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An Enhanced Adaptive Algorithm to Mitigate Mis-coordination Problem of the Third Zone of Distance Relays

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ABSTRACT

Cascaded tripping of power lines due to mal-operation of zone 3 distance relays is one of the main causes of many blackouts worldwide. The improved protection technique for zone 3 can help to prevent such mal-operation and, thus, more reliable power systems can be envisaged. This paper presents a novel zone-3 setting scheme based on impedance seen by distance relays in order to calculate zone-3 setting of the relays when faults are simulated on the reach of zone-2 of primary distance relays. The new technique is also enhanced to be used in an adaptive protection system. Since three phase fault rarely occurs in the system and in order to have better demonstration of effectiveness of the proposed scheme, it is tested for various type of faults such as, two phase (AB), single phase to ground (AG) and two phase to ground (ABG) as well as three-phase (ABC) using data simulated through DIgSILENT in the IEEE 30-bus test system during different topologies. The simulation results show that the novel zone 3 distance relay elements using the proposed method operate correctly for various events.

Keywords: Power system, Adaptive distance protection, Distance relay zone-3, Zone-3 setting, Seen impedance.

1. Introduction

Zone 3 of a distance relay is traditionally used to provide the remote backup protection in case of the failure of the primary protection at the remote substation and is typically set to cover about 120% of the longest adjacent line. Moreover, this zone is given a delay time twice that associated with zone 2 times to achieve time selectivity, and the time delay is typically set in the range of 1–2 s. On account of covering an adjacent line by zone 3, a large infeed from the remote terminal causes the relay to under-reach. Likewise, a large outfeed causes an over-reach. Thus, a very large load at the remote terminal may cause distance relays to mal-operate which, in turn, leads to loss of security due to undesirable zone 3 trip-ping [1-3]. Some approaches like adaptive relaying where proposed for this situation. The concept of adaptation has been introduced to protection relays [4], [5], which has received increasing interest during the last decade due to the advancement of computers, communication systems and software techniques [6], [7]. The benefit of adaptive protective relaying arises from the integration with substation control and data acquisition functions and interfacing with central energy management system [8]. In [9] a

new method is presented to increase the second-zone coverage of distance relays without causing over-reaching problems. A novel method to optimize the settings of the resistive and reactive reaches of the zones of the distance relays is represented in [10]. The method considers the probabilistic behavior of the variables that affect the apparent impedance seen by relays: pre-fault load flow, fault type, faulted line, distance up to the fault, fault resistance, and measurement errors. A new algorithm based on two new criteria: 1) the maximum value of the transient monitoring function obtained from three-phase currents and 2) the phase angle of the positive-sequence impedance is addressed in [11] to support zone 3 of the distance relay. The equivalent expression of the operation margin expressed by a function of bus voltage is established, and a preventive control model based on the sensitivities of the operation margin to power injection is proposed in [12] to overcome the overreaching property of zone 3 impedance relays (mho relays). A zone-3 revisited to re-examine the application of zone 3, to describe situations where it can be properly utilized, where it can be removed without reducing

the reliability of the system protection and, if used, to explore the ways it can be set, is presented in [13]. Zone-1 reach settings for transmission line distance relays to prevent overreach resulting from coupling capacitor voltage transformer (CCVT) transients is studied on [14]. This scheme focuses on digital distance relays and determining appropriate relay reach settings to account for the effects of CCVT transients during faults for CCVTs with active ferro-resonant suppression circuits. A new algorithm for adaptive setting of Zone 3 of distance relays during severe voltage fluctuations is proposed in [15]. The developed algorithm is based on dynamic adjustment of zone 3 setting of distance relays to avoid mal-operation. An adaptive first-zone distance protection scheme for line with fixed series compensation connected at one end using local measurements is proposed in [16]. Impedance offered by series capacitor in this technique is estimated using relay end fault current. The integration of the series capacitor (SC) into the transmission line makes the coordination problem more complex. The under-reaching and over-reaching of distance protection for transmission line is more severe with SVC at mid-point of the transmission line [17]. In order to mitigate the mal-operation of the distance protection, the adaptive scheme is presented based on recursive simulation study. A method based on calculating voltage across faulted open port and faulted electric parameters is proposed in [18] to improve calculation accuracy of relay setting and coordination. A new algorithm is proposed in [19] that utilizes Synchronized Phasor Measurements (SPM) to enhance the operation of distance protection zone 3 in many aspects such as distinguishing between actual system faults and load encroachment and not affecting the tripping decision by the value of fault resistances as well. A synchrophasor data-based technique for correct zone 3 operations is accomplished in [20] using impedances calculated from voltage and current signals from synchrophasors placed at strategic locations. In order to significantly change with the operating conditions, an adaptive zone 2 distance relay characteristics for multi-terminal power transmission system using PMU data is proposed in [21] in which the apparent impedance equation includes infeed, outfeed and line shunt capacitance of the multi-terminal system. Ref. [22] proposes an algorithm based on the detection of remote breaker operation following zone 2 fault detection by local

