An Agent-Based Fault Diagnosis System for Power System Operations

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Abstract- *Fault diagnosis is a paramount important issue in power system operations. In power engineering, most of the fault diagnosis methods are designed for a centralized computer system. Since each power substation is located in distributed environments, the tradition methods have some drawbacks in practical implementation. This work presents a new concept of planning an agent-based diagnosis system to assist operators to make right decision during fault events occur in power system operations.*

Keywords: Fault diagnosis, Multiagent systems, Power systems, SCADA systems.

1. Introduction

In modern power systems, the monitoring and control of power substations are based on the computerized Supervisory Control and Data Acquisition (SCADA) systems. In general, the SCADA systems have certain type of alarm processing mechanism to alert the operator when the analog values of monitored equipment out of normal ranges, state changes, communication errors, etc. Therefore, when a fault occurs, it will issue alarm messages in the operator's consoles of the master station. The master station is located in the control center and gathers information from remote terminal units (RTUs) located in distributed power substations.

Alarm processing is one of the important functions of the SCADA system. Alarms ensure that system operators are notified when an alarm condition occurs at a remote site. However, typical alarm functions of the SCADA system do not process the amount of alarms efficiently and offer alarms with informative messages. Hence, the operator still needs to analyze the real-time data to diagnose the system problem. Some estimates of the maximum number of alarms are up to one hundred and fifty records within two seconds for a power transformer fault [1]. At this moment, the operators are confronted by the problems that the overwhelming alarms change too fast to be read on the display and alarms are not listed in priority order. Hence, how to analyze the alarm messages to estimate the fault section is obviously a real challenge.

To sum up, when power systems encounter inevitable fault event, the operators are responsible for restoring the faulted system and must use their own judgment in deciding the possible fault event from a flood of alarms as the first step in the restoration procedures. Therefore, the development of a powerful diagnosis approach that can analyze the alarm messages to assist system operators is imperative.

In past years, considerable efforts have been made toward developing computer tools as operators' aid [2-4]. However, most of the methods are designed for a centralized computer system. Since each power substation is located in distributed environments, the tradition methods have some drawbacks under the consideration of practical implementation. Therefore, a suitable approach is needed to solve the aforementioned problems by managing the large quantity of available information from distributed power substations.

Recently, the agent technology has received a great deal of attention in the fields of modern artificial intelligence and complex distributed systems [5-7]. In this paper, a distributed computation strategy is proposed to process the fault-related alarms and estimate the fault section in the centralized SCADA system using multiagent technology.

The rest of the paper is structured as follows. Section II briefly reviews the architecture and characteristics of a typical SCADA system. Section III explains the proposed agent framework in solving the fault diagnosis problems. Section IV then shows an example to illustrate the effectiveness of the proposed method, and the conclusions are finally drawn in section V.

2. Overview of the SCADA system

In Taiwan, the Taiwan Power Company (TPC) has implemented a large SCADA system, called

Hierarchical Dispatch and Control System (HDCS), to meet the requirements of Taiwan's highly industrialized society in a better quality and higher reliability fashion. The HDCS is a three-level control system, which comprises a CDCC (Central Dispatch and Control Center), seven ADCCs (Area Dispatch and Control Centers) and twenty-one DDCCs (Distribution Dispatch and Control Centers). In addition, each DDCC equipped with a local small SCADA system as a backup system when the host computer of the ADCC has a breakdown. Fig. 1 shows the architecture of the small SCADA system in Keelung DDCC, which was designed by the author in 1998.

In Fig.1, the SCADA system is composed of one master station and sixteen remote stations. In the master station, there are two basic types of computer systems: the client type that caters for the human machine interaction and the data server type or the DAC (Data Acquisition and Control) server that handles most of the data control activities. DAC servers are connected to HMI clients via the Ethernet, and the RTUs are connected to the DAC servers via communication links in a long distance.

The platforms of the DAC servers and the client stations are Microware OS-9000 and Microsoft Windows, respectively.

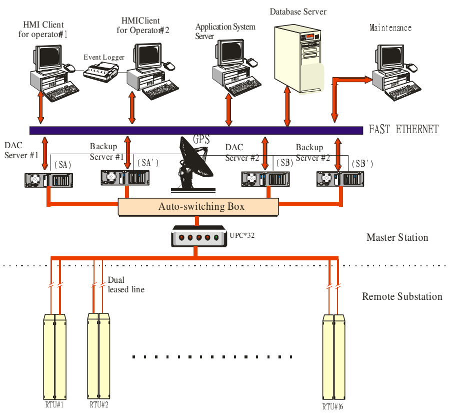

Figure 1. The SCADA system in Keelung DDCC

The master station of the small SCADA system comprises the following devices.

