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AN EFFICIENT DISTANCE RELAY SETTING STRATEGY

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ABSTRACT
In this paper, a new strategy for distance relay setting is introduced. The determination of fault zone by the proposed setting strategy (denoted P-SS) is based on data shared locally with other distance relays at the same station, and based also on a command from the distance relay on the other end of the protected line using any existing tele-protection system. With the proposed strategy, zone-1 covers the entire length of the protected line zone-2 covers the entire length of any next line irrespective of its length and zone-3 covers the entire length of any line next to zone-2. The governing rules for the proposed strategy are presented. The strategy is examined against setting problems of a real part of a HV network with real relay settings. The results confirm that the P-SS achieves the required accurate, sensitive and selective relay operation.

KEY WORDS
Distance relays, setting problems, pilot protection.

1. Introduction

Distance protection is one of the most important protection schemes for transmission lines. Generally, transmission lines are protected with a main and delayed backup protection schemes. Some errors may be included in the different stages of this process. With these inaccurate impedances the relays can overreach or under-reach the intentional distance coverage and it may deteriorate the performance of protective relays.

In addition, setting of the relay may be a cause of large portion of the errors. The setting process, especially for, backup zones in the distance relay faces a difficult dilemma when the targeted lines belong to closed loops and generators are connected to the buses as in most transmission network. This dilemma results from the variable distribution of fault current as a result of variable topology [1].

In almost all known setting strategies, the distance relays typically include two protective zones, namely the main zone and the backup zone. Some distance protection schemes use signaling to convey a command between local and remote relaying points. For high reliability EHV protection schemes, inter-tripping may be used to give back-up to main protections, or back-tripping in case of breaker failure [2,3].

Most existing setting strategies fail in solving setting problems; for example setting of the back-up zones for relays protecting long lines followed by long and short lines or vice versa, the problem of high in-feed current or faults through high impedance. In the best cases, the relay operates with unaccepted delay time. More on these problems can be found in Ref. [4].

Available solutions in the literature include trails to minimize the errors in estimating the impedances [5,[6]. Another adaptive technique in [7] adjusts its zone-reach based on the availability of input signals to achieve an optimal distance protection performance. Others try to increase the second-zone coverage of distance relays without causing overreach problems [8].

The objective of this paper is to present a setting strategy (denoted P-SS) for the relaying system that insures selectivity and security of the power transmission system. The scheme adjusts its zone-reach based on the availability of input signals to achieve an optimal distance protection performance. This strategy will alleviate problems inherent in present strategies using minor modifications to the frequency modulation circuit of the pilot scheme. The proposed strategy (P-SS) is presented in Section-3 of this paper. The P-SS is applied to a case-study from a real HV network in Section-4. The results show how the P-SS avoids practical problems that result from conventional setting strategies.

2. Distance Zones-Reach Setting

A digital distance relay usually contains three staggered distance zones (zone-1, zone-2 and zone-3) plus a starting zone (zone-4) which is usually non directional zone. Current increment, voltage decay or impedance decrease may be used as criteria for fault detection.

The first among the staggered zones (zone-1) is usually an under-reaching fast tripping, non-delayed zone. The reach for zone-1 is typically 80% of the line length to avoid relay over-reach as a result of measuring errors. The other two zones are over-reaching zones with time delay.
The reach of the second zone (zone-2) is chosen to protect the uncovered 20% of zone-1 and to provide time delayed backup protection for faults on the remote end bus bars. Zone-2 is usually set to cover the protected line plus 50% of the shortest adjacent line or 120% of the protected line whichever is the greater but should not exceed 150% of

the protected line to avoid interference with the second zone of the other circuit of the line [9].

The function of the third zone (zone-3) is to provide backup protection for uncleared faults in the adjacent sections. The reach of zone-3 should not be less than 150% of the protected line to provide the required back up protection for the second zone on the other circuit in case of double circuit lines, and also to provide good sensitivity for the high impedance faults on the same line. The fourth zone is used to provide back-up protection for the transformers in the local substation and for the other stages in the reverse direction. It usually coves about 10% of the protected line length in the reverse direction plus 300% of the line length in the forward direction.

