A Multi-Agent System Approach to Power System Topology Verification

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Abstract. The paper deals with power system topology verification, being an important problem in real-time power system modeling. In the paper, the approach with use of multi-agent system is proposed. At the beginning, benefits from utilization of the agent technology are presented. Then, a theoretical background for the power system topology verification is described. Next, multi-agent system for topology verification and functions of particular agents are characterized. At the end, features of the presented approach to power system topology verification are summed up.

Keywords: Power System, Power System Topology, Multi-Agent System

1 Introduction

Advances in computer technology (in the field of the hardware and software), telecommunication, and electric power engineering give new possibilities for control and management of power systems. On the other hand the power system control in a more and more demanding environment becomes more and more complex. The required attributes of the modern control and management of power systems are scalability, openness, flexibility and conformance to industry standards. Now, achievement of the solution, which has such attributes, seems to be easier, using (among other things) intelligent agents and multi-agent systems. The advantages of the Agent Technology (AT) from the view point of their utilization for solving problems of the mentioned control and management are underlined in many papers [1] - [5]. The following features of AT are especially interesting:

- AT can be effectively used to solve complex (distributed) problems,
- agents are loosely coupled,
- agents can communicate via messaging rather than by procedure calls,
- new functions can easily be added to an agent-based system by creating a new agent, which will then make its capabilities available to others,
- agents can be stopped without affecting the integrity of the other agents in the system
- AT permits the easy integration of data capture, data processing, and intelligent system interpretation processes,

- the management of data, information and interpretation can be devolved to individual agents, permitting dynamic and automatic decision making regarding which interpretation algorithms should be used,
- the data interpretation functions can be distributed, removing the need for wholesale data transmission,
- agents can ultimately reduce operator errors and improve control performance by responding to problems faster than a human operator.

AT is one of the recent developments in the field of distributed artificial intelligence. There is relatively small number of papers showing application of this technology to solving problems related to real-time power system modeling (power-system state estimation) [1], [2], [6], [7]. One of such problems is the problem of power system Topology Errors (TEs) and the problem of the Power System Topology Verification (PSTV). PSTV, i.e. proving or disproving the correctness of a power system topology model, is an important problem when a real-time power system model is built. The topology model, being a description of the physical connections in a power system, is essential part of a power system model. Only in [6] the problem of PSTV is considered.

The focus of the paper is utilization of AT for PSTV from the functional view-point. In the paper, other than in [6], an essential element of approach for PSTV is utilization of knowledge on a topology model which is contained in the relationships among measured quantities in a power system. Utilization of AT permits realization of a distributed PSTV. Results of such PSTV can be accessed locally by different applications.

2 The Theoretical Background of the Approach

2.1 A Power System Model

The considered approach assumes utilization of a bus/node power system model. In the model, nodes and branches are distinguished. The model nodes represent electrical nodes in a power system. The model branches represent connections between suitable electrical nodes in a power system, i.e. power lines, transformers etc.

The assumption is made that every branch in a power network is modeled as the π-equivalent circuit (Fig. 1). It is assumed that there is an accessible credible measurement data set of such quantities as active and reactive power flows at the ends of each branch, power injections, loads and voltage magnitudes at each node.

2.2 Utilized Relationships

A power system is described by:

- relationships among active and also reactive power flows for nodes:

$$\sum_{i \in I_k} P_{ki} = 0 \, , \ \sum_{i \in I_k} Q_{ki} = 0 \, , \qquad (1)$$

where: k – a number of the considered node; i – a number of the node which is connected with the node k by a branch; I_k – the set of nodes connected with the node k; P_{ki}, Q_{ki} – respectively active and reactive power flows at the node k in the branch connecting the nodes k and i;

