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Cooperation Mechanism of Wide-area Protection System Based on Multi-Agents

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Abstract

With the rapid growth of power system, it is becoming increasingly difficult to realize reach and time coordination for conventional backup protection. To cope with those problems, wide-area protection is widely researched. In this paper, a novel dynamic cooperation mechanism of wide-area protection is proposed, which can operate better than distributed and centralized systems with respect to reliability, section selectivity, and so on. The multi-agents technology is used to enhance adaptability and decrease communication traffic of wide-area protection system. The improvement of backup protection performance to overcome some specific conditions, such as communication bit error, protection failure, and breaker failure, is also illustrated by utilizing communication networks and distributed protection agents which enables an easy and flexible construction and operation of the proposed wide-area protection system. The example analysis on IEEE 5 nodes system shows the concrete cooperation processing among agents in the cases of typical faults.

Keywords*: Wide-area protection system, distributed-centralized structure, multi-agents technology, cooperation mechanism, state machine*

1. Introduction

The growing demand for electricity has brought many changes to long-distance power grid, bulk power and high voltage transmission, and set higher requirement for the relaying protection and the safety and stability control of power system [1]. The analysis of numerous large-scale blackouts at home and abroad indicates that the traditional backup protection is easier to mal-operate under abnormal operation modes, which could cause cascading trips to transmission lines [2]. With the development of wide area measurement system (WAMS), intelligence technology and communication networks, wide-area protection system (WAPS) based on wide area information have drawn wide attention [3], [4].

In recent years, studies on WAPS mainly focus on the system structure, fault identification algorithm, communication system, etc., while few have touched on the whole cooperation mechanism and tripping strategy. Reference [5] proposed wide-area protection adaptive trip strategy based on Petri networks, and reference [6] introduced a method to narrow the outage range based on wide area information. However, the above literature fails to analyze the synergy between master station and substations.

With wide application of intelligent agent technology in power system, the researches on multi-agents system of WAPS have made some fundamental achievements [7], [8]. The most concentrated on fault identification algorithm based on distributed system. In this paper, a novel adaptive multi-agents system of WAPS is proposed, based on the autonomy, interactivity and adaptability of agent technique. At the same time, the dynamic cooperation mechanism between master station and substations for WAPS is designed on the basis of multi-information fusion theory.

2. Hierarchy of WAPS based on multi-ahents

The hierarchy of multi-agents of WAPS is mainly based upon the distributed-centralized structure of transmission system. The power grid is divided into several sub regions, and in

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each sub regionthe protection function is realized respectivelyfor the limitation of WAPS function [9]. A master station is selected to realize system decision of WAPS in every sub region, and the other stations are seen as substations to achieve the local measurement and control function. The system structure is shown in Figure 1.

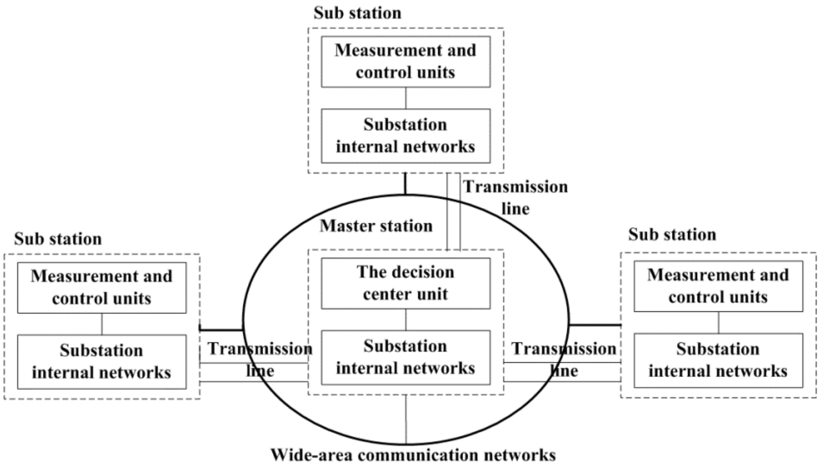

Figure 1. The hierarchy of wide-area protection on multi-agents

To design the hierarchy of master station and substations based on multi-agents,the layered structure is the best choice. The first layer is the decision center agent system (DCAS) and local measure and control agent system (LMCAS). And the second layer is sub-agent units of the agent system.

