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Optimal setting of distance relays quadrilateral characteristic considering the uncertain effective parameters

A. Mohajeri *, H. Seyedi, M. Sabahi

University of Tabriz – Faculty of Electrical and Computer Engineering – Tabriz 51666-15813, Iran

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ABSTRACT

In this paper a new method is presented for setting the quadrilateral characteristic of distance relay, considering sensitivity and selectivity criteria for protection zones. The main protection scheme used for transmission lines is distance protection. Due to the uncertainty of the effective parameters on relay's estimated impedance the issue of optimal setting of the relay arises. In the proposed method of the paper, in addition to the variations of fault resistance, pre-fault load flow and measurement errors, the probabilistic changes of system topology and their corresponding effects are also considered. Optimal characteristic search is applied using Genetic Algorithm (GA). The obtained results for new method demonstrates a noticeable increase in the accuracy of this scheme compared to the conventional ones.

Introduction

Distance protection with three zones and proper time delays is used as the main and backup protection of transmission lines. Therefore, in order to improve the conventional methods several methods have been proposed for setting and operation of this protection. Nowadays, with developing new technologies and implementation of digital distance relays and reliable communication systems, new algorithms for more accurate and comprehensive protection could be presented. One of the factors that cause mal-operation of distance relays is the uncertain behavior of the parameters that influence the relay's estimated impedance. Three of these uncertain parameters are fault resistance, measurement errors and pre-fault load flow. The effect of these parameters on the settings have previously been studied [1–7]. In addition to the mentioned factors, topological changes of power system also affect the estimated impedance of the relay. This effect is mainly due to the change in infeed currents. This may be the result of different events like outage of generators or transmission lines, related to either fault (non-planned) or repair (planned). These reasons all have a probabilistic nature. Many methods have been proposed for setting the distance relay including conventional methods [8–11], intelligent methods [12–17], optimization methods [1,7], adaptive methods [18–20] and probabilistic methods [2,7]. Many of the distance protection approaches apply quadrilateral characteristics [5,12,21–24]. In this paper all the mentioned uncertainties are considered together with their corresponding probabilities and two criteria of sensitivity and selectivity to find the optimal quadrilateral characteristic for the relay. The optimization is performed using GA. The rest of this paper is organized as follows: In section 'Primary concepts' the effective parameters on the estimated impedance are reviewed; in section 'The main structure of new method' the new method is presented. In section 'A sample power system' a sample power system is introduced and in section 'Simulation results', the simulation and comparison results are presented. Finally section 'Conclusion' presents the conclusions.

Primary concepts

Effective parameters on the estimated impedance of relay

To summarize the concept of uncertainty, the simple equivalent system of Fig. 1 is considered.

The impedance seen by the relay in the sending terminal of the transmission line could be calculated as:

$$Z_a = xZ_{1L} + \Delta Z \tag{1}$$

where Z_{1L} is the positive sequence impedance of line and ΔZ is the error impedance which undesirably appears in addition to the impedance from the relay to the fault point. ΔZ could be written as follows:

$$\Delta Z = f(Z_R, Z_S, Z_L, E_R, E_S, \delta_R, \delta_S, x, R_f) \tag{2}$$

* Corresponding author. Tel.: +98 914 407 9025.
E-mail address: a_mohajeri89@ms.tabrizu.ac.ir (A. Mohajeri).

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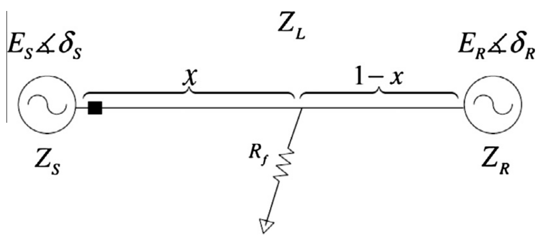

Fig. 1. Equivalent power system.

Some of the effective uncertainties on distance protection are included in ΔZ; These include the fault resistance R_f, the changes in infeed due to the outages which could be modeled as changes of Z_R and Z_S, and finally the changes in the power flow which could be modeled as the changes in δ_R and δ_S. In addition, measurement errors in voltage and current values affect the total value of estimated impedance Z_a.

Sensitivity and selectivity criteria in protection zones

In this part, the definitions of two main criteria of the proposed method for three protection zones are discussed.

Zone-1: for this zone the criteria of protecting a maximum possible length of the main line is desirable, so that the faults on the next terminal do not lie inside the trip zone. For the faults outside the main line, if the estimated impedance is inside the trip zone the selectivity is lost. Conversely, for the faults inside the main line if the estimated impedance is outside the trip zone, the sensitivity is lost.
Zone-2: for this zone the faults inside the main line with estimated impedances outside the trip zone are considered as loss of sensitivity and the faults in adjacent lines with estimated impedance that lie outside zone-1 of their main relay, and inside the zone-2 of their backup relay are considered as loss of selectivity. Hence, for setting zone-2 the setting of zone-1 of the relay and also the longest adjacent line is required.
Zone-3: for this zone the faults in adjacent lines with estimated impedances outside the relays trip zone are considered as loss of sensitivity and the faults in the adjacent lines with estimated impedances outside the zone-2 of their first backup relay, and inside the zone-3 of their second backup relay are considered as loss of selectivity. To ensure the maximum backup protection of adjacent lines, the longest line is considered. Moreover, for coordination with zone-3 of other relays, the shortest line after longest adjacent line is considered. Therefore, to set zone-3 the settings of zone-2 of the relay and the longest adjacent line are needed.