3. The Proposed Setting Strategy (P-SS)

The "setting strategy" means the way in which relays are set to achieve the goals of selectivity and security of the power transmission system. A relay setting strategy is translated into a number of rules for the relaying system. The main difference between the P-SS and strategies in conventional setting is that the P-SS doesn't depend on fixed zone reaches for backup zones. In the proposed strategy, there are three stages within the protective algorithm:

In the first stage, the relay at each side calculates *a self pre-estimated* fault zone based on its own readings (voltages and currents) like any conventional relay. The impedances calculated at this stage are affected by the problems mentioned in the introduction, and hence are not expected to be accurate.

In the second stage, each relay sends the pre-estimated fault zone to all local relays in the substation. Based on this new local information, each relay updates the pre-estimated fault zone and calculates a *modified -fault zone*. The value of the modified-fault zone is used only within the protective algorithm and no trip/block action is based on it.

In the third stage, each relay sends the value of modified-fault zone to the corresponding relay at the other end of the transmission line using a specific modulated frequency via any available communication media. Sending a command to the other end is similar to any conventional protective pilot schemes. However, in the proposed strategy, the value of the modulated frequency is translated by the protective algorithm to the value of the remote modified-fault zone as will be explained below. *The final decision* at each relay is based on comparing the *modified*-fault zone of *both sides*.

3.1 Remote Communication Requirements

Many types of pilot protective schemes are in common use today for example, permissive overreaching transfer trip (POTT), permissive under-reaching , directional comparison blocking, and direct transfer trip (DTT) [9]. These schemes require the relay at one line terminal to communicate to the relay at the other line terminal that it either does or does not "see" a fault in the forward or reverse direction.

In telecommunication equipment operating over power line carrier, radio or optical fiber media, a nominal bandwidth/channel of 4 kHz - often referred to as voice frequency channel- is continuously transmitted from one side to the other to ensure the readiness of the communication media [9]. Once a fault is detected, the relay closes a contact to allow for another signal - of different frequency, *f1*- to be modulated over the carrier frequency as shown in Fig. 1. A receiver and a de-modulation circuit at the other side extract the frequency, *f1* which is interpreted as an accelerating trip signal.

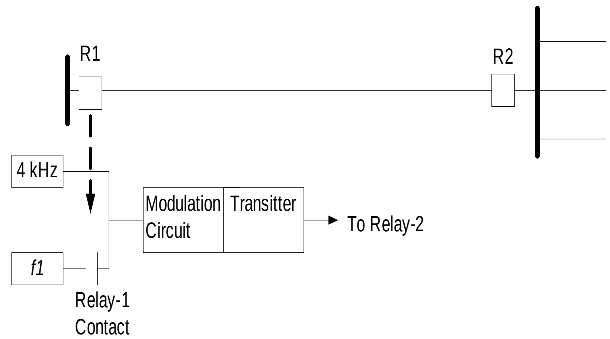

Fig. 1: Typical frequency modulation

In the proposed setting strategy, the value of the modulated frequency is interpreted as a fault-zone category. Instead of having one frequency to be modulated, there are eight frequencies available. However, only one of these frequencies is transmitted to the other side by closing the contact corresponding to the zone category required to be transmitted to the other side. A de-modulation circuit at the other side extracts this frequency. According the value of the received frequency, a specific digital input to the relay is activated.

Table 1: Relation between fault-zone-category and received frequency

Frequency	Fault-zone-category
f1	*forward* fault in *zone-1*
f2	*reverse* fault in *zone-1*
f3	*forward* fault in *zone-2*
f4	*reverse* fault in *zone-2*
f5	*forward* fault in *zone-3*
f6	*reverse* fault in *zone-3*
f7	*forward* fault in *zone-4*
f8	*reverse* fault in *zone-4*

3.2 Local Communication Requirements

Regarding exchanging local digital information (fault zone category of local relays), innovative approaches have been developed to share relay logic status between relays. These new approaches take advantage of the built-in communication capability and inherent digital logic processing capability of the microprocessor-based relays. Virtually every microprocessor-based relay has a communication port that is capable of sending and receiving digital messages [10].

