Coordination of Directional overcurrent, Distance, and Breaker failure relays using Genetic Algorithm including pilot protection.

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Abstract. Protection relays play an important role in the power systems to maintain stability, reliability, selectivity, and security for the power systems. In this paper, genetic algorithm (GA) optimization technique with pilot protection (PP) and without pilot protection (WPP) has been used to obtain proper coordination and the optimum value of transmission lines protection relays between distance relays (DRs) and directional overcurrent relays (DOCRs), as well as the critical case for fails in high voltage circuit breaker (HVCB) during faults, so using breaker failure relays (BFRs) for IEEE-8 bus system. The main aim of the used PP to reduce the overall time of DOCRs. A comparison is made with previous work in literature to show the efficiency and accuracy of the proposed algorithm with PP and the total operation time of DOCRs in the network is minimized.

1. INTRODUCTION

High voltage circuit breaker may be fails to clear faults during a fault. Therefore, it requires strong, secure, and correct coordination between protection relays especially at transmission and sub transmission lines due to frequent faults on this part of the power system.

Transmission and sub-transmission lines contain both distance relay (DR) and directional overcurrent relay (DOCR) widely [1]. The DR is used as the main protection relay and the DOCR as a backup protection relay in transmission and sub-transmission systems [2]. Protection relays detect a fault in which, part of a power system during abnormal conditions, and it is operating to isolate this faulty part of a system as fast as possible [3]. Therefore, proper coordination between main and backup protection relays have required, in case fails main protection relay to isolate HVCB during a fault, the Backup relay should isolate HVCB in the faulty part from the other healthy parts [4]. To improve power system reliability is required a functional duplicate of HVCB. This is a breaker failure relay (BFR) protection role, which distinguishes when HVCB fails to interrupt current after receiving a tripping signal from the main protection relay and operates with a suitable coordinate time delay to isolate backup breakers which feed HVCB faulty [5], [6]. Protection relays should have special specifications such as sensitivity, selectivity, speed, and proper setting for each relay to obtain reliability in the power systems [7] - [10]. Conventional methods such as (simplex, dual simplex, etc) have been used previously [11] - [15]. Nowadays, evaluation algorithms such as GA and particle swarm optimization are used as intelligent optimization methods to coordinate of overcurrent relays [16] – [18].
In this paper, GA optimization technique has used to obtain proper coordination between protection relays on transmission lines, also to obtain optimum values of TMS for DOCR, TZ2 for DR with PP and WPP as well as a time of BFR for IEEE-8 bus system.

2. PROBLEM FORMULATION

Transmission lines have contained on DR as the main protection, DOCR as backup protection, and BFR as local backup protection in the case of HVCB fails to isolate faulty part during faults as illustrated in Figure 1.

![Figure 1. Transmission line bay with protection relays.](image)

There are four scenarios that should be studied to achieve proper coordination of protection relays in the transmission lines. These scenarios are coordination between (main and backup DR, main and backup DOCR, local DOCR and TZ2 for backup DR, and critical case coordination between BFR and main DR and local DOCR at case fails HVCB.

Figure 2 illustrates a logic diagram of BFR. This BFR should exceed pickup current setting and waiting to receive a trip signal from any protection relays DR or local DOCR during faults, as well as HVCB, it must stay in the closing position. BFR has contained two-timer, the timer 1 operated re trip for the same HVCB but via second tripping coil. timer 2 is used as a backup trip to all HVCB which neighboring local HVCB at the case this local HVCB faulty.

![Figure 2. Basic logic scheme for BFR.](image)

Timer 1 set as an instantaneous trip but because of temporary and transient faults must be greater than any expected transient to change the state of auxiliary contact HVCB, so (0.025 sec) sufficient to avoid
that unnecessary faults. While, timer 2 should be set 0.1-0.11 sec to be greater than interrupting time of HVCB, current detector reset, and safety margin [19].

