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Zone-3 Impadance Reach Setting of Distance Relays by Including In-feed Current Effects in an Adaptive Scheme

M. Ojaghi *, K. Mazlumi, M. Azari

Electrical Engineering Department, Faculty of Engineering, University of Zanjan, Iran

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ABSTRACT

The undesired operation of zone-3 distance relay may be one of the most conspicuous protective relay due to the incorrect operations of this relay that have been conducive to the severity of blackouts. Therefore, determining the accurate zone-3 setting of the distance relay is deemed to be necessary. This paper focuses on the development of a new technique for calculating zone-3 setting of distance relays. The proposed technique utilizes impedance seen by distance relays in order to compute zone-3 setting of the relays when faults are modeled on the reach of zone-2 of primary distance relays for the maximum and minimum generation outputs of the power system. The new technique is also improved to be used in an adaptive protection system. The technique and its adaptive version are applied to the IEEE 30-bus test system under different operating circumstances to reveal its robust performance. System simulation studies show that the proposed scheme is able to increase the reach of zone-3 relays without causing mis-coordination problems. Therefore, the two main requirements of the protection system, namely security (without causing coordination) and simultaneity, would be satisfied.

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1. INTRODUCTION

One of the most demanding subjects in power system protection is perhaps the transmission line protection. Almost 65% of faults in power systems occur on the transmission lines. As a result, it has received substantial attention from the researchers and designers in the area of power system protection [1, 2]. Distance protection is the most frequent protection for transmission lines [3]. The fundamental principle of distance protection is based on the measurement of the short-circuit impedance, which is usually proportional to the distance from the fault point [4]. To protect a transmission line by distance relay several zones can be applied. The operation zones of the relay help to prevent load losses and technical destructions that might occur in consequence of mis-operation of the relays. These zones are usually selected based on the worst case scenarios of the combination of the factors that affect performance of the relay, seeing that the anticipated problem definition would introduce complexity [5]. Hence, in order to select the operation zones, two major requirements of the protection, i.e., security (without causing coordination) and simultaneity both should be satisfied.

Zone-1 of a distance relay is used to provide fast primary protection of a meaningful portion of a transmission line. Covering protection of the rest of the line and supplying some backup protection for the remote end bus as well as the lines emanating from the remote bus are performed by zone-2. Coordination between the zone-2 relays with the primary zone-1 relays protecting the lines emanating from the remote bus is achieved by delaying the trip command of the zone-2 relays properly. Normal zone-2 time delays are of the order of 0.4–0.5-s. Zone-3 provides a backup protection for all the lines connected to the remote end bus. Basically, Zone-3 is applied as a remote backup to zone-1 and zone-2 relays of the lines emanating from the remote end bus in the event that a relay or breaker

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[*] Corresponding Author Email: mojaghi@znu.ac.ir (M. Ojaghi)

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failure impedes removing of the fault locally. Therefore, zone-3 operation must be coordinated with the several zone-2 relays which are overlapped by this zone [6]. Standard zone-3 operation time is of the order of 0.8–1-s. However, the reach setting is an intricate problem and is the main goal of this study.

By deploying the microprocessor-based relays owing to communication capabilities, development and implementation of the adaptive protection systems is currently feasible [3, 4, 7-13]. In the adaptive protection systems, the relay settings can be automatically adapted to make the protection more attuned to prevail over the system conditions [14]. An adaptive distance protection scheme for parallel circuits is suggested in [15]. In this scheme, a correction factor based on the information of the surrounding system of the protected line under different operating circumstances has been used in the impedance reach calculation. In [16], a new method is presented to increase zone-2 coverage of distance relays without causing over-reaching problems. In [17], an optimum distance protection performance can be attained by modifying the distance relay zone-reach based on the attainability of input signals. The system represented in [18] pinpoints the line that includes the fault using the input information received about which distance relays have operated and their zones of operation. The information received must contain the zone in which the distance relays detect the fault. In [19], an adaptive protection scheme based on wide area information has been presented. In this scheme, adaptive setting algorithms for the second stage zero-sequence current and phase overcurrent relays have been proposed, which can provide larger line coverage than traditional relays. The design, implementation and testing of an adaptive distance relay has been presented in [20]. The relay has been equipped with a fault detector to determine the inception of a fault and then uses data windows of appropriate length to estimate phasors and the seen impedance. The trip delays can significantly be diminished using the proposed adaptive relay in comparison with a fixed data window distance relay. Re-examining the application of zone-3 to describe situations where it can be properly utilized or where it can be removed without reducing the reliability of the protection and, if used, to explore the ways it can be set, is presented in [21]. A new algorithm for adaptive setting of Zone 3 of distance relays during severe voltage fluctuations is proposed in [22]. The developed algorithm is based on dynamic adjustment of zone 3 setting of distance relays to avoid mal-operation. A new approach based on graph theory is introduced in [23] to calculate the break points in settings of overcurrent and distance relays in an interconnected power system network. An adaptive zone-1 distance protection scheme for power line with fixed series compensation connected at one end using local measurements is proposed in [24]. Series capacitor impedance is estimated using relay end fault current in this technique. The integration of the series capacitor into the transmission line makes the coordination problem more complex. A new systematic method is introduced in [25] for computing the optimal zone-2 timing of distance relays and optimal settings of directional overcurrent relays, in uncompensated and series compensated transmission systems. The under-reaching and over-reaching of distance protection for transmission line is more severe with SVC at mid-point of the transmission line [26]. In order to mitigate the mal-operation of the distance protection, the adaptive scheme is presented based on recursive simulation study. A novel method to optimize the settings of the resistive and reactive reaches of the zones of the distance relays is represented in [27]. The method considers the probabilistic behavior of the variables that affect the apparent impedance seen by relays: pre-fault load flow, fault type, distance up to the fault, fault resistance, and measurement errors. Zone-1 reach settings for transmission line distance relays to prevent overreach resulting from coupling capacitor voltage transformer (CCVT) transients has been studied in [28]. This scheme focuses on digital distance relays and determining appropriate relay reach settings to account for the effects of CCVT transients during faults.