1. HMI clients

   The HMI client stations can provide the system operators with the GUI-based human machine interface for operating the SCADA system.

2. Maintenance host

   The computer is used only for the system supervisor to update power system configuration and provide the SCADA system with the capabilities of on-line modification and function verification.

3. Database server

   The database server is responsible for providing persistent storage and structured query of historical data.

4. Application system server

   The dedicated computer is designed to develop customized software applications.

5. GPS receiver

   The GPS receiver is used to synchronize the time tag of each remote station and each computer in master station.

6. DAC servers and their backup machines

   The DAC server handles most of the data acquisition and control activities and is connected to field devices in the substations through the RTUs.

In the remote station, each substation is equipped with one RTU connected to the power facilities. In a standard substation, it contains three 69kV sub-transmission lines, three 25MVA main transformers, two tie circuit breakers, one 69kV primary bus bar and three 11.4kV secondary bus bars.

3. The proposed Agent architecture

An agent is defined here as a software module with autonomous and reactive properties, which can interact with the environment it situated. Multiagent systems are systems composed of multiple agents. Agents may rely on other agents to acquire or share information to reach their delegation goal. In multiagent systems, they can cooperate with each other to solve more complex tasks than the capabilities of an individual agent require and handle.

As shown in Fig. 2, the proposed agent architecture consists of the Java-based HMI, monitoring agent, data analysis agent, control agent and database agent. The Java-based HMI provides the user with a graphic interface to access the proposed system. The monitoring agent plays the role in gathering real-time raw data from the substation RTU over serial link. The data analysis agent is responsible for analyzing the receiving values from monitoring agent and generates diagnosis information by its reasoning process. The control agent is dedicated to executing control activities. The database, in each substation, connected to database agent is used for persistent data storage. The role of each agent will be described in subsequent subsections.

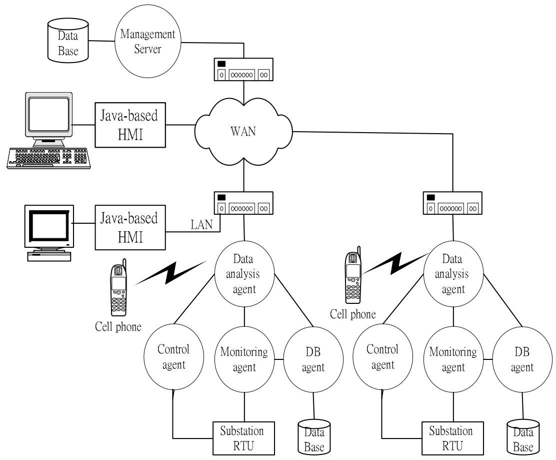

Figure 2. The proposed multiagent architecture

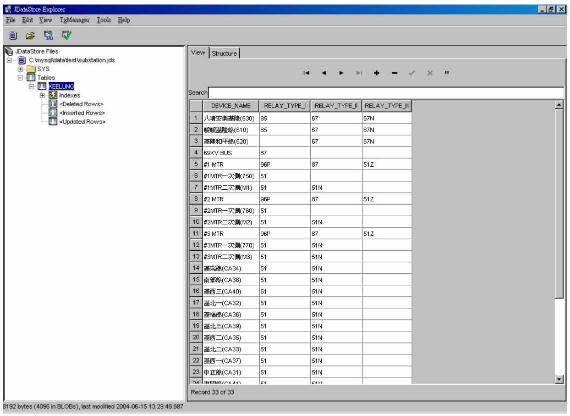

Figure 3. A sample run for the data access

3.1. Role of agents

3.1.1. Data Analysis Agent (DAA)

The data analysis agent, DAA, plays a leading role in the proposed framework. The DAA is dedicated to analyzing the data from the substation RTU. It consists of three software agents: messenger, fault analyzer, and learner. The messenger agent allows sending and receiving messages to other agents via Foundation for Intelligent Physical Agent (FIPA) compliant Agent Communication Language (ACL). The fault analyzer agent has the ability to analyze incoming data, passing from data monitoring agent, and identify fault sections using cause-effect networks [8] to determine the relevant fault event. The learner agent enhances accuracy of event identification by using past experiences from interaction with the user.

