Distributed Restoration System Applying Multi-Agent in Distribution Automation System

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***Abstract*-- In this paper, as make up for the weak points of the centralized restoration in DAS, Distributed Restoration method applying Multi-Agent is proposed for increasing the efficiency and saving time of the restoration time of blackouts. Distribution Restoration method is difficult to deal with a fault quickly because DAS manage, judge and order the states of distribution network after gathering all information from FRTUs when the fault occurs. If Feeder Remote Terminal Unit (FRTU) in distribution network performs restoration and separates minimized fault section itself by exchanging information using communication to each other, the efficiency and time of the restoration can be enhanced by much. In the case studies, this paper is proposed a distributed restoration method which can make up the weak points of the centralized restoration in DAS by converting FRTUs into Multi-Agents. The proposed method has been testified in Gochang power test field in Korea and the result in the restoration shows its performance.**

***Index Terms*—Intelligent Distribution Management System, Distribution Automation System, Multi-Agent, Restoration**

I. Introduction

DISTRIBUTION Automation System (DAS) which play an important role in power supply observes and controls FRTUs (Feeder Remote Terminal Unit). In the distribution system operation, it collects information of operation for distribution network such as voltage, current and automatically finds fault section and restores the blackout when there is a fault.

By DAS, it can reduced blackout time when fault occurs, and possible for optimal operation. It is possible to give high quality and secure service to customers. One of the most important roles is recovery ability when s fault occurs [1].

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DAS adjusts overall control related this function. The centralized restoration system performs restoration as follows. It confirms information from overall node, analyzes the information, calculates solution and confirms the remaining capacity in linking feeder for restoration. After that, operator performs switching action one by one. DAS has performed such a series of all process after fault occurs. It's a time consuming process.

If such a series of all process can be done be parallel, the restoration can be made a quicker and more accurate manner. Accordingly, this paper proposes distributed restoration system based on Multi-Agent System. An agent has an ability of decision making and communication to other agents for information exchange.

Recently, Power System makes progress many studies based on agent technology. It manages distribution network converting Feeder, Bus and Switch into agents. After that performs restoration and operates distribution network [2-3]. Distribution network based on the Ethernet communication converting switch into agents performs restoration using the information exchange [4-6].

Also, there are studies used Artificial Intelligence (AI) algorithms which is similar to Agent techniques for Distribution System Operation and restoration [7-8]. Then, many Studies have been progressing not only studying distribution network but also operating and protecting power system based on Multi-Agent [9].

In this paper, a distributed restoration system based on Multi-Agent system is proposed. It converts a FRTU into an agent by minimum change of the FRTU.

This paper consists of five sections. Section II describes distribution automation system structure and function. Section III introduces the proposed restoration system. Section IV shows a case study of proposed system in Gochang power system test center in Korea and finally, conclusions are given in Section V.

II. Distributed Restoration System Based on Multi-Agent System

A. Structure of DAS

Fig 1 is presented a general structure of DAS. Each unit group of distribution network exist equipment of DAS in distribution organization. DAS has 100~500 unit of FRTU within the maximum 20km regional property.

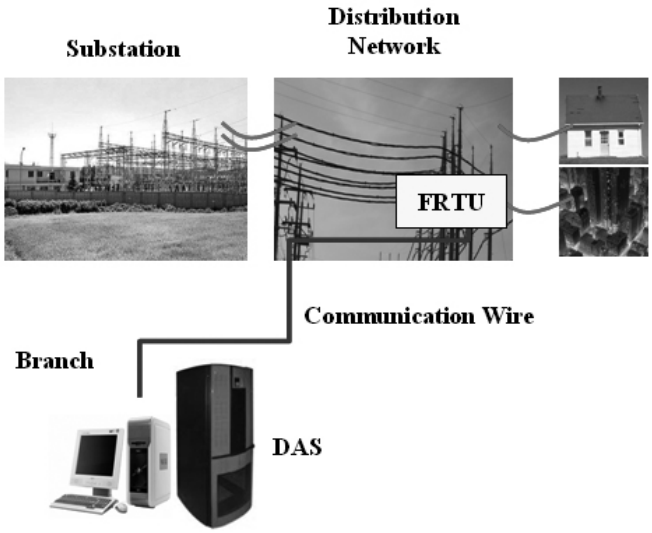

Fig 1. General structure of distribution automation system

Fig 2 shows DAS communication network based on the fiber optical network. DAS and FRTU are connected by the optical line using a optical modem with a communication protocol DNP3.0. The optical modem between E1 (2Mbps) and FRTU connects optic to serial communication.

