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Cooperative Multi-Agent Diagnosis Substation Faults Based on Artificial Immune Theory

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Abstract: - Based on Multi-Agent (MA) technology and Artificial Immune (AI) theory, a novel substation fault diagnosis approach is proposed in the paper. The method firstly considers substation fault diagnosis a global complicated problem in uncertainty environment, and decomposes it into several relatively-simple local sub-problems based on ontology concept. Then diagnosis agent is respectively designed for every local sub-problem and cooperative multi-agent systems are applied for distributed substation fault diagnosis. In process of diagnosis, the method fully embodies the characteristics of learning-memory-forgetting of immune diagnosis agents, and that consequently facilitates the evolution of agent colony. Related to substation fault diagnosis, that is, error tolerance ability of systems is dramatically improved. Eventually, a simulation example in substation fault diagnosis shows the availability of the method.

Key-Words: - Substation; Fault diagnosis; Ontology; Cooperative Multi-Agent Systems; Artificial Immunity

1 Introduction

In recent years, with the rapid advancement of Distributed Artificial Intelligence (DAI), agent and multi-agent have been used in an increasingly diverse range of applications including power systems [1][2], management engineering [3][4], information systems [5][6] and control systems [7][8] etc, particularly, and reported that it is very suitable to facilities fault duagnosis systems[9]. Conventional control methods [10][11] only uses a central agent to grasp and hold the overall systems, clearly, once the cell is in failure, the overall systems will suffer from disaster. To resolve the problem, reference[12] applies Autonomous Decentralized Systems(ADS)[13] to construct autonomous fields by which behaviour of each automous agent is restricted. It has no centre but whose architecture is more flexible, whether existence of each autonomous agent or not has no what influence on the overall systems, more robust characteristic makes it very adapt to dynamic enviromrnt.The overall risk therefore is partitioned and fault tolerance ability is dramatically improved. To further elevate substation fault diagnosis levels, Artificial Immune principle is also applied in Multi-Agent Systems (MAS) to establish Multi-Immune-Agent society[12][14], where the evolvement of the antobodies follows the innovation the antigens. In addition, the antibodies still can distinguish from numerous antigens in nature and yield random response characteristics to fully clear them, and this exhibits their excellent pattern recognition capability. The nature of distribution and decentralization lies in that there is no way to inflict impact from the outside, but can't implement central control in inside either. All the characteristics of AIS make it become an extraordinary technology measure exceeding any conventional means. Consistent with the trend, we have studied and proposed an AIS-based Multi-Agent architecture for substation fault diagnosis[12], in here we will further discuss its behaviour and thinking characteristics, and develop and enrich the related contents of substation fault diagnosis.Together with text[12], the paper aims at establishiong a Multi-Agent-based substation fault diagnosis architecture and discuss its availability.

2 Ontology

Ontology concept is proposed in reference[15], and is an important branch in artificial intelligence science. It supports knowledge share and reuse, and that also stresses the substantial concepts as well as the relationships among them. In present time, ontology has been a core of related research fields such as knowledge denotation and acquisition, plan, management and natural language processing etc. There are already several ontologies established such as CNR, Wordnet and ARPI and so forth.

A ontology-based model proposed in the paper is mainly based on substation fault diagnosis. By ontology concept, we may conveniently disassemble a global complicated problem into many small local sub-problems, and that more simple. For every local sub-problem, we design a local diagnosis agent for it, respectively, each agent can cooperate with other agents to jointly act to resolve respective problems.

Ontology-based substation fault diagnosis model is constructed from top to bottom, the method firstly divides the overall substation fault diagnosis into serveral relatively-independent area fault cells, then inside each fault area cell, taking the component as unit, each fault area is subdivided once, in the end, let the component act as the basic concept or datum to construct the architecture of ontology. Then based on every concept or datum, a diagnosis agent is defined, afterwards generalizing the defined agents and getting local agents, in the end, all the agents and the relationships among them inside ontology are clearly denoted out. For convienience anlysis, we have the following denotations:

Denotation 1(Ideal_Depth): The Ideal_Depth of the node A is the layer number from root node to leaf node. Set the Ideal_Depth of root node is zero, that is, ID=0, then the Ideal_Depth of child_nodes is ID=1, and the like.

Denotation 2(Generalized Concept): A process that the concepts in lower layers are transformed into ones in higer layers.

