Using of Genetic algorithm to obtain proper Coordination of Directional overcurrent relays.

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Abstract. Transmission and distribution lines are the most parts in power systems affected by faults during their operation. Therefore, it is required to maintain suitable coordination between all the protection relays is used to protect them during faults. In this paper, a genetic algorithm (GA) is utilized to solve the coordination problems of the directional overcurrent relays (DOC) in interconnected systems. GA is used to obtain the optimum time multiplier setting (TMS) of these relays. A comparison has been made with previous work in literature to show the efficiency and accuracy of the proposed algorithm and the total operation time of DOC in the network has been minimized. The results confirm the superior performance of the proposed algorithm and these results have been validated by using an electric transient and analysis program (ETAP).

1. Introduction
Power systems Over time, the need for new power plants to meet the needs of consumers and factories is growing around the clock. Therefore, it requires a strong and robust protection system and suitable coordination between protection relays to maintain energy continuity in case of faults in the grid equipment.

During short circuit current (faults, over-load and over-voltage ---etc.) in modern interconnected substations cause shutdown of power supply and may damage high voltage equipment in the power system. To secure reliability and stability in the power system the primary and backup protective relays have been used with a coordination time interval (CTI), if main protection relay fails in isolated the faulted line the backup relay will operate with delay time according to CTI used [1]-[3]. overcurrent relay generally uses in distribution and transmission systems [4], directional overcurrent relay with (IDMT) curve inverse definite minimum time is widely used as primary protection in distribution systems [5], the overall coordination of protection in the power system very difficult each relay in such a power system must be coordinated with the other one to protect equipment [6]

If OC protection relays were used in such system with non-directional protection, in such case relay coordination not only with the relay at the remote end of the line, but also with the relays behind them .so used direction OC protection relay to avoid coordination with the relays behind them and operate only with forward direction fault [6], [7]. Several optimization techniques used for solving setting and coordination problems for these relays to secure selectivity and speed in isolate faulted lines or equipment one of these methods is GA uses to get the minimum time value of each relay [8]. The DOC relay coordination problem in power system can be described as a constrained optimization problem and can be resolved with the GA technique [6], [9]. previously, mathematics optimization methods (simplex, dual simplex, etc.) have been used by some authors [10]-[14]. In last years,
evaluation algorithms such as genetic algorithm (GA) and used as intelligent optimization methods for coordination of overcurrent relays [15], [16]. In the field of coordination between the DOC relays GA optimization has been used to get the optimal values of time TMS in DOC relays [7].

Unfortunately, most researchers in the literature work have been used optimization techniques in MATLAB environment to see coordination between main and backup DOC relays from a single narrow side, which sees backup relays for only one transmission line. Therefore, this paper used IEEE -8 bus test system with the GA optimization technique to get optimal TMS of each relay in the power system mention above and validating the results by ETAP program as well as, to see the sequence of tripping of backup protection relays for more than one backup relays depending on short circuit current faults values during ETAP Tested.

2. COORDINATION OF DOC RELAY IN RAIDAIL AND RING SYSTEMS

Directional overcurrent relays feed on instrument transformers (voltage and current transformer) A radial system shown in Figure(1) have three bus bar with two DOC relays each one feed from voltage and current transformers belonging to it. At-fault F1 the relay R1 will operate as the main protection relay and R2 not sense by fault because the location of fault behind it and such depend on the polarity of current transformer must be toward bus bar, that is mean grounding secondary winding for current transformer must be toward bus bar. For fault F2 the relay R1 will operate as a backup protection relay and R2 will operate as the main protection relay, in this case, R1 will stay a certain time named coordination Time Interval CTI. If R2 fails to isolate the faulted line, R1 will operate as a backup relay to isolate that line.