distance relay and it uses as a basis the monitoring of changes on a proposed signal. Proposed algorithm allows the trip acceleration on zone 2 of non-communicated distance relays for cases where faults are located inside the protected line. The conventional methods of distance relay coordination usually disregard the effect of the fault current infeed at the remote buses. This impact 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 identified as one of the contributing causes of blackouts. Hence, determining the accurate zone-3 setting of the distance relay is an important issue. This paper proposes a new technique for determining settings of zone-3 distance relays. The proposed technique uses impedance seen by distance relays to calculate zone-3 setting of the relays when faults are simulated on the reach of zone-2 of primary relays. Results show that better backup protection and higher line coverage are provided using both adaptive and non-adaptive versions of the proposed technique. The adaptive version of the proposed method is utilized under normal circumstances, but during failures, such as communication failures its non-adaptive version is activated.

2. Zone-3 reach setting

2.1 Conventional method

Two different scenarios can be considered due to its significance for the third zone 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 third-zone relay located near the local bus A (R_{AB}):

$$Z_3(R_{AB}) = k_1 \times (Z_{AB} + \text{Maximum}\{Z_{BCi} ; i = 1, 2, \dots, k\}) \quad (1)$$

Where $Z_3(R_{AB})$ is the impedance setting for the third zone 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. $Z_3(R_{BCi})$ where $B-C_i$ is a line emanating from the bus B with a rather small length. Therefore, the time delay of the third-zone of R_{AB} should be properly increased.

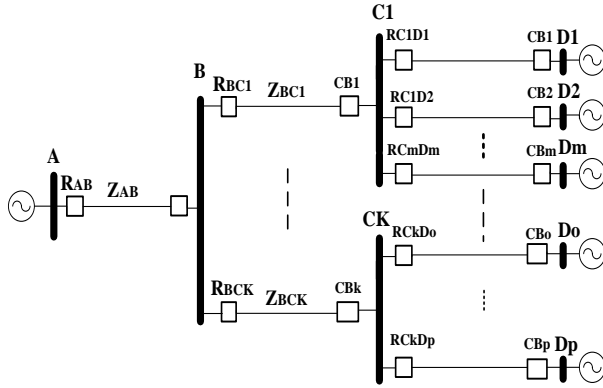


Figure 1. Sample transmission system.

Scenario 2. The third-zone reach should be as large as possible, but it never overlaps that of similar relays on the lines emanating from the remote bus B. Eq. 2 fulfils the second scenario:

$$Z_3(R_{AB}) = k_2 * (Z_{AB} + \text{Minimum}\{Z_2(R_{BCi}) ; i = 1, 2, \dots, k\}) \quad (2)$$

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

$$Z_2(R_{BCi}) = Z_{BCi} + 0.5 * \text{Minimum}\{Z_{CiDj} ; j = 1, 2, \dots, p\} \quad (3)$$

Where Z_{CiDj} is the positive sequence impedance of the far line C_i-D_j ($j=1, 2, \dots, q$) 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_{74} as follows. Zone-2 impedance setting of relays R_{72} is first calculated using (3) and then replaced in (2) to

achieve the required zone-3 setting. It yields zone-3 impedance setting of $112 < 4050^\circ \Omega$ for R_{74} .

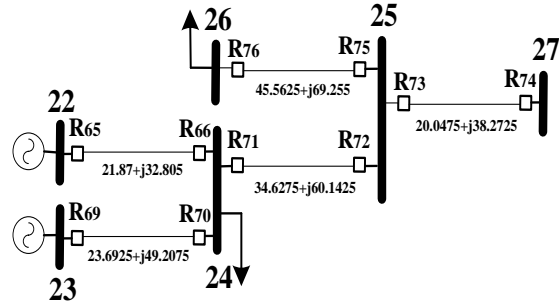


Figure 2. Portion of the IEEE 30-bus test system.

