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Applied Problems of Synchrophasor Measurements

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PMU, WAMS, application, synchronized phasor measurement, network parameters identification.

1 INTRODUCTION

The technology of synchronized phasor measurement of electrical parameters (hereinafter phasor measurement) develops since the beginning of 1990s, but the most significant increase in the number of installed PMUs (Phasor Measurement Unit) and systems based on PMUs is seen in the last five years. As it was noted in various publications [[2]], [[12]], use of phasor measurement practice to solve off-line tasks now is a matured technology and focus of research is being shifted to real time application domain.

Today, application of phasor measurements in Russia appears mostly in the framework of two systems: WAMS itself and Stability Margin Monitoring System (SMMS), which cover totally 38 of UPS (Unified Power System) 330-750 kV objects [3]. In the nearest future, all nuclear stations are additionally planned to be covered with WAMS means and SMMS is planned to cover all Ural Interregional Dispatching Office operational area.

Wide area monitoring and control system architecture based on PMUs (WAMS, WACS, WAMPACS etc.) usually includes several layers:

- PMUs themselves at power objects bays;
- data concentrators (PDC – Phasor Data Concentrators) and, when it is required, SuperPDCs at power objects and intermediate data acquisition centers;
- application layer at the dispatching control centers.

Herein, PMUs, as a rule, are tailored single purpose devices, data exchange between hierarchy layers is realized using the IEEE C37.118 special protocol based on UDP/IP, which provides high data rates (up to 25 measurements per second according to IEEE C37.118 and up to 50 measurements per second in a practical realization of SMMS).

Thus, it is possible to state the following preliminary considerations based on results of phasor measurement technology development:

1. Existing standards and technical solutions are justified and designed for operational and – in a future, automatic control of power system.
2. Currently, wide area monitoring and control systems are being developed independently and virtually have no interfaces to other automation systems. Traditional SCADA systems and WAMS duplicate each other to a certain extent. Phasor measurement data and their processing results are not used by companies, providing maintenance of power networks and generation objects, and existing SCADA systems are not adopted to use phasor measurement technology.
3. Distributed monitoring and control systems novelty and autonomy, higher average cost of specialized PMUs compared to traditional measurement IEDs, higher requirements to

communication channel bandwidth, and the specificity of target application obstruct wide application of the said technologies.

At the same time it appears that the capabilities of precise and synchronized measurements of geographically distributed electrical values provided by PMUs can be effectively used not only in a system-wide management. In [2],[4],[5] and other publications applied topics of phasor measurements were discussed, which can be interesting for transmission and, to a certain extent, for distribution network companies. At that in a number of cases, requirements to a measurement frequency and communication channel bandwidth can be significantly reduced. Multifunctional measuring IEDs and protection terminals with PMU functionality, comparable to traditional devices in terms of cost, have recently appeared on the substation automation system market.

In accordance with the aforesaid, it is reasonable to consider possibility of:

1. using multifunctional intellectual electronic devices as the main source of electrical parameters measurements for substation local control systems, as well as for WAMS, WACS and for traditional SCADA/EMS/DMS systems at dispatching centers;
2. phasor measurement transmission via existing telemetry channels using traditional protocol stacks (i.e. IEC 60870-5-104, DNP 3.0) with 1 to 2 sec cycle. Such transmission will not increase a communication channel load significantly;
3. development of substation control systems, SCADA/EMS/DMS algorithms with regard to the new information usage.

The foresaid is illustrated by the Figure 1. PMU data, as the single source of measurements, are sent to a substation control system and to an optional PDC data concentrator in case of necessity to have high speed data flow from the PMU.

The proposed scheme can be seen as transitional, as it excludes duplication only on the measuring IEDs level.

Along with communication channels bandwidth increase and dispatching center's hardware and software suites adaptation to processing of significant phasor measurement volumes, an implementation of PDC functionality by standard means of substation control system and elimination of data channels duplication can be possible.

In the framework of supposed extension of phasor measurement application area, the coordination of applied synchrophasor control development programs at System operator's and network companies' divisions can be reasonable. Taking this into account, a preliminary applied tasks classification is discussed in the next section.

