

Developing an Agent-based Backup Protection System for Transmission Networks

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INTRODUCTION

This paper proposes a system protection scheme to augment traditional backup relay methods in the transmission system. Agents are used to give each protection component its own thread of control as well as the ability to communicate with others. This leads to greater capabilities to self-check and self-correct. We feel that this method naturally points towards a new philosophy for backup protection. Simulations are used to illustrate our concepts, using a simulation engine that combines the EMTDC/PSCAD power simulator with the NS2 network communications simulator. Results illustrate the improved performance of our backup protection scheme. Preliminary results give us hope that the proposed protection scheme may be able to contribute towards the mitigation of wide-area disturbances and the power blackouts that frequently follow.

BACKGROUND

Relay misoperation, such as the failure to isolate a faulted line or incorrectly tripping a healthy line, is involved in major disturbances in the power system [1]. The primary protection systems for Extra-High Voltage (> 230 kV) and High Voltage (> 35 kV) transmission lines almost all rely on pilot relay schemes using direction, phase comparison, or the longitudinal difference principle. Many important relay research and development efforts have been conducted over the years resulting in improved primary relay performance and fewer instances of relay misoperation[1]. However, hidden failures still exist in the protection system, causing relays to incorrectly remove unfaulted lines

during abnormal system events. This can lead to catastrophic cascading events and can even cause blackouts [2]. The ability for relays to self-check and self-correct would be a significant addition to relays in critical locations in the power system by allowing them to reduce these hidden failures.

Backup relays are required to clear a fault when the primary relay fails. Backup protection is usually made up of step distance and step over-current relays. There are two main drawbacks to this backup protection scheme. First, it must be slow enough to coordinate with all the associated relays. Second, the isolated region can be much larger than it could be. In addition, the zone 3 backup relays sometimes operate incorrectly due to heavy loads in abnormal system events and this misoperation is the most familiar cause of cascading outages. The longer time lag for fault clearance of zone3 backup relays is also a major cause of reduced power system stability.

Various backup protection systems based on either expert systems or adaptive architectures have been proposed in an attempt to correct for the traditional relay systems' shortcomings. Both types of schemes require additional local and remote information [3-5]. In the adaptive method, the setting of the zone 3 distance relay was adapted to ensure optimized performance under widely varying power system operating conditions. The system used an integrated, hierarchical backup protection scheme with a system computer, a substation computer, and a number of distance relays. In a method utilizing expert systems, a single computer was placed in each substation where it was used to identify faulty lines and to trip the circuit breakers when faults were found.

This work was supported by the Chinese Scholarship Council, and by ARO/EPRI grants WO 8333-04.

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This paper describes an agent-based backup protection scheme, where agents are embedded in each of the conventional protection components to construct a

relay IED (Intelligent Electronic Device). The relay agent searches for relevant information by communicating with other relay agents. Agent communications can take place at the same substation or at remote substations. This information can be used to detect relay misoperation and breaker failures and to compensate for such problems with much better performance than that can be done in traditional schemes.

AGENT-BASED BACKUP PROTECTION SYSTEM

(1) The Architecture of the Agent Relay

The keyword ‘agent’ has been popularized in artificial intelligence and systems research activities, but there is still no single universally accepted definition about what an agent is. In this paper, we consider *an agent to be a self-contained piece of software that has the properties of autonomy and interaction.*

A few proposals in the protection literature have alternately used agents as components in a cooperative protection system [6], a distributed intelligence in a protection design [7], and an interactive, autonomous software process in an adaptive multi-terminal line protection system [8].

Our backup protection proposal uses geographically distributed agents located in every relay IED shown in Figure 1 improving on the more traditional isolated component system. In order to make this distributed systems work effectively, the IEDs must be capable of autonomously interacting with each other.

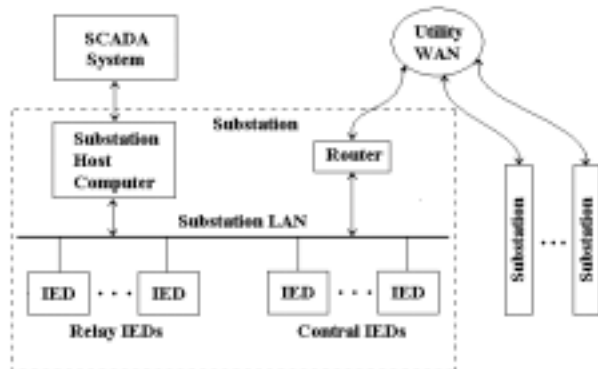


Figure 1: Backup Protection System

Our agent-based relays each have their own thread of control, but read local sensors and communicate with other agents (via LAN or via WAN) and act in response

to that environment. An agent makes decisions without the direct intervention of outside entities. This flexibility and autonomy adds reliability to the protection system because any given agent-based relay can continue to work properly despite failures in other parts of the protection system.

