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Intelligent coordinated adaptive distance relaying

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ABSTRACT

Malfunctioning of distance relay third zone has been identified as one of the leading factors of power system blackouts in several nations. This inconsistency in operation happens when heavy loads start encroaching the zone 3 settings. In this paper, a novel multi-agent system based methodology for power system protection coordination is proposed. Various system agents are designed to collaborate and adaptively modify the setting of distance relay zone 3 via communication with neighboring substations. The proposed coordination scheme aids in preventing fault misjudgment and possible network breakdown because of load encroachment. Furthermore, it enhances the relay selectivity and loadability. It has been tested using MATLAB®/Simulink™ with the agent programming in Java Agent DEvelopment Framework (JADE) platform. Analysis and test results demonstrate that the proposed method effectively mitigates distance relay malfunction under load encroachment.

1. Introduction

Distance relays are frequently susceptible to power system disturbances like power system transients, voltage instabilities, power swings and load encroachments. Power system protection designers apply distance relay third zone settings as a safeguard in the event of primary protection failure at remote substations [1]. However, heavy loads can cause relay malfunctioning when load impedance enters zone 3 of distance relay leading to an improper circuit breaker tripping. The distance relay zone 3 setting was of special concern after the US and Canada power system blackout in 2003 [2], when the North American Electric Reliability Corporation (NERC) recommended that "the third zone settings should not be encroached by loads up to an extreme level of thermal overload on all series connected elements in the transmission line" [3]. However, in [4] the authors identified several conditions where the NERC criteria cannot be met, and in [5] they developed a comprehensive rationale on why a third zone of distance relay is vital to the power system.

Prior literature in [6–15] presented various solutions to mitigate the malfunctioning of distance relays. In [6], the authors proposed a digital relaying algorithm in using a state diagram to lower the risk of third zone malfunction under heavy loading conditions as well as power system transient or voltage instabilities. While the state diagram presented in [6] incorporated transient components in addition to the steady-state components, its testing had revealed that the relay operated flawlessly only under the condition that the transient components were accurately extracted without any significant delay [7]. The relay performance was improved against voltage instability in [8] by employing the rate of change of voltage as a second criterion toward making the relay trip decision. As an alternative, a weighting procedure based algorithm that was dependent on fault type and location was proposed in [9]. An adaptive load encroachment prevention scheme was proposed in [10] based on the steady-state security analysis together with an adaptive anti-encroachment zone. In [11], the authors proposed a scheme to classify the power system events that affect a distance relay's performance using support vector machines. While the scheme of [11] successfully classified the power swing and voltage instability events, it however failed to classify the load encroachment events because it made use of the reactive power loss in the transmission line as the key indicator. The voltage stability indices were employed in [12] to enable the distance relay to distinguish between faults and other disturbances like voltage/transient instabilities. In [13], the authors suggested an algorithm based on rates of changes of current and voltage signals for being effective under stressed conditions when the scheme presented in [12] was found to respond improperly. However, this method may also fail under high impedance symmetrical fault conditions when the voltage and current rates of changes can be quite similar to some severe load encroachment scenarios. In [14,15], blocking schemes based on central control units were employed to prevent third zone malfunction. But such schemes require online monitoring in real

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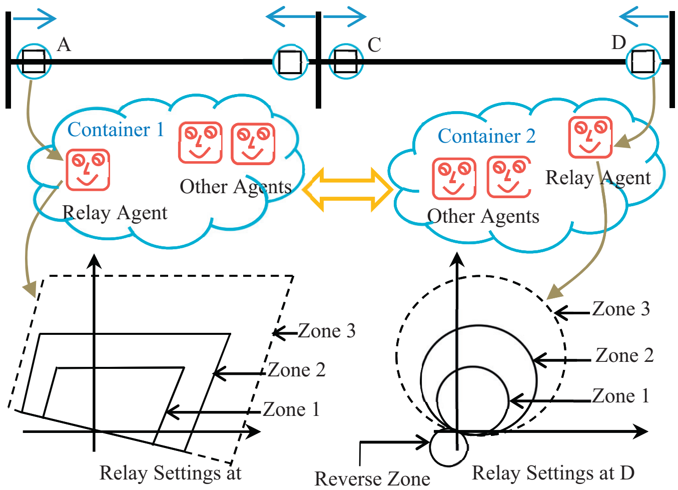

Fig. 1. Conceptual illustration of an agent-based scheme.

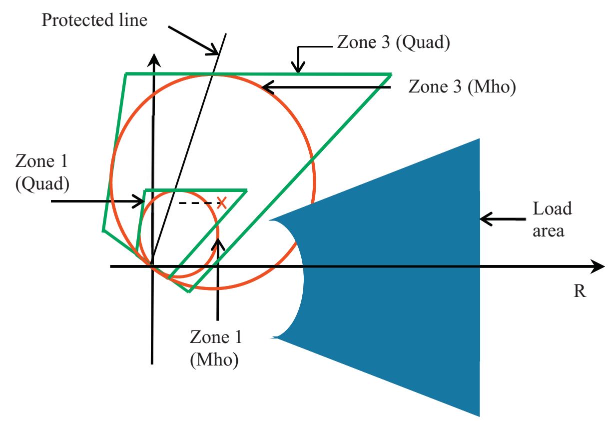

Fig. 3. Comparison between Mho and Quad settings performance against load encroachment.

time making use of synchronized measurements throughout the system.