Figure 3 illustrates the coordination of main and backup DOCR at near and far-end faults with the constraints of the following equations:

At the near-end faults (F1), the constraint is:
\[ \text{TRB}(F1) - \text{TRA}(F1) \geq \text{CTI1} \]  
(1)

Where TRA(F1) is the operating time of the main DOCR at near-end fault.

At the far-end fault (F2), the constraint is:
\[ \text{TRB}(F2) - \text{TRA}(F2) \geq \text{CTI2} \]  
(2)

Where TRA(F2) is the operating time of the main DOCR at the far-end fault.

Figure 3. Constraints to coordinate between main and backup DOCR.

Figure 4 illustrates the coordination of main DR with backup DOCR at far-end fault and coordination of main local DOCR with backup DR at near-end fault with the following constraints:

At the near-end faults (F3), the constraint is:
\[ \text{TRD}(F1) - \text{TRA}(F1) \geq \text{CTI2} \]  
(3)

Where TRD(F1) is the operating time of the second zone of backup DR at the near-end fault.

At the far-end fault (F2), the constraint is:
\[ \text{TRB}(F2) - \text{TRC}(F2) \geq \text{CTI2} \]  
(4)

Where TRB(F2) is the operating time of the backup DOCR at the far-end fault.

CTI2 is the coordination time interval between main RA and backup RB relays at the near-end fault (F1).

CTI2 is the coordination time interval between main RA and backup RB relays at the far-end fault (F2).
Figure 4. Constraints to coordinate between DR and DOCR.

The scheme of PUTT requires both underreaching (UR) and overreaching (OR) and Figure 5 is shown scheme logic of PUTT. UR function is represented as zone 1 setting 80% of the line length and OR function is set to reach beyond remote substations for both relay 1 and relay 2. If the fault occurs in the middle of a line at a zone of UR, the CB1 and CB2 at both substations are tripped instantaneous and if the fault occurs in one of the relays in OR zone 120% of line length at zone 2, the other one in UR will send signals to accelerate trip without delay time of zone 2 [20], [21].

Figure 5. PUTT scheme.

PP communication signal permissive under reach transfer trip (PUTT) has used to coordinate of main DR and backup DOCR in Matlab code simulation. The purpose of PUTT signal to accelerate and minimize tripping time between distance protection relays used to protect the same transmission line. The calculation of DR divided into three zones, zone 1 is set instantaneous tripping time, while zone 2 is set with an operating time equal to 0.4 sec. Therefore, PUTT used to accelerate the trip and minimize the time from 0.4 sec to 0.02-0.04 sec, and zone 2 in Figure 4 will become illustrates in Figure 6 with the same constraint but with different operating time.
Figure 6. Constraints to coordinate between DR and DOCR with PUTT.

Figure 7 illustrates coordinate BFR as a backup trip with main DR and local main DOCR, so used with the near end faults with the constraints of the following equations:

\[ \text{TRE}_1(F_1) = \text{TRC zone 1}(F_1) + T \text{ BFR} \]  \hspace{1cm} (5)

\[ \text{TRE}_2(F_1) = \text{TRA}(F_1) + T \text{ BFR} \]  \hspace{1cm} (6)

Where \( \text{TRE}_1(F_1) \) is the total operating time of the backup BFR when it fails HVCB trip with DR trip.

\( \text{TRE}_2(F_1) \) is the total operating time of the backup BFR when it fails HVCB with DOCR trip.

\( \text{TRC zone 1}(F_1) \) is the operating time of the first zone of the main DR at the near-end fault.

\( \text{TRA}(F_1) \) is the operating time of the main DOCR at the near-end fault.

\( T \text{ BFR} \) is the real setting time (backup trip) of BFR.