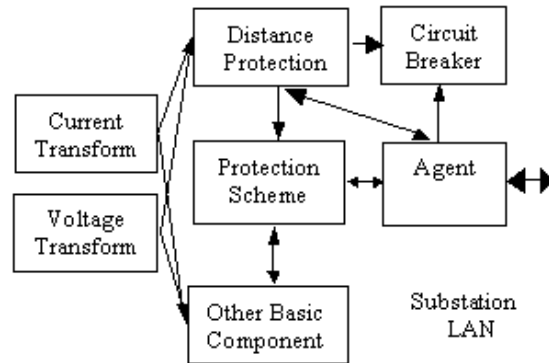


Figure 2: The Relay IED Architecture

A natural way to combine legacy protection systems with modern distributed information infrastructures is to “wrap” the protection components with an agent layer enabling them to interact with other agents and hence other components [9]. Our agent relay IED’s, shown in figure 2, illustrate this approach.

(2) A Description of the Communications System

Networked computing systems are becoming increasingly prevalent in many areas and we believe that this growth will occur within electric utility systems as well. Technology is constantly changing, but we can make some educated guesses about what such systems will look like. First, the network systems will almost certainly be built from off-the-shelf components. To do otherwise would be expensive both in terms of initial cost outlay and in system maintenance. This means that these networks will be based on Internet standards even if the systems remained independent of the global network conglomeration. We can already see hints that such changes are coming in recent standardization efforts such as the Utility Communications Architecture (UCA).

Communications protocols are methods for transmitting data between networked computers. The most popular low-level protocol in use on the Internet is IP (the Internet Protocol). IP packages a data unit into an entity known as a packet and makes a best-effort attempt to deliver that packet to the intended destination. Best-effort here means that if a problem occurs in the delivery

attempt, perhaps because of network congestion, then the packet will be lost. IP is rarely used by itself. Higher-level protocols run on top of IP to provide added functionality. The two most integral networking protocols to IP-based networks such as the Internet are the Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). The Transmission Control Protocol (TCP) is the more popular of the two. TCP's most notable contribution beyond IP's functionality is its ability to compensate for network losses by retransmitting data until it has been received by its intended destination. This is extremely valuable in many cases, but it can have drawbacks in time-sensitive situations since TCP delivers all data in a first-come first-serve manner. That means that information that is no longer relevant can stand in the way of current data if packet losses become too great. The User Datagram Protocol (UDP), by contrast, only makes minor additions to IP. UDP's best-effort delivery guarantees can be a blessing in situations where data is only relevant for a limited time. We have chosen to focus our initial communication investigations on backup protection systems using the UDP protocol for its nearly universal support and low latency despite its lack of delivery

guarantees. We rely on traditional backup protection behavior in the event of communication failure.

(3) The Strategy Employed by the Agent-Based Backup Protection System

Relay agents monitor their corresponding relays and take corrective actions when failures occur in the protection system. An agent achieves this by searching for relevant information within its transmission area and then takes action based on the preset rules given in Table 1. The information gathered generally includes the operational responses of conventional relays and circuit breakers' status. However, it may sometimes also include currents and voltages. A relay agents' transmission region generally consists of the transmission lines included in its primary and backup protection zones as well as those lines whose backup protection zones cover the current line. An agent can either receive the list of agents, which are in its transmission area and with which it will communicate, at initialization or it might learn this information through some type of network topology discovery algorithm.

Table 1
Rules for agent behavior

No.	Situation	IF	Then	Action
1	The primary relay trips	There are no zone 3 relay operations in the agent's transmission region of concern	There was an incorrect primary relay trip	Stop the breaker trip
		Most of the zone 3 relays in the concerned region trip	There was a correct primary relay trip	Monitor the breaker for operational failure
		Others	Uncertain1	Continue to rule 3
2	The zone 3 relay operates	At least one primary relay trips in the concerned region	The remote zone 3 relay operates correctly.	No action is required
		There was no primary relay trip in the concerned region	Uncertain 2	Continue to rule.4 and send notification messages to the agents in the concerned region
3	Uncertain 1 [So we use the Differential Method]	There is a fault in the primary protection zone	There was a correct primary relay trip	Monitor the breaker failure
		There is not a fault in the primary protection zone	There was an incorrect primary relay trip	Prevent the breaker from tripping
4	Uncertain 2 [So we use the Differential Method]	There is a fault in the primary protection zone	There was a primary relay	Trip the breaker and monitor the breaker for failures
		There is not a fault in the primary protection zone	There was an incorrect zone 3 relay operation	Stop the breaker trip
5	Get a notification message when no relay operations are in progress [So we use the Differential Method]	There is a fault in the primary protection zone	Both primary and zone 3 failures occur	Trip the breaker and monitor the breaker for failures
		There is not a fault in the primary protection zone	There is no fault in the primary protection zone	No action is required

As shown as in Table 1 Rule 1, when an agent observes a primary relay trip, the agent will check the status of its own zone 3 relays and will communicate with agents in its region to find their zone 3 relay status. The trip operation of the primary relay is considered to be correct if most of the zone 3 relays operate, or incorrect when none of the zone 3 relays operate. Otherwise, the situation is uncertain and the agent will search for additional information such as the local and remote currents and voltages. A differential measure is used to locate the fault. The primary relay trip is correct if a fault is found on its primary protection zone or is misoperating if that is not the case.