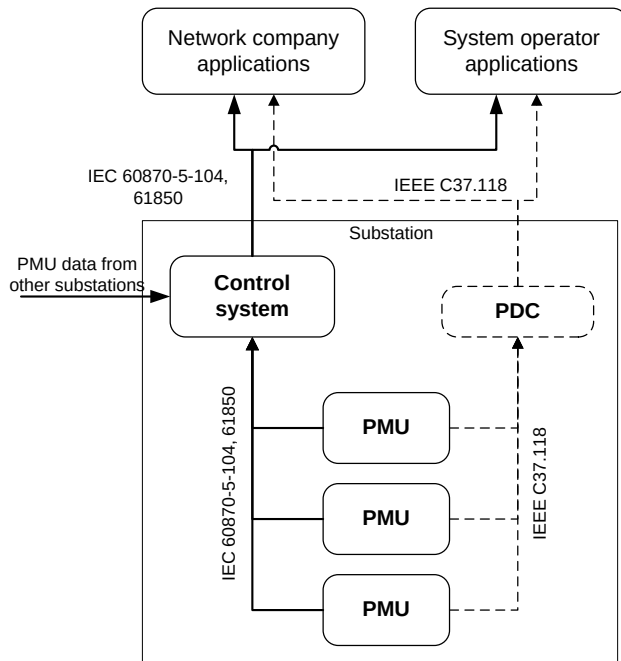


Fig. 1: PMU as a single data source on a substation

2 SYNCHROPHASOR APPLICATION TASKS

Description of possible synchrophasor applications in power system management can be found in [[1]], [[2]], [[5]] and other sources. Applied tasks, mentioned in these sources, and some additional tasks can be structured based on the main business processes of a System operator and/or Network companies:

- operational control (including dispatching control over power systems and technological control over power networks);
- electrical equipment maintenance management;

- planning of market operations.

In the framework of operational control, as the main area of phasor measurements application, the following problem groups can be described:

- basic algorithms of phasor measurement processing, that create a basis for implementation of subsequent control and management algorithms. Besides the network state estimation, algorithms of real-time identification of main substation and power lines equipment equivalent circuits parameters are proposed to be included into this set. This is discussed more comprehensively in the following section;
- provision for situational awareness of operating personnel and company management;
- operational provisions for power supply reliability;
- operational planning of electrical network.

The structured set of applications according to the aforesaid is shown in the Table 1. Additionally, the table includes a preliminary assessment of relevance of corresponding algorithms application for power systems (ISO), transmission networks (TN) and distribution networks (DN) management. Finally, the last column shows qualitative requirements to the necessity of high data rates provision from PMUs. More detailed data acquisition requirements can be found in [11].

Table 1: Proposed classification of management tasks based on phasor measurements

Application tasks	Relevance			Required acquisition rate ¹
	ISO	TN	DN	
Operational control				
Basic measurement processing algorithms				
Identification of network element equivalent circuit parameters	√	√	√	Low
State estimation:				
• data verification and unreliable data substitution on various levels of data acquisition and aggregation	√	√	√	Low
• registration of network topology changes out of the operating control limits (in adjacent power systems, other owners' systems)	√	√	√	Low
• state estimation	√	√	√	Low
Provision of situational awareness				
Mode parameters and network topology visualization and control of limits violation:				
• main frequency deviation	√			High
• inter-area low-frequency oscillation levels	√			High
• static stability margin	√			High
• voltage levels and reactive power margins	√	√	√	Low
• power line thermal limits	√	√	√	Low
• levels of technical power and electricity losses in electrical network elements		√	√	Low
Fault location				High
Operational network reliability provision				
Inter-area low-frequency oscillations analysis and damping	√			High
Automated real time control of active power equipment	√	√	√	High
Monitoring and balancing of intermittent power generation	√			High
Frequency and voltage sensitive load management	√	√	√	High
Planned power system separation and restoration	√			High
Adaptive protection	√	√	√	High
Operational planning				
Post disturbance analysis	√	√	√	High
Power system model benchmarking:	√	√	√	
• generator parameters refining	√	√		High
• passive and active power network equipment parameters adjustment	√	√	√	Low

¹ This assessment of requirements is rather rough. High rate corresponds to periods of 20 to 40 ms, Low rate corresponds to periods of seconds to several hours. It is anticipated that in the future requirements will shift to higher values.

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• load behavior analysis and models refining	√	√	√	High
Protection settings adjustment	√	√	√	Low
Equipment maintenance management				
Analysis of power lines and transformer equipment parameters dynamics		√	√	Low
Calculation of transformer ratings change, additional diagnostic methods		√	√	Low
Relay protection commissioning	√	√	√	High
Market operations				
Market operations planning based line ratings	√			Low

By planning rather large-scale implementation of intellectual electronic devices with PMU functionality it seems reasonable to consider using phasor measurement results on all levels of management hierarchy. Additional information about mutual phase angles of electric parameters, being measured in various network points, can be used:

- for different bays of a substation, for example, to provide data redundancy in a case when unreliable data substitution is needed;
- at adjacent substations: for fault location on a connecting power line, for cross-validation of measured parameters on both sides of a power line etc.;
- at regional and territorial divisions in operational management, equipment maintenance management etc.

