A MULTI-AGENT BASED LOGICAL INTERLOCKING IN SUBSTATION AUTOMATION SYSTEMS

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ABSTRACT

An improper switching operation can damage equipment and/or can affect the quality of supply to the customers. Normally, switches are opened and closed by operators using pre-generated guidelines for avoiding human errors. But all of that are changed after IEC61850 which require the interlocking should be based on network. However, IEC61850 didn't give the implementation of CILO where interlocking happens, so, a Multi-agent based logical interlocking method is proposed. Method of getting switch gear status, logical structure of substation, ways of expressing knowledge in substation is analyzed. Agents are assigned roles for different function. Task-allocated, communication mechanism, inside of agent will also be researched in this paper. Finally, on the case study of some simulations, this method can fulfill the function and real-time requirements in the substation automation systems.

Keywords: *Interlocking, IEC61850, Multi-agent, Switching operation, Distributed control.*

1 INTRODUCTION

According to IEC61850, data-layered model has been established and some new requirement for switching operation such as interlocking and logical node CILO was proposed. On the one hand, IEC61850 didn't give the method of implementing CILO. Most researches[1-4] on the interlocking is focused on the operation order expert system in the control center by far. Because the computation and store resources in IED are too limited to calculate interlocking rules and it is impossible to accomplish one complicated interlocking control via IED's distributed cooperation, method of implementing CILO can't be achieved completely like which used in operation order expert system in control center. New idea on interlocking have also been proposed such as in paper [5] which suggests that the operation rules can be taken to CILO from control centre via PMI/PKI. But there is no possibility to put it in practice at present. On the other hand, distributed artificial intelligence (AI) especially agent and Multi-agent system made large technology progress before entering the electric power systems[6]. It is used in conditions like that: distributed data and control resource, operation with coordination control, communicate each other for information. All of these exist in logical interlocking. But there is still no research about it in the world by far, which is the reason why we write this paper.

2 MODEL OF LOGICAL INTELOCKING IN IEC61850

Substation automation systems is divided into three levels in IEC61850[7]: process level, bay level, station level, and the means of interlocking in bay level and station level is also defined in IEC61850. Here is a logical interlocking model in one bay level (fig.1).

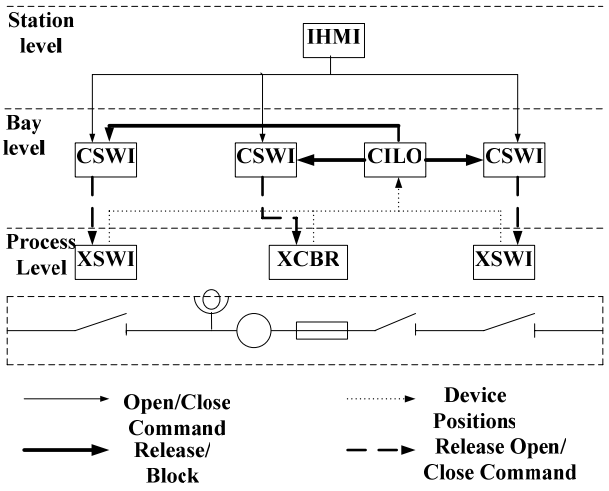

Fig.1 Interlocking model in one bay level

The breaker and switch are abstracted to logical node XCBR and XSWI, while control devices to CSWI and CILO. Open/close command from IHMI is sent to CILO where the system judge whether the command is allowed/un-allowed, then CSWI send released open/close command to XSWI after he received the release or block order from CILO. In the interlocking process, the CILO must require many other devices' positions from process level. IEC61850 provide a goose message based on subscriber/publisher model[8] to make the data- transmitted process higher reliability and real-time efficiency than before. (fig.2)

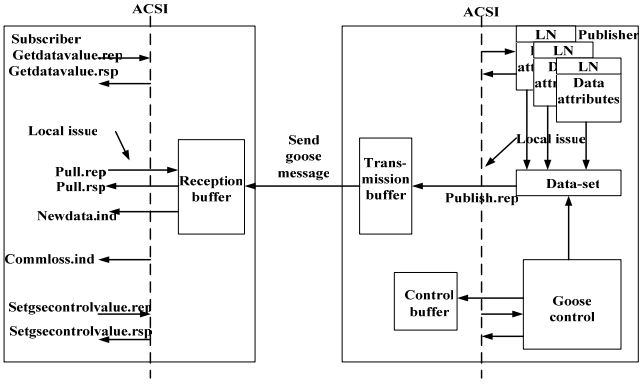

Fig.2 Goose message transmission model

According to IEC61850, we must abide by the model in fig.2 about transmitting the information from process level no matter which way we will choose for the logical interlocking.

3 FRAME OF MULTI-AGENT BASED LOGICAL INTERLOCKING

Since we think there is much resemblance between LN (logical node) in IED and agent, the frame of interlocking according to IEC61850 can be designed like in fig.3. The work defined in IED can be implemented by agent.