- relationships among active and reactive power flows and also voltage magnitudes at the ends of branches:

$$P_{kl} + P_{lk} + R_{kl}\frac{P_{kl}^2 + \left(Q_{kl} - B_{kl}V_k^2\right)^2}{V_k^2} = 0\,, \tag{2}$$

$$Q_{kl} + Q_{lk} + X_{kl}\frac{P_{kl}^2 + \left(Q_{kl} - B_{kl}V_k^2\right)^2}{V_k^2} - B_{kl}\left(V_k^2 + V_l^2\right) = 0\,. \tag{3}$$

where: k, l –numbers of the nodes between which there is the considered branch; V_k, V_l –voltage magnitudes at the nodes k and l respectively; R_{kl}, X_{kl}, B_{kl} – parameters of the π model of the branch.

The relationships (**1**) result from the Kirchhoff's Current Law. The relationships (**2**), (**3**) are a result of applications of the Kirchhoff's and Ohm's Laws for a branch.

2.3 A Classical Approach to Power System Analyses

If a node or a branch is not included in a power system model, then the appropriate measurement data related to this node or to this branch are not taken into account. In such a case the relationships (**1**) for the mentioned node or the relationships (**2**), (**3**) for the mentioned branch are not considered.

2.4 The Utilized Idea of Power System Analyses

In this paper, relationships for all possible nodes and all possible connections among these nodes are considered in all possible cases of network connectivity.

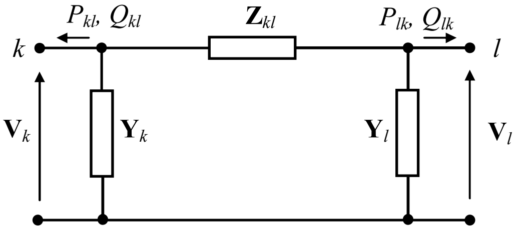

Fig. 1. The assumed π model of the branch. $\mathbf{Z}_{kl} = R_{kl} + \mathrm{j}\,X_{kl}$, $\mathbf{Y}_k = \mathrm{j}B_{kl}$, $\mathbf{Y}_l = \mathrm{j}B_{lk}$, $B_{kl} = B_{lk} = B$. B is a half of the capacitive susceptance of the branch.

If a node is not included in the power system model, then for testing the relationships (**1**) the assumption is made that all active and reactive power flows at the considered node are equal to zero. If the considered node occurs in a power system and also occurs in the topology model of the power system then there are taken into account measurement data of active and reactive power flows at the ends of the branches which enter or which could enter the node.

If the branch between the nodes *k* and *l* (the branch *k-l*) is not included in the power system model then for the terminal nodes of the branch

$$W_{Pk} = -P_{kl}, \quad W_{Pl} = -P_{lk}, \quad W_{Qk} = -Q_{kl}, \quad W_{Ql} = -Q_{lk}, \tag{\textbf{4}}$$

where

$$W_{Px} = \sum_{i \in I_x} P_{xi}\,, \; W_{Qx} = \sum_{i \in I_x} Q_{xi}\,, \tag{\textbf{5}}$$

$x \in \{k, l\}$.

For the considered branch, substituting in the relationships (**2**), (**3**) the power flows P_{kl}, P_{lk}, Q_{kl}, Q_{lk} with the values $-W_{Pk}$, $-W_{Pl}$, $-W_{Qk}$, $-W_{Ql}$ respectively, we have

$$W_{Pkl} = -W_{Pk} - W_{Pl} + R_{kl} \frac{W_{Pk}^2 + \left(W_{Qk} + B_{kl} V_k^2\right)^2}{V_k^2}\,, \tag{\textbf{6}}$$

$$W_{Qkl} = -W_{Qk} - W_{Ql} + X_{kl} \frac{W_{Pk}^2 + \left(W_{Qk} + B_{kl} V_k^2\right)^2}{V_k^2} - B_{kl}\left(V_k^2 + V_l^2\right). \tag{7}$$