3.1.2. Data Monitoring Agent (DMA)

The main function of DMA is to continuously monitor measured analog values that exceed the preset limit and/or digital values that change state from RTU. The monitoring agent gathers the real-time raw data from substation RTUs over DNP3.0 communication protocol. After receiving information from substation RTUs, the monitoring agent gives a copy of the receiving information to database agent for persistent data storage. The collected data will also be passed to DAA and store in the database via database agent. One of the advantages to detect data directly from each local RTU is the ability to suppress redundant alarms.

3.1.3. Control Agent (CA)

The control agent is respond to performing a low-level control action in a secure way. By clicking a component for operation requests in the diagram window, the user can perform an operation after confirming a pop-up dialog box. The control agent has capabilities to issue the executable command to the RTU in accordance with the rules defined in communication protocol. Through the rule of check-before-execution and software interlock functions, the control actions are secure against the negligence of the operator.

3.1.4. Database Agent (DBA)

The DBA is responsible for storing and accessing data to the database by establish a connection with the SQL database. Fig.3 shows a sample run for accessing data from the database.

4. Case Study

The section is prepared for giving an example to illustrate the proposed approach. As shown in Fig. 4, assume that a fault occurs on the transmission line of An-Lo substation located in northern Taiwan. Due to the topology of 69KV transmission lines, the serious fault caused the related protective devices to trip and neighbor substations out of services. Consequently, a serial of alarms presented in the console of the control center as shown in Fig.5.