In-feed fault current from the remote bus is a major factor threatening exact operation of zone-2 and zone-3 relays. The amplitude of this current is dependent on the grid topology and generation level when the fault occurs [16]. This paper is set out to develop a technique to calculate the zone-3 setting of distance relays by considering in-feed currents. Among the references, [16] proposes a rather similar work, but for zone-2 reach setting. The technique is based on modeling fault by considering single-level contingencies. Besides, in order to determine the settings, the worst case scenario is used. Then, the technique is adapted to existing topology of the grid. The effectiveness of the proposed approach is confirmed on the IEEE 30-bus test system under different operating conditions. The comparative analysis is made between the conventional method and the proposed method through some performance indices so as to demonstrate its efficient capabilities.

2. THIRD ZONE REACH SETTING

2. 1. Conventional Technique

Two different scenarios can be considered due to its significance for zone-3 setting of a distance relay. According to Figure 1, these scenarios are as follows:

Scenario 1: the longest line emanating from the remote bus B should be seen by the zone-3 relay located near the local bus A (R_{AB}):

$$Z_3(R_{AB}) = k_1 \times (Z_{AB} + Max\{Z_{BCi}\ ;\ i = 1,2,...,k\}) \tag{1}$$

where, $Z_3(R_{AB})$ is the impedance setting for zone-3 of the relay R_{AB}; k_1 is a safety margin within the range of 1.1 to 1.2; Z_{AB} is the positive sequence impedance of the protected line A-B and Z_{BCi} is the positive sequence impedance of the next line B-C_i. In this scenario, $Z_3(R_{AB})$ may overlap that of similar relays on the shorter lines emanating from the remote bus, i.e. $Z_3(R_{BCj})$ where B-C_j is a line emanating from the bus B with a rather small length. Therefore, the time delay of the zone-3 of R_{AB} should be properly increased. Scenario 2: the zone-3 reach should be as large as possible, but it never overlaps that of similar relays on the lines emanating from the remote bus B. Equation (2) fulfils the second scenario:

$$Z_3(R_{AB}) = k_2 * (Z_{AB} + Min\{Z_2(R_{BCi})\ ;\ i = 1, 2, \ldots, k\} \tag{2}$$

where, k_2 is a safety margin within the range of 0.8 to 0.9 and $Z_2(R_{BCi})$ is the zone-2 reach of relay R_{BCi} ($i=1, 2, \ldots, k$), which is usually calculated as follows:

$$Z_2(R_{BCi}) = Z_{BCi} + 0.5 * Min\ \{Z_{CiDj}\ ;\ j = 1, 2, \ldots, p\} \tag{3}$$

where, Z_{CiDj} is the positive sequence impedance of the far line C_i-D_j (j=1, 2, …, q) and q is the total number of buses connected to the far bus C_i. The second scenario is selected and used in this paper with k_2=0.85. Considering Figure 2, which is a portion of the IEEE 30-bus test system, the second Scenario is applied for the third-zone setting of relay R_{66} as follows. Zone-2 impedance setting of relays R_{42} and R_{64} are first calculated using (3). Then, among them, the minimum one is replaced in (2) to achieve the required zone-3 setting. It is easy to show that R_{42} has the least zone-2 impedance setting, which is equal to 13.7898<82.4 ° Ω, and yields zone-3 impedance setting of 44.34<62.98° Ω for R_{66}. On interconnected power systems, the effect of fault current in-feed at the remote bus would cause the impedance seen by the relay to be much greater than the actual impedance to the fault. This needs to be taken into account in setting zone-3 reach. The main drawback of the conventional technique is that it ignores such in-feed currents.