LMCAS can make a series of judgments and inferences through perceiving changes of external environment, and then actively cooperate with DCAS. DCAS is capable of fault component identification, information management, and learning. To adapt to the running changes of power system, WAPS should have a strong learning ability, an adaptive analysis method, and strongfault-tolerance ability. The basicfunctions of multi-agents system include the following:

1) Data sampling and pretreatment function. As there is a one-to-one correspondence between the local measurement and control device in every station and the breaker and TA/TV equipments, relaying protection should be able to acquire real-time information in power grid, including current information, voltage information andbreaker state information. Furthermore, it is also supposed to realize information pretreatment. Finally, WAPS should pack the information according to certain standard code format and send them to the decision center unit by wide-area communication networks.

2) Communication function. The strong communication system serves as foundation for the realization of WAPS. Master station needs to acquire multi-information of LMCAS and substations are expected to receive the decision result of DCAS via communication networks. The recent advancements in communication, information and computer networks, and the significant development in inter- and intra-substation communication standards, such as UCA 2.0 and IEC 61850, 61 968 and 61970, havemade it possible to broaden the scope of a protection system.

3) Fault component identification function. The essential job of WAPS is to find fault component and segregate it for the stability of power system. Therefore, fault component identification is central to WAPS. DCAS makes a decision to verdict the fault component based on wide-area protection algorithm using grid information. If the identificationoutcome is inconclusive, DCAS will quickly startupa new round of consults, and find the fault component with the fault-tolerance algorithm.

4) Knowledge base management function. Knowledge base is mainly responsible for the statistic of LMCAS' working pattern, the identification of grid networks topology, the selection of fault identification algorithm and fault-tolerance algorithm, etc. The management of

knowledge base includes the management of the entry, modification, and deletion of the knowledge. Meanwhile, WAPS supports the system to generate new rules according to the analysis results of fault identification and grid networks topology. In addition, knowledge base management can also be executed by hand.

5) Effective operation. The master station should be able to send trip command to corresponding substations immediately after the fault component has been confirmed, and the fault component should be rapidly segregated from power grid by LMCAS. At the same time, WAPS will initiate the monitoring function and breaker failure protection. The operation sequences should also be displayed on and printed by human interface.

6) Learning ability. The sub-agent system should have strong learning ability to adapting its operation behavior to new running environment. For example, DCAS should be able to review protection rules in timeto enhance the robustness of WAPS when the grid structure has changed. The learning ability of the multi-agents system will improve in long-time running.

According to the general agent structure and the basic functions of multi-agents, the hierarchy of multi-agents system for WAPS can be designed, as shown in Figure 2.

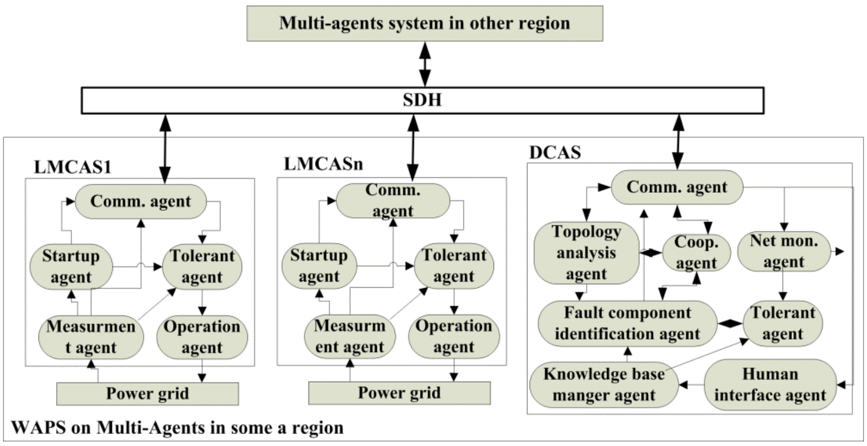

Figure 2. The hierarchy of wide-area protection on multi-agents

DCAS acquires protection information and switches state of every LMDAS in the region through wide area communication agent, and realizes fault component identification on multi-information fusion. LMCAS mainly completes the functions of local information measurement by measurement agent, and activates protection information calculation by startup agent, and breakers control by operation agent.

