MULTI-AGENT APPROACH TO BULK POWER SYSTEM RESTORATION

T. Nagata (1), Y. Tahara (1), T. Wakisaka (1), T. Aoyama (1), H. Fujita (2), M. Koizawa (2)

(1) Hiroshima Institute of Technology, Japan (2) Chubu Electric Power Co., Inc., Japan

ABSTRACT

In this paper, we propose a new decentralized multi-agent approach for a bulk power system restoration. The proposed multi-agent system is constructed with two-level hierarchical architecture. Several Local area Management Agents (LMAs), which are corresponding to the local area management system are located at the upper level. Correspondingly, Remote area Management Agents (RMAs) are located at the upper level. In contrast, several Load Agents (LAGs) and Generator Agents (GAGs) are located at the lower level. In order to demonstrate the capability of the proposed multi-agent system, it has been applied to a model bulk power system. The simulation results show that the proposed multi-agent approach is effective and promising.

Keywords: Bulk Power System, System Restoration, Multi-agent

INTRODUCTION

When electric power supply interruption is caused by a fault, it is imperative to restore the power system promptly to an optimal target network configuration after the fault. The problem of obtaining a target network is referred to as a power system restoration. To obtain the target network configuration, various approaches have so far been proposed, which can be roughly classified into four categories: heuristics [1-5, 13], expert systems (ESs) [4,6-11] mathematical programming (MP) [11], and soft computing [12]. Heuristics and ESs have been used in industries extensively, but they both have their own deficiency with respect to the optimality of solutions. MP, on the other hand, is able to obtain the optimal solution after the formulation, but it needs some engineering judgment in formulating restoration problems due to its sheer difficulty. Also, its long excursion time may sometimes make MP seem practical considering the time constraints on site. Although soft computing methods are easy to implement, they cannot obtain the optimal solutions in the true sense. Also, they need a long computation time to produce a solution.

In this paper, we propose a new decentralized multi-agent system for a bulk power system restoration. In the second section, we introduce architecture of multi-agent restoration system and describe about each agent. We present restoration process in the third section. In the section of the fourth and fifth, we present simulation results. Conclusions are presented in the last section of this paper.

MULTI-AGENT RESTORATION

Multi-agent Restoration System

In this section, we present the proposed multi-agent restoration system architecture. Figure 1 shows the proposed multi-agent system. The system is constructed with two-level hierarchical architecture. Several Local area Management Agents (LMAs), which are corresponding to the local area management system, are located at the upper level. Correspondingly, Remote area Management Agents (RMAs) are implemented at the upper level. In contrast, several Load Agents (LAGs) and Generator Agents (GAGs) are located at the lower level. LAG corresponds to the individual load, which has a different load pick-up characteristic, while GAG addresses the individual generator, which has a different generating characteristic such as ramp rate or capacity.
Local Area Management Agent (LMA)
Each LMA is implemented on local area management system. It has two principal roles. One is the restoration within the local area. The other is extensive restoration by interaction with other LMAs. The former is significant for all LMAs in order to carry out local optimization. The latter is realized by interaction between LMAs, or LMA and RMA. Coordination among agents on the upper layer (LMA and RMA) contributes to achievement of global optimization.

Remote Area Management Agent (RMA)
RMAs are implemented on remote area management system. RMA has only one purpose of which facilitate the restoration of loads within the remote area. In order to accomplish this purpose, RMAs must negotiate with neighboring LMAs, which have generator’s information, and receive power for loads in the remote area.

Load Agent (LAG)
LAGs are implemented on each load management system. They know characteristics of each load, such as predicted load demand. In order to restore the load, they request serving the load by interaction with agents on upper layer (LMA or RMA).

Generator Agent (GAG)
GAGs, which are corresponding to generator management system, know characteristics of each generator. They offer information about each generator to upper layer agent (LMA) and manage operation of the generator.

RESTORATION PROCESS

Restoration Process by Multi-agent System
In this section, we propose restoration process by means of multi-agent approach. First of all, we divide the intended system into local areas and remote areas. There are several generators and loads in a local area, and a remote load area has several loads only. A load, which has been provided the power, is not always restored at once. Therefore, we divide the restoration process by the constant time interval, and restoration process progresses by iterating four proceedings for a time interval as follows.
1. Planning of restoration in each local area.
2. Planning of extensive restoration except for remote areas.
3. Planning of extensive restoration include remote areas.
4. Execute plans created by above proceedings.

We describe more detail as follows.

Planning of Restoration in Each Local Area
Figure 2 shows the image of exchanging messages at the first proceeding in a local area and a remote area. Where, the arrows show behavior of the message between agents. First of all, when total blackout occurred, LAGs corresponding to outage load send information to LMA by XML formatted message. This message(s) triggers the multi-agent restoration system. These messages include load information, such as load value that they want to serve additionally. At the same time, GAGs send messages including information about each generator, such as ramp rate, capacity, minimum load and 0-1 variables that indicates start or not, to LMA. When LMA catch these messages, it calculates serving values for each LAG and generation values for each GAG.

On the other hand, LAGs in remote area also inform to RMA. However, RMAs doesn’t perform at this phase yet.