2. 2. Proposed Technique

The proposed technique uses short-circuit study method to determine the apparent impedance seen by the zone-3 relay (Z_{AF}) when faults are on the lines emanating from the far buses (i.e. buses C_i in Figure 1 for relay R_{AB}) including in-feed current effects. Corresponding zone-3 reach is then calculated using Z_{AF}. The required zone-3 reaches are computed for all network topologies considering single-level contingencies and for maximum and minimum outputs of generation sources. The least zone-3 reach computed in these outlines is selected as the final settable zone-3 reach of the relay. This procedure increases the reach of the zone-3 relays without any impedance via the operation of the related primary relays.

Consider again the sample transmission system shown in Figure 1; the proposed technique uses the following steps for computing the zone-3 reach of the relay R_{AB}:

1) Set the system to have a maximum generation output.
2) Remove the line C_i-D_j from the system.
3) As indicated in Figure 3, model a three-phase fault at the end of zone-2 reach of relay R_{BCi} within the line C_iD_{jj} ($jj \neq j$) when its remote end breaker is open, determine Z_{AF} and then, compute zone-3 impedance reach as follows:

$$Z_3(R_{AB}) = Z_{AB} + Z_{BCi} + k_3 \times \{Z_{AF} - Z_{AB} - Z_{BCi}\} \tag{4}$$

where, k_3 is a safety margin lower than unity (0.9 in this paper) to ensure non-overlap between $Z_3(R_{AB})$ and $Z_3(R_{BCi})$.

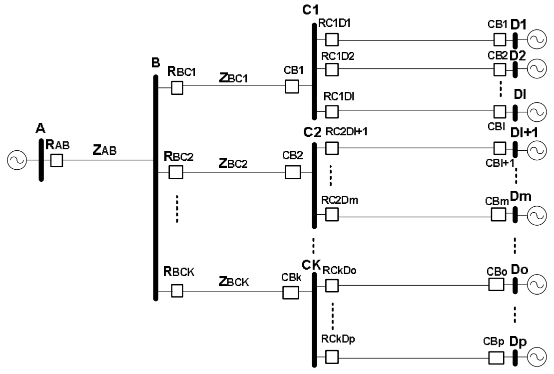


Figure 1. Sample transmission system.

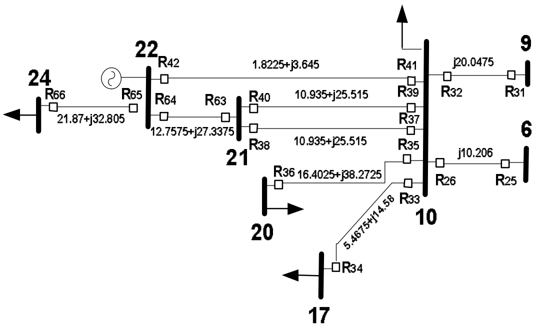


Figure 2. Portion of the IEEE 30-bus test system.

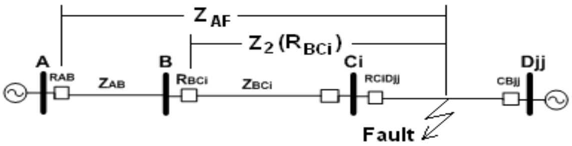


Figure 3. Portion of the power system used in step 3.

4) Repeat step 3 for faults at the end of zone-2 reach of relay R_{BCi} within the other lines emanating from bus C_i.
5) Return the removed line C_i-D_j back into service.
6) Repeat steps 2 to 5 for the remaining lines or other elements (transformers, generators, etc.) connected to bus C_i being taken out of service (removing one line or element at a time).
7) Repeat steps 2 to 6 for all buses C_i; $i=1, 2, \ldots, k$.
8) Remove the line B-C_i from the system.
9) Model three-phase faults at the ends of zone-2 reach of relays R_{BCii} ($ii=1, 2, \ldots, k$ and $ii \neq i$) in turn, with the remote end breaker of the faulty line being open, determine Z_{AF} and compute zone-3 impedance reach using (4) for each case.
10) Repeat step 8 for all lines or elements connected to bus B and then repeat step 9.
11) Model three-phase faults at the ends of zone-2 reach of relays R_{BCi} ($i=1, 2, \ldots, k$) in turn, when all the lines and elements are in service and all breakers are closed, determine Z_{AF} and compute zone-3 impedance reach using (4) for each case.
12) Select the least zone-3 impedance reach calculated in steps 1 to 11.
13) If the least zone-3 impedance has been obtained in the step 11, then go to step 16, otherwise continue with the following step.
14) Identify the line or element that the least zone-3 impedance (in step 12) has been reached by removing it out of service; remove it again while all the circuit breakers are closed. Then, model three-phase faults at the ends of the zone-2 relays R_{BCi} in turn, determine Z_{AF} and compute zone-3 impedance reach using (4) for each case.
15) Compare the least zone-3 impedance reach obtained in the step 14 to that obtained in the step 12 and replace the lower one as the least zone-3 impedance reach.
16) Repeat steps 1 to 15 for minimum outputs of generation sources.
17) Set the smallest zone-3 impedance obtained through the steps 1 to 16 as the final setting for the zone-3 impedance reach of the relay R_{AB}.

