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Decomposition algorithm for power system state estimation by the test equation technique and its implementation on the basis of multi-agent approach

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Abstract **-- State estimation in the modern power systems of large dimensionality is a sophisticated problem which is accompanied by the difficulties related to inhomogeneity of the calculated schemes, a large volume of information to be processed and the requirement for high-speed software. Distributed data processing in decomposition of the state estimation problem is an efficient method of tackling the difficulties.**

The paper addresses decomposition algorithm of state estimation by the test equation technique. The algorithm is based on the structural and functional decomposition of state estimation problem. The structural decomposition suggests dividing the calculated schemes into subsystems. A two-level algorithm is proposed to divide the calculated network into subsystems. Application of the test equation technique which makes it possible to fix the values of measured variables and set zero variances for them, as well as placement of Phasor Measurement Units (PMU) at boundary nodes make it possible to essentially simplify the procedure of coordinating the solutions obtained for separate subsystems. The functional decomposition is performed in accordance with the problems solved within state estimation: a priory detection of bad data, state estimation on the basis of quadratic and robust criteria.

The multiagent system proposed to implement the suggested state estimation algorithm is described. The example of calculating the estimates while dividing the calculated scheme into subsystems with PMU placed at boundary nodes is presented.

I. INTRODUCTION

The market environment, where a great number of independent subjects in the energy sector operate jointly within a single system but pursue their own interests, calls for changes in the requirements for mathematical modeling of Russia's UES, its power interconnections and power systems.

Currently the System Operator - Central Dispatching Office of Russia's UES is creating a single computational model, that reflects most completely the topology and operation of UES, to solve a set of online dispatching control problems instead of previous models that varied in degree of detail and were applied to solve individual problems.

The single computational model of UES/RPS covers the entire backbone network of 220 kV and higher; the lines of lower voltage classes, that are important for market participants in terms of correct description of power supply volumes, boundaries of federal network company, interstate power flows, electricity outputs of power plants; and power plants with an installed capacity above 5 MW and large consumption nodes [1]. Currently the single computational model includes about 7000 nodes, 10000 branches and 800 generators.

Similar situation is observed in the dispatching practices in other countries. Creation of Western European Power Pool (UCTE), North American Council for Reliability (NERC) that embraces most of the North-American power systems, etc. has lead to the necessity to make calculations for very large and sophisticated systems.

State estimation (SE) of electric power systems is an important procedure that allows on-line calculation of state variables for a current scheme of electric network on the basis of teleinformation. The obtained calculated model of power system is then used to solve various technological problems to effectively control electric power system.

In doing so the necessity arises to calculate load flows for the schemes of large dimensionality (several thousands of nodes). The calculations for a large system encounter the problems related to the inhomogeneity of calculated schemes, large volumes of uneven information to be processed and the requirement for high speed software.

Besides, the need for online state estimation of such systems increases the burden on the available computing resources in the EPS Control Center.

The distributed processing of data in decomposition of the state estimation problem is an effective method of solving these problems. Decomposition of power system state estimation problem is addressed in a great number of scientific papers in Russia [2,3] and other countries [4-6 and others].

Distributed SE includes the following main procedures: 1) decomposition of the entire calculated scheme into subsystems (local areas), 2) state estimation for each local area using available local area measurements, 3) solving a coordination problem to coordinate the SE results obtained for individual areas, 4) aggregation of calculation results for individual subsystems and transfer of aggregated data to the Control Center.

Until recently state estimation in EPS was mainly based on the SCADA system measurements: voltage magnitudes, branch power flow, nodal power injections and, occasionally, current magnitudes. The advent of WAMS (Wide-Area Measurement System) that contains phasor measurement units (PMU) as the main measurement equipment [7] makes it possible to control the EPS state synchronously and accurately, and

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improve essentially the results of state estimation [8]. The use of PMU measurements offers new possibilities in decomposition of the state estimation problem. The possibilities of using synchronized phasor measurements for distributed state estimation were discussed in [9-12 and others]. In [9] the method is suggested to decompose the calculated scheme into the areas with PMU to be installed in each area. The data from these PMU are then used to solve a coordination problem. In [10] the authors suggest placing PMU at a basic node of each area. The PMU measurements coordinate the SE problem solution of each area. [11] presents a diakoptic-based distributed SE algorithm, in which PMUs are used to coordinate voltage angles of each area SE solution. In [12] authors of this paper offer an algorithm to decompose the calculated scheme into the areas that consist of the nodes of the same voltage class, with PMU to be installed at boundary nodes. This decomposition method decreases essentially the negative impact of inhomogeneity of the calculated scheme and telemetry, and the PMU data considerably simplify solving the coordination problem. For complex schemes, however, the method inevitably leads to a great number of boundary nodes. Therefore the present work suggests a two-stage algorithm to decompose the calculated scheme into subsystems, that combines the advantages of both approaches.