If in a real power system the branch *k-l* is in operation, but it is not included in the topology model i.e. the branch is incorrectly modeled (the exclusion error), and power flows in this branch are not equal to zero then

$$W_{Pk} \neq 0, \quad W_{Pl} \neq 0, \quad W_{Qk} \neq 0, \quad W_{Ql} \neq 0, \quad W_{Pkl} = 0\,, \; W_{Qkl} = 0\,. \tag{\textbf{8}}$$

If in a real power system the branch *k-l* is out of operation and it is included in the topology model (the branch is incorrectly modeled – the inclusion error) or the considered branch is correctly modeled then

$$W_{Pk} = 0, \quad W_{Pl} = 0, \quad W_{Qk} = 0, \quad W_{Ql} = 0, \tag{\textbf{9}}$$

$$W_{Pkl} = R_{kl} B_{kl}^2 V_k^2\,, \; W_{Qkl} = X_{kl} B_{kl}^2 V_k^2 - B_{kl}\left(V_k^2 + V_l^2\right). \tag{\textbf{10}}$$

In the assumed approach the so-called unbalance indices for nodes and branches are introduced. The idea of such indices is described in [8]. In the presented approach, for nodes these indices (the indices W_{Px}, W_{Qx} x – a number of a node) are defined as in [8], i.e. with use of the formulae (**5**), for branches - with use of the following formulae:

$$W_{Pkl} = \begin{cases} -W_{Pk} - W_{Pl} + R_{kl} W & \text{if} \quad W_{Px} \neq 0 \text{ and } W_{Qx} \neq 0 \\ -W_{Pk} - W_{Pl} + R_{kl} W^0 & \text{if} \quad W_{Px} = 0 \text{ and } W_{Qx} = 0 \end{cases}, \tag{11}$$

$$W_{Qkl} = \begin{cases} -W_{Qk} - W_{Ql} + X_{kl} W - B_{kl}\left(V_k^2 + V_l^2\right) & \text{if} \quad W_{Px} \neq 0 \text{ and } W_{Qx} \neq 0 \\ -W_{Qk} - W_{Ql} + X_{kl} W^0 & \text{if} \quad W_{Px} = 0 \text{ and } W_{Qx} = 0 \end{cases}. \tag{12}$$

where:

$$W = \frac{W_{Pk}^2 + \left(W_{Qk} + B_{kl} V_k^2\right)^2}{V_k^2}, \quad W^0 = \frac{W_{Pk}^2 + W_{Qk}^2}{V_k^2}. \tag{13}$$

Using the mentioned indices, one can investigate the relationships among the measured quantities for branches independently of their inclusion into the power system topology model or exclusion from this model. It should be stressed that the behavior of unbalance indices for active power and for reactive power is the same for the same TE.

Unbalance indices create characteristic sets of values for different cases of modeling a power system. If the topology model is correct and there are no errors burdening measurement data then all the unbalance indices for nodes and branches are equal to zero. The same situation is in a case of the inclusion error.

The case in which:

- the unbalance indices for the distinguished node k and for each node connected with the node k by a branch are equal to zero,
- the unbalance indices for each branch incident to the node k are equal to zero,

is further called *Case* 0.

In a case of the exclusion error one can observe:

- the unbalance indices for terminal nodes of the branch, which is excluded from the topology model, are considerably different from zero,
- the unbalance indices for the considered branch (i.e. the branch k-l) are equal to zero,
- absolute values of the unbalance indices for each branch, being incident to the mentioned terminal nodes and not being the branch k-l, are especially large,
- values of the unbalance indices for each node, which is connected with the node k or with the node l by a branch (other than branch k-l), are equal to zero.

The case in which:

- the unbalance indices for the distinguished node k and for the node l, which in a power network can be connected with the node k by a branch (i.e. by the branch k-l), are considerably different from zero,
- the unbalance indices for the branch k-l are equal to zero,
- absolute values of the unbalance indices for each branch, that is incident to the node k and is not the branch k-l, have especially large values,
- absolute values of the unbalance indices for each node, which is connected with the node k by a branch and is not the node l, are equal to zero,

is further called *Case* 1.