Repeat steps 1 to 17 to determine zone-3 setting of the remaining relays in the system. The proposed technique is implemented on the system depicted in Figure 2 for zone-3 impedance reach setting of relay R_{66}. The resultant zone-3 impedance reaches at the above-mentioned steps are tabulated in Table 1 and Table 2. As seen, the smallest zone-3 impedance is obtained under dominant system configuration (without any elements being out of service), with the minimum generation outputs, when a three phase fault occurs at the zone-2 reach of relay R_{64} on any lines connecting buses 21 and 10. This smallest zone-3 impedance is $123.04 < 48.9^{o}$ Ω and is selected as final impedance setting for the zone-3 of distance relay $R_{66.}$ This value is about 2.8 times of the zone-3 reach setting obtained for the relay by the conventional technique and implies the effectiveness of the new technique.

2. 3. Comparison Figure 4 shows the covered percentage of the far lines (i.e. the lines emanating from buses 21 and 10) by the new zone-3 setting of relay R_{66} in the case where the system generation is at the maximum and minimum levels and when all the lines and elements are in service. Additionally, the covered percentage of the far lines in the case where the system generation is at the maximum level and one of the lines is out of service is illustrated in Figure 5. Similar results can be delivered for the minimum level of generation. Tables 3 and 4 show the covered percentage of the far lines by the new zone-3 reach of relay R_{66} in the case different lines which are out of service (one line at a time) for the maximum and minimum levels of generation, respectively. An important point here is that when the zone-3 relay is set by the conventional method, no part of the far lines emanating from the far buses is covered by the zone-3 reach due to the in-feed currents effects. Thus, the zone-3 relay cannot be a perfect backup protection for the next lines. The new setting method resolves this problem, while it also prevents the zone-3 of the backup distance relay from overlapping with the zone-3 of the next primary distance relays.

TABLE 1. Conceivable zone-3 impedance reaches on maximum generation- in Ohms

Line Removed	**The line on which the fault occurs at the end of zone-2 reach of primary distance relays**					
	L21-10 (1)&(2)	**L10-9**	**L10-6**	**L10-17**	**L10-20**	**L10-21(1)&(2)**
L21-10 (1)	Out (1) 159.2<49.42° (2)	-	-	-	-	-
L10-9	-	out	138.2<54.89°	201.8<46.12°	361.8<43.5°8°	364<43.4°
L10-6	-	173.3<58.08°	out	165.2<47.55°	273.7<45.4°	276.2<45.5°
L10-17	-	173.4<31.95°	142.2<53.75°	out	342.4<42.2°	331.2<42.6°
L10-20	-	226.4<57.26°	142.3<53.5°	192.5<45.5°	out	328.8<43.1°
L10-21 (1)	-	284.7<56.26°	179.24<53.3°	244.3<44.9°	428.4<42.5°	Out (1) 570.86<40.2° (2)
L22-10	139.96<47.5°	-	-	-	-	-
L22-21	-	444.8<51.5°	326.58<47.9°	429.15<42.3°	845.28<14.7°°	491.09<40.8°
None	**131.76<47.9°**	224.3<57.65°	151.45<54°	211.2<46.6°	418.3<43.1°	134.6<48.25°

TABLE 2. Conceivable zone-3 impedance reaches on minimum generation- in Ohms

Line Removed	The line on which the fault occurs at the end of zone-2 reach of primary distance relays					
	L21-10 (1)&(2)	**L10-9**	**L10-6**	**L10-17**	**L10-20**	**L10-21(1)&(2)**
L21-10 (1)	Out (1) 148.3<50.43° (2)	-	-	-	-	-
L10-9	-	out	127.3<55.77°	186.2<47.12°	331.9<45°	317<44.47°
L10-6	-	158.7<58.9°	out	151.9<48.54°	252.9<47.06°	246.5<46.6°
L10-17	-	209.55<46.8°	133.5<53.22°	out	313.9<43.22°	302.7<43.7°
L10-20	-	160.7<57.26°	131.4<55°	177.3<46.5°	out	300.6<44.1°
L10-21 (1)	-	260.9<57.23°	16437<54.22°	223.8<45.9°	390.8<43.5°	Out (1) 540.26<38.9° (2)
L22-10	129.88<48.7°	-	-	-	-	-
L22-21	-	328.6<41.84°	296.58<48.9°	388.2<43.35°	762.3<38.6°	443.8<41.86°
None	**123.04<48.9°**	206.8<58.54°	140<54.94°	194.94<47.6°	390.8<45°	125.5<49.22°'