3.3 How *the Modified-* Fault-Zone is Estimated?

In the first stage, the relay at each side estimates the fault zone reach according to the traditional setting rules. In the second stage, every relay sends its pre-estimated zone reach (Z1, Z2, Z3 or Z4) to the local relays at the substation.

The collected local information at each relay is compared together according to the following rules:

I. In general, the modified fault zone is taken as the smallest zone-number value.
II. The fault direction for the modified fault zone is chosen to be similar to fault-direction of the transmitter relay.

The modified fault zone is sent to the relay at remote end through the proposed frequency modulation system. The receiver circuit at the remote-end relay activates a specific digital input corresponding to the received frequency which represents the fault zone category estimated at the remote-end relay.

3.4 How the Final Fault-Zone is Estimated?

The modified fault zones at both sides are compared together in the third stage according to the following rules:

I. If the two fault-directions are forward in both sides, then the final zone reach is Zone-1 at both sides. For example, comparing (Z1, Forward) and (Z2, Forward), will result in a final decision (Z1, Forward) at both sides.
II. If the two fault-directions are opposite, then the final zone reach is the smaller zone-number plus one. For example, comparing (Z1, Forward) at side-1 and (Z2, Reverse) at side-2, will result in a final decision (Z2, Forward) at side-1 and (Z2, Reverse) at side-2. The fault direction at both sides is always unchanged.
III. To be consistent with the known setting rules, any zone reach in the final stage with a reverse direct will be reset to Z4. For example, (Z2, Reverse) will be reset to (Z4, Reverse).

4. Simulation Results

The power system used for evaluating the P-SS is shown in Fig. 2. It represents a real part of the Kuwait 275kV transmission network.

The part of the network under study includes seven 275/132 kV transformation stations. This part of the network is chosen as it includes a complicated transmission network where most of the difficult setting problems can be studied.

To study the performance of the P-SS, different fault conditions in the network are simulated using OneLine simulation program, V9.7. The program was supplied with the actual settings of the installed distance relays. Hence, the performance of the proposed strategy is tested using actual real data. Part of the results is presented in the next subsections.

Consider a fault in the middle of one of the four parallel under ground, UG cables between SALM W and JABR W, as shown in Fig. 2. The actual response of the distance relays using the conventional rules is shown in the figure.

There are two setting problems observed since the conventional setting strategies are applied:

The first problem is related to relays J4, J5, and J6 at JABR W (J). These relays incorrectly determined the fault to be in (Z4, Forward). This is because the larger part of the fault current passes through the fault, while the smaller part is divided between three parallel circuits. The fault should be cleared with zone-2 clearing time not zone-4.
The second problem is related to relays D1 and D2 at the SRRD W (D) station. These two relays incorrectly determined the fault to be in zone-3, not in zone-2 as it should be. The solutions obtained by the *proposed strategy* for these problems are presented in Tables-2 and Table-3 respectively.

4.1 Analyzing Problem-1 Using P-SS.

Table-2 shows the *P-SS* analysis for the first problem. Consider, as an example, the relays J4 and M2. The self-estimated impedance by each relay is presented in the first group of the table. The information from other local relays is shown in the second group. The relay information of the first and second group is obtained directly from the simulation results shown in Fig. 2.

Again, this information represents the actual performance of the installed relays based on conventional setting rules since the OneLine simulation program is supplied with the actual relay settings.

The modified fault zone is determined in the third group of the table which is equal to the smaller zone-number of local relays listed in group-1 and group-2 according to rule (I) in Section 3-3. The fault direction is identical to the fault direction of the transmitter relays (J4 and M2) according to rule (II) in Section 3-3.

In the last step, the two modified fault zone-numbers with its fault directions are exchanged between the two end relays: M2 and J4 using the modified modulation frequency system. A digital input corresponding to *f2* (Z1, Reverse) is activated by the de-modulation circuit at relay J4, where a digital input corresponding to *f1* (Z1, Forward) is activated at relay M2.