Analyzing unbalance indices for nodes and branches one can observe that the exclusion error of the branch k-l has no influence on:

- unbalance indices for nodes, that are not terminal nodes of the branch k-l,
- unbalance indices for branches, that are not incident to terminal nodes of the branch k-l.

This observation shows existence of the local effect of TE. In this situation one can conclude about correctness of modeling the distinguished branch k-l on the basis of investigations of unbalance indices for certain areas of the power network: A^{k}_{k-l}, A^{l}_{k-l}.

The area A^{x}_{k-l} $x \in \{k, l\}$ comprises:

- the node x,
- the branch k-l and all other branches incident to the node x,
- all nodes which are connected with the node x by the earlier-mentioned branches.

The analysis of unbalance indices is relatively simple in the case of a single TE and when impact of errors burdening measurement data is not considered. In real cases, existence of multiple TEs and errors burdening measurement data should be taken into account. In such cases, the problem of PSTV is a complex problem. PSTV can be treated as a problem of pattern recognition and then ANNs can be utilized for solution of this problem, e.g. as it was presented in [9].

3 A Description of the Approach

Process of PSTV consists of many processes, which are not independent. Each distinguished process is performed by an intelligent agent. There are two types of agents. There are agents related to nodes (the node agents) and agents related to branches (the branch agents). The agents related to nodes are denoted by N_j $j = 1, 2, ..., n$, where j – the number of a node, and the agents related to branches are denoted by $B_{j\text{-}i}$ $i, j = 1, 2, ..., n$ $i \neq j$, where i, j – the numbers of terminal nodes of a branch. Relationships among agents are shown in Fig. 2 and Fig. 3. The agent N_k $k \in \{1, 2, ..., n\}$ co-operates with:

- each agent N_{i1} $i_1 \in I_k$, i.e. with each agent related to the node which is connected or can be connected (when in the power system topology model there is not a connection) with the node N_k by a branch,
- each agent $B_{k\text{-}i1}$ $i_1 \in I_k$, i.e. with each agent related to the branch which connects or can connects the node k with the node i_1.

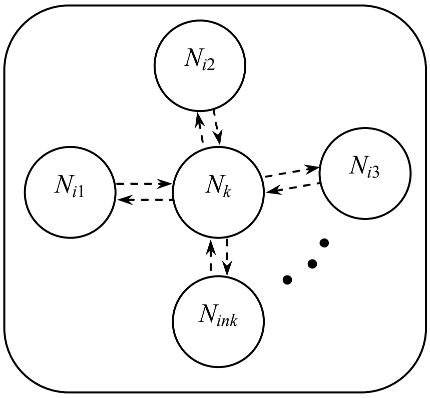

Fig. 2. Co-operation among the node agents

3.1 The Node Agents

Each of the node agents realizes functions: F_{N1}, F_{N2}, F_{N3}, F_{N4} (Fig. 4). It observes its environment (a substation), more exactly, measurement data of active and reactive power flows at the ends of branches and voltage magnitudes at the buses. When there is any change of measurement data the appropriate node agent starts its action. The aim of this action is to take local decisions on correctness of modeling of branches entering the node with which the node agent is related.

The possible decisions are as follows: D_c – the branch is correctly modeled, D_b – the branch is incorrectly modeled (there is TE), D_0 – there is no basis for taking decision D_c or D_b. Information on these decisions is sent to the appropriate branch agents.

Information is exchanged among node agents with use of data sets. These are:

DS$_{Nkx}$ – the data set created by the node agent N_k and addressed to the node agent N_x. The set contains the unbalance indices: W_{Pk}, W_{Qk} and the data informing the node agent N_x about a request of sending the unbalance indices: W_{Px}, W_{Qx} to the node agent N_k.