The main structure of new method

The main structure of new method for finding the optimal setting consists of 6 stages:

Stochastic review

The first stage includes the review of probabilistic behavior of the efficient parameters. The probabilities required to be considered in this stage are the corresponding probabilities of fault resistances, units' outages, pre-fault load flow and measurement errors. The mentioned probabilities could be modeled by a continuous stochastic model or simply by discrete values. The availability of these data could be considered in two cases; in the first case, the goal is to revise settings of the system relays optimally. In this case, the data are available. In the second case, the goal is to obtain the optimal setting of relays in a new transmission line; In this case, the stochastic data of similar adjacent networks along with the forecasts could be used. It should be noticed that the corresponding probability of units' outages, considering single outage in the network (conditional probability) is calculated based on the Mean Time to Failure (*MTTF*) and Mean Time to Repair (*MTTR*) parameters. Coefficient c is defined for outage of each unit as follows:

$$c_i = \frac{MTTR_i}{MTTF_i} \tag{3}$$

Then, the conditional probability of each unit's outage (p_{out_i}) is calculated based on the following normalization:

$$p_{out_i} = \frac{c_i}{\sum_k c_k} \tag{4}$$

Here, k represents the number of units (generators or transmission lines), the outage effects of which are considered for setting the relay. According to (3) and (4), decreasing *MTTF* or increasing *MTTR* will cause an increase in the outage probability of the unit.

Simulation

At this stage, in order to find the optimal settings for relay's ground and phase units, different types of ground and phase faults are simulated at N points of the main line and M points of the longest and the shortest adjacent lines, using a computer based program. If simulation is applied to more points, the accuracy will be increased. All different combinations of the effective random variables are considered and the estimated impedances are stored.

Probability calculation

At this stage, the corresponding probabilities for each stored impedance are calculated using the models of the first stage. Since the variables are considered to be discrete-independent variables, the probability of occurrence of each impedance is calculated using the product of the probabilities of the effective random variables. The probability of fault resistance p_{Rf_i}, pre-fault load flow p_{PLF_i}, and the measurement error p_{ER_i} in the ith case are multiplied to obtain the corresponding estimated impedance probability:

$$p_{Z\,est_i} = p_{Rf_i} \times p_{PLF_i} \times p_{ER_i} \tag{5}$$

Calculation of objective function

Now, the main and secondary objective functions of the method are introduced:

Base scenario
In this scenario, assuming that all the units are connected to the grid (base topology), the sensitivity and selectivity criteria are checked using two functions; Base Objective Function of sensitivity, BOF_{sen}, and Base Objective Function of selectivity, BOF_{sel}:

$$BOF_{sen} = \sum_i p_{loss\_sen_i} \tag{6}$$

$$BOF_{sel} = \sum_i p_{loss\_sel_i} \tag{7}$$

$p_{loss\_sen_i}$ and $p_{loss\_sel_i}$, are the probabilities of losing sensitivity and losing selectivity in the ith case respectively. Therefore, if in the ith case, there is a loss of selectivity or sensitivity, probability calculated by (5) will be replaced here:

$$p_{loss\_sen_i} \quad \text{or} \quad p_{loss\_sel_i} = p_{Z\,est_i} \tag{8}$$

Otherwise, these probabilities are equal to zero. If the objective is only to decrease the probability of loss of sensitivity, then the goal is to minimize BOF_{sen} and the same is true about BOF_{sel}. Finally, the two functions are combined using weighting factors w_1 and w_2 to obtain the total *BOF*, constructing a multiobjective optimization problem:

$$BOF_t = w_1 \times BOF_{sel} + w_2 \times BOF_{sen} \tag{9}$$

Two functions are combined, since in the protection systems, the selectivity and sensitivity criteria should be considered together to obtain the optimal solution regarding the systems conditions and the importance of these two criteria. The coefficients have complementary values:

$$0 < w_1, w_2 < 1, \quad w_2 = 1 - w_1 \tag{10}$$

The single outage scenario

In this scenario, the effect of single outages on the estimated impedance by relay is considered.

Determination of effective outages. To assess the effect of unit outages, firstly the units that have considerable effect on the estimated impedance should be specified. For this purpose, the criterion of the Average Apparent Impedance (*AAI*) at a boundary point is used, which is defined as the following:

$$AAI = \sum_i p_{Z\,est_i} \times Z_{est_i} \tag{11}$$

For example, the *AAI* in base scenario could be obtained for a fault at the point of 80% line length. Then, this value is obtained for every single outage scenario of units, starting from the point of relay. In this way, the calculation continues as long as the relative difference of obtained values is greater than a specified number (e.g. 1%). If this condition is not satisfied, no more units are checked. It should be mentioned that if there is a tie-line or a prominent generation unit in the grid, even if it is out of this region, it should be considered in the calculations separately.