The decision center unit, which serves as the important links in the system hierarchy, has the risks of single point error. To solve this problem, three measures are taken to enhance the reliability of WAPS.

1) The decision center unit is realized based on double configurations.

2) A substation is selected as backup master station when the master station failure occurs.

3) When the substation is out of contact with the master station, the system will take the distributed structure scheme, andthe wide-area protection function will be realized via the communication between the substation and its adjacent substation.

3. Dynamic on mechanism of WAPS

3.1. References Fault Identification Mechanisms

The decision center unit of distributed-centralized system structure realizes fault component identification through collecting wide-area information from multiple spots in the region. In order to reduce the communication traffic and to speed up the information transmission, the GOOSE based on IEC 61850 standards is taken as the information transmission mode. At the same time, with the cooperation among multi-agents, the decision center unit only requires limited area information to realize backup protection function. Only when fault-tolerance algorithm starts up will the decision center calls for lots of information.

To better illustrate the cooperation mechanism among multi agents, the command words must be pre-defined. Four command words---Agent_status, Fault_Unit, Fault_Status and Trip_command, are often used, as shown in Table1.

Table 1. Definitions of command words

Command words	Values	Detailed explanation
Agent_status	Act(Active).	Activate protection agent.
	Fnd(Found).	Fault has been found.
	Blk(Block).	Block trip operation.
	Toli(Tolerancei).	DCAS start up different tolerant rules (i=1, 2, 3).
Fault_Unit	Lx、Bx.	Fault component has been affirmed.Lx, Bx is fault components respectively.
Fault_status	Conf(Confirmation).	Confirm fault existence.
Trip_command	Fst(Fast).	Send trip command directly.
	Req(Request).	Send trip request.
	BF(Breaker failure).	Send trip request upon breaker failure.

WAPS cannot completely substitute the traditional protection due to some limitations, such as the communication delay, the reliability and sensitivity of distributed communication system. So the purpose of WAPS is to enhance the backup protection performance using the new WAPS algorithm. As WAPS takes the segregation of fault component as its main purpose and it demands higher reliability and rapidity than traditional backup protection, the paper utilizes the dynamic cooperation between master station and substations to realize the identification and clearing of fault. The fault component identification function is the core of WAPS. The logical calculation algorithm based on cooperation among multi agents is proposed. The concrete cooperation mechanisms are shown in Table 2.

Table 2. Dynamic cooperation mechanisms of fault identification

Serial number	Fault identification mechanisms	
	Conditions	Results
1	Anyprotection component starts up in the region.	Activate DCAS, start consults among multi-agents, subscribe fault direction information of corresponding LMCAS, and set Agent_status=Act.
2	The fault identification results are different between master station and sub stations.	Some agents have mal-operation. Block fault component identification agent, set Agent_status=Blk, meanwhilesend Agentt_status=Tol1 to tolerant agent.
3	The fault identification results between master station and substation are the same.	There is a fault in the region, and set Agent_status=Fnd.
4	Agent_status=Fnd, and fault component is single line.	Send Trip_Comd=Req to the opposite side line protection LMCAS actively.
5	Agent_status=Blk, and receive Trip_Comd=Req from the opposite side line protection LMCAS.	DCAS Set Agent_status=Tol2, start the tolerant rules, and subscribe fault information of corresponding LMCAS.
6	Agent_status=Fnd, and receive Trip_Comd=Req from the opposite sideline protection agent.	Set Trip_Comd=Conf, and send Trip_Comd=Fst to the opposite side protection LMCAS actively.
7	Agent_status=Fnd, and fault component is a bus line.	Send Trip_Comd=Req to other line protection LMCAS actively connected to the same bus.
8	Agent_status=Blk, and receive Trip_Comd=Req from other line protection agent connected to the same bus.	Set Agent_status=Tol2, start the tolerant rules, and subscribe fault information of all lines protection LMCAS connected to the same bus.
9	Agent_status=Fnd, and receive Trip_Comd=Req from other line protection agent connected to the same bus.	Set Trip_Comd=Conf, and send Trip_Comd=Fst to other line protection LMCAS actively connected to the same bus.
10	Agent_status=Fnd, but there are more than a fault components.	Set Agent_status=Tol3, start the tolerant rules, and subscribe fault information of all LMCAS.