The paper considers the algorithm of state estimation by the test equation technique [4] that employs structural decomposition of state estimation problem, i.e. division of the calculated scheme into subsystems, and functional decomposition of the SE problem (detection of bad data, state estimation on the basis of quadratic and robust criteria). The two-level algorithm is proposed to divide the calculated scheme into subsystems for state estimation by the test equation technique. Application of the test equation technique, that allows one to fix the values of measured variables by setting zero variances for them, and placement of Phasor Measurements Units at boundary nodes [5] make it possible to essentially simplify the procedure of coordinating the solutions obtained for separate subsystems.

One of possible approaches to implementation of the decomposition algorithm of the power system state estimation is application of multi-agent (MA) technologies [13].

The paper consists of 6 sections. The first section is an introduction into the problem. The second section describes the decomposition of state estimation problem and decomposition techniques. The third section presents a multi-agent system developed to implement the decomposition algorithm of SE, the fourth section describes the complete algorithm for state estimation of EPS on the basis of multi-agent system. The fifth section gives an example of the algorithm operation for a real scheme of EPS and in the end the sixth section presents the conclusions made.

II. DECOMPOSITION OF SE PROBLEM

A multi-agent approach to EPS state estimation is based on the structural (by subsystems) and functional (by the problems solved) decomposition of the SE problem. The structural decomposition is made by dividing the calculated scheme into subsystems by one or another method [12]. The functional decomposition is made in accordance with the problems solved within SE. The main of them are: analysis of network topology (formation of current calculated scheme); analysis of observability; analysis of bad data; calculation of estimates and calculation of steady state with regard to the estimates obtained.

A. Methods of structural decomposition.

The calculated scheme can be divided into subsystems by the following techniques: decomposition utilizing geographical characteristics [3,14], decomposition by boundary nodes [2,4], by tie-lines [2,3,15], based on the structure of gain matrix [16], by Danzig-Wolf decomposition algorithm [17] and others.

The main algorithms of SE problem decomposition suggest dividing the calculated scheme into subsystems whose boundaries are either nodes or branches. In this case the SE problem is solved iteratively unless the boundary conditions are met.

1. The boundaries of subsystem are nodes

Here the equality of voltage magnitudes and phases at the boundary nodes should be met [2]:

$$U_i = U_j = \ldots = U_k\,; \tag{1}$$

$$\delta_i = \delta_j = \ldots = \delta_k\,; \tag{2}$$

Besides the boundary balance relationships should be met. For example for boundary node 1, common for the i, j, …, k-th subsystems

$$P_l + \sum_{s=i,j,\ldots,k} \sum_{m\in\omega_s} P_{lm}(U_l,\delta_l,U_m,\delta_m) = 0\,; \tag{3}$$

$$Q_l + \sum_{s=i,j,\ldots,k} \sum_{m\in\omega_s} Q_{lm}(U_l,\delta_l,U_m,\delta_m) = 0\,, \tag{4}$$

where ω_s - a set of nodes of the s-th subsystem, that are adjacent to the l-the node.

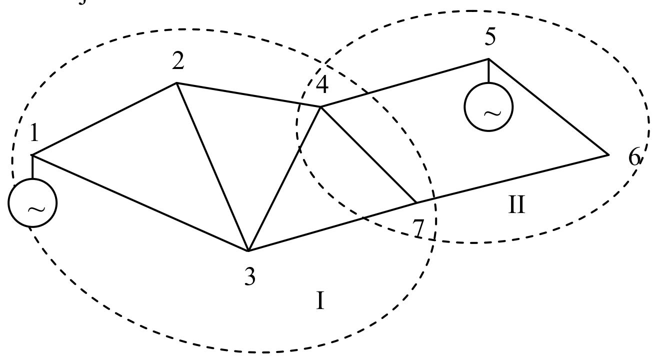

Fig.1. An example of the calculated scheme division into subsystems with boundary nodes

2. The boundaries of subsystem are branches

Here a boundary condition should be met for the flows of active and reactive power [2]:

$$P_{ij}(x_i,x_j) = -P_{ji}(x_i,x_j)\,; \tag{5}$$

$$Q_{ij}(x_i,x_j) = -Q_{ji}(x_i,x_j)\,, \tag{6}$$

Where P_{ij} and Q_{ij} - vectors of power flows from the i-th subsystem to the j-th one in the cutset at one of the nodes.