Ontology-based data mining algorithm mostly includes the two process, one is the generalized process of knowledge, that is, all knowledge in knowledge base requires to be abstracted to Ideal_Depth, the process is realized by hunting concepts in ontology model. Another one is mining associated rules from the disposed knowledge base, that is knowledge discovery, searching for more significant knowledge.

3 AIS-Based System Architecture

MAS-based substation fault diagnosis, combined by AIS and ADS, has been proved a super agent with extraordinary ability, the related algorithm and diagnosis process are studied in [12], here not to say any more. Text [12] mainly presents algorithm of single agent and cooperative relationship among MAS, however related description but retains in scale of root nodes, whose interior work principle hasn't been introduced in detail. Therefore, the paper inherits its some views and extends it, and makes it more abundant and lucid.

In the paper, there are two kinds of agents applied in substations fault diagnosis. They are diagnosis and management agents, respectively. Diagnosis agent is a soft program groupware, and is designed for special electrical facilities, switch cells and installations etc. diagnosis agents are assigned to special cells and installations in accordance with substation topology structure. As a superior of diagnosis agents, management agent presides over task assignment and harmonizes colony behavior. When diagnosis agents find faults, they send out diagnosis request to management agent immediately, management agent receives and records it, analyses the faults reason and yields corresponding suggestions, and that generates a fault diagnosis book. In addition, under some circumstance, management agent also may assign task to other agent to harmonize diagnosis.

3.1 Diagnosis Agent

The diagnosis cells of diagnosis agents express some executed parts connected by topology structure, such as switches, circuits, buses and transformers and so on. In accordance with decomposing results of substation topology structure, diagnosis agents of special function are assigned to diverse executing cells. Each agent has internal knowledge base which is used to reserve some description information that it represents, and cooperation diagnosis information with other agents as well as response ability description etc. Other agent information therefore is also required to conserve in home knowledge base, and that agent also can coordinate own knowledge base according to practical environment and select suitable cooperative objects, which makes diagnosis process more effective. Since substation fault diagnosis not only requires the exactness and reliability, but also needs higher diagnosis speed. Diagnosis agents therefore apply hierarchical structure, that is, inner sub-function is realized by each sub-agent, for instance, fault monitoring agent, knowledge library hunting agent, synthesis evaluation agent and communication agent as well as sensor agent etc, the hierarchical model structure is shown in Fig.1.

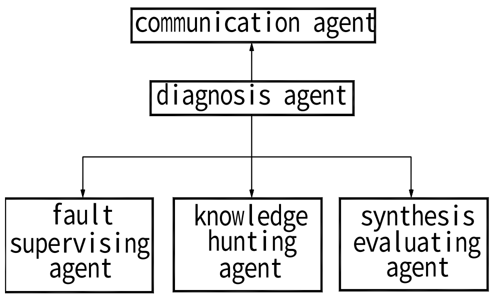

Fig.1 Hierarchical architecture of diagnosis agent

3.2 Intendant Agent

Intendant agent is a management center of all agents, and also is an exchanging centre of collaboration diagnosis information. It presides over diagnosis task assignment and cooperation for every agent. In addition, it still runs each agent, and also it may exchange information with man by man-machine interface. Intendant agent is composed of communication interface, management engine, knowledge base agent and reasoning agent etc. There are two parts knowledge left in knowledge base, that is, one is task decomposing knowledge related to task assignment, another one is knowledge of running diagnosis agents, which answers for establishing time of each diagnosis agent, diagnosis process groupware as well as some service that can offer other agents. When establishing an agent, register in intendant agent is required, while deleting an agent, logout is also required. Intendant agent firstly decomposes task and assigns it to related agents while it receives a diagnosis message.

Based on the above analysis, obviously, it may be seen that MAS not only keeps many excellences of conventional hierarchically recursive methods, but still can adapt to concrete process and dynamic environment. Several prominent characteristics now are described as follows:

1) Decomposing and assigning a more complicated task to each diagnosis agent by the use of hierarchical structure, which may reduces the complexity of solution.

2) Each agent possesses independent decision organ and local controlling ability, they connect each other by a very incompact coupling format. Single agent fault don't influence intelligent behaviour of other agents, and so, fault tolerance ability of systems is dramatically improved.