TABLE 3. Percentage of far lines covered for maximum level of generation when different lines are out of service

Line Removed	Percentage of far line covered					
	L10-9	**L10-6**	**L10-17**	**L10-20**	**L10-21 (1)&(2)**	**L21-10 (1)&(2)**
L10-9	out	21%	8%	3%	11%	44%
L10-6	14.5%	out	16%	6%	31%	45%
L10-17	8%	24%	out	3.5%	13%	42%
L10-20	8.5%	25%	11.5%	out	14%	42%
L10-21 (1)	0%	0%	0%	0%	Out (1) 40% (2)	Out (1) 42% (2)
None	7%	20%	8%	3%	10%	39%

TABLE 4. Percentage of far lines covered for minimum level of generation when different lines are out of service

Line Removed	Percentage of far line covered					
	L10-9	**L10-6**	**L10-17**	**L10-20**	**L10-21 (1)&(2)**	**L21-10 (1)&(2)**
L10-9	out	23%	9.5%	3.5%	12%	41%
L10-6	16%	out	18%	6.4%	34%	46%
L10-17	9%	27%	out	4%	15%	43%
L10-20	9.5%	28%	11.3%	out	15%	44%
L10-21 (1)	0%	0%	0%	0%	Out (1) 41% (2)	Out (1) 42.8% (2)
None	7.5%	21%	9%	3.5%	11.5%	40%

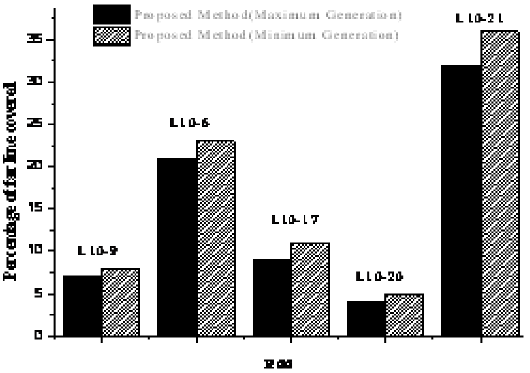


Figure 4. Percentage of far lines covered by zone-3 element of R_{66} for minimum and maximum levels of generation when all lines are in service.

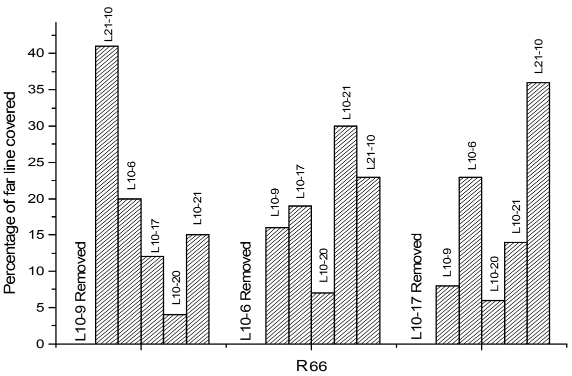


Figure 5. Percentage of far lines covered by zone-3 element of R_{66} for maximum level of generation when one of the lines is out of service.

3. ADAPTIVE SETTING

Knowing the power system current topology and the generation level, an adaptive version can be introduced for the proposed zone-3 setting scheme. The adaptive version is principally alike to the non-adaptive scheme apart from the fact that there is no need to compute impedances for the maximum and minimum levels of generation and no contingencies need to be supposed. The apparent impedances and zone-3 reaches are computed for the existent states. The adaptive setting scheme for zone-3 distance relays is reported with supposing the system of Figures 1 and includes the underside steps for determining the zone-3 setting of the relay R_{AB}.

1) Acquire the present operating state of the power system (i.e. topology, power flow, and generation).
2) Model a three-phase fault at the end of zone-2 reach of relay R_{BCi} within the line C_iD_j when its far end breaker is open, determine Z_{AF} and compute zone-3 impedance reach of relay R_{AB} by using Z_{AF} and Equation (4).
3) Repeat step 2 for faults at end of zone-2 reach of relay R_{BCi} on all far lines i.e. lines C_iD_j for $j=1, 2, \ldots, p$ (fault at one line at a time).
4) Repeat steps 2 to 3 for all zone-2 distance relays R_{BCi}, $i=1, 2, \ldots, k$.
5) Model three-phase faults at the ends of the zone-2 distance relays of the next lines (R_{BCi}, $i=1, 2, \ldots, k$) when all circuit breakers are closed. Determine Z_{AF} and compute zone-3 impedance reach of relay R_{AB} by using Z_{AF} and Equation (4).
6) Set the smallest zone-3 impedance obtained through the steps 2 to 5 as the final setting for the zone-3 distance relay R_{AB}.
7) Repeat steps 1 to 6 to determine zone-3 setting of the remaining relays in the system.