For the boundary tie line m-l

$$U_m^2 - (U_l - \frac{P_{ml}r_{ml} + Q_{ml}x_{ml}}{U_m})^2 - (\frac{P_{ml}x_{ml} - Q_{ml}r_{ml}}{U_m})^2 = 0; \quad (7)$$

$$\delta_m - \delta_l - arctg\frac{P_{ml}x_{ml} - Q_{ml}r_{ml}}{P_{ml}r_{ml} + Q_{ml}x_{ml}} = 0. \quad (8)$$

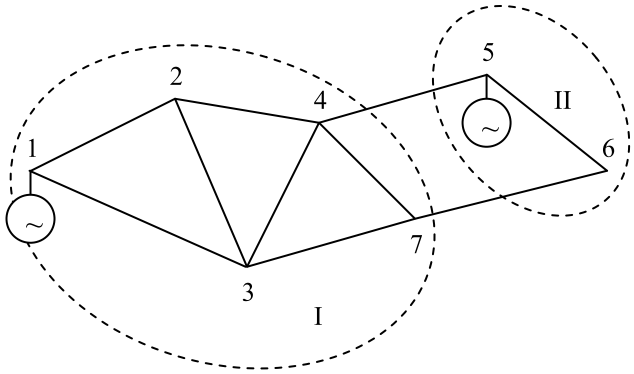

Fig.2. An example of the calculated scheme division with boundary branches

B. Using of PMU data in structural decomposition.

Development and improvement of software for monitoring and control of power systems on a qualitatively new level have become possible owing to WAMS (Wide-Area Measurement System) that allows the EPS state to be controlled synchronously and accurately. The devices for measuring phasors (Phasor Measurement Units) are the basic measurement equipment in this system.

The results of solving the state estimation problem can be essentially improved by using the PMU data. As compared to the standard set of measurements received from SCADA system PMUs placed at a node provide accurate (the error is 0.2-0.5%) measurements of voltage magnitude and phase at this node as well as the magnitudes and phases of currents in the branches adjacent to this node.

PMUs are placed in EPS according to the criteria determined by the conditions of the problem stated [18]. However, this number of PMUs may turn out to be insufficient to solve other problems. Then the so called calculated PMUs [7] are additionally set at the nodes neighboring the real (originally placed) PMU. The voltage magnitudes and phases at these nodes are calculated on the basis of real PMU measurements.

The paper suggests the use of PMU measurements for distributed state estimation to coordinate the solutions obtained for individual areas. If decomposition of the calculated scheme is made by boundary nodes PMUs are placed at these nodes. If the boundaries of subsystems are branches a real PMU is placed on one end of the branch and the calculated one - on the other. As was shown in [7] the accuracy of calculated voltage magnitudes and phases is virtually the same as that of the real PMU measurements.

Placement of PMU at boundary nodes makes it possible to register boundary variables U and δ measured highly accurately. In this case the operating conditions of some subsystems can be calculated independently of one another and solution of the coordinated problem consists in calculating nodal injections by (3) (4) using the estimates of power flows.

C. Algorithm of structural decomposition using test equations.

The idea of decomposing the state estimation problem with PMU placement at boundary nodes is rather attractive. In reality, however, due to high cost of PMU they can only be used when the number of boundary nodes is small.

To calculate large inhomogeneous schemes the authors propose a method of dividing the calculated scheme with respect to voltage levels [12]. This method decreases essentially a negative impact of inhomogeneity of calculated scheme and telemetric information in calculation of subsystems of one voltage class but for the complex scheme inevitably leads to a large number of boundary nodes. Therefore, the paper proposes a two-stage algorithm to decompose the calculated scheme into subsystems, that combines the positive properties of both approaches.

At the first stage the scheme is divided into rather large areas with minimum number of intersystem ties and boundary nodes. This decomposition can be made on the basis of administrative division, for example, the entire scheme of Russia's UES is decomposed into regional power subsystems of large regions in the country that operate in parallel or it can be decomposed artificially into separate areas by special algorithms [3]. PMUs are placed at the boundary nodes of the areas. Highly accurate measurements obtained from PMU make it possible to register the values of magnitudes and phases of nodal voltages at the boundary nodes and make calculations for the areas in parallel.