On interconnected power systems, the effect of fault current in-feed at the remote bus would cause the impedance presented to the relay to be much greater than the actual impedance to the fault and this needs to be taken into account in setting the third-zone each. The main drawback of the conventional technique is that it ignores such in-feed currents.

2.2 Proposed method

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, simulate a fault (ABC, AB, ABG or AG) at the end of zone-2 reach of relay R_{BCi} within the line $C_i D_{jj}$ ($jj \neq i$) when its remote end breaker is open, determine Z_{AF} and then, compute zone-3 impedance reach as follows:

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

Where k_3 is a safety margin lower than 1 (0.9 in this paper) to ensure non-overlap between $Z_3(R_{AB})$ and $Z_3(R_{BCi})$.

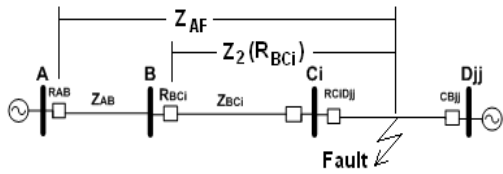


Figure 3. Portion of the power system used in third step.

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 ; $i=1, 2, \dots, k$.

8) Remove the line B - C_i from the system.

9) Simulate a fault (ABC, AB, ABG or AG) at the ends of zone-2 reach of relays R_{BCij} ($ij=1, 2, \dots, k$ and $ij \neq i$) 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) Simulate a fault (ABC, AB, ABG or AG) at the ends of zone-2 reach of relays R_{BCi} ($i=1, 2, \dots, k$) 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, Simulate a fault (ABC, AB, ABG or AG) 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} .

18) Repeat steps 1 to 17 to determine zone-3 setting of the remaining relays in the system.

The proposed technique is tested on the system depicted in Figure 2 for zone-3 impedance reach setting of relay R_{74} . The resultant zone-3 impedance reaches are tabulated in Table 1 and 2.

As seen, the smallest zone-3 impedance is obtained (for all type of faults) when line 24-23 is removed and fault occurs at the zone-2 reach of relay R_{72} on line connecting buses 24 and 22 for both minimum and maximum generation output cases. The smallest zone-3 impedance between min and max generation output will be chosen as final impedance setting for relay R_{74} . Therefore, $124.04 < 59.91^\circ$, $136.24 < 32.71^\circ$, $117.24 < 61.80^\circ$, $118.89 < 61.10^\circ$ are respectively selected as final impedance in case of three phase (ABC), two phase (AB), two phase to ground (ABG) and single phase to ground (AG) faults.

Fault Type	Fault on end of zone-2 line	Max. Generation			Min. Generation		
		Line 24-23 Removed	Line 24-22 Removed	None	Line 24-23 Removed	Line 24-22 Removed	None
ABC	24-23	Line out	136.88<61.36°	208.73<62.71°	Line out	125.96<60.80°	200.48<63.71°
	24-22	130.05<60.16°	Line out	167.76<58.21°	124.04<59.91°	Line out	159.01<57.41°
AB	24-23	Line out	153.85<33.69°	241.31<34.33°	Line out	140.38<34.42°	223.81<31.54°
	24-22	145.99<32.58°	Line out	194.6<29.65°	136.24<32.71°	Line out	178.13<30.63°
ABG	24-23	Line out	136.76<61.36°	211.14<63.06°	Line out	120.75<61.94°	199.69<61.94°
	24-22	129.95<60.16°	Line out	157.59<58.24°	117.24<61.80°	Line out	157.59<58.1°
AG	24-23	Line out	136.82<61.31°	213.89<63.38°	Line out	121.25<60.88°	197.47<63.6°
	24-22	130.00<60.12°	Line out	170.56<58.24°	118.89<61.10°	Line out	168.83<58.24°

Table 1. Possible zone-3 setting calculated for relay R74 on maximum and minimum generation for various faults.

Fault Type	Primary relays	Fault on end of zone-2 line	Line 24-23 removed	
			Max. Generation	Min. Generation
ABC	R72	24-23	Line out	Line out
		24-22	131.99<60.08°	125.43<60.12°
AB	R72	24-23	Line out	Line out
		24-22	147.06<34.47°	138.31<33.77°
ABG	R72	24-23	Line out	Line out
		24-22	131.9<60.09°	115.19<60.10°
AG	R72	24-23	Line out	Line out
		24-22	131.94<60.06°	115.83<59.59°

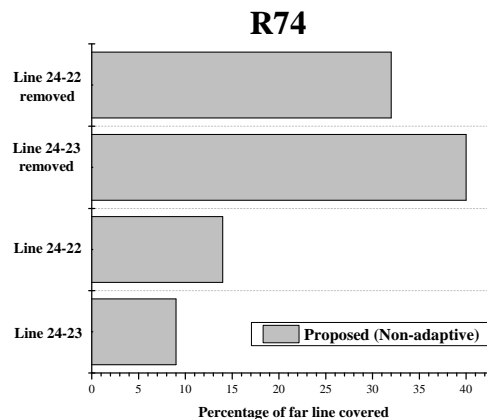
Table 2. Fault impedance seen by relay R₇₄ with fault at the end of zone-2 of each line for various faults.