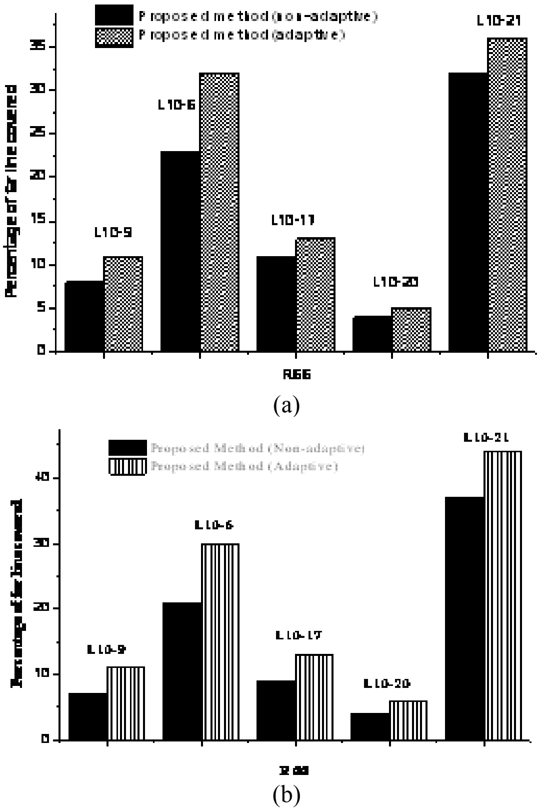
The adaptive version of the proposed scheme applied to determine zone-3 setting of relay R_{66} in the system is depicted in Figure 2. In this instance, both maximum and minimum generations are considered as distinct operating circumstance of the power system. The possible zone-3 impedance reaches of the relay when three-phase fault occurs at the end of zone-2 reach of the next primary distance relays on the far lines which are tabulated in Tables 5 and 6, respectively. As seen, the smallest computed zone-3 impedance for the maximum and minimum generations are 138.5535 < 47.6344°Ω and 129.6177< 48.5039° Ω, respectively. These impedances are selected as final impedance setting for the zone-3 of distance relay R_{66} under related operating circumstances of the power system. Figure 6 depicts that the adaptive version of proposed technique for determining zone-3 impedance settings supplies more coverage of the far lines than the non-adaptive version.

TABLE 5. Conceivable zone-3 setting for Relay R66 on maximum generation – in Ohms

Fault on Line	When the end breaker is open	When the end breaker is close
L21-10	175.342<48. 4878°	141.6631<47.6189°
L10-9	241.4350 <57.2679°	224.8902 <56.9449°
L10-6	152.4286 <54.4175°	151.1277<53.2527°
L10-17	212.8267 <45.6378°	208.3313 <45.7643°
L10-20	367.2735 <42.4881°	422.3296 <42.6333°
L10-21	354.2728<42.6945°	**138.5535 <47.6344°**

TABLE 6. Conceivable zone-3 setting for Relay R66 on minimum generation – in Ohms

Fault on Line	When the end breaker is open	When the end breaker is close
L21-10	175.342<48. 4878°	139.6824<47.9739°
L10-9	217.6059< 57.9998°	202.3742< 57.6593°
L10-6	138.3614< 55.2140°	136.4212< 54.0282°
L10-17	192.6275< 46.7000°	187.7448< 46.6626°
L10-20	329.9753< 43.2410°	371.2241< 43.5120°
L10-21	315.2252< 43.6118°	**129.6177< 48.5039°**



(a)

(b)

Figure 6. Percentage of the far lines covered: a) maximum generation state, b) minimum generation condition.