3) Expansion and maintenance are easy, new establishing agents can be entered or existing agents can be coordinated at any time not to consider other parts of systems.

4) Agents hold stronger self-learning ability. Agent can evaluate diagnosis result every time and compare with practice, if discrepancy is larger, then learning again. Learning results are added up to diagnosis knowledge base to repair or adjust related knowledge.

5) Task structure of intendant agents includes time stab and priority and so on, which improves ability of resolving conflict information.

6) Knowledge base and reasoning mechanism can be inherited, that is, sub-agents may inherit knowledge from their father agents.

4 Cooperation and Communication

All agents can independently execute fault diagnosis, and give out diagnosis information related to each task. However, under some cases, single agent can't implement diagnosis or monitor faults according to own status, effectuvely, at the time, Multi-Agent is required to collaborate for fault diagnosis. Concrete method is that the agent sends out diagnosis request to those agents related to it in topology conjunction, if the agents haven't find fault information with relation to inquiry information, then, on one hand they send it to other related agents so as to get further diagnosis information, on another hand, they send back response information.

Cooperation among the agents is realized by communication, each agent owns a communication interface, that is, a communication agent, which is in charge of buffer and memory of information, sending/receiving each diagnosis or monitoring results. MAS-based fault diagnosis holds stronger function than single agent. KQML[16] is more popular international communication language, which is a kind of language and protocol applied to exchange information and knowledge, and has been considered a standard agent communication language, which makes the agents applying the language may exchange and share information resources. In accordance with KQML rules, message types can be defined as original language of KQML, including intention, content, dialog name, sender and receiver etc. To ensure reliable communication under heterogeneous environments, the overall system is established on the basis of CORBA criterion, that is, KQML transmits message by transferring CORBA service objects, this makes communication program exploitation of agents greatly simplified, KQML information transmission is more convenient and reliable, and easy software expansion and reuse etc. In view of a fact that developing program of Java language is independent of any flats and can conveniently run in any virtual Java computers as well as more perfect security than any other language, therefore, Java is selected as reasoning program and exploration language of expert systems.

5 Task Programming

Based on ontology concept and topology data base of substation fault diagnosis, diagnosis task of each diagnosis agent can be projected. The method first considers substation fault diagnosis as a whole, then according to substation fault topology structure, hierarchically decomposing it up to every concrete fault cell such as circuit, switch, bus and transformer etc. And then, diagnosis agent is installed for each fault cell. System structure of substation fault diagnosis is shown in Fig.2.

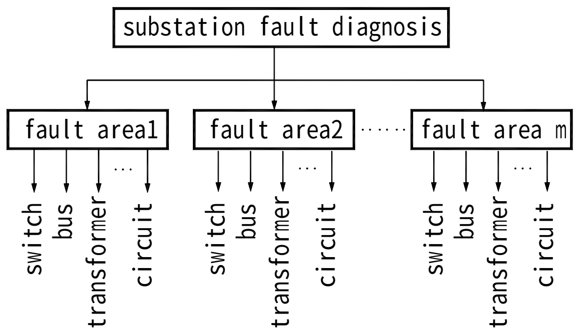

Fig.2 Substation fault diagnosis topology structure

According to Fig.2, the overall substation fault mode is partitioned into three layers, that is, root node with ID=0, area nodes with ID=1, and the isolated components with ID=3, those nodes with ID=3 respectively outfit a diagnosis agent. Moreover, after generalized concepts, areas also are installed diagnosis agents to monitoring area fault.

Fig.3 shows a MA architecture of fault diagnosis composed of super intendant agent, local agent, sensor (sense agent) and communicator (communicating agent) and so forth.