2.3 Discussion

Figure 4 shows the covered percentage of the far lines (by the new zone-3 setting of relay R₇₄ (Figure 2) in the case where the system

generation is at the maximum generation level for different topology.

Similar results can be delivered for the minimum level of generation. Tables 3 shows the covered percentage of the far lines by the new zone-3 reach of relay R₇₄ in the case different lines are out of service. 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 (that is why it is not shown in Figure 4 and Table 3 as well), thus, the zone-3 relay cannot be a perfect backup protection for the next lines. The new setting method has resolved this problem, while it prevents the zone-3 of the backup distance relay from overlapping with the zone-3 of the next primary distance relays. The same results are obtained for other relays whose zone-3 settings were established using the proposed technique.

Figure 4. Percentage of far line covered by relay R₇₄ for ABC fault when the level of generation is maximum and different lines are out of service.

		Fault Type							
		ABC		AB		ABG		AG	
		24-23	24-22	24-23	24-22	24-23	24-22	24-23	24-22
Line Removed	None	11%	17%	9%	14%	10%	15%	10%	15%
	24-23	-	41%	-	43%	-	42%	-	42%
	24-22	34%	-	30%	-	31%	-	31%	-

Table 3. Percentage of far line covered by relay R_{74} for ABC fault when the level of generation is minimum and different lines are out of service through different faults.

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) Simulate a fault (ABC, AB, ABG or AG) 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 Eq. 3.

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 $j=1, 2, \dots, p$ (fault at one line at a time).

4) Repeat steps 2 to 3 for all zone-2 distance relays R_{BCi} , $i=1, 2, \dots, k$.

5) Simulate a fault (ABC, AB, ABG or AG) at the ends of the zone-2 distance relays of the next lines (R_{BCi} , $i=1, 2, \dots, k$) when all circuit breakers are closed. Determine Z_{AF} and compute zone-3 impedance reach of relay R_{AB} by using Z_{AF} and Eq. 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 is applied to determine zone-3 setting of relay R_{74} in the system 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 ($Z_2(R_{72})$) reach of the next primary relay on the far lines are tabulated in Table 4.

Fault Type	Fault on end of zone-2 line	Possible zone-3 settings (End Breaker (EB) is open)		Fault impedance at $Z_2(R_{72})$ as primary relay ((EB) is close)	
		Max. Generation	Min. Generation	Max. Generation	Min. Generation
ABC	24-23	197.21<93.80°	173.38<80.99°	207.681<62.418°	185.16<63.65°
	24-22	162.23<58.40°	139.24<54.465°	168.351<58.105°	146.77<56.94°
AB	24-23	227.33<35.98°	213.26<35.21°	236.5<37.65°	221.79<36.02°
	24-22	184.85<31.46°	171.79<35.41°	189.44<32.67°	174.73<36.25°
ABG	24-23	201.27<62.94°	181.07<63.70°	210.11<62.77°	189.52<62.66°
	24-22	163.38<58.42°	139.89<58.63°	169.3<58.14°	151.14<58.76°
AG	24-23	203.094<63.05°	179.14<62.24°	213.16<63.18°	188.22<61.51°
	24-22	164.75<58.42°	141.97<57.61°	170.60<58.17°	150.61<57.63°

Table 4. Possible adaptive zone-3 setting for relay R_{74} on maximum and minimum generation and different faults.

As seen the smallest calculated zone-3 impedance for the maximum and minimum generations in case of ABC, AB, ABG and AG faults are respectively $162.2385 < 58.4035^\circ$, $139.24 < 54.465^\circ$; $184.8527 < 31.4629^\circ$, $171.7902 < 35.4175^\circ$; $163.3826 < 58.4264^\circ$, $139.8956 < 58.6378^\circ$ and $164.7506 < 58.4248^\circ$, $141.974 < 57.6118^\circ$ Ω respectively. These impedances are selected as final impedance setting for the zone-3 of distance relay R_{74} under related operating circumstances of the power system. Figure 5 depicts that the adaptive version of proposed technique for determining zone-3 impedance settings provides more coverage of the far lines than the non-adaptive version.