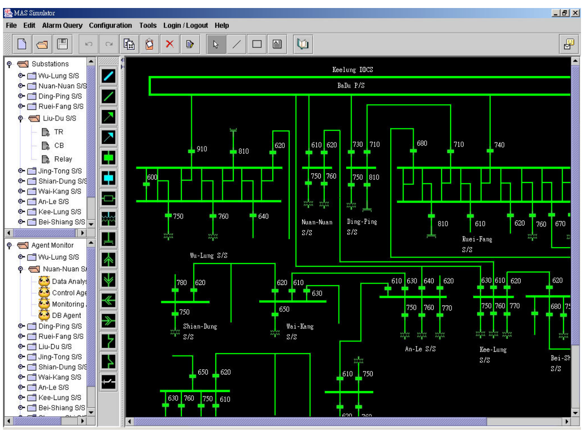

Figure 4. A screenshot of the system diagram

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06/05 08:24:29        DP02,T1SUNV #1MTR SOURCE UNDER VOLT         ALARM
06/05 08:24:30        NN01,6UVA      69KV UNDER VOLTAGE ALARM     ALARM
06/05 08:24:30        NN01,69KV      69KV BUS VOLTAGE       LO       53771.37   66000.
06/05 08:24:30        NN01,11KV      11KV BUS VOLT               LO       5469.466   6600
06/05 08:24:30        NN01,#1M11K  #1MTR 11KV BUS VOLT           LO       5724.473   6600
06/05 08:24:32        ST01,69KVRS    69KV BUS VOLTAGE V-RS    LO       659.5017   65000
06/05 08:24:32        ST01,CHACFL          CHARGER AC I/P FAULT     ALARM
06/05 08:24:32        ST01,69KVST    69KV BUS VOLTAGE V-ST    LO       659.5017   65000
06/05 08:24:32        ST01,69KVTR    69KV BUS VOLTAGE V-TR    LO       659.5017   65000
06/05 08:24:32        ST02,T1COOL    #1MTR #1MTR COOLING SOURCE FAL ALARM
06/05 08:24:32        ST01,FREQ.      SYSTEM FREQUENCY         LO       46.38270     59.500
06/05 08:24:32        ST01,B1V-RN     11KV #1BUS   VOLT V-RN    LO       35.17341     6600
06/05 08:24:32        ST01,B1V-SN     11KV #1BUS    VOLT V-SN   LO       39.57009     6600
06/05 08:24:32        ST01,B1V-TN     11KV #1BUS    VOLT V-TN   LO      43.96677     6600
06/05 08:24 :37       WK01,69KVRS    69KV BUS VOLTAGE V-RS     LO      131.9003     66000
06/05 08:24:37        WK01,69KVST    69KV BUS VOLTAGE   V-ST   LO      43.96678     66000
06/05 08:24:37        WK01,69KVTR    69KV BUS VOLTAGE   V-TR   LO      43.9667     66000
06/05 08:24:37        WK01,FREQ.      SYSTEM FREQUENCY            LO      46.31776     59.500
06/05 08:24:37        WK01,B1V-RN     11KV #1BUS   VOLT V-RN    LO     -13.1900      6600
06/05 08:24:37        WK01,B1V-SN     11KV #1BUS   VOLT V-SN    LO     4.396677      6600
06/05 08:24:37        WK01,B1V-TN     11KV #1BUS   VOLT V-TN      LO     4 .396677      6600
06/05 08:24:39   (CL)       NN01,69KV    69KV BUS VOLTAGE       LO       53771.37   66000.
06/05 08:24:39   (CL)       NN01,11KV     11KV BUS VOLT          LO       5469.466   6600
06/05 08:24:39   (CL)       NN01,#1M11K   #1MTR 11KV BUS VOLT      LO     5724.473   6600
06/05 08:24:41        ST01,CHACFL          CHARGER AC I/P FAULT     NORMAL
06/05 08:24:41   (CL)       ST02,T1COOL    #1MTR #1MTR COOLING SOURCE FAL ALARM
06/05 08:24:42        WK01,CHACFL          CHARGER AC I/P FAULT     ALARM
06/05 08:24:45        ST01,CHACFL          CHARGER AC I/P FAULT     ALARM
06/05 08:24:45        ST02,T1COOL    #1MTR #1MTR COOLING SOURCE FAL ALARM
06/05 08:24:49        ST01,CHACFL          CHARGER AC I/P FAULT     NORMAL
06/05 08:24:49   (CL)       ST02,T1COOL    #1MTR #1MTR COOLING SOURCE FAL ALARM
06/05 08:24:50        WK01,S-DC-V    STATION    DC24V    VOLTAGE    LO     23.91792   24.000
06/05 08:24:53        ST01,CHACFL          CHARGER AC I/P FAULT     ALARM
06/05 08:24:53    ST02,T1COOL    #1MTR #1MTR COOLING SOURCE FAL ALARM
06/05 08:24:56        ST01,CHACFL          CHARGER AC I/P FAULT     NORMAL
06/05 08:25:00        ST01,CHACFL          CHARGER AC I/P FAULT     ALARM
06/05 08:25:41        ST01,S-DC-V    STATION    DC24V     VOLTAGE    LO    23.82011   24.000
06/05 08:29:06        OPEN CD33      CB                      FROM   SCREEN   02
06/05 08:29:09        ST02,CD33CB #1MTR CD33 CB              OPEN
06/05 08:29:10        OPEN CD31      CB                      FROM   SCREEN   02
06/05 08:29:14        OPEN CD32      CB                      FROM   SCREEN   02
06/05 08:29:16        ST02,CD31CB #1MTR CD31 CB              OPEN
06/05 08:29:16        ST02,CD32CB #1MTR CD32 CB              OPEN
06/05 08:30:33        OPEN CU31     CB                 FROM   SCREEN   01
06/05 08:30:35        WK02,CU31CB #1MTR CU31 CB              OPEN
06/05 08:30:38        OPEN CU32     CB                 FROM   SCREEN   01
06/05 08:30:40        WK02,CU32CB #1MTR CU32 CB              OPEN
06/05 08:30:42        OPEN CU33     CB                 FROM   SCREEN   01
06/05 08:30:45   (CL)       WK01,CHACFL        CHARGER AC I/P FAULT       ALARM
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Figure 5. A piece of alarm message used for the test example

When an event occurs, the goal of the proposed agent system will try to reach the event from overwhelming alarm messages by agent cooperation in related substations. Form the test example, the monitoring agent will receive the data and pass them to the data analysis agent. In order to effectively analysis system alarms, all agents are capable of communicating with other agents in different substations. Since all the three-phase 69kV and 11kV bus voltages under threshold values, the data analysis agent will check the system configuration and send a request to the vicinity substation by messenger for getting further information.

In this example, the JADE platform is used as the simulation platform for agent communications. After concluding communication processes among agents, the cause of the fault event in An-Lo substation can be found based on the observation that circuit breaker #630 is tripped. In addition, Wai-Kang substation out of service will cause Shian-Dung substation out of service. Meanwhile, the fault section is estimated by using the information of actuated circuit breakers and protective relays. Therefore, a fault on AnLo-to-WaiKang transmission line can be identified.

5. Conclusions

Fault diagnosis is an important issue for power system operations. This paper focuses on processing the fault-related alarms and estimating the fault sections by using the agent technology. The proposed agent-based framework is suitable for integrating in the existing SCADA systems to assist system operators in minimizing the effects of alarm problems when a system disturbance occurs.

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Biographies

Wen-Hui Chen was born in Taiwan in 1965. He received his B.S. degree from National Taiwan University of Science and Technology, and the M.S. and Ph.D. degrees from National Taiwan University, all in electrical engineering. In 1992, he joined eight years in Taiwan Power Company as an engineer in automation department. He is currently an assistant professor at the Graduate Institute of Automation Technology, National Taipei University of Technology.

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