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Research and Improvement of the Reliability of the Multi-agent System

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Abstract

Currently, there are very few platforms, allowing to organize the work of multi-agent systems. It is therefore necessary to develop a methodological approach for the development of multi-agent systems in the field of energy. In previous papers by the authors proposed an approach to the development of multi-agent systems (MAS). Based on this approach, it was developed by MAS «EstateMAS» for distributed state estimation Electric Power Systems. This article will focus on assessing the reliability of the MAC, as well as its testing on real examples.

Keywords: Multi-agent systems, reliability assessment, graph theory, evaluation of EES states, agent scripts.

1. Introduction

Multi-agent technologies are a promising direction for the development of complex adaptive distributed systems of industrial level. Attachments for multi-agent technologies are still tasks of collective robotics, but you can specify a number of other classes of applications for which the multi-agent paradigm is evaluateapplicable, for example, to applications of managers of complex objects, including transport, manufacturing, health and energy [1]. One of the most promising research areas of creating self-restoring energy systems is the development of multi-agent intelligent control systems for different levels of management based on the theory of group management.

Unfortunately, with regard to multi-agent technologies there are no clear methods of development and functioning algorithms. The main achievements in this part are still oriented towards the aspects of theoretical realization, and the number of practical implementations is not very large.

In [2], the authors proposed a methodical approach for constructing multi-agent systems in power engineering. On the basis of this approach, the multi-agent system for estimating the states of the EPS "EstateMAS" was implemented. At the present time, an agent for the decomposition of raw data containing unverified information about the current mode by voltage levels has been developed. Also, the main module and agents for assessing the state, cooperation and aggregation were implemented. To test the correctness of the agents' work, a user interface has been added to them. Prior to the development of MAS "EstateMAS", the task of assessing the state was solved with the help of the "Ocenka" only for individual subsystems (now it has passed to the category of legacy software). In the computer appliance, there was no task of specifying and changing scenarios and operations of decomposition and coordination, which were realized and automated in the MAS "EstateMAS".

Fig. 1 shows the general architecture of the multi-agent system for evaluating the state of EPS. Using the MAC in the decomposition of the state estimation task provides the ability to calculate separate subsystems in parallel from each other, which on systems with a large number of nodes allows to speed up the processing of data, but this requires solving the coordination problem, which can lead to additional iterations of the calculation. Thanks to agent scenarios [3], the user can edit the algorithm, which provides a more flexible approach to solving the problem.
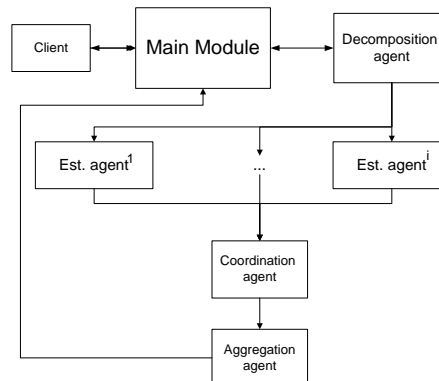

Fig. 1. Architecture of a multi-agent system for estimating the state of EPS.

This article will be devoted to the proposed approach for assessing the reliability of the MAC, as well as approbation of the work of MAS "EstateMAS" on real examples, using two agent scenarios.

2. The proposed approach to assess the reliability of MAC

To operate a multi-agent system, it is necessary that all its components work properly. The failure of one or more agents can affect the speed of the system and completely disable it. The solution to this problem can be the introduction of reserve agents into the system, which can replace the failed ones. Such a solution is effective, but it expends additional power, which can adversely affect the system's performance. Thus, it is necessary to identify critical agents whose failure will lead to maximum damage, and duplicate them.

Brokered MAS [4], DARX [5], Meta-Agent [6] and [7] existing methods for providing fault tolerance of multi-agent systems (MAS) are based on agent redundancy or redundancy of agents and some tasks. Such techniques confirm an increase in the level of reliability of multi-agent systems, that is, a reduction in the number of failures, only experimentally [8]. The authors propose a technique for assessing the reliability of MAS, based on graph theory, which allows in a short time to determine the agents critical for the operation of MAS, without the need to conduct field experiments.

The methodology for assessing the reliability of MCA includes four stages:
1. Construction of the graph of agent interactions.
2. Construction of an adjacency matrix.
3. Determination of the degree of vertices based on the determination of the degrees of approach and outcome.
4. Highlighting the vertices.

This technique is described in more detail in the next section, using examples of numerical experiments.

3. Approbation of MAS "EstateMAS" and evaluation of system operation reliability

Approbation was carried out on the example of the "Moscow Ring" scheme [9], the graphical representation of the scheme is shown in Fig. 2.