3.2 Information Tolerance Mechanism

Susceptible to environmental factors, the distributed sampling and transmitting of wide-area information would easily cause information loss or information distortion. With incorrect information, it would be difficult for traditional wide-area protection algorithms to accurately identify fault component. In order to improve the reliability of the system, the paper adopts GA information fusion algorithm proposed by reference [10] to realize information tolerance mechanism of WAPS.

Once the decision center unit receives the tolerance requests from substations (four types of requests included, which are the decision inconformity between master station and sub stations, the judgment inconformity between substation and other substation, multiple failure components, and breaker failures), DCAS will start tolerance mechanism based on the subscribed information in compliance with the grid topology structure and algorithm requirement. The specific cooperation mechanisms are shown in Table 3.

Table 3. Tolerance mechanism

Serial number	Tolerance mechanism	
	Conditions	Results
1	Agent_status =Tol1.	Subscribe the main protection and backup protection information, breaker state information of suspected fault line, and the backup protection information of adjacent lines (the information can be acquired by communication networks between regions when the adjacent lines don't belong to the region). Activate tolerant agent of DCAS. At last, send Trip_comd= Req to LMCAS.
2	Agent_status =Tol2.	Subscribe the main protection and backup protection information, breaker state information of suspected fault bus, and the backup protection information of all lines connected to the same bus. Activate tolerant agent of DCAS. At last, send Trip_comd= Req to LMCAS.
3	Agent_status =Tol3.	Subscribe the main protection and backup protection information, breaker state information of all protection agents in the region. Activate tolerant agent of DCAS. At last, send Trip_comd= Req to LMCAS.
4	Agent_status =Tol4.	Subscribe the main protection and backup protection information, breaker state information of all upper lines backup protection agents of breaker failure agent. Activate tolerant agent of DCAS. At last, to send Trip_comd= Fst to LMCAS.

3.3 Operation Mechanism

Wide-area protection technique brings a significant improvement in backup protection. As compared to main protection, backup protection takes more responsibility and requires higher reliability because the scope protected by backup protection before fault and segregated after fault are both larger. This is especially true for wide-area protection, in which case an execution error or decision error will lead to unimaginable consequence. Therefore, to enhance the reliability and security of WAPS, an effective operation mechanism is especially important in guaranteeing the cooperation among multi-agents. At the same time, when breaker failure occurs, the dynamic cooperation can realize a fast and reliable segregation of the fault. Specific operation mechanisms are demonstrated in Table4.

Table 3. Operation mechanism Serial number Operation mechanism

Serial number	Operation mechanism	
	Conditions	Results
1	Line protection set Agent_status=Fnd, and receive Trip_comd= Req of the opposite side line protection agent or the center unit.	Set Fault_status= Conf, and send Trip_comd=Fst to the opposite side line LMCAS.
2	Bus protection set Agent_status=Fnd, and receive Trip_comd= Req of all lines protection agent connected to the bus or the center unit.	Set Fault_status= Conf, and send Trip_comd=Fst to all lines LMCAS connected to the bus.
3	LMCAS set Agent_status=Fnd, and receive Trip_comd=Fst.	Directly trip, and activate breaker failure protection monitoring function. And then send Trip_comd=BF to the upper protection LMCAS and Agent_status=Tol4 to DCAS after breaker failure is confirmed.
4	LMCAS set Agent_status=Fnd, and receive Trip_comd=BF from other LMCS.	Wait the results of DCAS, and then directly trip after the result cannot be received in the stipulated time.
5	LMCAS set Flt_sts= Conf, and receive Trip_comd=Fast.	Directly trip.
6	LMCAS set Agent_status=Fn, and receive Trip_comd=Fast fromDCAS.	Directly trip.