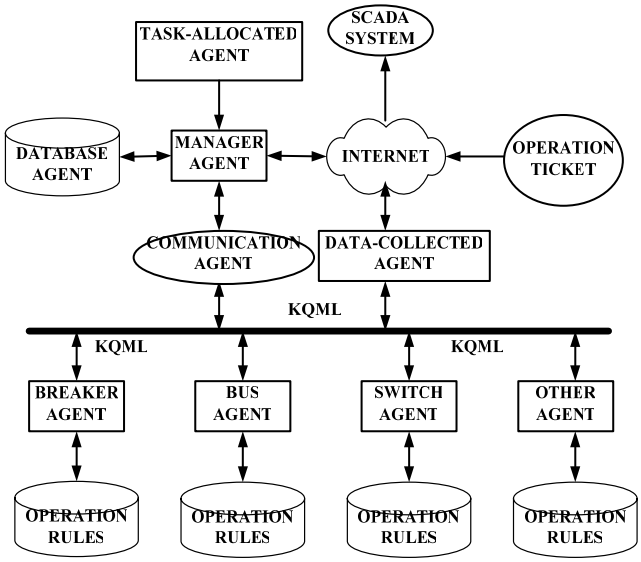

Fig.3 Frame of multi-agent based logical interlocking

The system will be running based on Ethernet network with KQML which is a agent's communication language, and it consists of the following agents.

- Manager Agent: take agents action in harmony when they cooperate to accomplish logical interlocking.
- Communication agent: choose and send the information to the right agent
- Task-allocated agent: allocate operation task less ones, which is important to system.
- Switch agent etc: judge and achieve the command. It is the core of this system.
- Database agent: store device's knowledge like device position, device name and so on.
- Operation rules agent: store operation rules.
- Data-collected agent: collect data SCADA needs in system.

4 RUNNING STRATEGIES IN THIS SYSTEM

4.1 Knowledge in agent

The BDI[9] (Belief, Desire, and Intention) is the most important model used in agent. The Belief and Desire is mapped to device knowledge while Intention to operation rules. For example, we can express the device knowledge with object-orient class where substation is parent class and device is subclass.

Switch agent:

```
{ string number   // substation name
  string number   // switch name
  int    voltage   // voltage
  int    type      // type of switch
  int    agent 1  // conjoint agent
  int    agent 2  // conjoint agent
  int     state    // close or open
}
```

And the operation rules in operation rules agent can be expressed:

```
IF (condition one is ture)
   IF (condition two is true);
        ......;
          IF (condition n is true);
     Then (implement the command);
```

4.2 Way of task-allocated

Thinking the fact that operation in electric power systems is the addition of a series of alone operations to device, we can come true the way of task-allocated based on device task. For example,

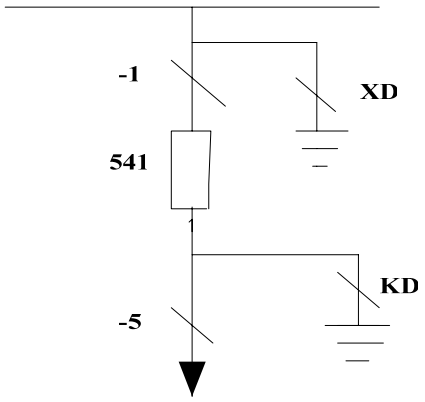

Fig .4 Switch 541

The operation items of operation ticket are as follows when switch 541 is through running to repairing.

- Open switch 541, ensure it in open position
- Open breaker 541-5, ensure it in open position
- Open breaker 541-1, ensure it in open position
- Pull switch 541 switch on fuse out
- Pull switch 541control fuse out
- Ensure no voltage exists between load side of 541-5 and wall bushing. Close 541-5XD
- Ensure no voltage exists between switch 541 and breaker 541-1. Close 541-1KD

Nine devices in sequence is listed in items above (we treat second device as the part of first device in this system, so it is not accounted in the list), which nine tasks in sequence originate from. Obviously, task based on device has clear line, self-governed operation which can make the system more effective and simple. In fact, many operation rules also originate from device task.

4.3 Cooperation among agents in system

The way of logical interlocking must abide by sequences. Supposing it contains n tasks in one operation ticket, we can accomplish logical interlocking like in fig.5.

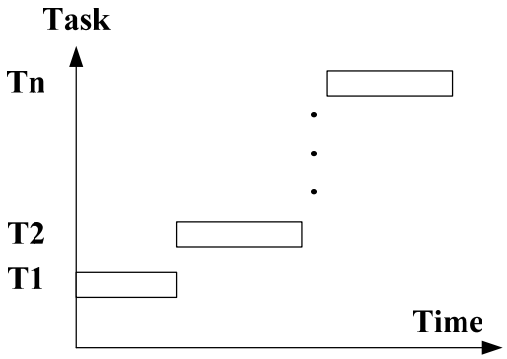

Fig. 5 Way of running task

Each task will be finished like the process below.

a. Manager agent accepts the operation ticket.

b. Task-allocated agent allocates operation ticket into task 1, task 2, ... task n.

c. Communication agent send task i (0<i<n+1) to device agent.

d. Device agent gets device position from manager agent and then judge whether the command is allowed. Send Release or block command to device.

e. Task i is accomplished. Return device data to data-collected agent, task i+1 continues.

