 0,3°	± 16,5 µs
Error of measurement devices and error of calculation method	± 0,1°	± 5,5 µs

The systems used in the power process data in a system with different speed:

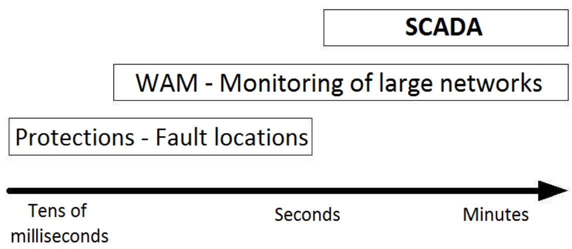

Fig. 6. Requirements for the measurement/communication speed for various systems

V. CONCLUSION

Experience with the WAMS applications raised some important conclusions:

- The WAMS systems in distribution networks will be used for monitoring and control of distributed sources (intermittent sources).
- The WAMS benefits are significantly better if the system covers a bigger scope of interconnected systems, i.e. if the SF measurement is interchanged between individual TSO.
- The WAMS outputs expand the functionality of existing systems of early warning. The WAMS allows detection of potentially critical states and also unstable dynamic states.
- Applications allowing effective usage of the WAMS outputs for the operative dispatch control, i.e. on-line operation represent significant contribution to the present way of control.
- The trend probably leads to the WAMPAC systems that represent one of assumptions of the Smart Grids in the transmission systems. Such systems need more PMU or PMC units.

ACKNOWLEDGMENT

The fundamental works on the synchrophasor measurement and WAMS made prof. Phadke and prof. Thorp, one of later issue of their book is [6]. Many thanks them.

REFERENCES

[1] Böhm V, Popelka A, Sadecký B, 2005, SYNCHRONOUS MEASUREMENT IN ELECTRICAL NETWORKS, CIRED Torino 2005

[2] B.I.Ajujev et al, 2006, IPS/UPS Wide Area Measuring System. Paper C2-211, CIGRÉ 2006 Paris

[3] IEEE Std C37.118-2005, IEEE Standard for Synchrophasor Measurement for Power Systems

[4] IEEE Std C37.118-2011, IEEE Standard for Synchrophasor Measurement for Power Systems

[5] https://www.naspi.org/

[6] Phadke A.G., Thorp J.S., Synchronized Phasor Measurements and Their Applications, Springer, 2008