FRTU can not directly exchange information with each other FRTU in DAS with centralized communication network.

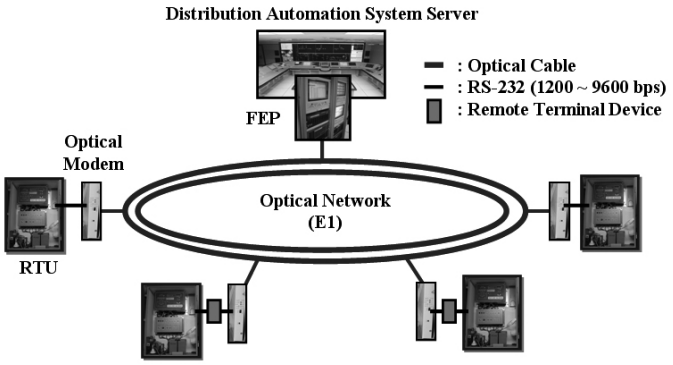

Fig 2. Communication structure of Korean DAS

B. Service Restoration of DAS

Restoration step of DAS is shown in Fig 3. When a fault occurs, FRTUs in distribution network transmit collecting information to DAS. Specially, when a FRTU senses the fault current, it transmits the information of fault indicator (FI) to DAS. The operator decides fault section by analyze the FI information.

After finding the fault section, the restoration should be done to restore the blackout of the load side after the fault section. The Operator who manages DAS separates fault section using automation switch, calculate load of normal state and margin of related feeders, then makes switching action to restore the blackouts Fig 3 is present the restoration of DAS.

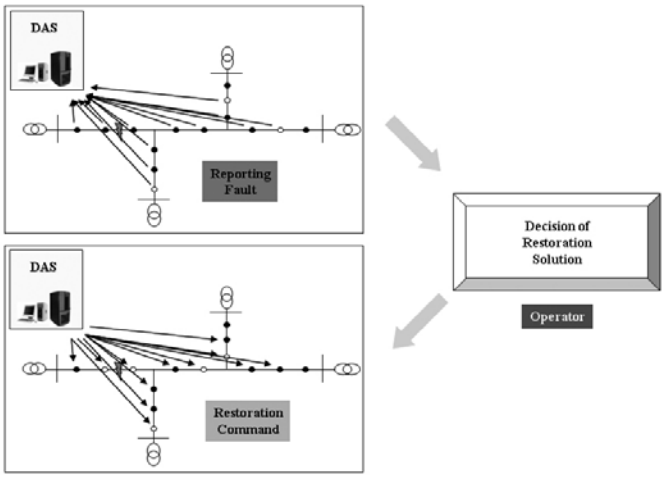

Fig 3. Service restoration process in DAS

The centralized DAS needs much time for restoration because centralized DAS has to communicate with all nodes one by one. The restoration time is the most important performance of DAS [10].

III. Distributed Restoration System based on Multi-Agent

A. Construction of Distributed Restoration System

Proposed system in this paper has largely two elements. At the first, it is terminal agent which performs independent judgments and action using the exchange of information from the measured data of distribution network. Secondly, it is central agent which helps terminal agent to acknowledge the distribution system. The terminal agent has an information restoration strategy which is downloaded from the central agent.

1) Role of central Agent

The role of the central agent is finding the restoration solution. The central agent gathers system topology information from the terminal agent. When there is a topology change in the system the central agents finds the restoration solution and requires the conformation of operator of DAS. After the conformation, the central agent downloads the information of the restoration solution to terminal agents.

2) Role of terminal Agent

Terminal agent which is the kernel of proposed system. Fig 4 shows flow chart of the action of the terminal agent. Terminal agent waits two events after adapting the network. The first is FI detected from the measured information. The second is the request from other agents by communication.

If FI occurs, it means there is a fault at the load side, then, it asks whether FI experienced to detect the fault section. When it receives positive answer, it makes perform appointed task with network information, restoration information.