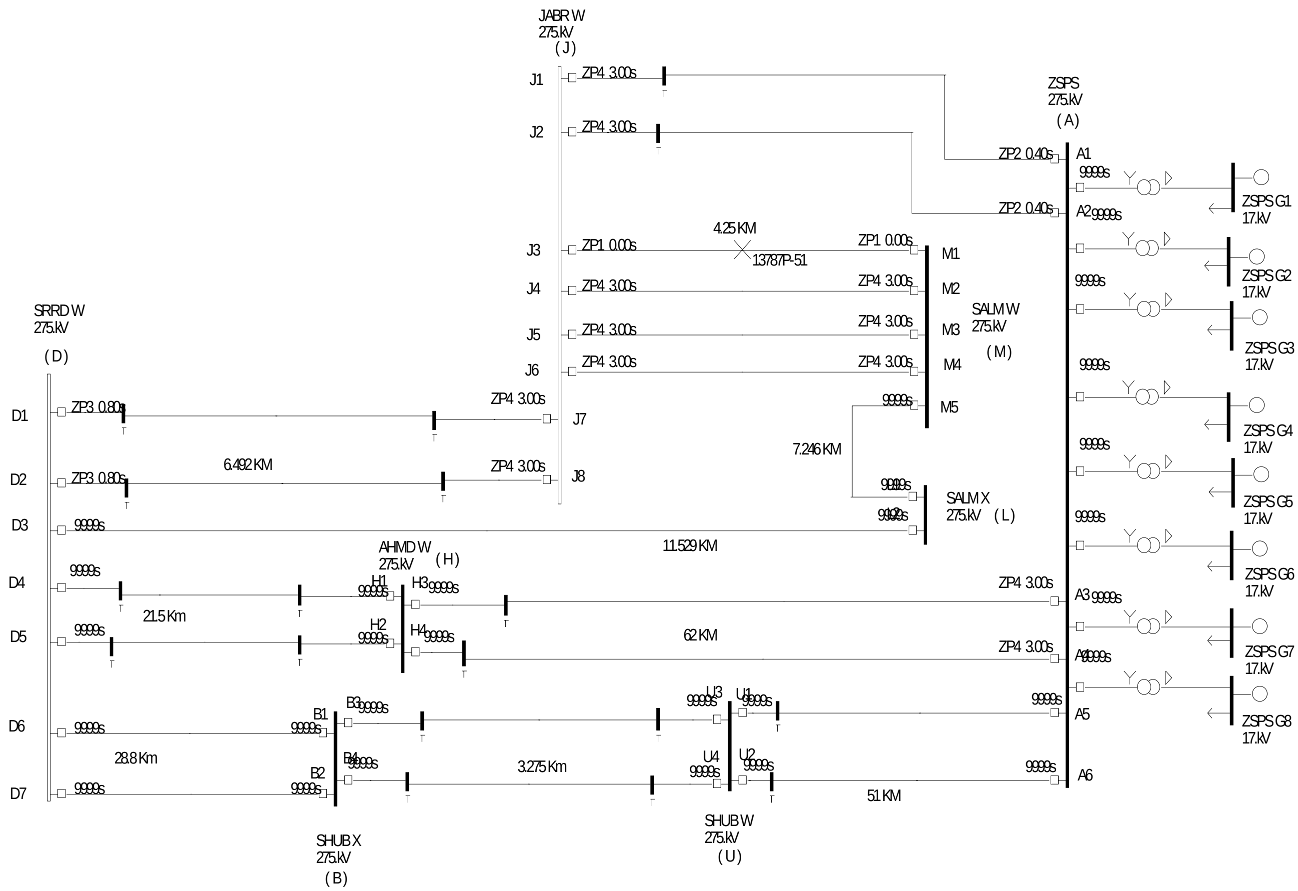

Fig. 2: The system under study

Table 2: Recorded data at Stations: JABR W and SALM W (Problem-1)