If a primary relay trip has occurred and it is operating correctly or if a fault is confirmed in the primary protection zone then the agent will try to clear the fault in as small a region as is practicable. The agent takes note of breaker trip signal events. It then waits until the breaker clearance time has passed. If the breaker is still closed at that time then the agent will send trip message to all other agents in the area surrounding the fault in order to clear it. These agents will send trip signals to their breakers and will then initiate their respective breaker failure supervision routines. This process continues until the fault is cleared. In this way, the agent system provides fast backup protection with a high selectivity.

The agent-based protection system has many benefits over traditional systems. As shown as in Table 1, zone 3 relays can be monitored allowing corrections to prevent false breaker trips. This correction has the potential to greatly reduce the number of incorrect trips in cases where there is a heavy load. In addition, in the case of both primary and local backup relay failure, the agent can locate the faulted line using notification messages and can send a trip signal to potentially only clear the faulted line. Traditional backup systems clear such faults using remote backup relays with a bigger isolated region and with a greater delay time. If an incorrect primary relay trip is found by the agent then a block signal can be sent to stop an unwarranted breaker trip. Breaker failure protection trips all breakers connected in the same bus in most bus arrangements and induces a big disturbance. The reliability gains can be significant in those cases.

In summary, our agent-based backup protection system has the ability to self-check, self-correct, and achieves highly selective and fast backup functions when primary protection or circuit breakers fail. To illustrate the agent's advantages, we will look at an example involving transmission line MN in Figure 3.

CASE STUDY

We created two experiments to illustrate the advantages of our agent-based backup protection system. Experiments were run using EPOCHS [13], a simulator that combines the PSCAD/EMTDC transient simulation environment [11] with the NS2 network communication simulator [12]. We designed the agents and their supporting infrastructure using an object-oriented approach. All experiments revolved around the 400 kV example system shown in Figure 3.

The simulation was simplified by only considering three-phase faults and by using the zone 1 distance relay as primary protection. The transmission network is equipped with an agent-based backup protection system. Any agent can communicate with any other agent. The emittances of current transformers, voltage transformers, and anti-aliasing filters are included and the DFT is used to obtain inputs needed for mho distance relays. Both distance and time delay relays have been placed into operation with traditional settings. The tests include an incorrect operation of a zone 1 relay and a breaker failure. All experiments assume that the power system begins operation at time 0.

Agent communication was simplified to the most basic level. We assumed that there is a 1 ms delay between each bus and that there is no network congestion. Agent messages consisted of either requests for voltage, current, and relay status, breaker set requests, or replies to those requests.

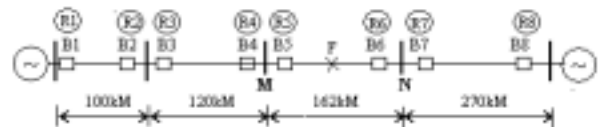


Figure 3: The example power system

(1) Case I: Primary Relay Misoperation

In the first experiment, a zone1 relay misoperation occurs at time 0.2 seconds. The simulation results are shown in Figure4. It can be seen that there is a block signal sent by the relay agent 5 to breaker 5 near time 0.2 seconds, preventing the breaker trip initiated by the incorrect operation of relay zone 1. The resulting phase A current can be seen in Figure 4(c). Had the agents not been in the system, the phase A current would look like Figure 4(d).

(2) Case II: Break Failures Occur

In the second experiment, a fault is located at the midpoint of line MN and is scheduled to occur at time 0.3 seconds as can be seen in Figure 5(d). Moreover, after a fault occurs at time of 0.3 seconds, the relay 5 agent monitors the line to ensure the correct operation of zone 1. It perceives a breaker 5 failure when the setting time is longer than the breaker clearing time. The agent will react by sending a trip message to agent 4 (see Figure 5(b)), which initiates a signal to breaker 4 to clear the fault. However, breaker 4 is faulty leading to another message from agent 4 to agent 3 as shown in Figure 5(c). Agent 3 finally sends a signal to breaker 3 to clear the fault. The phase A current values for the entire experiment can be seen in Figure 5(d). However, much more time is needed for the fault to be cleared in remote zone 3 in the same situation without the agent system, as shown in Figure 6.