Once the effective units are determined, simulation for the estimated impedance in single outage cases should be applied similar to stage 2.

The single outage objective function (SOOF). In this section, the *SOOF* is determined by:

$$SOOF_j = w_1 \times SOOF_{sel_j} + w_2 \times SOOF_{sen_j} \tag{12}$$

Here, the $SOOF_{sel}$ and $SOOF_{sen}$ are related to the selectivity and sensitivity respectively, and formulated as:

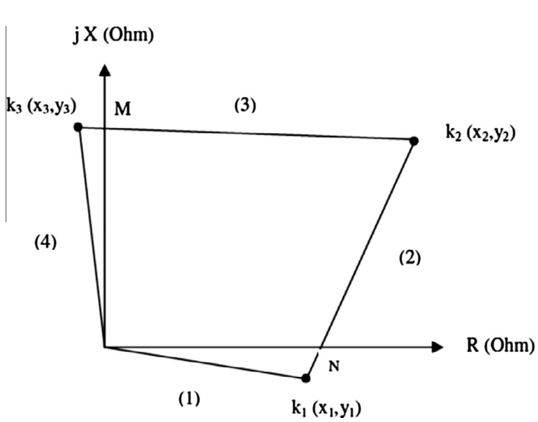

Fig. 2. Quadrilateral characteristic of distance relay.

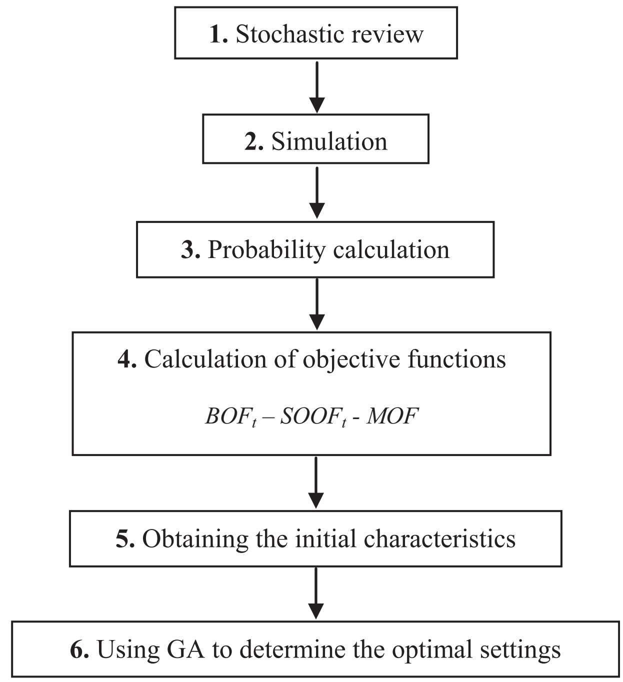

Fig. 3. Flowchart of the proposed method.

$$SOOF_{sel} = \sum_i p_{loss\_sel_i} \tag{13}$$

$$SOOF_{sen} = \sum_i p_{loss\_sen_i} \tag{14}$$

In this case, (5) should be modified to take into account the probability of outage, p_{out_i} as follows:

$$p_{Z\,est,outage_i} = p_{Rf_i} \times p_{PLF_i} \times p_{ER_i} \times p_{out_i} \tag{15}$$

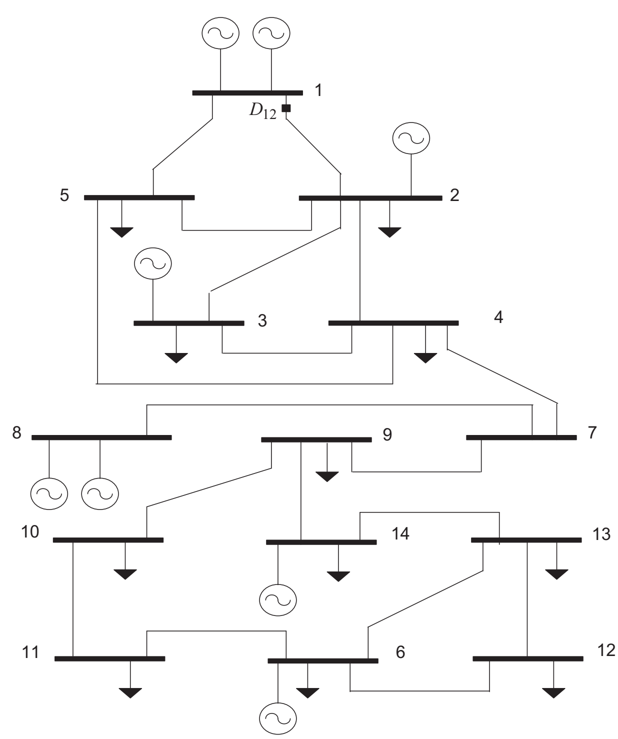

Fig. 4. One-line diagram of the sample power system.