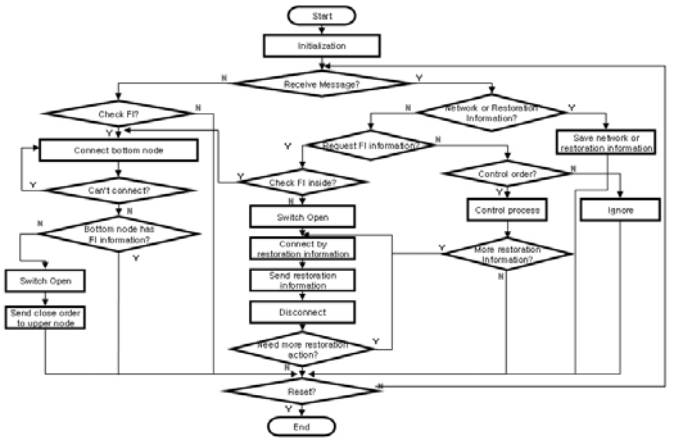

Fig 4. Flow chart of agent based service restoration

Main functions that go through this action is that

1. It confirms FI information of the one's bottom section from FRTU.

2. It detects the fault section through information exchange of among MASXs.

3. It restores the blackout through the information exchange of among MASXs.

3) Distributed Restoration Method

a) .Acknowledgment of System

When there is a change in the system such as switching status of terminal agents, Fig 5, shows downloading of the information for network and restoration from the central agent. From the information terminal agents acknowledges the distribution system. Terminal agent can know which agent is the neighborhood and which agent is to communicate with.

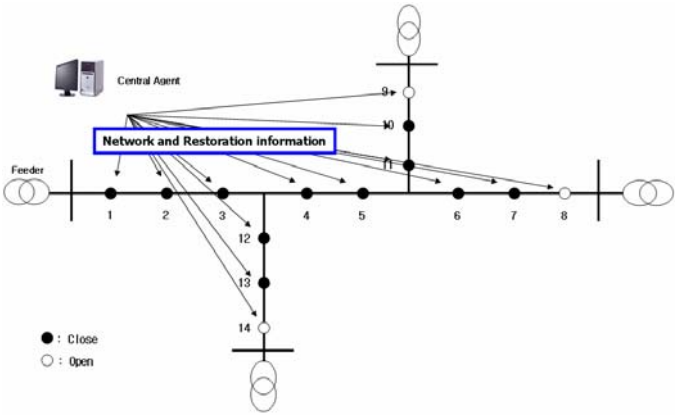

Fig 5. Downloading of restoration strategy

b) Breakdown segment search phase

When there is a fault Fig 6 shows fault section detecting step. Each number from Fig 6 is a terminal agent. The Recloser is established in node 1 and it will be able to intercept fault current, but agents at node 2 and node3 with automation switch are able to intercept only load current. If fault occurs from between node 2 and 3 then node 1 intercepts fault current and the bottom part from the fault section becomes blackout. At this time, FI information occurs from the FRTU which experienced fault current. When the terminal agent who observes the communication between the FRTU and the DAS confirms that FI information occurs from the FRTU, it tries to ask a FI information occurrence to terminal agent of the bottom part.

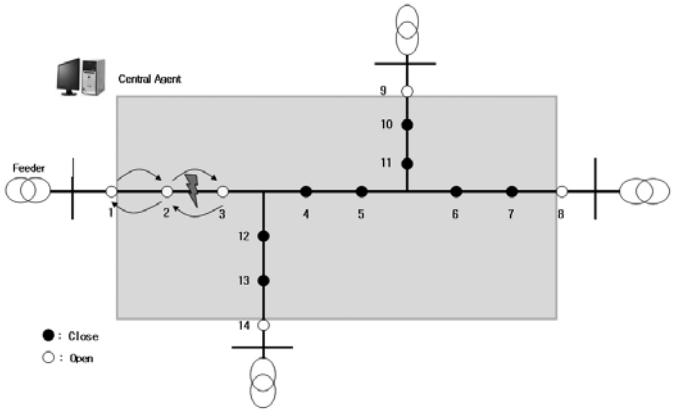

Fig 6. Identification of faulted section

In the answer, there are two possibilities. One is that there is not fault between two sections when the FI becomes confirmation from bottom part node, the other is there is the fault in the corresponding section when the bottom part node does not detect a FI information. In this case the agents in the top and bottom node of the fault section order the switch in correspondence FRTU to open to remove the fault section from the system.

c) Distributed Restoration step based on Multi-agent

Fig 7 shows the restoration step from a corespondant restoration solution downloaded information before the fault. When fault occurs between node 2 and 3, node 3 leads the restoration action by restoration information which was delivered by the central agent in advance. In this case, it hands down the open command to node 5 and 11. After the accomplishment of that the command is confirmed, it hands down the close command to node 14. Node 1, 8 and 9 are handed down a close command from node 2, 5 and 11. And then, they rehabilitate the blackout section. The distributed restoration system performs restoration quickly by the parallel communication which is necessary between each other agents.

