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새로운 에이전트 기반의 결함극복 IED시스템 및 신뢰성 분석

A New Agent Based Fault Tolerant IED System and Its Reliability Analysis

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Abstract - Nowadays, Intelligent Electronic Devices (IED) are widely used in power system. In order to improve the selectivity, sensitivity, and reliability of the power system composed by IEDs, A new fault tolerant IED system based on agent technique is presented in this paper. In the presented system, different with existing IED systems, the redundancies are drawn out from IED devices, and compose a standby backup system. And those redundancies are not specified to a particular type of IEDs. By using the agent technique, redundancies can download agents to modify their functions to fit different types of IEDs. As a conclusion, the reliability of the presented system is estimated in this paper.

Index Terms - power system reliability, power system computer control, power system protection, fault detection, fault tolerance

1. Introduction

Digital relays, which is also called Intelligent Electronic Device (IED), have been widely used in power system control, protection and monitoring since early 1970's. Many techniques such as digital filters, embedded computer techniques, and real-time techniques are been applied in digital relays.

On the other hand, fault tolerance technique is suggested to reduce the risk of error both in computer software and hardware. Fault tolerance technique does not prevent the error from occurring, but when an error occurs, it provides mechanisms to the system to prevent system failure [4].

The Mobile Agent System which is proposed in this paper introduces the fault tolerance technique into the power system in order to improve the reliability. The main idea is that when an error occurs on a digital relay, a backup relay will replace the error one automatically, with the same function to it, so that the system will continue working correctly.

In order to make the system more flexible, agent technique is used in this system when implementing the fault tolerance scheme. A mobile agent is a software module which can travel from the equipment it located the equipment is digital relay in our system to another equipment in the network, with its functionality remained. By using the agent technique, we implement the replacement of digital relay's functionality when an error occurs.

According to the system structure, model is established to estimate the reliability of this mobile agent system. The estimation result shows that the new system improved system reliability greatly.

2. System Scheme

The objective of the mobile agent system is that when error occurs, the system can tolerate the error, and continue working correctly. As we mentioned in the introduction, what we have to do is to replace the error device automatically.

The mobile agent system we design is composed of several devices: process emulator, server, bay IED, and trouble detector. Actually all these devices are Intelligent Electronic Devices, and they can be viewed as embedded computer systems.

In the system, there can be several process emulators. Process emulators receive the analog data from the circuit, such as voltage and current. Then process emulators convert the analog data into digital data, and send the data to bay IEDs.

Bay IEDs receive the data from process emulators, and then process the data. But the software module which is responsible for processing data does not stay at bay IEDs at the beginning. It stays at the server. All the Bay IEDs are divided into two groups: working group and backup group. The IEDs in the working group can download the data processing software module, and then receive data from process emulator and process it; and the IEDs in the backup group can not download the software module, they work as the redundancy we have mentioned in the introduction. When error occurs on the IED in the working group, server will choose a bay IED to replace the error one, and that IED will download the software module, receive the data from process emulators and process the data, in order to prevent the system failure.

As we mentioned above, the server's job is to maintain the data processing software module, and send it only to the bay IEDs in the working group. Another job is that when error occurs on an IED in working group, the server will receive an error report from trouble detector, and according to the content of the report, sever will select an IED in the backup group to be the backup IED, and then inform the process emulators about the error and backup IED. Process emulator then can stop sending data to error IED; instead, it will send data to the backup IED.

Trouble detector is the device responsible for detecting the hardware error of the bay IEDs. It maintains a TCP/IP connection to each bay IED, no matter it's in working group or in backup group, and sends test data to IEDs through the connection. If the test result is not correct or there is any problem of the TCP/IP connection such as disconnected trouble detector will realize an error, and send an error report to server immediately.

When we start the system, the scheme is as follows(see Fig. 1):

1. At the beginning, trouble detector establishes TCP/IP connection to each bay IEDs. After the connection is established, trouble detector sends the test data to test bay IEDs for the first time. Bay IED receives the test data, and then process the data and send back the result. The result is received by trouble detector and will be compared with a

correct result which is calculated beforehand. If the result calculated by bay IED is different from the correct result, or if there is any problem about the TCP/IP connection, the trouble detector will realize that there is an error on the corresponding bay IED.

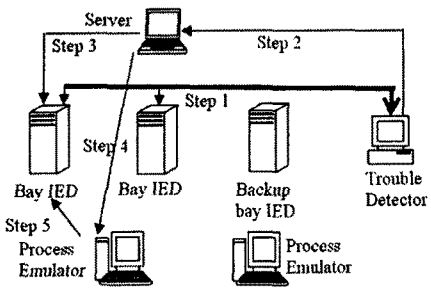

Fig. 1. Procedures when mobile agent system is started

2. After the first round test, trouble detector knows the initial statuses of all the bay IEDs. Then, trouble detector will report those statuses to the server. After sending the statuses, trouble detector will test bay IEDs continuously in the same way.
3. After receiving the bay IED statuses from trouble detector, server divides those well working bay IEDs into 2 groups working group and backup group according to some strategy, in our implementation, the strategy is to choose the last bay IED to be backup IED. Then, server sends the data processing software module to IEDs in working group.
4. After all working IED have downloaded the software module completely, server sends a working IED list to process emulators, which includes all IEDs in working group. And then, server listens to the port connecting to trouble detector, and waits for error report from the trouble detector.
5. As we mentioned above, process emulators receive analog data from circuit, and convert it into digital data. Now process emulators received the working IED list, so they know where to send the digital data. Then process emulators will establish TCP/IP connection to each working IED and send data to them continuously. On the other hand, each process emulator will also maintain a connection to server, waiting for error report.