4. CASE STUDY

The implementation and more evaluation of the adaptive and non-adaptive versions of the proposed method so as to determine zone-3 setting of distance relays protecting the transmission lines of a test power system is demonstrated in this section. The transmission system under study is the 30-bus IEEE test system as illustrated in Figure 7 and consists of 43 transmission lines (86 distance relays) operating at 138kV levels. The technical information of the network is given[1] . Zone-3 settings determined by the non-adaptive version of the proposed method can be saved on the relays as a setting group. This setting group will be activated in the instance of adaptive setting system failure for example due to communications failure. Numerous scenarios of the power system are investigated in order to set and examine the coverage supplied by zone-3 distance relays. The next and far lines coverage supplied by proposed technique is compared with the conventional setting techniques and some results are drawn and presented. Table 7 compares the zone-3 reach settings of some distance relays obtained using conventional and proposed methods for the maximum generation condition. As seen, a higher zone-3 impedance setting can be achieved using the proposed method compared with the conventional method for all the relays. For example, the possible setting for relay R70 via the conventional method is 92.4881<63.7°Ω while this value is 411.841<45.114°Ω and 524.62<44.327°Ω via non-adaptive and adaptive version of the proposed method, respectively. The results reveal a significant increase in the impedance setting for the relay. As the previous cases in the section 3, the zone-3 relays set by the conventional method have no coverage of the far lines due to in-feed currents. Therefore, in order to make a comparison between the proposed and conventional methods, the percentage of remote lines (next adjacent lines) covered by the conventional method is determined as tabulated in Table 8. As seen, expect for relay R74, in the rest of the cases remote lines are not even covered completely using the conventional method. However, the reach settings obtained by the proposed technique not only cover remote lines, but also they cover significant percentage of far lines emanating from the far buses without any coordination problems.

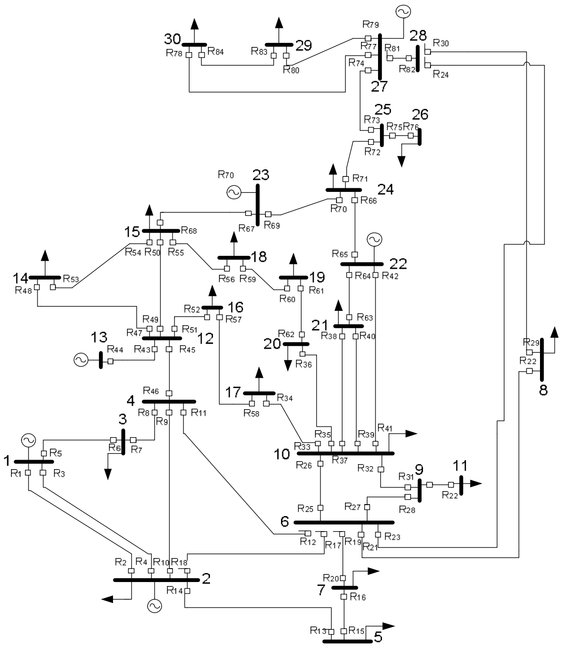


Figure 7. 30-bus IEEE test system used for evaluating the proposed method.

TABLE 8. Percentage of next (adjacent) line covered using conventional method for maximum generation circumstance

Relay	Remote line	Percentage of remote line covered
R58	Line 16-12	83%
R74	Line 25-24	100%
R70	Line 23-15	16%
R5	Line 7-6	80%
R46	Line 12-15	90%
	Line 12-14	37%
R15	Line 3-4	86%

TABLE 7. Conceivable zone-3 impedance setting for different relays using conventional and proposed techniques for maximum generation circumstance

Method	Relay					
	R58	**R74**	**R70**	**R5**	**R46**	**R15**
Conventional	85.0578<66.88°	112.4050<60.25°	92.4881<63.7°	36.536<68.875°	76.1373<69.829°	40.0157<75.43°
Proposed (Non-adaptive)	115.457<69.456°	135.465<61.517°	411.841<45.114°	44.654<71.324°	137.224<65.609°	61.272<75.298°
Proposed (Adaptive)	130.24<73.06°	161.75<85.45°	524.62<44.327°	54.1<75.47°	155.46<64.708°	66.7<70.04°

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[1] Power system test cases. 1999. [Online]. Available: http://www.ee.washington.edu/research/pstca/pf30/ieee30cdf.txt

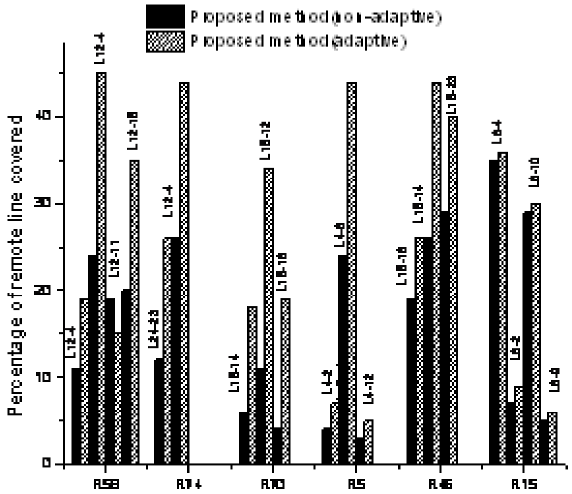

Figure 8. Percentage of the far lines covered when power system is operating at maximum generation circumstance.