Station JABR W (J)				Station SALM W (M)			
	Id	Z	D		Id	Z	D
1- Self Pre-estimated fault zone at J4	J4	Z4	F	1- Self Pre-estimated fault zone at M2	M2	Z3	R
2-Local Information at JABR W sent to J4	J1 J2 J3 J5 J6 J7 J8	Z4 Z4 Z1 Z4 Z4 Z4 Z4		2-Local Information at SRRD W sent to M2	M1 M3 M4	Z1 Z4 Z4	
3-Modified fault-zone at J4	J4	Z1	F	3-Modified fault-zone at M2	M2	Z1	R
4-Final decision at J4	J4	Z2	F	4-Final decision at M2	M2	Z2	R

The fault zone-number in the final decision is one digit higher than the smaller zone-number of the two modified fault zone according to rule (II) in Section 3-4. The fault direction is unchanged.

By analyzing the two modified fault zones available now at each side, relay J4 - which original sees the fault in (Z4, Forward) - will now locate it correctly as (Z2, forward) as shown in group-4 of Table-2. The other relay, M2 will continuously see the fault in reverse direction. To be consistent with the known setting rules, (Z2, Reverse) for relay M2 will be reset to (Z4, Reverse) according to rule-III in Section 3.4.

The previous analysis can be repeated for the other corresponding relays (J5 – M3) and (J6 – M4).

4.2 Analyzing Problem-2 Using P-SS.

Table-3 shows the *P-SS* analysis for the second problem. Consider the performance of relays J7 and D1. The pre-estimated impedances obtained from the conventional relay readings are presented in the first and second group of the table. The information is obtained from the OneLine simulation output (shown in Fig. 2).

It can be seen that these two relays located the fault in zone-3 (not in zone-2) since the conventional setting rules are used.

The modified-fault-zone and fault direction are calculated in the third group at SRRD W and JABR W according to the rules of Section 3.3.

The two modified fault zones are compared together according to rule (II) of Section 3-4. The fault zone-number in the final stage is one digit higher than the smaller zone-number of the two modified fault zones according to rule. It can be seen that with the P-SS, the fault will be cleared correctly at relay D1 (similarly at relay D2) with zone-2 delay time. To be consistent with the known setting rules, (Z2, Reverse) for relay J7 will be reset to (Z4, Reverse) according to rule-III in Section 3.4. With P-SS, the fault will be cleared faster (with zone-2 clearing time). This is logically accepted as the two relays (D1 and D2) are the first backup relays to the fault. It is cleared from the previous example that with P-SS, the second zone covers the total length of any next line to the relay, irrespective of its length.

Table 3: Recorded data at Stations: JABR W and SRRD W (Problem -2)

Station JABR W (J)				Station SRRD W (D)			
	Id	Z	D		Id	Z	D
1-Self Pre-estimated fault zone at J7	J7	Z4	R	1- Self Pre-estimated fault zone at D1	D1	Z3	F
2-Local Information at JABR W sent to J7	J1 J2 J3 J4 J5 J6 J8	Z4 Z4 Z1 Z4 Z4 Z4 Z4		2-Local Information at SRRD W sent to D1	D2	Z3	
3-Modified-fault-zone at J7	J7	Z1	R	3-Modified-fault-zone at D1	D1	Z3	F
4-Final decision at J7	J7	Z2	R	4-Final decision at D1	D1	Z2	F

5. Conclusion

A new scheme (P-SS) for estimating the correct zone fault in distance relays is introduced. It depends on exchanging information between local adjacent relays and receiving a command from the remote end relay. Based on analyzing this information the relay decides the proper zone fault. Zone-1 in the P-SS covers the total length of the protected line and zone-2 covers the total length of any next line irrespective of its length. The P-SS succeeds in solving distance relays backup setting problems, e.g. the problem of a long line following a short line or vice versa and high impedance faults. No sophisticated requirements are required for the new strategy. The performance improvement of the proposed strategy has been verified on the simulated example system in OneLine simulation program in comparison with real distance relay settings. Application of the new strategy would provide an enhanced performance for distance protection.

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