At the second stage the calculated scheme of each area in turn is divided into subsystems that correspond to the levels of nodal voltages. The calculations start with the subsystem of the highest voltage level (750-500 kV). Normally this part of the scheme is well provided with highly accurate telemetry and contains a basic node. Then the calculations are made successively for the rest of the subsystems. The subsystems are ranked by voltage levels (220 kV, 110 kV, etc.). Every time the node bordering the subsystem of higher voltage level is chosen as a basic one.

After the calculation of the low level subsystems a coordination problem is solved for all areas. In this case boundary conditions (1), (2) met automatically, and the coordination problem implies calculation of nodal injections at the boundary nodes on the basis of power flow estimates obtained for each area (formulas (3) and (4)).

D. Functional decomposition.

The functional decomposition of the SE problem is performed in accordance with the problems solved within state estimation. The main of them are: analysis of network topology; analysis of observability; analysis of bad data; calculation of estimates and steady state by the estimates obtained.

The current calculated scheme is formed for the entire scheme. Bad data analysis and calculation of estimates and steady state is performed by the test equation technique for each subsystem of a certain voltage class before solving the state estimation problem [8].

State estimation is made by two criteria: the method of weighted least squares and the robust criterion, that allows the estimates to be obtained and bad data to be suppressed simultaneously.

Control is transferred to one or another state estimation program depending on operation of the bad data detection program. In case of bad data detection or their absence the program for calculation of estimates operates on the basis of the least squares method. However, if it is impossible to detect erroneous measurements and, hence, identify bad data the program operates on the basis of the robust criterion [19]. State estimation is made starting from the upper level of the structural decomposition.

III. MULTI-AGENT SYSTEMS AND THEIR APPLICATION FOR STATE ESTIMATION

Multi-agent systems (MAS) and multi-agent technologies that employ them [13] are a comparatively new area related to the methods of distributed artificial intelligence. The main notion in the multi-agent system is *agent*.

MAS can be defined as a network of agents that work together to solve the problems that are impossible for an individual agent to solve. The agents exchange information and coordinate their actions through an agent-coordinator.

The multi-agent approach to the power system state estimation is based on the structural (by subsystems) and functional (by the problems solved) decomposition of state estimation problem.

For each agent the subsystem of a certain voltage class is used as an object to be modeled. The paper addresses two state estimation problems: - analysis of bad data and calculation of estimates by two criteria: the method of weighted least squares and the robust criterion that allows one to simultaneously obtain estimates and suppress bad data. Each of the problems is solved using individual agents of each subsystem, i.e. for example the agent of the *i*-th subsystem of the *j*-th voltage level MAS_{ij} itself represents some local multi-agent system the consists of the agents of subproblems - $MAS_{ij} = \{A_{BD}, A_{SQ}, A_R\}$. Transfer of control to one or another state estimation agent is performed depending on the operation results of A_{BD}.

To implement the algorithm of state estimation by the test equation technique a multi-agent system has been developed on the basis of multi-agent technologies (Fig.3).