$p_{Z\,est,outage_i}$ is the occurrence probability of the estimated impedance by the relay in ith case.

Hence if in the ith case, there is a loss of sensitivity or selectivity, then the corresponding value of probability is replaced from (15):

$$p_{loss\_sen_i} = p_{Z\,est,outage_i} \tag{16}$$

$$p_{loss\_sel_i} = p_{Z\,est,outage_i} \tag{17}$$

Finally, the total *SOOF* value is obtained by:

$$SOOF_t = \sum_j SOOF_{sel_j} \tag{18}$$

The main objective function of proposed method

In the proposed method, to calculate the main objective function, the base and single outage functions are combined as:

$$MOF = BOF_t + h \times SOOF_t \tag{19}$$

Here, h is a coefficient which represents the importance of effective outages in setting the relay and has a value between 0 and 1.

Obtaining the initial characteristics

Since the optimal settings in this method are searched using GA, an initial setting should be obtained for three zones. This is performed by using the conventional settings with a typical value for fault resistance and without considering the infeed currents for zone-1 and considering the full infeed for other two zones. Then, some random deviations are applied to the settings to obtain N_p number of answers, which N_p is the number of population.

Table 1
General information of the power system.

No. of transmission lines	No. of independent generators	No. of buses	Frequency (Hz)	Voltage (LL-kv)
18	8	14	60	132

Table 2
Transmission line parameters.

R_0 (Ω/km))	X_0 (Ω/km)	R_1 (Ω/km)	X_1(Ω/km)
0.446	1.374	0.118	0.555

Table 3
Length of transmission lines.

Line	1–2	1–5	2–3	2–4	2–5	3–4	4–5	4–7	6–11	6–12	6–13	7–8	7–9	9–10	9–14	10–11	12–13	13–14
Length (km)	100	50	60	60	70	50	110	50	60	90	130	70	50	60	70	80	50	60

Table 4
Connected loads.

Bus	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P (Mw)	0	30	40	35	59	35	0	0	50	20	30	35	39	45
Q (MVar)	0	13.65	18.2	15.93	22.75	15.93	0	0	22.75	9.1	13.65	15.93	13	20.48

Table 5
MTTR and *MTTF* values of transmission lines.

Line	6–11	4–7	4–5	3–4	2–5	2–4	2–3	1–5	1–2
MTTF (h)	6000	8000	7000	6500	7500	7500	9000	7000	6500
MTTR (h)	10	8	8	6	7	11	6	10	8
Line	13–14	12–13	10–11	9–14	9–10	7–9	7–8	6–13	6–12
MTTF (h)	7000	6000	9500	9000	6500	8000	8500	7500	6000
MTTR (h)	7	19	8	8	11	9	6	9	7

Table 6
MTTR and *MTTF* values of generators.

Generator	G1_1	G1_2	G6	G2	G3	G8_1	G8_2	G14
MTTF (h)	3200	3500	3600	3100	3300	3500	3500	3700
MTTR (h)	20	30	35	30	25	40	40	30

Table 7
Fault resistances for phase to ground faults and corresponding probabilities.

R_f (Ω)	0	2	5	10	20	30	40	50	60	70
Probability	0.067	0.15	0.205	0.166	0.111	0.083	0.067	0.056	0.05	0.044

Using GA to determine the optimal setting

The variables used in this method, to find the optimal characteristic are the (x, y) coordinates of the points k_1, k_2 and k_3 (Fig. 2). In other words, 6 variables are considered for the optimization problem $(x_1, x_2, x_3, y_1, y_2, y_3)$.

To form any chromosome as an answer of the problem, it is assumed that each variable has an integer and a fractional part. Considering the maximum value for the variables which is defined by maximum values of fault resistance and infeed currents, the number of bits for each variable is defined.

For instance, assuming that the integer part is between 0 and 100 and the fractional part is between 0 and 0.9 with steps of 0.10, then a total 10 bit is needed for the variable, 7 bits for integer part and 3 bits for fractional part. Finally, encoding decimal variables into binary form and setting them together, the ith answer is obtained as follows:

$$z(i) = \{x_{1,bin}(i), y_{1,bin}(i), x_{2,bin}(i), y_{2,bin}(i), x_{3,bin}(i), y_{3,bin}(i)\} \tag{20}$$

As discussed in stage 5 of the algorithm, the initial population with N_p answers is defined with conventional setting for a rapid convergence. In this step, the *MOF* values for the initial population are calculated, then answers are sorted respectively considering their value (cost). To obtain the next generation, GA operators are applied on the answers to obtain new offspring. To perform this, first N_{keep} number of the top answers are selected as the parents and then the $N_p - N_{keep}$ offspring are made using mutation and cross-over operators. To increase the probability of choosing the answers with relatively less values of *MOF* as the parent, the probability of choosing the jth answer as a parent is obtained using [25]:

$$P(j) = \left| \frac{MOF(z(j)) - MOF(z(N_{keep}+1))}{\sum_{i=1:N_{keep}} MOF(z(i))} \right| \tag{21}$$