Figure 7. Constraints to coordinate between BFR and DR & DOCR.
2.1. Objective function for main DRs and backup DOCRs

The problem of DRs and DOCRs coordination in the interrelated power systems can be defined as an optimization problem the main purpose of it to minimize total operating time and the objective function formula as

\[
OF = \text{MIN} \left[ \sum_{i=1}^{N} T_i + \sum_{j=1}^{M} TZ2_j \right]
\]  

(7)

Where \( OF \) is Objective function, \( T_i \) is Operating time for \( i^{th} \) DOCR for near-end fault, \( N \) is the total number of DOCRs, \( TZ2_j \) is operating time for the second zone \( j^{th} \) DR, \( M \) is the total number of DRs.

2.2. The setting of DOCRs in optimization problems.

The time multiplier setting (TMS) bounded between two values lower and upper bound to each DOCR, as well as pickup current setting (Ips) to each one depends on lower minimum fault current and max load current.

\[
\text{TMS}_j \text{Min} \leq \text{TMS}_j \leq \text{TMS}_j \text{Max}
\]

(8)

Where \( \text{TMS}_j \text{Min} \) is minimum bound of TMS for \( j^{th} \) DOCR.

\[
\text{TMS}_j \text{Max} \text{ is maximum bound of TMS for } j^{th} \text{ DOCR.}
\]

\[
\text{Ips}_j \text{Max} - \text{load} \leq \text{Ips}_j \leq \text{Ips}_j \text{Min} - \text{fault}
\]

(9)

Where \( \text{Ips}_j \text{Max} - \text{load} \) is pickup current setting for max load.

\( \text{Ips}_j \text{Min} - \text{fault} \) is pickup current setting for min fault.

According to the bounded value for TMS in equation (8) will obtain the operating time in equations (1) and (2).in this study according to IEC60255 standard, the normal inverse characteristic curve(IDMT) has used with the following equation [22] - [24]: -

\[
T' = \left[ \frac{0.14}{\left( \frac{I_{sc}}{I_{ps}} \right)^{0.02} - 1} \right] \times \text{TMS}
\]

(10)

Where \( T' \) is operating time for each DOCR.

\( I_{sc} \) is the value for short circuit current passing during the relay coil. \( I_{ps} \) is the pickup current setting for each DOCR.

2.3. Flow chart of the tripping sequence of protection relays.

The sequence of tripping to clear fault during faults according to the priority of main and backup protection relays as well as a critical case, in case of CB fails to clear a fault. All these sequences illustrated in Figure 8.
3. GENETIC ALGORITHM OPTIMIZATION TECHNIQUE

Flow chart for GA used for coordination between main and backup DOCR and the main local DOCR and DR is illustrated in Figure (9). While Table 1 shows the parameters setting of GA used in this work.

Table 1. Genetic algorithm parameter.

| Parameters       | Value or function |
|------------------|-------------------|
| Number of iteration | 272               |
| Population size  | 200               |
| Crossover        | Arithmetic        |
| Mutation         | Adapt feasible    |
Figure 9. Flow chart for GA to solve the coordination problems between protection relays.

4. RESULTS AND DISCUSSION
In this paper, the IEEE-8 bus system has been used to coordinate protection relays for transmission lines and BFR for the critical case at case fails HVCB to clear faults. This system consists of two step-up transformers, two generators, an extension network at bus 4 with 400 MVA short circuits, and seven transmission lines as illustrated in Figure (10). The near-end, far-end three-phase short circuit fault current, pickup current for DOCR, and current transformer ratio have been taken from [25]. The system has forty-two protection relays, fourteen DRs, fourteen DOCRs, and fourteen for BFRs according to the number of transmission lines and HVCB in the network.
The range of CTI is (0.2-0.5) second [22]- [28]. The CTI1 and CTI2 in equations 1 to 4 have taken 0.2. According to equation 8, TMS lower and upper bound limited values chosen 0.1 to 1.1 to each DOCR. While zones setting time to each DR is chosen, zone 1 = 0 sec. zone 2= 0.4 sec and zone 3= 0.8 sec [29]. The system has tested with GA optimization in an environment Matlab 2017b and compared with the results in [25]. GA has tested with PP and WPP. There are (sixty-eight) linear inequality constraints and (twenty-eight) variable fourteen for DOCRs and fourteen for DRs, all these constraints in MATLAB simulation have achieved. Table 2 and Table 3 illustrate the optimum TMS values for DOCRs from relay 1 (R1) to relay 14 (R14) and TZ2 for DRs from relay 15 (R15) to relay 28 (R28) with proposed GA with PP and WPP respectively.