A ring system is shown in Figure (2) the benefit of this system maintains load despite isolate any line because of the faults. there are two loops the first in clockwise contain on R1, R3 and R5 and the other in counter-clockwise contain on R6, R4 and R2, the operating time for each relay must be equal or bigger than Coordination Time Interval CTI between relays for each group. Group one and two can be setting according to operation time

\[
\text{TR1} > \text{TR3} > \text{TR5} \quad \text{in a clockwise direction.}
\]

\[
\text{TR6} > \text{TR4} > \text{TR2} \quad \text{in a counter clockwise direction.}
\]

As the extent of complexity of the ring system continues the relays, whenever it increases the lines and the number of relays it becomes more complex to coordinate between relays with the same idea of coordination as mention above the issue can be solved by using Artificial intelligence such as GA technique [17].
3. FORMULATION OF COORDINATION PROBLEM

The problem of DOC relay coordination in the interrelated power system can be defined as an optimization problem the main purpose of it to minimize TMS and calculate pickup current IP, SO that the summation of minimum Operation time for the relays, for close-in fault is to be minimized [4], [6], [7], [18],[19].

\[ \text{MIN OF} = \sum_{i=1}^{n} T_i \]  \hspace{1cm} (1)

Where n is the number of DOC relay and Ti is the sum of operating time of all relays in the system.

the minimum object function in equation (1) is achieved under the following constraints: -

3.1. Coordination time between primary and secondary relays.

\[ T_{Bj} - T_{Mi} \geq CTI \]  \hspace{1cm} (2)

Where TMi is the operating time of the primary relay at i, for close-in fault, TBj is the operating time of the secondary relay at j, for the same close-in fault. CTI is the coordination time interval.

3.2. Bounds of TMS.

Effect TMS on operating time for each relay in the system according to bounds below

\[ T_{MSi Min} \leq T_{MSi} \leq T_{MSi Max} \]  \hspace{1cm} (3)

Where TMSi min is a minimum value of time multiplier setting of i\textsuperscript{th} relay. TMSi max is a maximum value of time multiplier setting of i\textsuperscript{th} relay. The value of TMSi Min and TMS i Max was taken 0.05 and 1.1 respectively.

3.3. Relay characteristics
Numerical relays contain on several curves can be used according to need. In this paper, the Normal Inverse Definite Minimum time curve (IDMT) has been used for all relays [1], [6], [19], [20].

\[ T_{op} = \left( \frac{\lambda}{(PSM)^{\gamma - 1}} \right) T_{MS} \]  \hspace{1cm} (4)

\[ a = \left( \frac{\lambda}{(PSM)^{\gamma - 1}} \right) \]  \hspace{1cm} (5)

\[ PSM = \frac{I_{sc}}{I_{p}} \]  \hspace{1cm} (6)

Substitute equation (5) in equation (4)

\[ T_{op} = [a]T_{MS} \]  \hspace{1cm} (7)

Substitute equation (7) in equation (1)

\[ MIN\ OF = \sum_{i=1}^{n} [a_i]T_{MSi} \]  \hspace{1cm} (8)

Where \( \gamma \) and \( \lambda \) is 0.02 and 0.14 for normal IDMT curve.

Top is operating time for the relay, TMS is time multiplier setting, PSM is plug setting multiple, Isc is short circuit current input to relay in secondary value, Ip is the setting pick up current for relay, MIN OF is minimum object function, ai is the value of \( i^{th} \) relays at various fault locations, and TMSi is the time multiplier setting for each relay will calculate by using genetic algorithm optimization.

4. COORDINATION OF DOC RELAY BASED ON GA TECHNIQUE

The parameters setting of the Genetic Algorithm which used in this work as shown in table (1), as well as flow chart for the Genetic Algorithm used for DOC relay coordination problem, illustrated in figure (3).

| Parameters       | Value or function |
|------------------|-------------------|
| Number of iteration | 120               |
| Population size  | 200               |
| Crossover        | Arithmetic        |
| Mutation         | Adapt feasible    |
5. RESULTS AND DISCUSSION

The advanced algorithm in this paper was simulated using MATLAB R2017b environment to find an optimal value to TMS for DOC relays and electric transient and analysis program ETAP 16 to validate the results by drawing the IDMT curve for each relay according to fault location and short circuit current in the network. The computer used has the following features: Core i7 CPU with a frequency of 2.7 GHz and RAM 16 GB. This work was done by using IEEE 8 bus system with seven transmission lines and fourteen DOC relays, two generators, two step up transformers and an extension network at bus four with 400 MVA short circuit as illustrated in Figure (4).