In adaptive relaying, on the other hand, the relay settings are adjusted to protect the power system through continuous surveillance of the prevailing conditions. However, such supervision requires a platform that can also facilitate independent decision making in addition to data sharing. These intelligent features can be easily accomplished in the adaptive distance relays by widely employing Multi-Agent Systems (MASs). In this paper, a novel adaptive relaying scheme based on MAS is proposed to enable/block the third zone and prevent relay malfunctioning caused by load encroachments. The control of third zone is supervised by knowledge sharing between relays at the outlying ends of two successive lines as depicted in Fig. 1. MASs were successfully employed earlier in [16–19] for providing the necessary information exchange framework with greater autonomy and distributed intelligence. However, none of them had dealt with the resolution of distance relay third zone settings problem.

2. State-of-the-art on distance relay zone settings and shapes

The zones of distance relay along with their protected lines and load line are shown in Fig. 2. More details on the zones reach and time settings can be found in [5]. The key observation to be noted

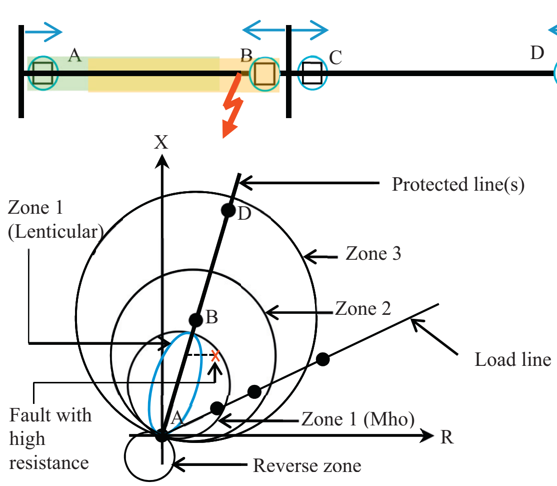

Fig. 2. Distance relay protection zones.

from this figure is that the reverse zone settings depend on the line length; and if this zone is associated with tele-protection schemes, its reach settings may extend over the conventional limits [20].

As the impedance of some faults may be larger than heavy load impedance values [21], at remote location(s) the heavy loads can be mistaken as faults occurring in zone 3. Such a condition then leads to a malfunctioning of the distance relay. The incorrect response of the third zone of distance relay for heavy loads was the root cause of several large historical blackouts that took place worldwide [2,22–24]. Traditional solutions for dealing with such a problem included changing the relay zone shapes in order to box-out the load [21,25]. In the past when electromechanical relays were the only distance devices in use, circular zones were the only possible choice. It is because the electromechanical relays produce only circular boundaries between operation and restraint zones. But nowadays a variety of zone shapes can be realized with the availability of solid state and numerical relays. Fig. 2 shows a lenticular setting of zone 1 with the same reach as its Mho counterpart. It can be observed from this figure that Mho settings are more sensitive to heavy loads. However, the use of lenticular or elliptical shapes (or zone blinders) will desensitize the relay to faults with high resistance [21]. Fig. 2 indicates that zone 1 of Mho settings will detect a designated high resistive fault while the lenticular settings of first zone do not detect it. It is to be noted that avoiding load area is usually done at the expense of reducing the fault coverage. As an alternative solution, quadrilateral settings were adopted in [26] since they make the relay more sensitive to high resistance faults and less sensitive to heavy loads. Fig. 3 depicts the quadrilateral settings along with their equivalent Mho settings. However, it was observed that for very high loading conditions the load impedance can encroach quadrilateral settings as well.

Non-pilot distance schemes, i.e. schemes without inter-tripping communication signals, are unable to protect 100% of the protected line instantaneously due to coordination issues between successive relays. In most cases, these schemes are not acceptable due to stability considerations [27]. In order to instantaneously protect the 10–15% portion of the line that is not covered by distance relay zone 1, inter-tripping information to confirm the fault occurrence and to clear it without the time delay of zone 2 is needed. Fig. 2 indicates that there is also a likelihood of fault within the line AB that is not detected by zone 1 of relay A, but which is seen in zone 1 of relay B; so a notification signal could be sent from relay B to relay A in order to make it trip the circuit breaker immediately. That being the case, neglecting the communication channel delay the line AB is protected swiftly. This protection mechanism is called Permissive Under-reach Transfer Trip (PUTT), and it is the most common tele-protection philosophy in the USA [25]. In this paper, a