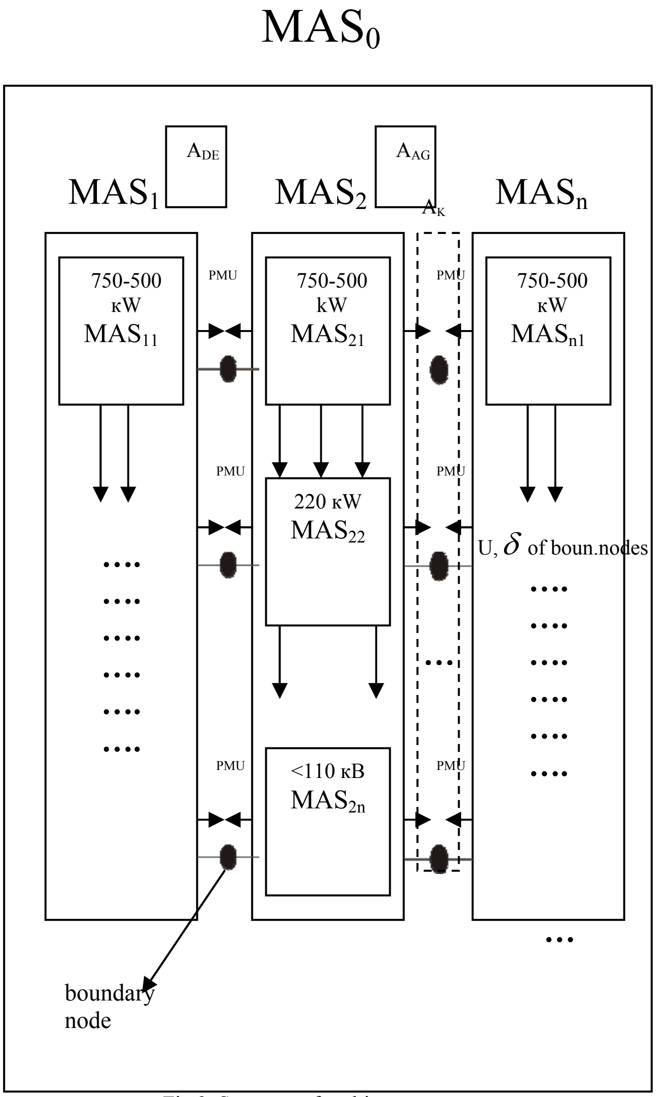

Fig.3. Structure of multi-agent system

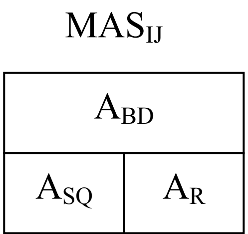

Fig 4. Structure of MAS_{ij} agent

Functionality of agents:

MAS_0 – a common MAS, that contains all subsystems and all agents.

A_{DE} – a decomposition agent, that makes decomposition of the calculated scheme into subsystems by voltage level;

A_{AG} – an aggregation agent, that makes aggregation of data obtained by the agent-coordinator in individual subsystems;

MASi , i=1,…,n – a MAS, that makes state estimation for the i-th area of the first level of decomposition.

MAS_{IJ} – an agent of subsystem of the j-th voltage level (Fig.4) that transfers the values of voltages and phase angles at its boundary nodes to a lower level. It contains a local multi-agent system that consists of three agents:

A_{BD} – an agent of bad data that detects bad data and, depending on results of its operation, starts either agent A_{SQ} or agent A_R;

A_{SQ} – an agent of state estimation by the least squares method is started by the agent A_{BD} if bad data are found or there are no bad data;

A_R – an agent of state estimation in accordance with the robust criterion. It is started by the agent A_{BD} if it is impossible to identify bad data.

A_K – an agent-coordinator that coordinates the calculations of individual subsystems and calculates active and reactive powers at boundary nodes.

IV. FULL ALGORITHM

The entire algorithm for solving the state estimation problem based on structural and functional decomposition is as follows.

1. The complete calculated scheme of EPS is decomposed into rather large areas. Phasor measurement units are placed at the boundary nodes of the subsystems. In the subsystems that do not have a basic node of the complete scheme one of the boundary nodes with PMU of the highest voltage class is chosen as a basic one. Measurements of nodal injections at boundary nodes are excluded from the vector of measurements.
2. At the second stage of decomposition the calculated scheme of each area is divided into subsystems that correspond to the levels of nodal voltages. The boundaries of the subsystems are the nodes adjacent to the nodes of the voltage class of this subsystem. For example for the 750-500 kV voltage class subsystem the nodes with the voltage of 220 kV are boundary nodes and vice-versa.
3. The calculation starts with the subsystem of the highest voltage level (750-500 kV) for each subsystem. Normally this part of the scheme is well provided with highly accurate measurements and contains a basic node. The state estimation algorithm for subsystems with boundary nodes is implemented on the basis of MAS and is as follows:

3.1. For each subsystem that contains boundary nodes the agent A_{BD} is used to solve the problem of bad data detection by the test equation technique.

3.2. In the event that erroneous measurements can not be detected and hence it is impossible to detect bad data, the agent A_{BD} transfers control to the agent A_R for state estimation by the robust criterion (bad data suppression).

4. The rest of the subsystems in the scheme are successively calculated. They are ranked by voltage level (220 kV, 110 kV, etc.). Every time the node bordering the subsystem of higher voltage level is chosen as a basic node. The estimates of the boundary variables of the state vector that are obtained at the upper level of decomposition are registered.
5. The agent-coordinator is used to calculate the injections at boundary nodes between the subsystems of different voltage class.
6. After the calculation of all subsystems of the first level of decomposition has been finished similar problem is solved for the boundary nodes with PMU.

V. CALCULATION EXAMPLE

Application of the algorithm will be illustrated on a fragment of the real scheme (fig.5). The scheme consists of 15 nodes of the voltage 500 kV, 220 kV and 110 kV and 26 tie lines. All the measurements in lines that do not connect the nodes belonging to the scheme will be considered to be load powers.