3.4 Cooperation Mechanism Described by FSM

Finite state machine (FSM) has been put into wide application as it can well describe the operation, transformation and state association in cooperation mechanism [11]. Multi-agents cooperation mechanism of WAPS has the following functions, such as the perception of external environment, the transformation of input information, the association of multi-information, and the cooperation among agents, all of which can be well described by FSM. Take DCAS as an example, the cooperation mechanism on state machine is shown in Figure 3.

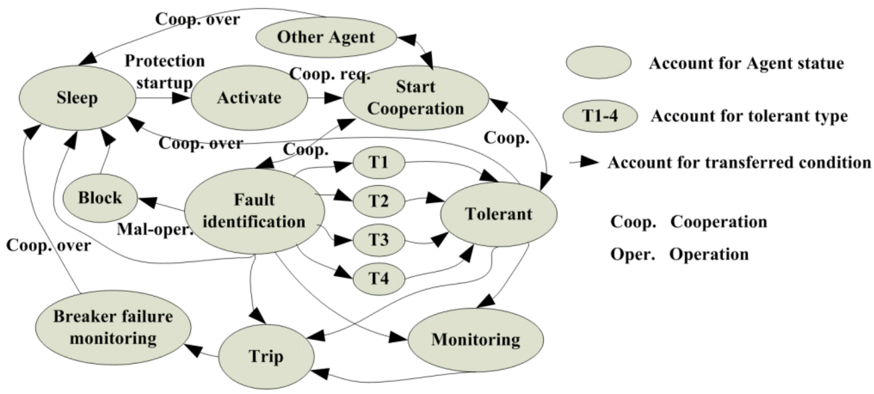

Figure 3. Flow chart of substation 'm' pickup procedure

The protection information and the state information are used as input signals. Every sub-agent accounts for the state of FSM, and the startup information is seen as the transferred condition of FSM.

4. Examples

4.1. Models

Taking IEEE 5 nodes system as models of the examples, the paper simulates some fault types under different information errors. The dynamic cooperation mechanism of WAPS is illustrated by analyzing the organizational form and the cooperation process among multi-agents. IEEE 5 nodes system is shown in Figure 4. B1-B5 is bus, L1-L5 is line, and A1-A10 is breaker, corresponding to LMCAS. B2 station is set as the master station, corresponding to DCAS, and other stationsare substations.

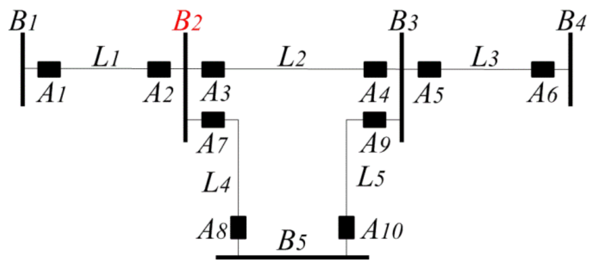

Figure 4. IEEE 5 nodes system

4.2 L2 Line Fault and B3 Communication Failure

LMCAS of A3, A4 can perceive failure state when fault occurs on L2. DCAS subscribes B2 and B3 directional protection information to realize fault identification. Assume that B3 information sent to DCAS has error, the fault component L2 would be diagnosed as healthy component while B3 as the fault one. At this moment, the decision center agent activates tolerance mechanism to rectify the wrong result. Specific cooperation mechanism is shown in Figure 5.

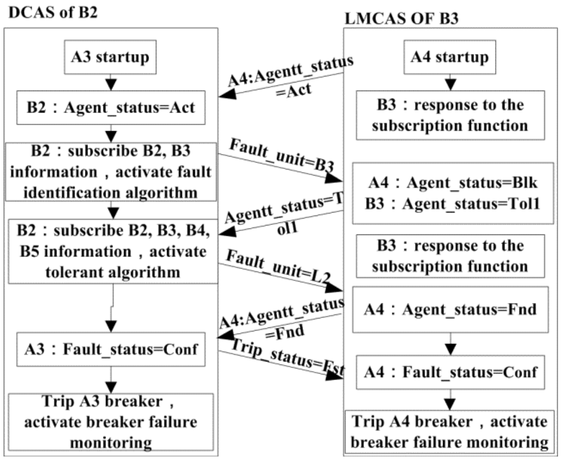

Figure 5. Cooperation mechanisms among agents in communication failure

4.3 L3 Line Faultand A5 Protection Failure

The fault component should be segregated by the pilot protection composed of A5 and A6 when fault occurs on L3. Assume that LMCAS of A5 fails for some reasonwhile the communication networks stays normal, WAPS will serve as backup protection to realize fault component identification. In this instance, the cooperation mechanism is shown in Figure6.