DS$_{NkxR}$ - the data set, created by the node agent N_x, with the unbalance indices: W_{Px}, W_{Qx} and addressed to the node agent N_k. The data set is an answer for the request contained in the data set DS$_{Nkx}$.

DS$_{NkBk\text{-}x}$, DS$_{NxBk\text{-}x}$ – the data sets created by the node agent N_k or by the node agent N_x respectively with the decision on correctness of modeling of the branch k-x, taken by the node agent, and addressed to the branch agent $B_{k\text{-}x}$.

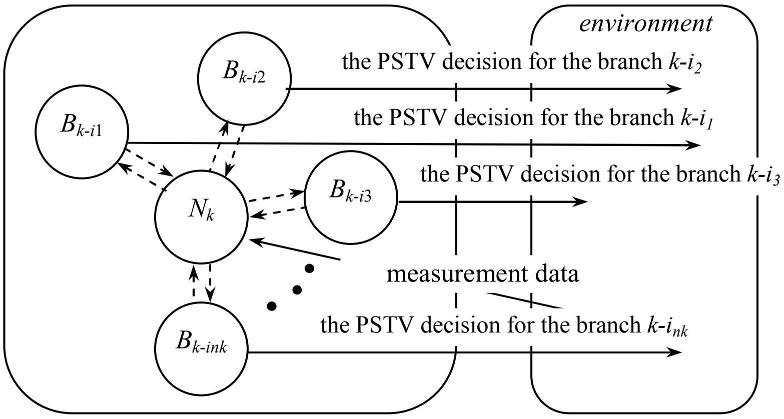

Fig. 3. Co-operation between the node agent N_k and the branch agents $B_{k\text{-}x}$ $x = i_1, i_2, ..., i_{nk}$

$DS_{Bk\text{-}xNk}$, $DS_{Bk\text{-}xNx}$ - the data sets created by the branch agent $B_{k\text{-}x}$ and addressed to the node agent N_k or to the node agent N_x respectively with the data informing the node agent about a request of sending its decision on correctness of modeling of the branch *k-x* to the branch agent $B_{k\text{-}x}$.

$DS_{Bk\text{-}xNkR}$, $DS_{Bk\text{-}xNxR}$ - the data sets created by the node agent N_k or by the node agent N_x respectively with the decision on correctness of modeling of the branch *k-x*, taken by the node agent, and addressed to the branch agent $B_{k\text{-}x}$. The data sets are answers for the requests contained in the data sets $DS_{Bk\text{-}xNk}$, $DS_{Bk\text{-}xNx}$ respectively.

3.2 The Branch Agents

Each of the branch agents realizes functions: F_{B1}, F_{B2} (Fig. 5). The branch agent takes the final PSTV decision for the branch to which it is related. The bases for taking this decision are the decisions taken by both node agents related to the terminal nodes of the considered branch.

5 Conclusions

Utilization of unbalance indices for PSTV gives new possibilities. A process of PSTV can be considered as many processes which are performed locally. For the so-considered PSTV the multi-agent system approach is proposed. According to this approach the intelligent agents for nodes and the intelligent agents for branches of a power network are foreseen. One electrical node is related to one substation. In one substation, one or more electrical nodes can occur. Thus more than one node agent can be related to one substation. A decision on correctness of modeling selected branch is produced as a result of co-operation of the intelligent agent for the considered branch, the intelligent agents for the terminal nodes of the branch and for nodes neighboring to the mentioned terminal nodes.

Analyzing the described utilization of AT in PSTV gives basis for listing, among other things, the following benefits of the presented multi-agent system approach:

1. The problem of PSTV can be considered as a set of many smaller problems.
2. The system for PSTV is easily scalable - the organizational structure of the agents can dynamically change as the power network grows in size.
3. The locally-verified data on connections in a power network can be transmitted to each control centre and in effect a time of real-time modeling of a power system in this control centre can be shorter what is very important from the view point of real-time power system applications utilizing the real-time power system model.