By now, all the procedures in starting the mobile agent system are accomplished.

The system is in a normal status now: trouble detector is detecting bay IEDs continuously, sending test data, receiving result, and determining the correctness; server is listening to the port, waiting for error report, process emulators are sending data to bay IEDs and bay IEDs are processing those data, and show the processing result to the system operator. Also, process emulators are listening to a port to server, waiting for its error report.

Assume that a hardware fault on a bay IED occurs, now the system scheme will try to tolerate the fault, by replacing the error bay IED automatically, in order to prevent system failure.

The scheme is as follows(see Fig. 2):

1. First, trouble detector detects the error at once. It realizes the error either because of the incorrect result or because of the connection problems.
2. Then an error report including the information about the error bay IED is composed and sent to server, using the error reporting ports which sever is listening to.
3. After receiving error report, server realizes the error and the information about error IED. Then server chooses an IED in backup group and moves it to the working group, and then sends this IED the software module.
4. After all these procedures, sever will send an error report to process emulators. This report includes the information of both error bay IED and the newly chosen bay IED.
5. Then process emulators receive the error report sent by server and know the error IED and the new working IED. Process emulators will first disconnect with the error IED, and then establish connection to the new working IED and send the digital data to it.

Now again, the system comes back to the normal status, and the fault is tolerated.

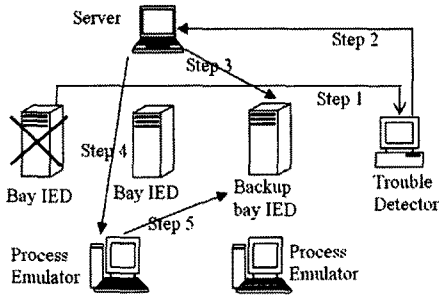

Fig. 2. Procedures when mobile agent system tolerates an fault

3. Reliability Analysis

In the system we presented, server and trouble detector is used as a switching system, it switch between the failed working IED and the backup IED. Let λ be the fail operation rate of the server and trouble detector, then for this switching system, its reliability P can be expressed as

$$p = (1-\lambda)^2$$

When there is a fault in the working IED, if the switching system works well at this time, the fault can be detected and the faulted IED can be replaced by the backup IED. In this case, we can view the working IED andthe backup IED together as a parallel backup system, which reliability distributioncan be expressed as

$$R_I(t) = \sum_{i=m}^{n} \binom{n}{i} R(t)^i (1-R(t))^{n-i}$$

where "m"is the number of working IED, "n" is the sum of working and backup IED, $R(t)$ is the general reliability distribution of an IED device.

But, if the switching system has failed when fault occurs on working IED, the faulted working IED cannot be replaced by backup IED, and system will fail. In this case, there is only working IEDs in the system, and the reliability distribution can be expressed as:

$$R_{II}(t) = (1-F(t))^m$$

where $F(t) = 1 - R(t)$ is the cumulative distribution function of the lifetime of a general IED.

So, the reliability distribution of the new system can be expressed as:

$$R_{mas}(t) = R_I(t)p + R_{II}(t)(1-p)$$

In the existing IED system, each IED device has its own backup components and only has one, so from the point of view of backup system, the existing system can be viewed simply as figure 3.

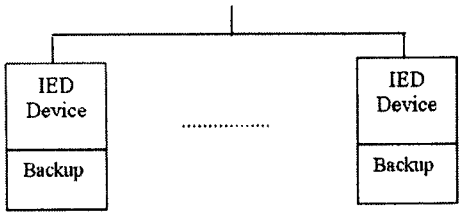

Fig.3.backup system structure for existing IED system

Simply, we can think the lifetime distribution of IED device and that of the backup components is same, that is F(t), then the reliability distribution of existing system can be expressed as:

$$R_{es}(t) = (1 - F(t)^2)^m$$

where "m" is the number of IED devices.

Before seeing the results, we made some assumptions as follows:

1. the fail operation rate of a general IED device is 37.28/1000000 [4];
2. the fail operation rate of server and trouble detector is also 37.28/1000000, because this two devices can also be IEDs;
3. the lifetime distribution of a general IED device is a exponential distribution, so

$F(t) = 1 - e^{-\lambda t}$ and $R(t) = e^{-\lambda t}$

where λ is the fail operation rate mentioned above.

Now, let's see the reliability of our new system.

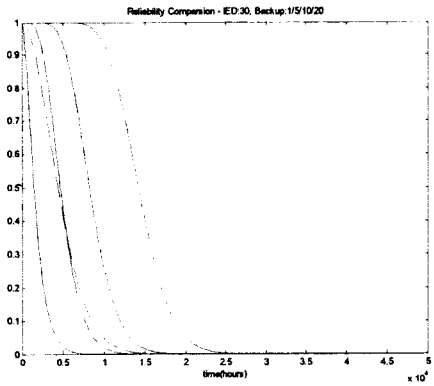

Fig.4. Reliability comparison between new system and existing system.

In figure 4, the broken line shows the reliability distribution of existing system with 30 IEDs and therefore 30 backup components, other curves showthe reliability distributions of the new system with 30 IEDs, and from left to right, with 1, 5, 10, 20 backup IEDs respectively. And the x axis is time, in 104 hours.

From this figure, it is clear that the new system has improved the reliability greatly.

4. Conclusion

This paper presented a new IED system, which employs the Fault tolerant technique and the agent technique. The analysis result proved that the new system has improved the reliability greatly.

Acknowledgement

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