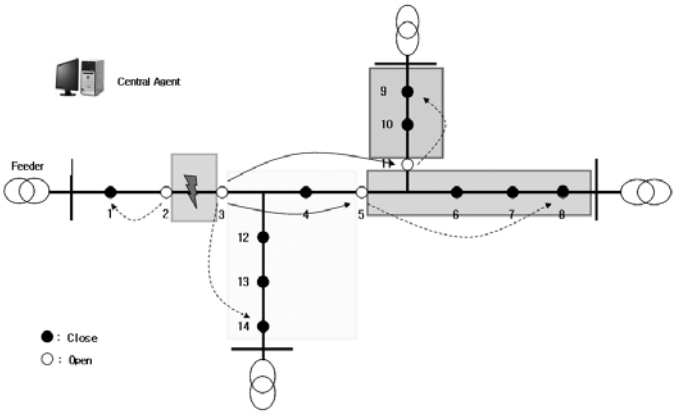

Fig 7. Multi-agent based service restoration

IV. Case Study

In this paper, an actual test was made in Gochang Power Test Center in Korea to show the efficiency of the proposed system. All FRTUs have to be changed to terminal agents to have agent characteristics. Terminal agents are developed. Fig 8 shows the terminal agent device (i.e. MASX) that can change FRTU into new FRTU with agent characteristic. The developed environment of MASX is PXA 255 Arm series MCU and Linux kernel 2.4.19 O/S.

Fig 8. Prototype of DAS agent

A. DAS communication architecture

This paper has proposed a structure of MASX in communication, protocol and installation position in DAS for being applied distributed restoration based on Multi-Agent in actual distribution network.

1) Applying structure of MASX in distribution network

MASX is installed between FRTU and relay communication modem to connect FRTU and FEP. MASX installed the position does not have to disturb communication between FRTU and DAS and read DNP 3.0 response packet from FRTU to DAS. MASX decides fault section through the information to get from the packet.

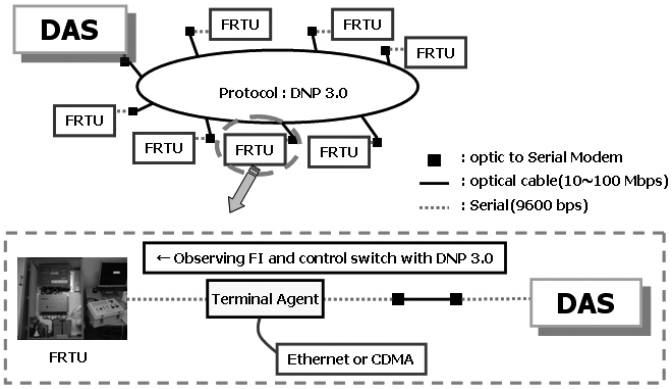

Fig 9. Structure for applying distribution network of terminal agent

FRTU can be acted open/close action of switch from command of MASX in the position of MASX. So proposed system can do distributed restoration through switch open/close action from command among MASXs.

2) Communication structure of MASX

MASX include three communication types that serial, CDMA and Ethernet as like Fig 10. First of all, serial communication is necessary for observing packets between FRTU and DAS. CDMA is wireless communication for changing information among MASXs in the space where can't install a wire network. Ethernet is a communication to intend to all of power system to user communication network.

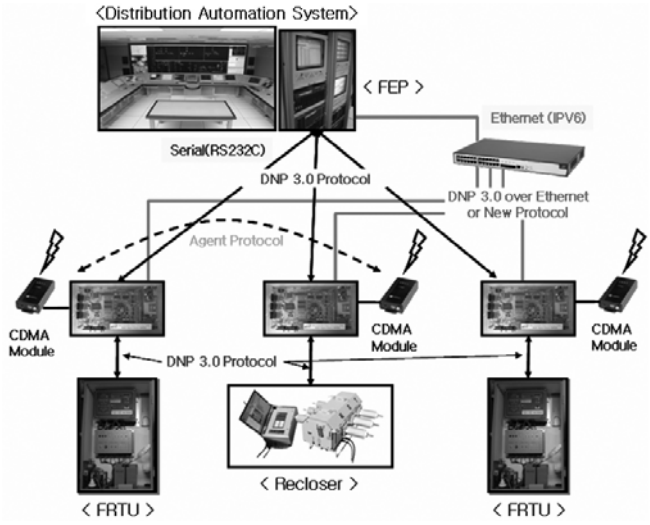

Fig 10. Structure of distributed service restoration system

Fig 10 is presented a communication structure of distributed restoration system based on Multi-Agent in this case study