References

1. Biernatzki R., Bitzer B., Zivanovic R., Els A., Els S.: Agent Technology Used in Power Systems. In: The 7th AFRICON Conference in Africa. 2, 705--710 (2004)

2. Moslehi K., Kumar A.B.R., Dehdashti E., Hirsch P., Wu W.: Distributed Autonomous Real-Time System for Power System Operations-a Conceptual Overview. In: IEEE PES Power Systems Conference and Exposition. 1, 27--34 (2004)
3. McArthur S.D.J., Davidson E.M.: Concepts and Approaches in Multi-Agent Systems for

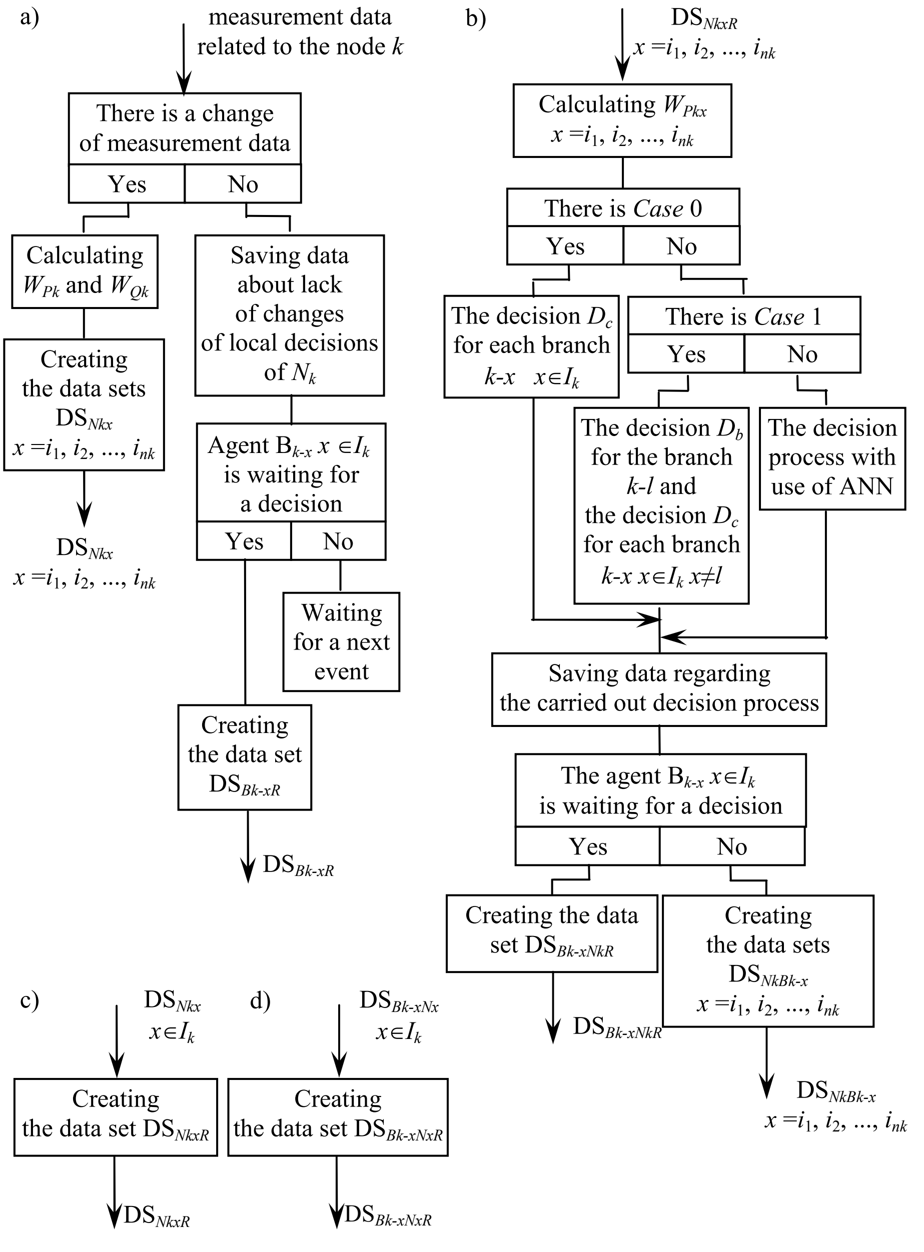

Fig. 4. The functions of the node agent: a) the function F_{N1}, b) the function F_{N2}, c) the function F_{N3}, d) the function F_{N4}. Description of the designations is in Subsection 3.1.

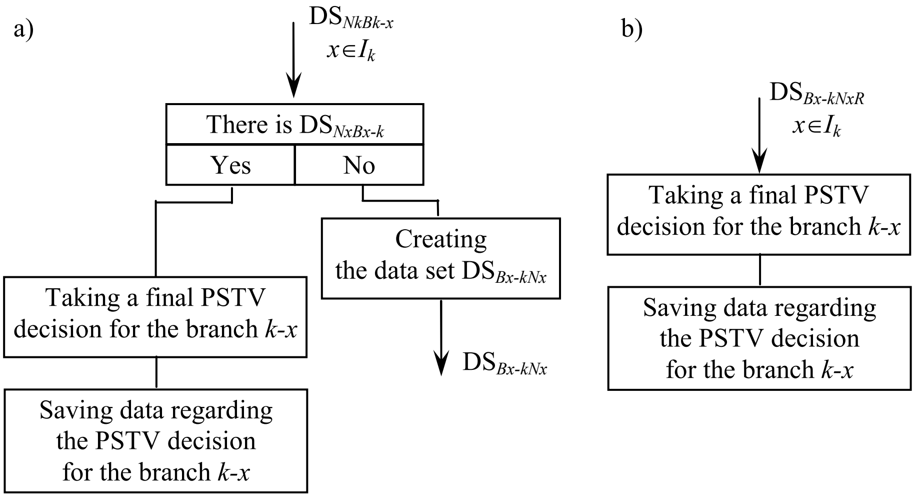

Fig. 5. The functions of the branch agent: a) the function F_{B1}, b) the function F_{B2}. Description of the designations is in Subsection 3.1

Power Applications. In: The 13th International Conference on Intelligent Systems Application to Power Systems, pp. 391--395 (2005)