The scheme was decomposed by voltage levels. The first group included nodes with voltages from 750 kV and higher, the second group consisted of nodes with voltages from 500 kV and below. Each group also
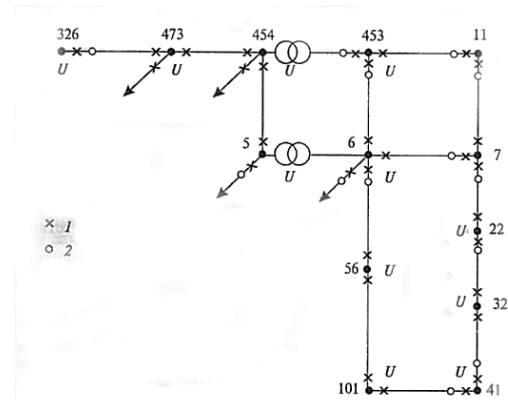

Fig. 2. The scheme "Moscow Ring"

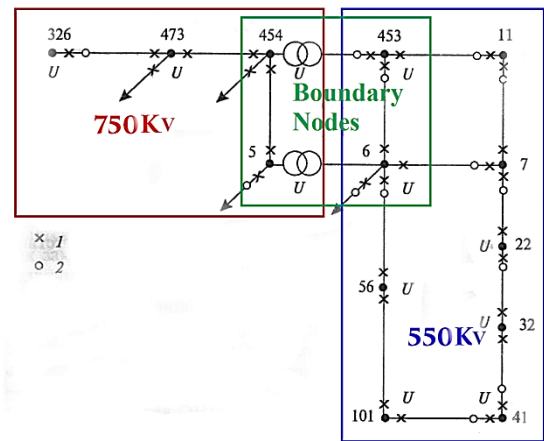has boundary nodes and connections. The decomposition results are shown graphically in Fig. 3.

Fig. 3. The scheme "Moscow Ring" after decomposition.

For comparison, the calculation of the complete scheme and the resulting subsystems is performed. The results of the calculations in the "Ocenka-PC" are shown in Table 1 (the values in the boundary nodes are indicated), where U is the voltage (kV), and δ is the phase angle (in degrees). The problem of coordination of values in boundary nodes was solved, after which the state estimation with the corrected values was repeatedly carried out, therefore the difference between the indices is minimal, does not exceed the error established in the coordination agent.

An agent interaction graph was constructed in which the agents are mapped to vertices: Amm - the main module, Ad - the decomposition agent, Aesi - the state estimation agents, Acoop - the coordination agent, Aagr - the aggregation agent. The vertices are connected by arcs, and the arc from Ai goes to Aj only if agent Ai refers to agent Aj. The resulting graph is shown in Fig. 4.

Table 1. Results of calculations.

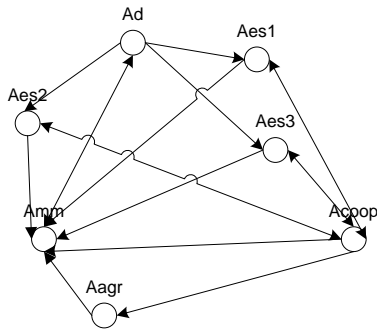| Node №	Measured Voltage kV	Estimated values					
	Full Scheme	Full Scheme		First subsystem		Second subsystem	
		U	δ	U	δ	U	δ
5	**752,7**	**747**	**-5,85**	**746,63**	**-5,42**	**746,65**	**-5,44**
6	**509**	**517,5**	**-7,03**	**517,72**	**-7,71**	**517,8**	**-7,73**
7	500	502	-9,39	-	-	502,41	-8,77
11	500	505	-10,14	-	-	505,34	-9,24
22	500	498	-9,03	-	-	498,055	-9,79
32	500	497	-6,71	-	-	496,775	-6,47
41	500	512	-6,16	-	-	511,595	-6,08
56	500	515	-6	-	-	515,125	-5,36
101	500	515	-6,08	-	-	514,98	-5,84
326	750	741	-11,08	740,64	-10,29	-	-
453	**510,3**	**512**	**-7,06**	**512,045**	**-6,92**	**512,029**	**-6,92**
454	**740**	**740**	**-4,8**	**740,35**	**-4,36**	**740,35**	**-4,36**
473	750	753	-0,01	753,26	-0,04	-	-

Fig. 4. The graph of agent interactions.

We construct the adjacency matrix for this graph (Table 2). Using the properties of the adjacency matrices, one can find the degree of the vertices $P(a) = P_i^+(a) + P_j^-(a)$, where $P_i^+(a)$ is the half-degree of the approach (the indicator of the incoming connections), $P_j^-(a)$ is the half-stage of the outcome.

$$P_i^+(a) = \sum_{j=1}^{m} q_{ij}; \quad P_j^-(a) = \sum_{i=1}^{m} q_{ij};$$

where m - the number of vertices

$$q_{ij} = \begin{cases} \textit{1, if an arc from the vertex i} \\ \textit{approaches the vertex j;} \\ \\ \textit{0, if there is no arc from vertex} \\ \textit{i to vertex j;} \end{cases}$$

It follows that agents (Acoop, Amm, Ad) most often (most often interact with other agents) must be taken into account when assessing the reliability and fault

tolerance of the system, as well as when starting backup agents.