3) Protocol structure of MASX

MASX observes packets from FRTU to DAS and then do necessary restoration between FRTU and DAS. MASX has to have special DNP 3.0 protocol structure for observing communication packets between FRTU and DAS.

Fig 11 is presented for special structure of DNP 3.0 in MASX. MASX has to have no modify and setting when it was applied in DAS. So the communication between FRTU and DAS continues normal state and then MASX can get more needed information. Accordingly, MASX has only to have master of between master and slave of DNP 3.0 [13-14].

More information that MASX can get them between FRTU and DAS got from FRTU. So DAS has DNP 3.0 master and can request needed information and control switch when considered DNP 3.0 construction elements. FRTU has DNP 3.0 slave and then respond to, act on a request and do unsolicited function when FI occur.

MASX needs only DNP 3.0 master that can analyze packets of DNP 3.0 slave and to request information and control to slave because only communicates with FRTU. Port control thread charges of the actions.

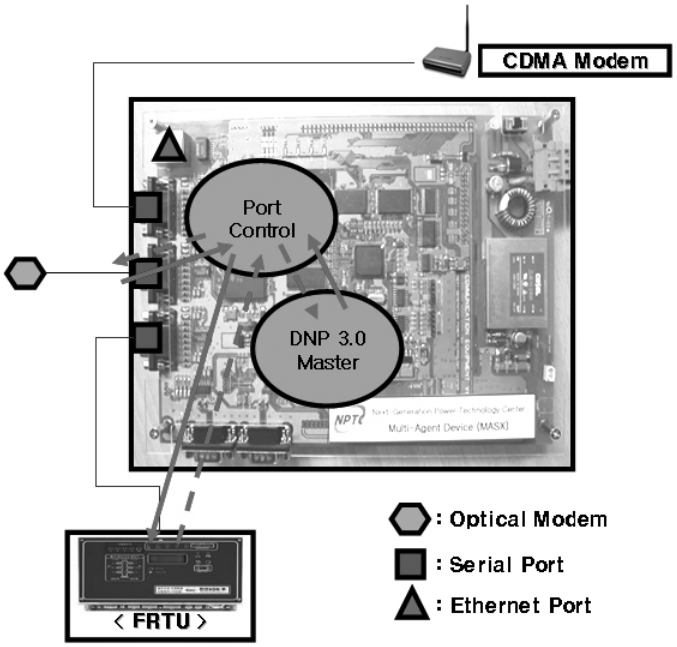

Fig 11. DNP 3.0 structure for MASX

B. Gochang actual test of distributed restoration system based on Multi-Agent

Proposed system in this paper provides efficiency through an actual test in Gochang Power Test Center. Fig 12 is single line diagram of distribution test network in Gochang Power Test Center, and we make an example network for actual test of our proposed the system in Fig 13.