4.4 Inside structure of agent

There are eight modules designed for agent in this system.

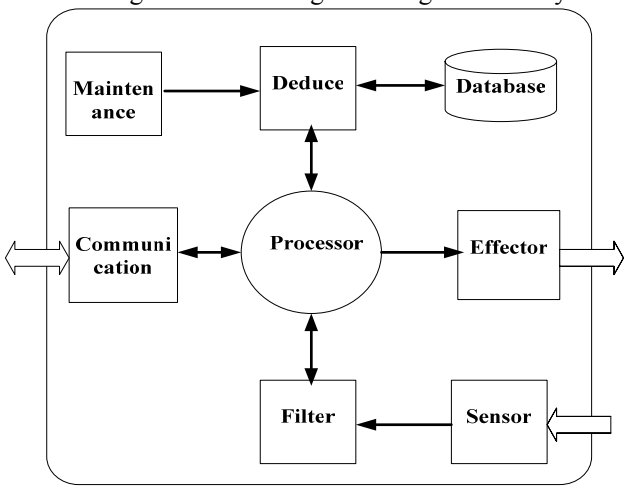

Fig .6 Inside of agent in this system

Sensor and effecter can be connected with sensor devices in electric power systems while communication module with other agent. All actions in agent are guided by processor. Otherwise, agent has the ability of learning from environment and other agent through maintenance module. The agent in fig.6 is universal, so, we can construct agents even different agents by comply with it.

4.5 Communication mechanism

There is much information exchanged in interlocking process, which makes the system's communication mechanism among agents very important. The Agent_Comm_Mechanism can be expressed by BNF below[10]:

Agent_Comm_Mechanism>::=<protocol><Agent_Comm _Language><Comm_relation>*

<Protocol>::=<TCP/IP>

<Agent_Comm_Language>::=<KQML>

KQML[11] is a communication language based on speech-act theory. It consists of language type, parameter name, and parameter. We enlarge some new language types necessary simultaneously we keep reserved types in using.

Reserved types: (Only explain the language by nature language)

Tell (A, B, X) // A want to tell B about X

Insert (A, B, X) //A want B to insert X

Ask-one (A, B, X) // A want to know X from B

Ask-all (A, B, X) // A want to know all things about X from B

Achieve (A, B, X) // A want B to achieve X

New types:

Open/close command (A, B) // A want B to implement open/close command generally used from manager agent to device agent.

Release/block (A, B) // A want B to accept release/block generally used from device agent to device agent.

Release open/close command (A, B) // A want B to open lock to implement open/close command generally used from device agent to device.

Open/close comm_allowed (A, B) // A want B to know the open/close command is allowed generally used from device agent to manager agent.

Open/close comm_unallowed (A, B) // A want B to know the open/close command is unallowed generally used from device agent to manager agent.

5 SIMULATIONS

Agent in this system is alone in function, and communicate through network, so we can simulate the Multi-agent by using pc (personal computer). The frame is below.

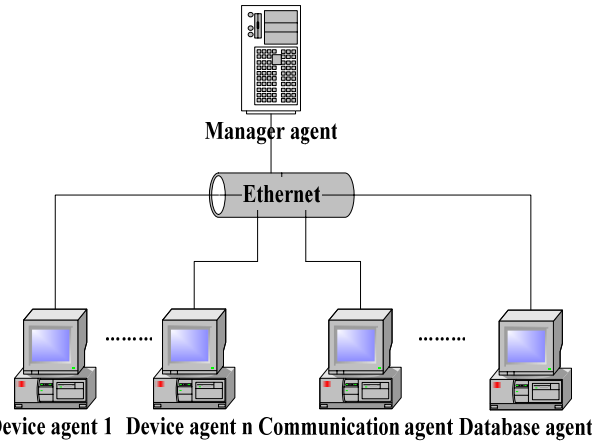

Fig. 7 Frame of simulation about this system

One pc (Pentium IV 2.0G, DDR 256M, Windows 2000) is corresponding to one agent while their communications are based on 100Mbps Ethernet. We choose the JAFMAS based on java[12] which is more suitable to the electric power systems to be agent builder. JAFMAS has already provided the ability of communication and cooperation, which can make us concentrate on agent detail and function-defined in practice we discussed in part 4 in this

paper. So, it is convenience to simulate agent with pc. We take 50 typical operation tickets for simulation. The results shows: The maximum delay time t<4ms, and the rate of success is 100%.

6 CONCLUSIONS

In the electric power systems, devices in disparate area are produced by different factory with different technology, and methods used for interlocking at present should be improved according to IEC61850. All of those determine that we can choose the Multi-agent system to implement logical interlocking. In this paper, we discuss some important things of this system amply like task-allocated, cooperation, communication mechanism and so on, and prove this method is feasible and has higher real-time and reliability than before through some simulations in the end. Of course, there is also much works we must do in the future such as the system needs farther practice and some problems exist in detail. Anyway, since the intelligence, automation, flexibility Multi-agent system possesses are the developing direction in electric power systems in the future, we have the reasons to consider this method is one of the best methods which will be used in logical interlocking before long.

Acknowledgments

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