The scheme was divided into three subsystems corresponding to the voltage levels 500, 220 and 110 kV. PMUs were installed at boundary nodes.

The subsystem of the upper voltage level is modeled by the agent MAS_{11} and includes 500 kV nodes 14 and 889 and boundary nodes 8, 9, 888. Node 889 is a basic node for the entire scheme.

The second subsystem is modeled by the agent MAS_{12} and includes 220 kV nodes 7 and 54 and boundary nodes 8 and 55.

The rest of the 110 kV nodes belong to the third subsystem which is modeled by the agent MAS_{13}. The boundary nodes in this subsystem are nodes 9, 8, 889 and 55.

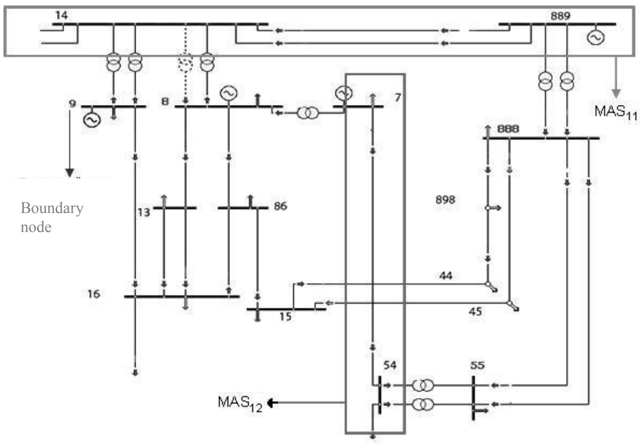

Fig 5. Test scheme

The state of the complete scheme that was obtained based on real measurements was taken as a reference state for calculations. In the calculations of subsystems the PMU measurements were taken equal to reference values and the SCADA measurements were modeled by introducing an error in the reference values.

The state of the complete scheme that was obtained based on real measurements was taken as a reference state for calculations. In the calculations of subsystems the PMU measurements were taken equal to reference values and the SCADA measurements were modeled by introducing an error in the reference values.

According to the decomposition method suggested in the paper in order to solve coordination problem without iteration it is necessary to place PMUs at the nodes of subsystems. However, since PMU placed at a node allows one to calculate accurate values of voltage magnitudes and phases in adjacent nodes in our case study it is enough to place PMUs at three nodes: 9, 8 and 888 or 55. PMUs were placed at nodes 9, 8 and 55 which provided each subsystem with a PMU, and at node 888 the values of *U,δ* were calculated. As the calculations show the accuracy of calculated values *U, δ* is practically the same as that of the values measured by PMU. Nodes 8 and 55 were taken as reference nodes for the second and third subsystems.

Table 1 presents the calculation results of the state vector that were obtained in the reference state and in the calculations of subsystems. The boundary nodes are shown by the bold type.

Table 1. The calculation results for subsystems

N	Reference state		MAS0		MAS1		MAS2		ΔU	$\Delta\delta$
	U	δ	U	δ	U	δ	U	δ		
7	230.3	0.92			230.0	0.9			0.3	0.02
8	**118.4**	**-0.8**	**118.4**	**-0.8**	**118.4**	**-0.8**	**118.4**	**-0.8**		
9	**118.9**	**-1.04**	**118.9**	**-1.0**			**118.9**	**-1.0**		
13	116.3	-3.0					116.1	-3.2	0.2	0.2
14	507.4	-7.7	508.2	-7.4					0.8	0.3
15	115.8	1.2					114.9	-1.6	0.91	0.4
16	115.9	-2.8					115.6	-2.7	0.3	0.1
44	114.5	-3.7								
45	116.8	-8.22					117.1	-8.0	0.3	0.22
54	220.6	-3.09			220.5	-3.1			0.1	0.01
55	**118.9**	**-8.46**			**118.9**	**-8.5**	**118.9**	**-8.5**		
86	113.9	-6.3					113.9	-6.0	0	0.3
888	**120.0**	**-5.8**	**120.0**	**-5.8**			**120.0**	**-5.8**		
889	516.0	0	516.0	0					0	0
898	116.9	-8.61					116.9	-8.0	0	0.61

The Table shows that the maximum deviation in voltage is 0.91 kV, in phase angle – 0.61 degree. Injections at the boundary nodes were calculated from the estimates of power flows determined for subsystems. . The reference values are given in brackets.