Next, with decoding the binary forms of variables into decimal form, the value of *MOF* is calculated. After checking inequality constraints, if the answers are within the limits, similar to previous step, the selection and mating procedure is applied again on feasible answers to obtain the next generation. This process will continue until either the solution converges to the top answer which is corresponding to the minimum *MOF*, or the number of defined iterations is finished. Finally, the first answer from the last generation will be chosen as the optimal answer and after decoding the variables, the coordinates of the three points of characteristics will be obtained. This process is applied to all 3 zones. The inequality constraints of the problem are:

$$\begin{cases} x_{i\,\min} < x_i < x_{i\,\max}, & i = 1,2,3 \\ y_{i\,\min} < y_i < y_{i\,\max}, & i = 1,2,3 \\ x_1 < x_2, \end{cases}$$

The overall flowchart of the proposed method is shown in Fig. 3.

Table 8
Load flow of line 1–2 and the corresponding probabilities.

	Case I	Case II	Case III
P (MW)	32	25.6	12.8
Q (MVAr)	6	4.8	2.4
Probability	0.35	0.45	0.2

A sample power system

A sample power system is shown in Fig. 4. The basic structure of this power system is the conventional IEEE 14 bus network. However, this model is not proper in its basic format to test a protection method due to voltage levels and related transmission lines, so the parameters of the network are modified using a real network data which are given in Tables 1–6.

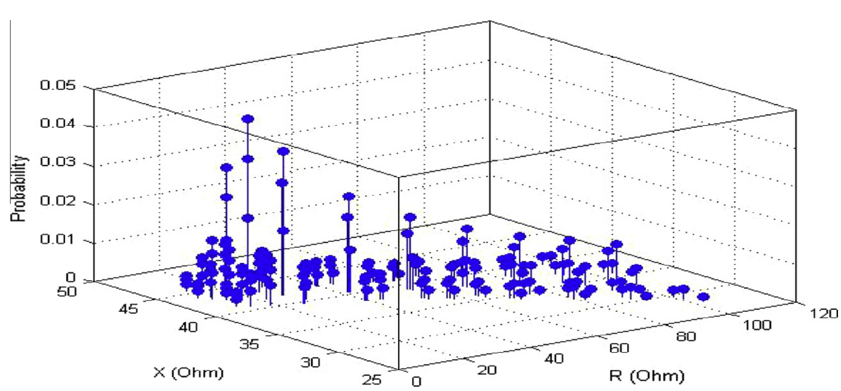

Fig. 5. Apparent impedances and their corresponding probabilities for a SG fault at 0.8 length of line 1-2.

Table 9
Units with effective outages and their relevant %*AAI* difference for relay D_{12}.

Unit	Line 1–5	Line 2–3	Line 2–4	Line 2–5	Line 3–4	Line 4–7	Line 5–4	Line 7–8
AAI % difference	4.25%	4.57%	1.55%	2.85%	1.03%	1.61%	1.61%	1.42%
Unit	(G1_1 & G1_2)		(G2)		(G3)		(G8_1 & G8_2)	
AAI % difference	4.01%		4.34%		2.77%		1.61%	

Simulation results

Primary calculations

In this section the new method is applied to test system, to find the optimal settings of ground units in the distance relay on line 1–2 next to terminal 1 (D_{12}); the same trend could be applied to other relays in the system. The typical values for fault resistance and their probabilities are listed in Table 7, [26]. For measurement error, a maximum error of 5% on CT and 3% on VT are considered. The pre-fault load flow on line 1–2 is also considered in 3 cases as in Table 8.

In the test power system, there are 17 cases for line outage and 8 cases for generator outage. For simulation, the PSCAD software is used. Firstly, a single phase to ground fault (SG) is simulated on 30

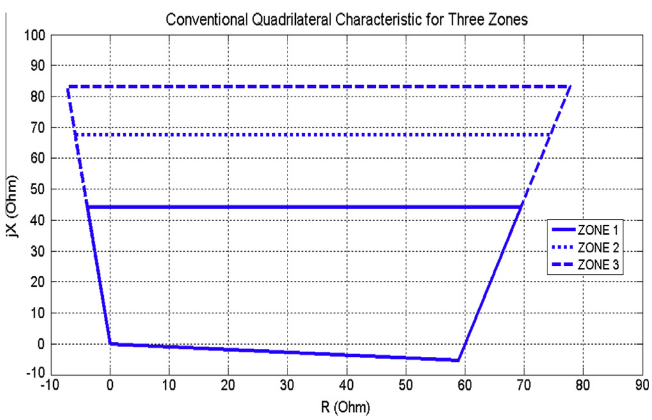

Fig. 6. Initial characteristics of relay D_{12}.