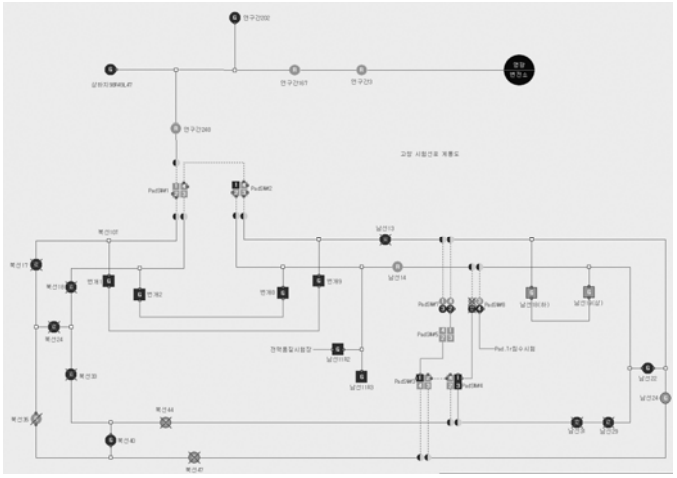

Fig 12. Single line diagram of distribution test network in Gochang

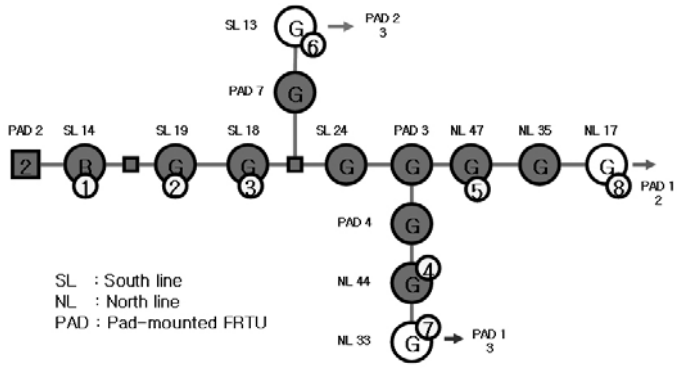

Fig 13. Single line diagram of example network and installed position of MASX

In Fig 13, 'R' is Recloser and 'G' is FRTU. PAD 2-2 is feeder of example network. PAD 2-3, PAD 1-2 and PAD 1-3 are related feeders for supplying power from fault location to load section when restoration. The fault location is between 2 and 3, the fault type is a single phase grounded fault.

The communication network of our proposed system is CDMA type because there is not other communication network except it for operating DAS in Gochang Power Test Center.

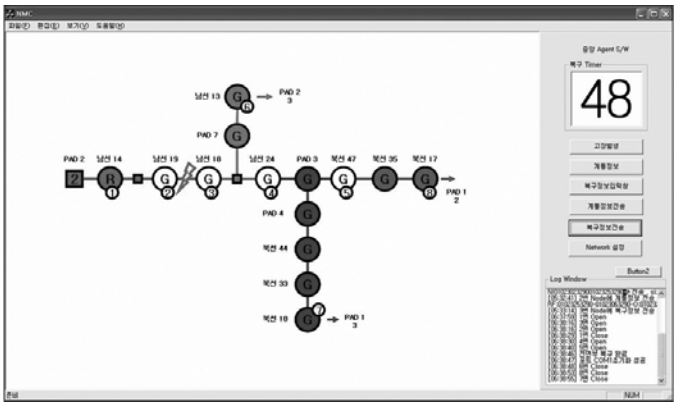

Fig 14. The result of test of three related scenario

It is presented test results that 1, 2 and 3 related restoration to apply our proposed system in example network. Each restoration solutions and spending times are presented to Table 1. Restoration necessary time measured from occurring FI and is average of 5 times. The restoration solution is structured "sender – receiver – command." 'C' is close and 'O' is open.

TABLE1. RESTORATION SOLUTION AND NECESSARY TIME

Index	Restoration solution	Necessary time(s)
1 related	03-06-C	24
2 related	03-04-O, 03-06-C, 04-07-C	36
3 related	03-04-O, 03-06-C, 04-05-O, 05-08-C, 04-07-C	48

Table 2 is presented comparison of restoration service of central and distributed type to have same restoration solution in 3 related restorations. Total switch action needs 8 times,

central type has necessary times of 8 times and distributed type has necessary times 4 times by parallel communication. So distributed restoration system decide and separate fault section more than central type restoration in DAS.

TABLE 2 COMPARISONS OF COMMUNICATION TIMES

Index		Central Type	Distributed Type
Action Switch		8	8
Com-muni-cation times	1	D-2-O	Detect fault section(2, 3 open)
	2	D-3-O	2-1-C, 3-4-O
	3	D-1-C	3-5-C, 4-7-C
	4	D-4-O	3-6-C, 5-8-C
	5	D-5-O	
	6	D-6-C	
	7	D-7-C	
	8	D-8-C	

V. CONCLUSION

In this paper, a real application of agent techniques to a real distribution power system. A distributed restoration system based on Multi-Agent is proposed to apply to DAS. A terminal agent device that called MASX is developed to have agent characteristic and communication function. A FRTU can do agent function with this terminal agent. In the field test result of the distributed restoration system shows the performance enhancement in the restoration of the proposed system based on Multi-Agent.

VI. ACKNOWLEDGMENT

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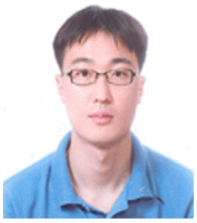

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