Figure 2 shows possible distribution of applications through the network or power system management hierarchy levels. This distribution takes into account that ongoing implementation of communication channels between substations creates preconditions for localization of some management task on lower hierarchy levels.

At the conclusion it is appropriate to draw attention to the task of passive and active network elements equivalent circuit parameters identification. This task was discussed in domestic [7] and foreign [[8]], [[9]] publications, but was not considered for the full-scale implementation yet.

3 IDENTIFICATION OF EQUIVALENT CIRCUIT PARAMETERS

Accurate information about state of a controlled object is vitally important, especially during migration to adaptive methods of management in order to utilize resources (e.g., power network capacity) most efficiently. The task of power system state estimation is a key instrument of provision of full and consistent information about network parameters to operating personnel and various automated systems. This task is widely discussed in publications, devoted to analysis of phasor measurements applications.

At the same time, existing implementations of state estimation algorithms, as a rule, are based on assumptions like fixed values of equivalent circuit parameters and steady-state balanced conditions (single-line equivalent circuit). Parameters of equivalent circuit traditionally are derived from rating and design specifications (for example, of a power line) and are not changed during the life cycle of equipment. However, as it was shown in [6], neglect of influence of meteorological and network operating conditions etc., results in possible inaccuracy in determination of equivalent circuit parameters (up to 20 % for resistive and 10 % for inductive reactance, so as up to 30 % for capacitive susceptance). Foreign publications also show inaccuracy assessment on the level of 25-30 % [8]. Taking this into consideration, possibility of dynamic identification of network parameters using phasor measurements can be considered as quite attractive.

One of possible approaches here is the classical analysis of multipoles using known current and voltage phasors, taken for all poles at the same time. A solution of such problem can also be produced using instantaneous current and voltage values, received, for example, from synchronized digital fault recorders (DFR), installed at the different sides of the network element [10]. However, using phasor measurement devices in this case gives clear benefits due to:

- higher synchronization accuracy, which directly influences calculation accuracy. Thus, typical time synchronization accuracy for DFR is about 1 ms, while this parameter for phasor measurement devices is less than 5 μ s;

- better responsiveness (data for calculation are presented with required periodicity, not only when DFR trips);
- less load on data communication channels.

As it was shown in [7], calculation inaccuracy when calculating equivalent circuit parameters using synchronized phasor measurements is about 1-2 %, which is comparable to mode parameters measurement inaccuracy² and can significantly improve state assessment precision.