4. McArthur S.D.J.: Agent Technologies for Power System Plant Monitoring and Diagnosis. In: The IEE Seminar on Autonomous Agents in Control, pp. 51--65 (2005)
5. de Azevedo G.P., Feijo B.: Agents in Power System Control Centers. In: IEEE Power Engineering Society General Meeting. 2, 1040--1041 (2005)
6. Nordman M.M., Lehtonen M.: Distributed Agent-Based State Estimation for Electrical Distribution Networks. IEEE Trans. on Power Systems. 2, 652--658 (2005)
7. Qiong W., Wenyin L., Yihan Y., Chuan Z., Yong L.: Intelligent Decision Support System for Power Grid Dispatching Based on Multi-Agent System. In: International Conference on Power System Technology (PowerCon), pp. 1--5 (2006)
8. Lukomski R.: New Approach to Power System Topology Verification. In: The International Conference on Modern Electric Power Systems, pp. 517—521. Wroclaw, Poland (2002)
9. Lukomski, R., Wilkosz, K.: Method for Power System Topology Verification with use of Radial Basis Function Networks. In: Sandoval, F., Prieto, A., Cabestany, J., Graña, M. (eds.) Computational and Ambient Intelligence. LNCS, vol. 4507, pp. 862—869. Springer, Heidelberg (2007)