Table 2. The adjacency matrix for the graph.

	Amm	Ad	Aes1	Aes2	Aes3	Acoop	Aagr	$P_j^-(a)$
Amm	0	1	0	0	0	0	0	1
Ad	1	0	1	1	1	0	0	4
Aes1	1	0	0	0	0	1	0	2
Aes2	1	0	0	0	0	1	0	2
Aes3	1	0	0	0	0	1	0	2
Acoop	1	0	1	1	1	0	1	5
Aagr	1	0	0	0	0	0	0	1
$P_i^+(a)$	6	1	2	2	2	3	1	

A more extensive experiment was also carried out, based on data from the Krasnoyarskenergo system (Figure 5), consisting of 111 nodes and 176 connections. The original scheme was divided into 2 subsystems of 27 (including 11 boundary nodes from another subsystem) and 95 nodes (including 12 boundary nodes from another subsystem). A total of 23 boundary nodes were identified, into which PMU sensors were installed (software). Since the values of the node voltages (data from the PMU) at the boundary nodes are taken as accurate, and the calculation is relative to this condition. Thus, we can eliminate the coordination agent from the OS algorithm. As a result, the calculated values of both subsystems and the general scheme were identical, without the need to make corrections to the values at the boundary nodes.

The degrees of the vertices are indicated in Table 3:

Table 3. Degrees of vertices.

a	A_{mm}	A_d	A_{es1}	A_{es2}	A_{es3}	A_{coop}	A_{agr}
P(a)	7	5	4	4	4	8	1

For this example, the graph of agent interactions (Figure 5), the adjacency matrix (Table 4), and the degrees of the vertices were also constructed (Table 5). It was found that the agents have the greatest degree: Amm and Ad.
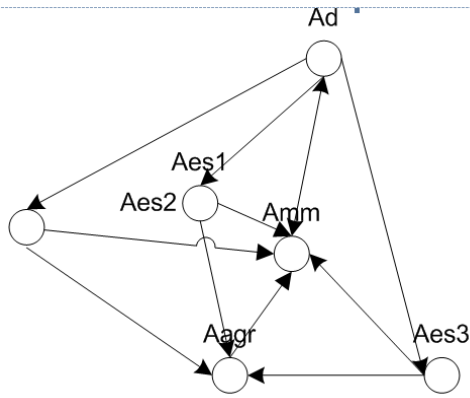

Fig. 5. The graph of agent interactions.

Table 4. The adjacency matrix for the graph.

	A_{mm}	A_d	A_{es1}	A_{es2}	A_{es3}	A_{agr}	P_j^-(a)
A_{mm}	0	1	0	0	0	0	**1**
A_d	1	0	1	1	1	0	**4**
A_{es1}	1	0	0	0	0	1	**2**
A_{es2}	1	0	0	0	0	1	**2**
A_{es3}	1	0	0	0	0	1	**2**
A_{agr}	1	0	0	0	0	0	**1**
P_i^+(a)	**5**	**1**	**1**	**1**	**1**	**3**	

Table 5. Degrees of vertices.

a	A_{mm}	A_d	A_{es1}	A_{es2}	A_{es3}	A_{agr}
P(a)	6	5	3	3	3	4

4. Future work

The application of the latest information technologies in the field of energy is due to the concept of Smart Grid. An important part of this concept is occupied by multi-agent technologies. The author of this article developed his own universal approach for building MAS in power engineering using agent scenarios and event models. The next stage in the development of this approach can be the transformation of the MAS into a web service, with the possibility of remote access.

The combination of multi-agent approach and cloud computing carries a lot of positive aspects, both for the user and for the developer of such systems. Users will be able to remotely access the system without using special software, all interaction with the MAS will be carried out through the interface in the Internet browser (fig. 6). Developers of the system will be able to make changes to any of the agents, without the need for interaction, both with the user and with his local computer. Moving computing agents from local personal computers to the cloud can increase the fault tolerance of the system and allow the system to grow without the need to reconfigure the agent interaction infrastructure.
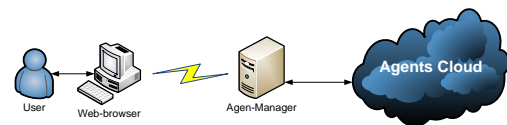

Fig. 6. Interaction scheme.

In addition to obtaining the advantages described above, combining these approaches introduces additional implementation difficulties that require additional research. Since the exchange of data between the user and the MAS will occur via the Internet, there is a need to ensure the security of information from loss and interception and change. Therefore, in addition to developing the architecture of a web-based multi-agent system, it is necessary to solve tasks to ensure cyber-security and data encryption.

adjacency matrix was obtained, and the degrees of vertices were determined.

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