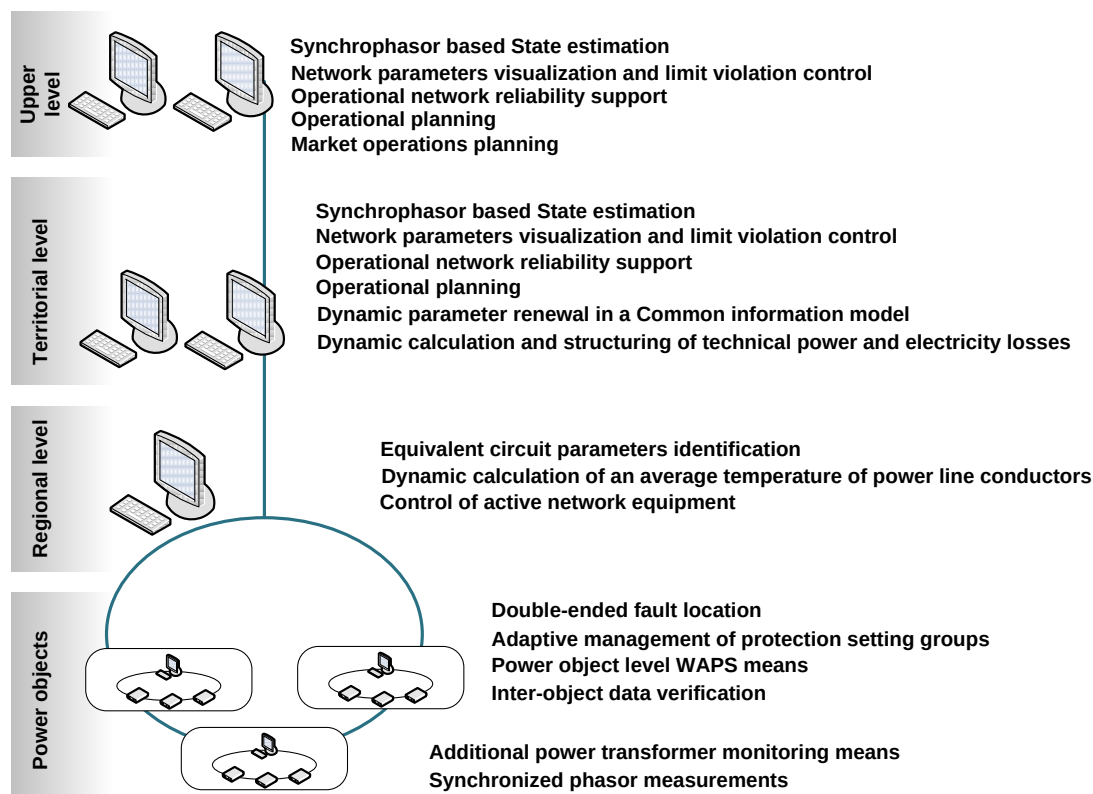


Fig. 2: An example of task distribution through management hierarchy

Possibility to define equivalent circuit parameters separately for each phase adds extra value to dynamic parameter identification, and creates preconditions for state estimation, load flow calculation etc., using real unbalanced equipment.

Thus, it seems that traditional approach to state estimation could be extended with dynamic equivalent circuit parameters estimation based on incoming phasor measurements. Required periodicity of network parameters identification can be defined based on practical considerations and, by preliminary estimation, can vary from several minutes to several hours. It is expedient to keep equivalent circuit parameters database both for various operating management scenarios evaluation and for equipment maintenance management.

Additional use of parameters dynamics is intended in applications, noted in the previous section, such as:

- control of average temperature of power line conductors;
- additional equipment monitoring algorithms;
- electricity technical losses structuring;
- fault location;
- protection settings adjustment etc

Taking into account practical significance of the equivalent circuit parameters identification, RTSoft experts performed an experimental assessment of power line parameters identification algorithm which uses one instantaneous set of phasor parameters. Experiments were performed based

² Using instrument transformers with accuracy at least 0,5.

on physical model of a power line, built by chair of Relay Protection and Automation of the Moscow Power Engineering Institute using MIP-02 multifunctional IEDs. Experimental results are shown in the Table 2, which includes rated and calculated parameter values and corresponding measurement errors. Calculated values were received by averaging of 50 measurements made within 1 s. The last table row shows standard deviation for all sets of parameters.

The results confirm practicability of dynamic parameter identification. Additional researches are required to define origin of the maximal error of active resistance measurement. Other sources [7] also noted increased level of active resistance measurement errors compared to other parameters.

Table 1: Results of power line parameters identification

Phase	Parameter	R (Ohm)		Parameter	L (H)		Parameter	C (μF)	
		Calc. value	Error %		Calc. value	Error %		Calc. value	Error %
Phase A	29	29,723	2,4938	0,15	0,1498	0,136	0,36	0,367	1,934
Phase B		29,641	2,2112		0,1498	0,1483		0,3731	3,6339
Phase C		29,879	3,0325		0,1516	1,0598		0,3699	2,758
Phase A	33	34,299	3,9362	0,3	0,3026	0,8729	0,8	0,8052	0,6451
Phase B		34,256	3,8061		0,2977	0,7693		0,8204	2,5483
Phase C		34,651	5,0041		0,2978	0,7208		0,8052	0,6462
Phase A	37	39,073	5,6022	0,45	0,452	0,4354	1,16	1,176	1,3766
Phase B		39,053	5,5486		0,4486	0,3027		1,186	2,2439
Phase C		39,511	6,7868		0,4508	0,1777		1,1663	0,5417
Phase A	37	38,933	5,2248	0,45	0,4518	0,3944	0,36	0,3623	0,6437
Phase B		39,158	5,832		0,4483	0,3687		0,3691	2,538
Phase C		39,433	6,5755		0,451	0,2113		0,3597	0,0718
			4,9			0,555			1,958

4 CONCLUSION

This publication discusses current development state of synchrophasor measurement technology. Proposals are made to expand phasor measurements application area, for example, for network management tasks and to define possible classification of applications. Practicability of developing applications based on identification of equivalent circuit parameters of power network elements is pointed out, experimental proof of applicability of power line parameters identification algorithm is shown.

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