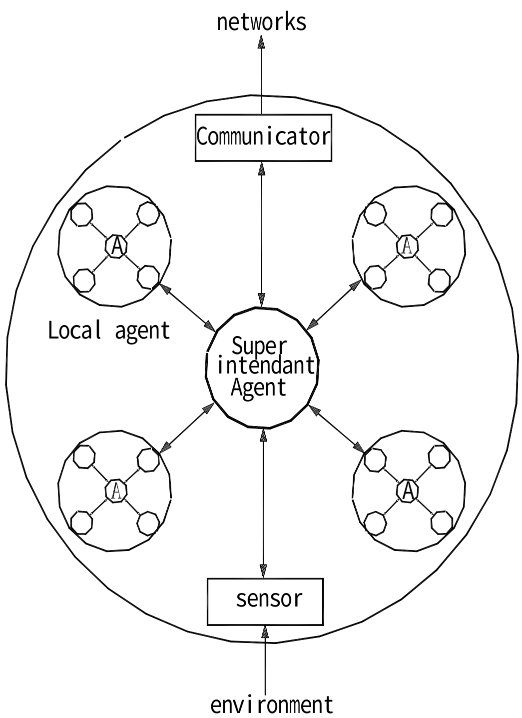

Fig.3 Multi-agent architecture for substation fault diagnosis

Seen from Fig.3 that more local agents locate inside local agent, forming a hierarchically architecture, it therefore is quite suitable to fault diagnosis.

6 MA-Based Fault Diagnosis Method

Ontology-based substation fault diagnosis method is introduced as follows:

1) In accordance with local fault information sensed by sensor, related agents such as diagnosis agent and area agent are started up to diagnose fault and give out diagnosis information, meanwhile, fault information is sent to other related agents to review the related parameters are normal or not. If local agents can't give out diagnosis results, then send a request to other agents for cooperation diagnosis.

2) Other diagnosis agents receive request and look over whether the related parameters is normal or not.

3) If the agent doesn't check out abnormities, this means no fault in the cell. And inversely, if fault is checked out by the agent, then abnormity is surveyed, and conclusions and diagnosis decision to intendant agent is given out. Under solicitation faults or transfer faults, information is needs to spread to other agents related to it, holding on it till the original fault source is found.

4) Learning and memory results for next diagnosis

7 Example Analysis

Fig.4 is local main connection diagram of one substation, M and N are bus cells, T is transformer, CB1,CB2,CB3 and CB4 are breakers, L1 and L2 are circuits. In addition, there are still 10 protection relies such as bus protection Mb, Nb, transformer main protection Ta1,Tb1 and spare protection Ta2, Tb2, other four relies La1,Lb1,La2 and Lb2 for circuits overloads and fast cutting off.

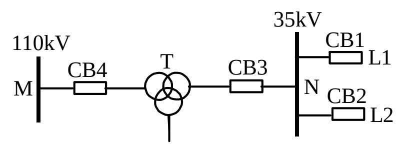

Fig.4 Circuit connection diagram for 35kV part of 110/35/6kV substation

According to the proposed method in the paper, substation fault area is divided into two isolated fault areas centered in M and N named as D1 and D2 shown in Fig.5. In accordance with ontology theory, area is partitioned again, the abstracted concepts in ID=3 are M, N, T, CB1, CB2, CB3, CB4, L1 and L2 as shown in Fig.6.

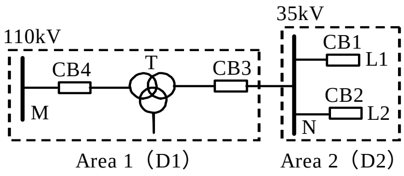

Fig.5 Sketch map of fault area partition

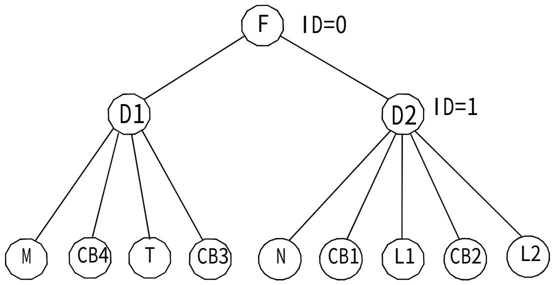

Fig.6 Ontology model of substation fault diagnosis

Then based on every concept in Fig.6, respectively designing a diagnosis agent to monitor and diagnose it, all installed diagnosis agents is shown Fig.7.

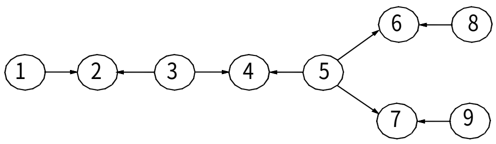

Fig.7 Agent allocation for substation fault diagnosis

In Fig.7, arrowhead orientation expresses the diagnosis agent senses fault information, and sends it to the related agents, for example, agent 5 finds bus N is in fault, then it sends the message to agent 4, agent 6 and agent 7 related to it, to see whether the supervised objects by them change site or not, and the related electrical parameters alter or not and the like. According to substation fault diagnosis knowledge base, the established diagnosis decision information is shown Table 1, where *F* expresses diagnosis result, "1" is change site information, and "1" is no change site information.