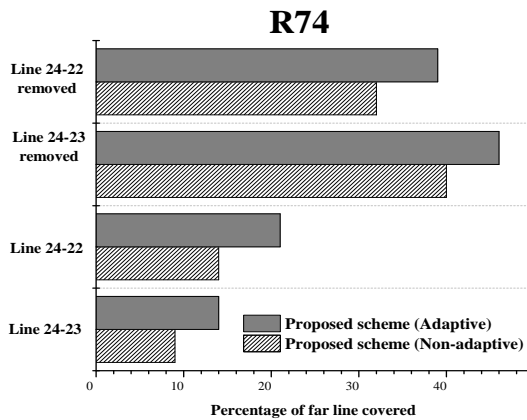


Figure 5. Comparison between the adaptive and non-adaptive version of the proposed method for relay R_{74} in terms of ABC fault and maximum generation condition.

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 6 and consists of 43 transmission lines (86 distance relays) operating at 138kV levels. The technical information of the network is given in [23]. Zone-3 settings determined by the non-adaptive version of the

proposed (PNA) method can be saved on the relays as a setting group.

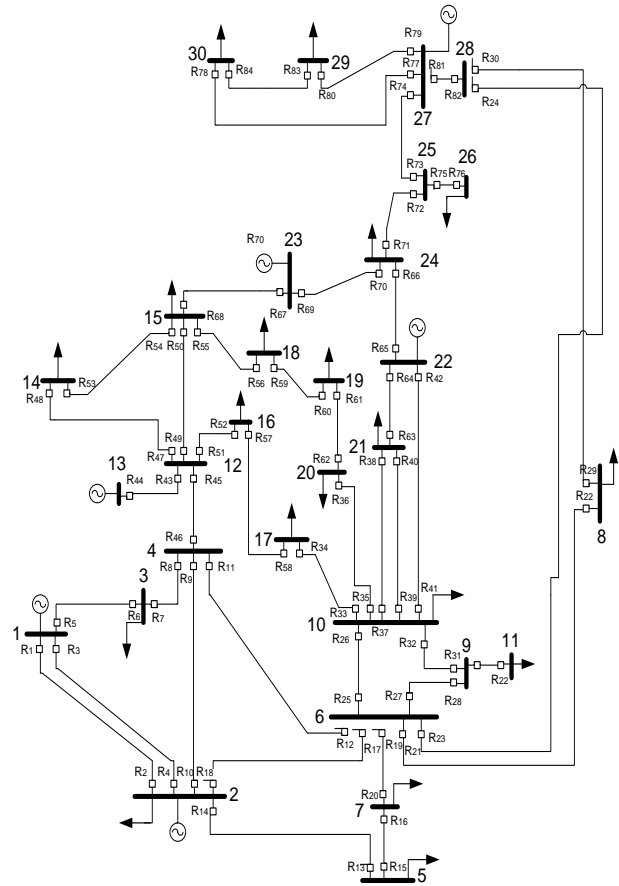


Figure 6. 30-bus IEEE test system used for evaluating the proposed method.

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 of distance relays. The next and far lines coverage supplied by proposed technique is compared with the conventional setting techniques and some results are drawn here. Table 5 compares the zone-3 reach settings of some distance relays obtained using conventional and proposed methods for the maximum generation condition.

Fault Type	Method	Relays					
		R58	R66	R70	R5	R46	R15
ABC	C	85.05<66.88°	44.34<62.98°	92.48<63.7°	36.53<68.875°	76.13<69.829°	40.01<75.43°
	PNA	115.45<69.45°	123.04<48.9°	411.841<45.114°	44.654<71.324°	137.22<65.609°	61.27<75.298°
	PA	130.24<73.06°	129.61<48.504°	524.62<44.327°	54.1<75.47°	155.46<64.708°	59.74<70.04°
AB	PNA	118.31<31.84°	158.42<46.26°	746.595<46.63°	58.42<45.11°	160.58<46.77°	73.48<31.09°
	PA	129.05<33.57°	167.69<54.07°	937.8<47.00°	63.79<45.87°	185.05<45.45°	86.08<29.87°
ABG	PNA	94.96<66.32°	155.18<46.63°	564.33<46.42°	50.61<75.23°	137.7<69.58°	53.64<68.67°
	PA	105.2<66.73°	164.28<54.69°	704.016<46.68°	55.2<75.68°	158.1<69.15°	63.32<69.95°
AG	PNA	95.36<66.24°	154.18<46.63°	1118.07<47.93°	50.45<75.18°	146.03<68.78°	54.89<68.67°
	PA	106.23<66.79°	165.28<54.69°	1416.78<47.89°	55.17<75.65°	166.63<68.3°	63.54<69.78°

Table 5. Possible zone-3 setting for different relays in terms of various faults and maximum generation condition.