Table 10
GA parameters.

Number of kept answers (N_{keep})	Number of maximum iterations (N_g)	Number of answers (chromosomes) in every generation (N_p)	Number of variables (N_v)
8	500	32	6

Table 11
Maximum values and required number of bits for each variable with 1 fractional part (3 bit).

x_1	$\|y_1\|$	x_2	y_2	$\|x_3\|$	y_3	Variable
130	10	185	120	8	120	Maximum
10	7	11	9	6	9	Required bit number

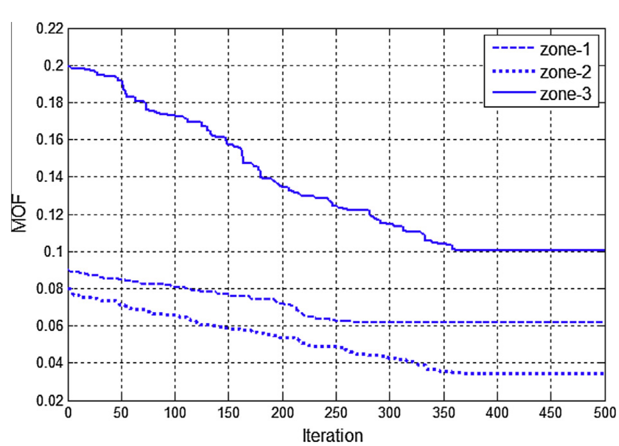

Fig. 7. The convergence plot of the GA for obtaining optimal characteristic of three zones.

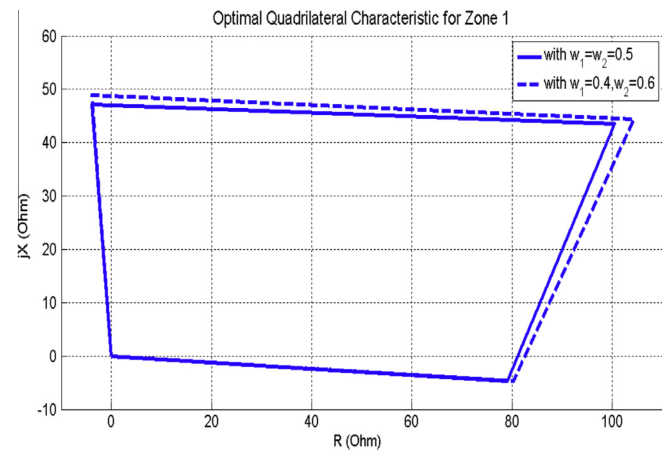

Fig. 8. Optimal setting of zone-1 for two cases of w_1 and w_2.

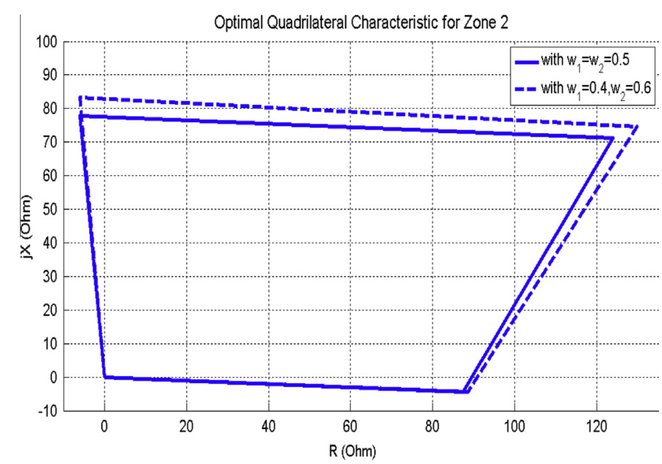

Fig. 9. Optimal setting of zone-2 for two cases of w_1 and w_2.

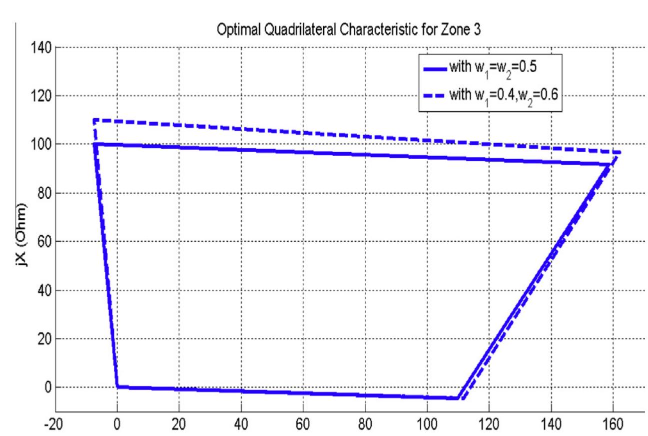

Fig. 10. Optimal setting of zone-3 for two cases of w_1 and w_2.