$$P_8 = P_{8-14} + P_{8-13} + P_{8-86} + P_{8-7} = 152 \text{MW (154 MW)};$$

$$P_9 = P_{9-14} + P_{9-16} = 368 \text{ MW (365 MW)};$$

$$P_{888} = P_{888\text{-}889} + P_{888\text{-}898} + P_{888\text{-}45} + P_{888\text{-}55} = -250 \text{ MW (-242 MW)};$$

$$P_{55} = P_{55-54} + P_{55-888} = -124 \text{ MW (-127 MW)};$$

$$Q_8 = Q_{8-14} + Q_{8-13} + Q_{8-86} + Q_{8-7} = -57 \text{ MVar (-58 MVar)};$$

$$Q_9 = Q_{9-14} + Q_{9-16} = 94 \text{ MVar (98 MVar)};$$

$$Q_{888} = Q_{888889} + Q_{888898} + Q_{88845} + Q_{88855} = -68 \text{MVar (-66 MVar)};$$

$$Q_{55} = Q_{55-54} + Q_{55-888} = -36 \text{ MW (-38 MVar)}.$$

The maximum deviation of estimates from the standard is within the measurement accuracy.

Compared to the PMU-based decomposition methods proposed in [9]-[11] the number of PMUs in our case study did not increase, yet made it possible to perform parallel state estimation by subsystems, to solve coordination problem without iteration and obtain an optimal but not pseudo-optimal, as in [9], solution that coincides with the solution for the entire network.

In order to test the efficiency of the suggested decomposition algorithm of state estimation the calculations of a real scheme consisting of 107 nodes and 175 branches were made. The calculations were based on real measurements. The efficiency of the algorithm was assessed by comparing the results of calculations made for subsystems to the results of the calculation made for the entire scheme.

At the first stage the genetic algorithm [20] was used to divide the entire scheme into two subsystems containing 55 and 52 nodes with 6 boundary nodes in which the PMU data (measurements of magnitudes and phases of nodal voltages) were modeled. The calculations of these subsystems were carried out in parallel which reduced the time of solving the SE problem almost twice: from 0.49 s to 0.27 s.

At the second stage of decomposition each of the subsystems in turn was decomposed into three subsystems corresponding to the voltage levels of 500 kV, 220 kV, 110 kV and lower. The calculation of these subsystems according to the above algorithm was made successively, therefore the full time of solution could increase. However, owing to the improved convergence of the iteration processes in the calculation of subsystems of the same voltage class the total time of the calculation for all the three subsystems practically did not change.

More efficient operation of bad data detection algorithm and application of the robust criterion of SE [19] for two of six subsystems improved considerably the results of state estimation: the value of the SE objective function at the point of solution decreased almost by a factor of 6 and the estimates at boundary nodes were noticeably improved.

VI. CONCLUSIONS

1. Structural and functional decomposition of state estimation problem is an effective method to solve the problems arising during calculation of large schemes.
2. The proposed two-level algorithm for structural decomposition of the SE problem allows one to simultaneously process the data for local subsystems of considerably smaller dimensionality; decrease the adverse impact of inhomogeneity of the calculated scheme and telemetric information when calculating one-voltage-class subsystems; essentially simplify solution of the coordination problem which, in this case, does not require iterative calculations by subsystems; and reduce the time for SE problem solving for the entire scheme.
3. Multi-agent system is suggested for implementation of the decomposition algorithm of state estimation.
4. Application of the MA technologies for solving the state estimation problem allows one to 1) simultaneously process the data for local subsystems of considerably smaller dimensionality, 2) coordinate interaction between the problems solved at different levels, 3) organize flexible choice of a method to solve one or another state estimation problem for each subsystem, 4) integrate the methods of artificial intelligence and numerical methods, 5) accelerate the process of measurement processing, and, thus, reduce the time of system state estimation.
5. Simulation calculations as well as the calculation of a real scheme demonstrate the efficiency of the suggested approach to electric power system state estimation.

REFERENCES

[1] B.I. Ayuyev, P.M. Erohin, V.G. Neuymin, E.V. Mashalov, N.G. Shubin, "The Software Complex of Optimal Power Flow Solution for United Power System of Russia in a Competitive Market", in *Proceedings IEEE Power Tech Conference*, St. Petersburg, 2005, Paper 697.