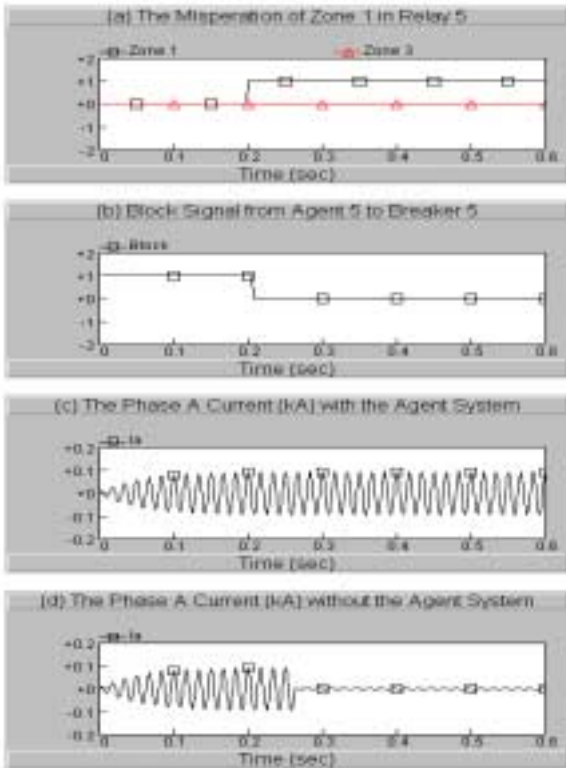


Figure 4: In this experiment, a primary relay misoperates at time 0.2 as can be seen in (a). The agent-based backup protection system responds to the failure (b) and does not open the breaker resulting in (c). The traditional system responds by opening the breaker (d).

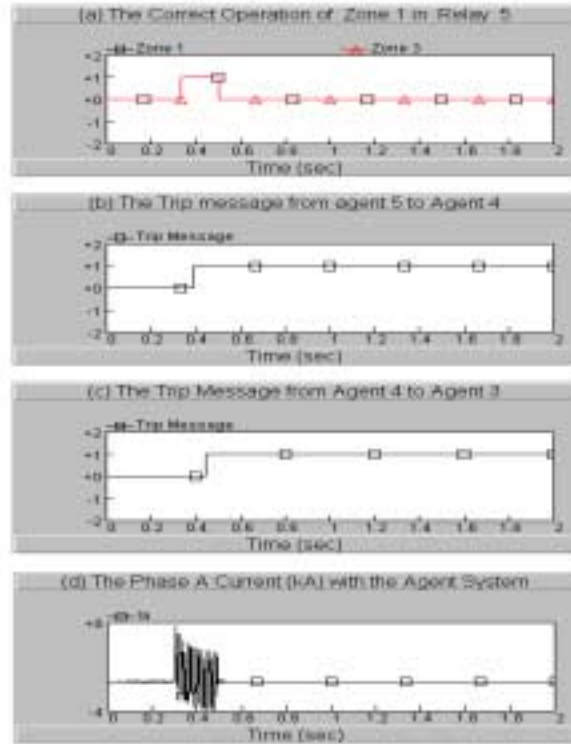


Figure 5: Both breakers 4 and 5 fail when a fault occurs at time 0.3 seconds. The agent-based backup protection system clears the fault in just a little additional time beyond twice the breaker clearing time.

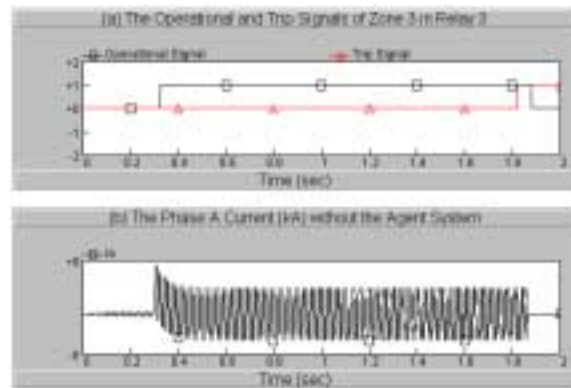


Figure 6: This is the same situation as in Figure 5 without the agent-based protection system. It takes a traditional zone 3 backup system more than 1.5 seconds to clear the fault remotely.

CONCLUSION

In this paper we developed a backup protection system that improves on the traditional trip zone while simultaneously decreasing clearing times. We have introduced a distributed architecture based on interactive autonomous agents. The agents embedded in each relay IED all communicate with other relay agents in order to check the status of relays, locate fault lines, and to minimize the isolated region when primary protection systems or circuit breakers fail. Experimental results show that this technique has promise and we hope to refine our ideas in future work where we plan to explore the expected communication traffic patterns and to make our agents more intelligent and robust towards network conditions.

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