As seen, a higher zone-3 impedance setting can be achieved using the proposed method (PM) compared with the conventional (C) method for all the relays. For example in terms of ABC fault, the possible setting for relay R46 via the conventional method is $76.1373<69.829^\circ \Omega$ while this value is $137.224<65.609^\circ \Omega$ and $155.46<64.708^\circ \Omega$ via non-adaptive (PNA) and adaptive version (PA) of the proposed method, respectively. The results divulge significant increase in the impedance setting for the relay. The same result can be derived from other type of fault for all relays. As 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. Not only

does the proposed technique cover remote lines, but also it covers significant percentage of far lines emanating from the far buses without any coordination problems. Figure 7 depicts this fact.

As can be seen from the figure, the better coverage is provided by the adaptive version for all relays. For example, 19% of the line connected between buses 12 and 15 can be covered by zone-3 relay R58 using non-adaptive (PNA) version of the proposed method whereas this value is increased to 38% using the adaptive version (PA). The same consequences can be acquired of other relays in terms of different faults and operating conditions (minimum generation).

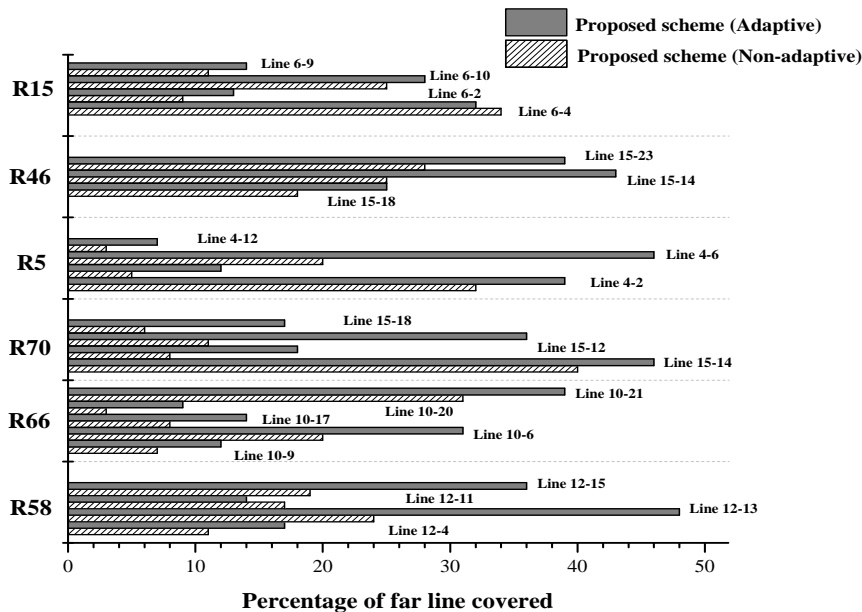


Figure 7. Comparison between the adaptive and non-adaptive version of the proposed method for different relays in terms of ABC fault and maximum generation condition.

5. Conclusion

One of the most noticeable protective relay characteristic may be the undesired operation of the third zone of DRs on account of the incorrect zone 3 relay operations which is contributive to the severity of blackouts. In this regard, the accurate zone 3 setting is supposed to be unavoidable. This main contribution of this study is to develop a new scheme for calculating zone-3 setting of DRs. The proposed method employs impedance seen by DRs to calculate zone-3 setting when faults are simulated on the reach of zone-2 of primary DRs. The proposed method and its adaptive version are tested in the IEEE 30-bus system through different conditions including various types of faults (ABC, AB, ABG and AG) and the maximum and minimum generation outputs of the power system to indicate its remarkable efficiency and adaptivity with the operating conditions. Simulation results divulge the ability of the proposed technique to significantly increase the reach of zone-3 relays and better line coverage compared to conventional technique without causing mis-coordination problems. The core advantages of having longer zone 3 reach consist of better backup protection for primary relays, increasing security of the power system, covering all the lines emanating from far buses and mitigating mis-coordination problems between primary and backup relays.

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