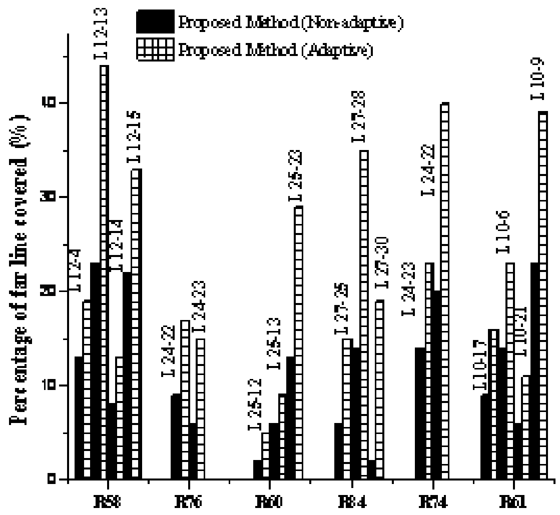

Figure 9. Percentage of the far lines covered when power system is operating at minimum generation circumstance.

Figures 8 and 9 depict this fact for maximum and minimum generations, respectively. As can be seen from the graphs, the better coverage is supplied by the adaptive version for all the relays. For example, in the maximum generation conditions (Figure 8) 11% of the line connected between buses 15 and 12 can be covered by zone-3 relay R70 using non-adaptive version of the proposed method whereas this value is increased to 34% using the adaptive version. Similar consequences are obtained for other operating circumstances of the power system such as minimum generation conditions and other zone-3 relays as shown in the figures.

5. CONCLUSION

The effect of the fault current in-feed at the remote buses is usually ignored by the conventional methods of distance relay coordination. This effect causes the impedance presented to the relay to be much greater than the actual impedance and leads to the under-reach of the relays. This problem is more effective in the zone-3 setting of the distance relay and makes this zone be recognized as one of the contributing causes of blackouts. Hence, determining the accurate zone-3 setting of the distance relay is an important issue. In this paper, a new scheme for determining settings of zone-3 distance relays is presented. It is revealed that better backup protection and higher line coverage have been provided using the proposed technique in comparison with the conventional method. In order to evaluate the performance of the adaptive and non-adaptive versions of the proposed technique, many scenarios of the power system are examined using the 30-bus IEEE test power system. It is shown that both adaptive and non-adaptive versions of the proposed method provide reasonable coverage of lines emanated from far buses, while they may not be covered by zone-3 relays set using the conventional setting technique. The adaptive version of the proposed scheme may be utilized under normal circumstances, but during failures, such as communication failures, its non-adaptive version becomes activated. Reducing the number of steps, especially in the non-adaptive technique, could be future topic of research in this area.

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Zone-3 Impadance Reach Setting of Distance Relays by Including In-feed Current Effects in an Adaptive Scheme

M. Ojaghi, K. Mazlumi, M. Azari

Electrical Engineering Department, Faculty of Engineering, University of Zanjan, Zanjan, Iran

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چکیده

عملکرد نامطلوب ناحیه سوم شاید یکی از بارزترین مشخصات حفاظتی رله های دیستانس باشد که از عملکرد نادرست این ناحیه ناشی شده و به افزایش شدت خاموشی ها منجر می گردد. بدین منظور تعیین تنظیمات صحیح ناحیه سوم رله های دیستانس امری ضروری به نظر می رسد. این مقاله بر ارائه یک الگوریتم جدید جهت محاسبه تنظیم ناحیه سوم متمرکز می شود. الگوریتم ارائه شده، بر اساس محاسبات خطا در انتهای ناحیه دوم رله های اصلی و محاسبه امپدانس دیده شده توسط رله ها پایه ریزی شده است. الگوریتم بیان شده در مرحله قبل با اندکی تصحیح می‌تواند در یک سیستم حفاظت تطبیقی به کار گرفته شود. به منظور بررسی صحت و دقت الگوریتم پیشنهادی و نسخه تطبیقی آن، شبکه استاندارد ۳۰ باس IEEE تحت شرایط مختلف عملکرد به کار گرفته می شود. نتایج شبیه سازی نشان می دهد که با اعمال روش مرسوم هیچ درصدی از خطوط دور توسط رله ها پوشش داده نمی شود. این در حالی است که با به کار گیری روش پیشنهادی، درصد قابل توجهی از خطوط دور توسط رله های ناحیه سوم پوشش داده می شود بدون اینکه مشکلی در هماهنگی نواحی عملکرد رله ها پیش آید. در نتیجه با به کار گیری الگوریتم ارائه شده دو اصل اساسی حفاظت، یعنی امنیت (عدم بروز مشکل هماهنگی) و همچنین همزمانی بر آورده خواهد شد.

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