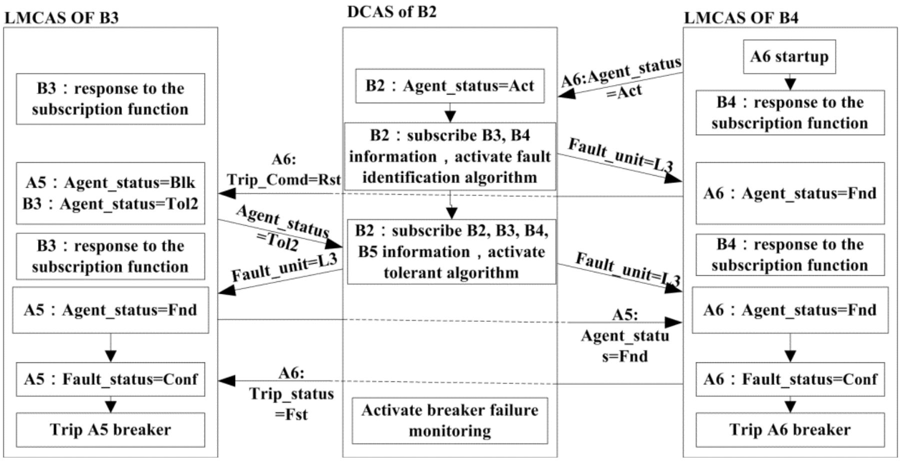

Figure 6. Cooperation mechanisms among agents in protection failure

4.4 L2 Line Faultand A4 Breaker Failure

The fault component should be segregated by the pilot protection composed of A3 and A4 when fault occurs on L2. But on account of the breaker failure of A4, A4 must activate breaker failure protection to segregate the fault to the minimum scope. LMCAS of A4 activates breaker failure monitoring function after receiving the trip command, and quickly sends Trip_Comd=BF to LMCAS of B3 after finding the breaker closed. Meanwhile, DCAS activates tolerance mechanism to segregate the upper breakers. Specific cooperation mechanism is shown in Figure 7.

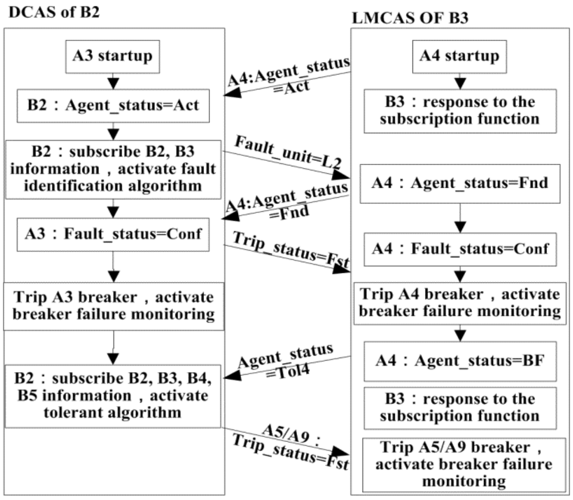

Figure 7. Cooperation mechanismsamong agents in breaker failure

5. Conclusion

Based on fault identification algorithm and distributed-centralized system structure of WAPS, the dynamic cooperation mechanism of WAPS based on multi-agents is proposed for the purpose of improving WAPS performance. The system can effectively overcome the following conditions, such as communication bit error, protection failure and breaker failure. According to multi-agents technology, the dynamic cooperation rules are researched between master station and sub stations, sub stations and other sub stations to enhance the reliability of WAPS. The example analysis on IEEE 5 nodes system validates the effectiveness of WAPS under some typical faults.

Acknowledgments

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