**Figure 10.** IEEE-8-Bus system.

| No of relays | TMS with GA          | TMS for NLM [25]          |
|--------------|----------------------|---------------------------|
|              | PP       | WPP       | Only with near-end fault | PP       | WPP       | Only with near-end fault |
| R1           | 0.1551   | 0.1551    | 0.1551                   | 0.1562   | 0.1562    | 0.1562                   |
| R2           | 0.1900   | 0.1900    | 0.1904                   | 0.1913   | 0.1913    | 0.1913                   |
| R3           | 0.1742   | 0.1742    | 0.1742                   | 0.1751   | 0.1751    | 0.1751                   |
| R4           | 0.1366   | 0.1366    | 0.1368                   | 0.1375   | 0.1375    | 0.1375                   |
| R5           | 0.1347   | 0.1347    | 0.1350                   | 0.1357   | 0.1357    | 0.1357                   |
| R6           | 0.1458   | 0.1458    | 0.1458                   | 0.1465   | 0.1465    | 0.1465                   |
| R7           | 0.3599   | 0.3599    | 0.3605                   | 0.3623   | 0.3623    | 0.3623                   |
| R8           | 0.1254   | 0.1254    | 0.1254                   | 0.1261   | 0.1261    | 0.1261                   |
| R9           | 0.1437   | 0.1437    | 0.1440                   | 0.1447   | 0.1447    | 0.1447                   |
| R10          | 0.1301   | 0.1301    | 0.1388                   | 0.1310   | 0.1310    | 0.1395                   |
| R11          | 0.1358   | 0.1357    | 0.1360                   | 0.1367   | 0.1367    | 0.1367                   |
| R12          | 0.1895   | 0.1895    | 0.1870                   | 0.1880   | 0.1880    | 0.1880                   |
Table 2 shows the TMS results and the overall operating time for DOCRs are best with GA optimization technique by using PP and WPP and reduced about 0.0337 sec in case of GA with near-end fault only, 0.0371 in case nonlinear multivariable (NLM) with PP and WPP and 0.0689 sec in case NLM only with near end fault only.

Table 3. TZ2 for DRs

| No of relays | TZ2 with GA | TZ2 for NLM [25] |
|--------------|-------------|------------------|
| R13 | 0.1073 | 0.1076 | 0.1081 | 0.1081 | 0.1081 |
| R14 | 0.3547 | 0.3553 | 0.3570 | 0.3570 | 0.3570 |
| \( \sum_{i=1}^{N} T_i \) | 7.0244 | 7.0581 | 7.0615 | 7.0615 | 7.0933 |

Table 3 shows The TZ2 results and GA optimization technique is better than NLM optimization in obtained optimal values and performance. The overall time is reduced by about 0.0037 sec.

The time of T BFR is 0.1 in equations (5) and (6) and the BFR from relay 29 (R29) to relay 42 (R42). Therefore, the operating time for each DOCR, TZ2 for DR, the timing of third zone (TZ3) will be (TZ2+ 0.4), the operating time for each BFR, and constraints CTI1, CTI2 are illustrated in Table 4 and represent as a bar chart in Figure 11. According to results if the main zone 1 of DR and main DOCR fails to clear faults, TZ2 for backup DR and time of backup DOCR will clear a fault at the same time almost. This study gives more reliability, stability, and sensitivity to the tested system.
Table 4. The operating time for DOCRs, DRs and BFRs.