[2] A. Z. Gamm, "Decomposition algorithms for solution of power system state estimation problem", *Electronnoye modelirovanie*, 1983, No.3, pp.63-68. (in Russian)

[3] A.Z. Gamm, Yu.A. Grishin, "Distributed information processing in automated power system control systems", in Proc. V Int. Workshop "Distributed information processing», Novosibirsk, Russia, 1995, pp. 243-247. (in Russian)

[4] K.A. Clements, O.J. Denison, R.J. Ringle, "A multy-area approach to state estimation in power system networks," in *Proc. IEEE Power Eng. Soc. Meeting*, San Francisco, CA, 1972, Paper C72 465-3.

[5] A.A. El-Kleib, J. Nieplocha, H. Singh and D. J. Maratukulam, "A decomposed state estimation technique suitable for parallel processor implementation", *IEEE Transactions on Power Systems*, vol.7, no.3, pp.1088-1097, Aug.1992

[6] S. Iwamoto, M. Kusano, V.H. Quantana, "Hierarchical state estimation using a fast rectangular-coordinate method", *IEEE Transactions on Power Systems*, vol.4, no.3, pp.870-879, Aug.1989

[7] G. Phadke. Synchronized Phasor Measurements. A Historical Overview. in *Proc.IEEE /PES Transmission and Distribution Conference*, 2002, №.1, pp.476-479.

[8] A.Gamm, Y.Grishin, A.Glazunova, I.Kolosok, E.Korkina, "New EPS state estimation algorithms based on the technique of test equations and PMU measurements", in *Proc* of the *International Conference "PowerTech'2007"*, Lausanne, 2007, Paper 256.

[9] L. Zhao and A. Abur, "Multiarea state estimation using synchronized phasor measurements", *IEEE Transactions on Power Systems*, vol.20, no.2, May 2005, pp.611-617.

[10] W. Jiang, V. Vittal and G. T. Heydt, "A Distributed State Estimator Utilizing Synchronized Phasor Measurements", *IEEE Transactions on Power Systems*, vol.22, no.2, May 2007, pp.563-571.

[11] W. Jang, V. Vittal, G.T. Heydt, "Diakoptic state estimation using Phasor Measurements Units", *IEEE Transactions on Power Systems*, vol.23, no.4, pp.1580-1589, Nov. 2008.

[12] A.Z. Gamm, I.N.Kolosok, A.S. Paltsev, "Methods for decomposition of EPS state estimation problem when solving it on the basis of multiagent technologies", *in Scientific Proceedings of Riga Technical University "Power and Electrical Engineering"*, Riga, 2007, pp.205-214.

[13] S.J. Russell and P. Norwig. "Artificial Intelligence. A Modern Approach." Prentice Hall, Englewood Cliffs, New Jersey, 1995.

[14] D.M. Falcao, Wu, and L. Murphy, "Parallel and distributed state estimation", *IEEE Trans. Power Syst.,* vol.10, no. 2, pp. 724 – 730, May 1995.

[15] K. Abdel-Rahman, L. Mill, A. Phadke, J. De La Ree, and Y. Liu, " Internet based wide area information sharing and its roles in power system state estimation", *in Proc. IEEE Power Eng. Soc. Winter Meeting,* vol. 2, 28 Jan. – 1 Feb. 2001, pp. 470 – 475.

[16] Y. Wallach and E. Handschin, "An efficient parallel processing method for power system state estimation", *IEEE Trans. Power App. Syst.,* vol. PAS – 100, no. 1, pp. 4402 – 4406, Nov. 1981.

[17] A.A. El-Keib, J. Nieplocha, H. Singh, and D.J. Maratukulam, "A decomposed state estimation technique suitable for parallel processor implementation", *IEEE Trans. Power Syst.,* vol. 7, no. 3, pp. 1088 – 1097, Aug. 1992.

[18] A.Z. Gamm, I.N.Kolosok, A.M. Glazunova, E.S. Korkina, " PMU Placement Criteria for EPS State Estimation", in *Proceedings of the International Conference DRPT'08*, Nanjing, China, 2008, Paper 525.

[19] A.Z. Gamm, R.A. Zaika, I.N.Kolosok, "Robust methods of EPS state estimation based on the test equations and their software support using genetic algorithms", *Electrichestvo*, 2005, No10, pp.2-8. (in Russian)

[20] I.N.Kolosok, R.A.Zaika, "A genetic algorithm as a means of enhancing the efficiency of information validation methods for the power system control", in Proc. 30 International Conf. "Information technologies in science, education, business and protection of natural resources", Гурзуф, Украина, 2003, pp.145–147.

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