The data was given in Table A, table B, table C, table D and table E for the network in the appendix [7]. The range of CTI is (0.2-0.5) second [21]-[25]. The range of TMS was set from 0.05 to 1.1 for fourteen relays and CTI 0.3 to compare the results with [7]. The constraints were linear and consist of twenty linear inequality constrain and fourteen numbers of variables and the matrix becomes...
20*14 and 20 *1. In addition to the above constraints and the equations from (1) to (8), all these helped get the best results for the optimal values for TMS and all these constraints during the test in MATLAB simulation have achieved. Table (2) shown CTI between main and back up DOC relays according to constraints.

Table 2. CTI between main and back up DOC relays.

| Main Relay No | Back up Relay No | CTI   | Main Relay No | Back up Relay No | CTI   |
|---------------|------------------|-------|---------------|------------------|-------|
| R1            | R6               | 0.3   | R8            | R7               | 0.5736|
| R2            | R1               | 0.3   | R9            | R10              | 0.3   |
| R3            | R2               | 0.4   | R10           | R11              | 0.3   |
| R4            | R3               | 0.3   | R11           | R12              | 0.3   |
| R5            | R4               | 0.3   | R12           | R13              | 0.3437|
| R6            | R5               | 0.4813| R13           | R14              | 0.3   |
| R7            | R13              | 0.3   | R14           | R1              | 0.4919|

The optimal setting of TMS which obtained in Matlab simulation is shown in table (3) and compare with the results in [7]. Represent the results of TMS as a bar chart in figure (5).

Table 3. The optimal TMS for DOC relays.

| Relay No | Pick up current | TMS obtained results | TMS Results IN (7) |
|----------|-----------------|----------------------|-------------------|
| R1       | 1               | 0.24                 | 0.28              |
| R2       | 2.5             | 0.29                 | 0.3               |
| R3       | 2.5             | 0.26                 | 0.25              |
| R4       | 2.5             | 0.2                  | 0.19              |
| R5       | 1.5             | 0.2                  | 0.18              |
| R6       | 1.5             | 0.23                 | 0.25              |
| R7       | 0.5             | 0.54                 | 0.54              |
| R8       | 2.5             | 0.2                  | 0.24              |
| R9       | 2               | 0.18                 | 0.17              |
| R10      | 2.5             | 0.19                 | 0.18              |
| R11      | 2.5             | 0.19                 | 0.2               |
| R12      | 2.5             | 0.27                 | 0.3               |
| R13      | 1.5             | 0.17                 | 0.22              |
| R14      | 0.5             | 0.52                 | 0.51              |

\[
\text{MIN OF } = \sum_{i=1}^{n} Ti
\]

10.01 10.35
Figure 5. TMS setting for DOC relays

The DOC relays used in ETAP simulation in the network chose the same type multifunction relay type Siemens 7SJ64 from ETAP library as represented in figure (4) in the transmission network above. All protection relays in the network were tested and no coordination problem was found according to the values obtained in Matlab simulation. During the test in the ETAP program, the operation of all backup relays that sensitive to the value of the current according to the fault current and the location of that fault. Figure (6) and figure (7) shown The IDMT curve for one of these faults which applied at the network. This fault was a close-in fault from relay 1(R1) at the transmission line (1-2) and far-end fault from relay 8 (R8). The backup relays of relay 1 R1 which saw and specified the fault current according to pick up setting are R6, R5, and R4 as illustrated in figure (6) as well as, the sequence of tripping and operating time for each relay has been achieved correctly.
While the backup relays for relay 8 R8 at the same transmission line at far end fault that saw and specified by the fault current according to pick up setting are R9 only as illustrated in figure (7).