Table 12
Optimal answer and related variables for two combinations of weighting factors for zone-1.

x_1	$\|y_1\|$	x_2	y_2	$\|x_3\|$	y_3	Variable
$z(opt)$ = 1001111001010011001100100101101011101100000101111001						Optimal answer for $w_1 = w_2 = 0.5$
1001111001	0100110	01100100101	101011101	100000	101111001	Binary form
79.1	4.6	100.5	43.5	4.0	47.1	Decimal form
$z(opt)$ = 1010000100010011001101000100101100100100000110001000						Optimal answer for $w_1 = 0.4$, $w_2 = 0.6$
1010000100	0100110	01101000100	101100100	100000	110001000	Binary form
80.4	4.6	104.4	44.4	4.0	49.0	Decimal form

Table 13
Objective function values for optimal settings of three zones of relay D_{12} for two combinations of w_1, w_2.

$w_1 = 0.4$, $w_2 = 0.6$	$w_1 = w_2 = 0.5$	$w_1 = 0.4$, $w_2 = 0.6$	$w_1 = w_2 = 0.5$	$w_1 = 0.4$, $w_2 = 0.6$	$w_1 = w_2 = 0.5$	Weighting factors
Zone-3		Zone-2		Zone-1		Objective function
0.109	0.118	0.001	0.009	0.050	0.061	BOF_{sen}
0.078	0.066	0.064	0.054	0.059	0.051	BOF_{sel}
0.0966	0.092	0.0262	0.0315	0.0536	0.0560	BOF_t
0.0854	0.084	0.0249	0.0285	0.0518	0.0597	SOF_t
0.1051	0.1004	0.02869	0.03435	0.05878	0.06197	MOF

points of the main line and also on 20 points of the longest and the shortest adjacent lines (lines 2–5 and 2–3 respectively) in all different combinations of the effective random variables and the seen impedances by relay D_{12} are obtained. The corresponding values for probabilities are also calculated using (5). For example, these probabilities are shown together with their apparent impedances in Fig. 5 for a single phase to ground fault at 80% of line 1–2.

Next, for defining the units with effective outages, the *AAI* at 0.8 p.u. length of line 1–2 for a SG fault is calculated using (11), while all the units are connected to system; then, starting with adjacent lines and generators and disconnecting them, the previous stage is repeated to obtain the *AAI*, at 0.8*L*. These values are compared with the base value. This trend is repeated until the difference become less than 1%. The effective units are obtained and listed in Table 9.

As listed in Table 9, only the outages of 8 lines and 6 generators cause a difference of more than 1% on the *AAI*. Next, the same simulations are applied in different cases of effective outages for SG faults on the main line and also on the longest and shortest adjacent lines.

In the next stage, the initial characteristics of three zones are obtained using conventional methods (Fig. 6).

Searching the optimal setting, using GA

For GA, the related parameters are listed in Table 10.

The maximum values for variables considering maximum fault resistance and infeed, together with the required bit numbers are listed in Table 11.

Hence, the total length of every answer is equal to 52 bits. In binary form of variables, three right bits show the fractional part and the rest are dedicated to the decimal part. Moreover, in y_1 and x_3, the binary number only shows the magnitude and in decoding to the decimal form, they are multiplied by -1.

To start using GA, the *MOF* is calculated for every answer of initial generation and the answers are sorted according to their *MOF*,

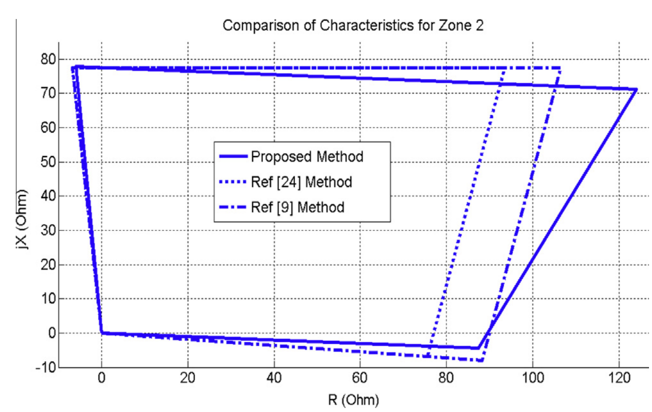

Fig. 12. Characteristic from proposed method and two other methods for zone-2.

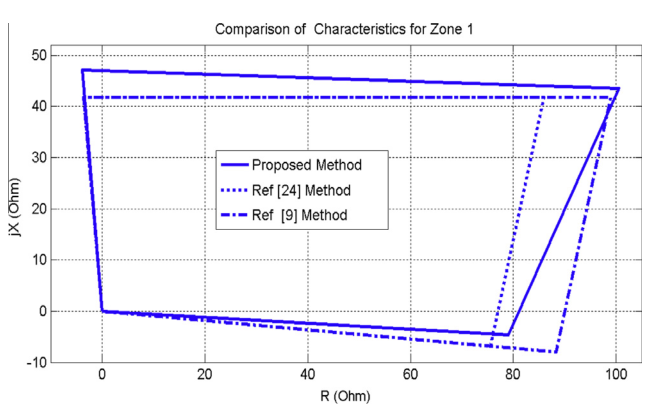

Fig. 11. Characteristic from proposed method and two other methods for zone-1.