Table 1 Decision table 1

Mb	Nb	La1	Lb1	La2	Lb2	Ta1	Tb1	Ta2	Tb2	CB1	CB2	CB3	CB4	F
1	0	0	0	0	0	0	0	0	0	0	0	0	1	M
0	0	0	0	0	0	1	1	0	0	0	0	1	1	T
0	0	0	0	0	0	0	1	1	0	0	0	1	1	T
0	0	0	0	0	0	0	0	1	1	0	0	1	1	T
0	1	0	0	0	0	0	0	0	0	1	1	1	0	N
0	0	1	0	0	0	0	0	0	0	1	0	0	0	L1
0	0	0	1	0	0	0	0	0	0	1	0	0	0	L1
0	0	0	0	1	0	0	0	0	0	0	1	0	0	L2
0	0	0	0	0	1	0	0	0	0	0	1	0	0	L2

According to Table 1, we know that knowledge base has nine antibody modes in all, while exterior antigens stimulate, by hunting the best matching fault components are finally determined. Due to fault information in Table 1 supervised by agents, each agent therefore receives and response stimulation, by cooperation decision information is given out, and so diagnosis process owns initiative ability. According to immune doctrine, every diagnosis agent may be seen an antibody, only those agents who receive the largest stimulation can be propagated, inversely, the agents whose stimulation level is relatively low may be forgotten, after long competition, Table 1 is evolved into Table 2.

Table 2 Decision table 2

CB1	CB2	CB3	*F*
0	0	0	M
-	0	1	T
-	1	1	N
1	0	0	L1
-	1	0	L2

According to ontology theory, we still may abstract more generalized concepts, for example, taking area as example, according to Fig 5 and Table 1, Table 2, we gain the generalized decision rules shown in Table 3.

Table 3 Decision table 3

CB1	CB2	*D*
0	0	D1
1	-	D2
-	1	D2

According to Table 1, Table 2 and Table 3, we will easily deduce the generalized decision rules shown in Table 4.

Table 4 Decision table 4

CB2	CB3	*D*	*F*
0	0	D1	M
0	1	D1	T
1	1	D2	N
0	0	D2	L1
1	0	D2	L2

According to Table 3 and Table 4, we can know that the three diagnosis agents named as no.4, 6 and 7 who respectively monitor and control CB1, CB2 and CB3 are the active antibodies, only because their suffered stimulation levels is larger. Therefore, they are recollected, and inversely, other diagnosis agents are forgotten due to their suffered lower stimulation levels. However, once undergoing stronger stimulating, they still can be aroused. The following three examples are helpful to illuminate the point.

Example 1: Set change site information are CB4=1, TA2=1, TB1=1, CB3=1. Then according to agent 4, agent 6 and agent 7 and their cooperation, judging fault component is T. Practical checking proves the diagnosis result is right.

Example 2: Like example 1, change site information doesn't alter, but information CB4 loses and TB2 can't be sent over. At this time by cooperation each agent still can give out right diagnosis result, that is, T is in fault.

Example 3: Like example 1, change site information are also CB4=1, TA2=1, TB1=1, CB3=1. but information CB3 can't be sent over, that is, core information loses. This time, diagnosis agent 1 who control Mb is aroused to generate a new antibody, algother agent 6 and agent 7, cooperates to given out diagnosis result, that is, T is in fault.

4 Conclusion

The proposed method effectively simulates the characteristic of learning-memory-forgetting of immune systems of organism. Every antibody of organism is considered a diagnosis agent that can undergo antigens stimulation and responds it. By this means, expansion, dissipation and suppression of agent itself are accomplished. Reduction of decision antibodies is determined by out antigens stimulation, and that once core stimulation vanishes, new antibody may be rapid yielded again. This shows that it not can apply less core information (antibodies) to yield a rapid response, but fully make use of existing information (no core attributes) to adapt more complicated environment. Therefore, the proposed method in the paper possesses higher robustness and more flexibility, and is a dynamic substation fault diagnosis method.

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