In this paper, the total operating time in the proposed algorithm was less than the comparator with the total time in [7] as illustrated in the table (3) and different TMS values in figure(5) above. This gives a super performance for the proposed algorithm as well as whenever the overall time of the network less will give high stability to the system so that the faulted transmission line can be separated as fast as possible and maintains of operating the generators during the transient stability according to the load on the network during a fault.
6. CONCLUSION
An optimization technique is presented in this paper to get the optimum value for Time multiplier setting TMS for Directional overcurrent and the optimal operating time to each relay by using a genetic algorithm with linear inequality constraints and the bounded of TMS to get the optimal solution. The proposed technique has accurate and good performance to get results, also can be applied to large networks with more relays and transmission lines. In addition, the TMS results that have been obtained from the test system in Matlab were verified by using the ETAP program, also checked the sequence of tripping and operating time to each relay in the network during the test.

7. APPENDIX
IEEE-8 bus- system-data: -
Number of buses =8, Number of lines =7 Number of generators =3, Number of transformer=2 and No of DOCR = 14

Table A. Generator data.

| Nodes | S(mva) | Vpri(KV) | Reactance% |
|-------|--------|----------|------------|
| 7     | 150    | 10       | 15         |
| 8     | 150    | 10       | 15         |

Power grid modeled by short circuit capacity 400 MVA
### Table B. Transformer data.

| Nodes | \( S \text{(mva)} \) | \( V_{pri}(\text{KV}) \) | \( V_{sec}(\text{KV}) \) | Reactance% |
|-------|-----------------|------------------|------------------|------------|
| 7-8   | 150             | 10               | 150              | 4          |
| 8-6   | 150             | 10               | 150              | 4          |

### Table C. Line data.

| Nodes | Resistance(ohm/KM) | Reactance(ohm/KM) | \( Y \text{(ohm/KM)} \) | Length(KM) |
|-------|-------------------|-------------------|-------------------|------------|
| 1-2   | 0.004             | 0.05              | 0                 | 100        |
| 1-3   | 0.0057            | 0.0714            | 0                 | 70         |
| 3-4   | 0.005             | 0.0563            | 0                 | 80         |
| 4-5   | 0.005             | 0.045             | 0                 | 100        |
| 5-6   | 0.0045            | 0.0409            | 0                 | 110        |
| 2-6   | 0.0044            | 0.05              | 0                 | 90         |
| 1-6   | 0.005             | 0.05              | 0                 | 100        |

### Table D. Pick up current and current transformer ratio.

| Relay NO | I pick up | CT ratio | Relay NO | I pick up | CT ratio |
|----------|-----------|----------|----------|-----------|----------|
| R1       | 1         | 1200/5   | R8       | 2.5       | 1200/5   |
| R2       | 2.5       | 1200/5   | R9       | 2         | 800/5    |
| R3       | 2.5       | 800/5    | R10      | 2.5       | 1200/5   |
| R4       | 2.5       | 1200/5   | R11      | 2.5       | 1200/5   |
| R5       | 1.5       | 1200/5   | R12      | 2.5       | 1200/5   |
| R6       | 2.5       | 1200/5   | R13      | 1.5       | 1200/5   |
| R7       | 0.5       | 800/5    | R14      | 0.5       | 800/5    |

### Table E. Primary/secondary relay pairs and the fault current in the main network.

| Primary/Secondary pairs | Close in fault current(A) |
|-------------------------|---------------------------|
| Primary Relay No | Secondary Relay NO | Primary relay | Secondary relay |
| R1               | R6                        | 3200          | 3200          |
| R2               | R1                        | 5900          | 990           |
| R3               | R7                        | 5900          | 1800          |
| R4               | R2                        | 3556          | 3567          |
| R5               | R3                        | 3883          | 2244          |
| R6               | R4                        | 2400          | 2400          |
| R7               | R5                        | 6101          | 1197          |
| R8               | R7                        | 5203          | 1180          |
| R9               | R13                       | 5203          | 980           |
| R10              | R10                       | 2480          | 2480          |
| R11              | R12                       | 3707          | 3707          |
| R12              | R13                       | 5890          | 980           |
| R13              | R14                       | 5890          | 1870          |
| R14              | R8                        | 2990          | 2990          |
| R9               | R1                        | 5190          | 990           |
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