Planning of Extensive Restoration Except for Remote Areas
When finished the first planning for restoration inside local areas, planning of extensive restoration except for remote areas is begun as the second proceeding. Figure 3 shows the dialog in this proceeding. However, in order to restore the each local area preferentially, this proceeding is invoked after the load restore rate in the local area is over 30 percent.

Firstly, each LMA has to determine whether the local area needs the power or not. If the local area lacks the power, the LMA continue to wait a “succorable

Figure 1 Proposed Multi-agent System

Figure 2 Planning of Restoration in Each Local Area

Figure 3 Planning of Extensive Restoration Except for Remote Areas
“message” from a neighboring LMA. Inversely, if the generators in the local area have the reserve to space for transmit to the other area, the LMA sends a “succorable message” to the neighboring LMAS on the order of precedence. The messages include the information for the generators.

Secondly, when the neighboring LMA received the “succorable message”, it may send a reply considering own demand. If the neighboring LMA had been waited for the “succorable message” in order to accept the power supply, it may calculate the request power and send a reply as a “request message”. Conversely, the neighboring LMA hadn’t been needed power supply, it may send back a “rejection message”.

Finally, when the LMA as supply side received the “request message”, the LMA add the calculate results into the plan.

Execute plans created by above proceedings
Based on the above three proceedings, the proposed multi-agent system executes the restoration in a time interval. Each LMA informs the information of generation and restoration to GAGs and LAGs, respectively. Each GAG increases generation according to the information from the LMA. Also, each LAG operates the breakers through the load management system. At the same time, LMAs operate the line breakers through the local area management system and transfer the power to the accepted local area from the supply side local area. Then we should note that transfer power is within the power flow constraint of the transmission line.

SIMULATION OF RESTORATION

Simulation Test System
Figure 5 is a test system used for restoration simulation [14]. There are three local areas, three remote areas, twelve generators, twenty-four loads and seven branches in this system. We implemented three LMAs, three RMAS, twelve GAGs and twenty-four LAGs on the test system. There are forty-two agents in this system. Each area has four loads respectively. Local areas have several generators. In figure 5, several circles and squares indicate generators and loads, respectively. We assume that a load is an integration model including the large number of distribution system.

Simulation Condition
We assume that the time interval as one minute. In the test system, load in Local area 1 and 2 are 150MW, and load in Local area 3, Remote area 1, 2 and 3 are 300MW.

It is assumed that there are four transformers (Type1-Type4) in each local or remote area and total load in each area is divided equally into four sub-loads. In addition, we considered that the energizing of bus
ensures cranking power because it is vanishingly small. We assumed that generator 1 (G1) and 12 (G12) are the gas turbine, which don’t need cranking power to start. Therefore, G1 and G2 is the initial power source. Other generators generate by steam. Therefore, these generators need the cranking power for ten minutes. All transmission line has 400MW capacity. Table 1 and Figure 6 show the generator characteristics and load characteristics, respectively.

<table>
<thead>
<tr>
<th>Table 1 Generator Characteristics</th>
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At 12th minute, the restoration of Local area 2 has begun. Figure 8 shows the system at 12th minute. Because restore load rate in Local area 1 exceeded over 30%. The LMA of this area became to be able to serve power to another local area. The LMA sent “succeedable message” to LMA of the Local area 2 and negotiated each other. As a result, G6, G7, and G8 began to be provided the cranking power from this minute.

SIMULATION RESULTS

In order to demonstrate the effectiveness of the proposed approach, it has been applied to a test system that we introduced in preceding section. We present the significant part of result of the simulation test below.

1st minute

Figure 7 shows the results of our simulation at first minute. In this figure, the black area corresponds to the de-energized area, while the white area corresponds to the energized area. First of all, G1 and G12 started simultaneously and loads A3 and C4 were begun to restore. At the same time, Local area 1 and Local area 3 was energized, hence, G2, G3, G4, G5, G9, G10 and G11 would be standby at 11th minute when clanking power was going to be provided for ten minutes.

12th minute

Figure 8 Restoration Result at 12th minute

Figure 9 Restoration Result at 73rd minute
73rd minute
Third proceeding began to invoke from 73 minute. Since all loads in the Local area 1 began to restore, LMA in local area 1 sent a “succeivable message” to RMA of the remote area 1, and interacted with each other. Figure 9 shows results of simulation test at 73rd minute. In this minute, Branch 6 is energized and load RA1 began to restore.

Finally, the test finished at 135th minute in the simulation. We implemented proposed multi-agent system on the seven workstations by Java. The result load restoration curves are shown in Figure 10.

CONCLUSIONS
In this paper, we propose a new decentralized multi-agent system for a bulk power system restoration. In order to demonstrate the capacity of the proposed multi-agent system, it has been applied to a model bulk power system, which consists of three local area networks including twelve generating units and twelve loads and three remote area networks with twelve loads. A large number of simulations are carried out on this model network with changing conditions. The simulation results show that the proposed multi-agent approach is effective and promising.

We will improve the proposed simulator to consider system frequency and power flow calculation.

REFERENCES

AUTHOR’S ADDRESS
The first author can be contacted at
Department of Information and Intellectual Systems Engineering
Hiroshima Institute of Technology
Shin-10 Gokan
2-1-1 Miyake
Saekiku Hiroshima City Hiroshima Pref
Japan 731-5193
email nagata@cc.it-hiroshima.ac.jp