| NO of Main relay | Time main DOCR (sec) | NO of backup relay | Time backup DOCR (sec) | NO of DR | TZ2 DR (sec) | TZ3 DR (sec) | NO of BFR (sec) | BFR time after DR (sec) | BFR time after DOCR (sec) | CTI 1 (sec) | CTI 2 (sec) |
|------------------|----------------------|-------------------|------------------------|----------|-------------|-------------|----------------|------------------------|--------------------------|--------------|--------------|
| R1               | 0.4152               | R6                | 0.6152                 | R20      | 0.6152      | 1.0152      | R29            | 0.1                    | 0.5152                  | 0.2          | 0.2          |
| R2               | 0.5892               | R1                | 0.7874                 | R15      | 0.7892      | 1.1892      | R30            | 0.1                    | 0.6892                  | 0.2          | 0.2          |
| R3               | 0.5606               | R2                | 0.7584                 | R16      | 0.9182      | 1.3182      | R31            | 0.1                    | 0.6606                  | 0.2          | 0.3576       |
| R4               | 0.5192               | R3                | 0.7192                 | R17      | 0.7192      | 1.1192      | R32            | 0.1                    | 0.6192                  | 0.2          | 0.2          |
| R5               | 0.4948               | R4                | 0.6935                 | R18      | 0.6948      | 1.0948      | R33            | 0.1                    | 0.5948                  | 0.2          | 0.2          |
| R6               | 0.4438               | R5                | 0.7873                 | R19      | 0.7889      | 1.1889      | R34            | 0.1                    | 0.5438                  | 0.3435       | 0.3451        |
| R7               | 0.5889               | R13               | 0.7867                 | R27      | 0.7889      | 1.1889      | R35            | 0.1                    | 0.6889                  | 0.2          | 0.2          |
| R8               | 0.3823               | R7                | 0.7879                 | R21      | 0.7892      | 1.1892      | R36            | 0.1                    | 0.4823                  | 0.4056       | 0.4069        |
| R9               | 0.4873               | R10               | 0.6442                 | R24      | 0.6873      | 1.0873      | R37            | 0.1                    | 0.5873                  | 0.3972       | 0.3987        |
| R10              | 0.4873               | R11               | 0.7176                 | R25      | 0.7190      | 1.1190      | R38            | 0.1                    | 0.5873                  | 0.2303       | 0.2317        |
| R11              | 0.5293               | R12               | 0.7389                 | R26      | 0.7293      | 1.1293      | R39            | 0.1                    | 0.6293                  | 0.2096       | 0.2          |
| R12              | 0.5889               | R13               | 0.7867                 | R27      | 0.7889      | 1.1889      | R40            | 0.1                    | 0.6889                  | 0.2          | 0.2          |
| R13              | 0.3564               | R8                | 0.5564                 | R22      | 0.5564      | 0.9564      | R41            | 0.1                    | 0.4564                  | 0.2          | 0.2          |
| R14              | 0.5810               | R1                | 0.7874                 | R15      | 0.7892      | 1.1892      | R42            | 0.1                    | 0.6810                  | 0.2064       | 0.2082        |
| R9               | 0.7795               | R23               | 0.7810                 | R18      | 0.7892      | 1.1892      | R42            | 0.1                    | 0.6810                  | 0.2          | 0.2          |
The operating time of protection relays in Figure 11 above are matching according to the flow chart in Figure 8 which explains the sequence of operating time protection relays during a fault.

5. CONCLUSION
In this paper, GA optimization technique to coordinate between protection relays at transmission lines has used. The results obtained with this algorithm have compared with NLM algorithm, and it was better and more accurate for reducing the overall times for all protection relays in the network.

TZ2 of DR has set as autonomous value to each relay and the main aim of that is to obtain proper coordination and give priority for the main local DOCR to clear the fault before TZ2 of backup DR and backup DOCR. It is so important to study critical case for HVCB to fail during faults, so BFR has used to coordinate with DR and DOCR.

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