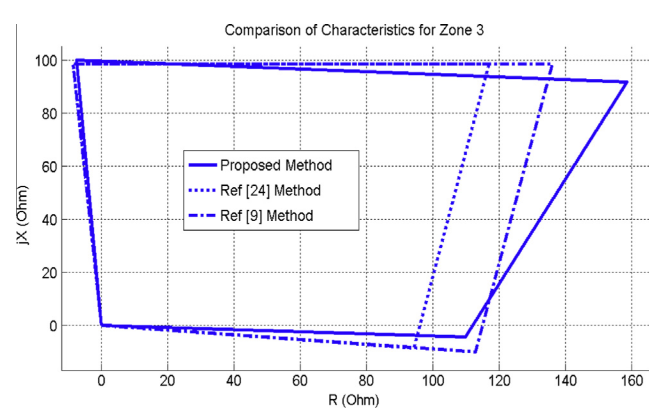

Fig. 13. Characteristic from proposed method and two other methods for zone-3.

Table 14
Objective functions for proposed method and two other methods.

BOF_t			$SOOF_t$			MOF			Objective function
3	2	1	3	2	1	3	2	1	Zone
0.092	0.0315	0.0560	0.084	0.0285	0.0597	0.1004	0.03435	0.06197	Proposed method
0.104	0.0392	0.0741	0.097	0.0350	0.0712	0.1137	0.0427	0.08122	Ref. [24] method
0.099	0.0381	0.0695	0.091	0.0321	0.0685	0.1081	0.0413	s	Ref. [9] method

then the variables are encoded to their binary form. The next generation is obtained using the process explained in stage 6 of the method. The optimal settings are obtained for three zones. Fig. 7 shows the convergence plot.

Here $w_1 = w_2 = 0.5$ and $h = 0.1$. Figs. 8–10 show the obtained optimal characteristics. The corresponding values for variables of zone-1 characteristic are listed in Table 12. In addition, *MOF* values are listed in Table 13.

Two cases are considered for w_1, w_2, and as seen, an increase in the value of w_2 increases the coverage of protection zones. The results demonstrates that the new method could give an accurate characteristic for protection zones, considering the probabilistic behavior of parameters and the protection criteria.

Comparison with other methods

In this part, the characteristics of three zones obtained by the new method are compared with two other methods. In [24], the characteristic is obtained using conventional methods. In [9], the reactive reach is obtained using conventional methods and the resistive reach using a new method. in [9,24], the reactive reach setting of zone-1 is found ignoring the infeed currents (under-reach setting), while in zones 2 and 3, the setting is found considering the full infeed currents (over-reach setting) and also the reactive reach calculation is based on distribution factors of fault currents. The resistive reach in [9] is found considering a 20% safety margin between the estimated impedance with maximum fault resistance curve and the maximum load curve to ensure the load curve does not enter the protection zone. In [24], in reactive reach point, the value of fault resistance is changed and based on the behavior of the estimated impedance, the resistive reach is defined. The characteristics obtained using the two mentioned methods and the new one, are shown in Figs. 11–13 (with $w_1 = w_2 = 0.5$). The values for objective functions are also listed in Table 14.

As seen in Figs. 11–13 and Table 14, since in the mentioned methods, the infeed currents are not included in the setting of reactive reach in zone-1, the reach is smaller in comparison with the new method, and this increases the probability of loss of sensitivity. Moreover the conventional zero slope on the upper side of the characteristic increases the probability of loss of sensitivity. While, the new method with a proper slope on the upper side solves this problem. For zone-2 and zone-3 the reactive reach of conventional methods is a little greater, since these methods consider all the infeed currents in, which cause over-reach settings. In the new method there is a different slope on the right side of the characteristic which is selected considering the nonlinear change of the estimated impedance instead of conventional slope, which is defined by transmission line impedance slope. Finally, considering Table 14, it is obvious that with the mentioned advantages, the value for *MOF* in new method is less than previous methods.

Conclusion

One of the factors that cause mal-operation of distance relays is the uncertain nature of the parameters which influence the relays estimated impedance. In addition to the parameters like fault resistance, measurement error and pre-fault load flow, the infeed current variations due to the line and generator outages also increase the uncertainty.

Since distance protection is the most common protection used for transmission lines, in this paper, a complementary method for the previous studies, is presented. This method applies detailed objective functions and also considers the impacts of topological changes on the relay settings. The proposed method uses the complete quadrilateral characteristic for relay setting. Finally GA is used to find the optimal characteristics of protection zones, considering all the uncertainties and weighting factors for sensitivity and selectivity criteria. In the last section, the results of simulations and comparison with conventional method shows that a more accurate and reliable protection is obtained using the proposed method. In other words, using the proposed method for setting distance relay characteristics, both selectivity and sensitivity of the protection scheme are preserved, despite the common topological and parameter changes in the power system.

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