

Coordination of overcurrent relay using Hybrid GA-NLP method

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Abstract—the overcurrent relays are major protection devices in distribution system. The relays in the power system have to be coordinated so as to and hence to avoid unnecessary outage of healthy part of the system. This paper presents hybrid genetic algorithm (GA)-nonlinear programming approach to find optimal value of Time multiplier setting(TMS) and Plug setting(PS) of overcurrent relay. It also presents load flow and short circuit analysis of 9 bus ring main system using Electrical Transient Analysis Program (ETAP).

Key words —Overcurrent relay, TMS, PS Constraints, Genetic Algorithm ,MATLAB optimization toolbox.

1. INTRODUCTION

Overcurrent relays are used as back up relays. The problem of coordinating protective relays in protection systems consists of their suitable settings such that their fundamental protective function is met under the requirements of sensitivity, selectivity, reliability, and speed [6].

A typical power system may consists of hundreds of equipment and even more protection relays to protect the system. A relay must get sufficient chance to protect the zone under its primary protection. Only if the primary protection does not clear the fault, the backup protection should takeover tripping. If backup protections are not well coordinated, mal-operation can occur and, therefore, overcurrent relay coordination is a major concern of power system protection[5].

In this paper the problem of determining the optimum values of TMS and PS of OCRs is formulated as NLPP(Non linear programming problem) and GA-NLP method is used to find the optimum solution. GA is a multipoint search method but sometimes, it converging to the values which may not be optimum, and NLP methods, being single point search methods, have a drawback of being trapped in local optimum point, if the initial choice is nearer to the local optimum. NLP method gives global optimum solution, if proper initial choice is made. GA searches a large solution space. To make use of the advantages of GA and NLP methods, and at the same time to overcome the drawbacks of these methods, GA has been used to determine the initial value of TMS and PS of OCRs. These values are then used as initial choice in NLP method, which gives the global optimum solution[1].

2. GENERIC PROBLEM FORMULATION

The coordination problem of directional OCRs in a ring fed distribution systems, can be stated as an optimization problem, where the sum of the operating times of the relays of the system, is to be minimized[1][2][3].

$$\min z = \sum_{i=1}^m W_i . t_{i,k} \quad (1.1)$$

Where,

m=number of relays;

t_{i,k}=operating time of relay R_i, for fault at k;

W_i=weight assigned for operating time of the relay R_i ;

In the distribution system, since the lines are short and are of approximately equal length, equal weight (=1) is assigned for operating times of all the relays. The objective of minimizing the total operating times of relays is to be achieved under five sets of constraints, as discussed in the following sections.

Constraint Set I-Coordination Criteria

Fault is sensed by both primary as well as secondary relay simultaneously. To avoid mal-operation, the backup relay should take over the tripping action, only after primary relay fails to operate. The minimum operating time of backup relay is decided by the operating time of primary relay, operating time of circuit breaker (CB) associated with primary relay, plus the overshoot time. This is necessary for maintaining the selectivity of primary and backup relays. The sum of operating time of CB associated with

primary relay, and the overshoot time is called the coordination time interval (CTI). If R_j is the primary relay for fault at k , and R_i is backup relay for the same fault, then the coordination constraint can be stated as [1][2][3].

$$t_{i,k} - t_{j,k} \geq \Delta t \quad (1.2)$$

Where

$t_{i,k}$ = operating time of the relay R_j , for fault at k ;
 $t_{j,k}$ = operating time of back up relay R_i , for the same fault at k ;
 Δt = CTI.

Constraint Set II-Bounds on Relay Operating Time

Howsoever fast we want the relay to operate; it needs a certain minimum amount of time to operate. Also a relay should not be allowed to take too long time to operate. Constraint imposed because of restriction on the operating time of relays can be mathematically stated as [1][2][3].

$$t_{i,\min} \leq t_{i,k} \leq t_{i,\max} \quad (1.3)$$

Where

$t_{i,\min}$ = minimum operating time of relay at location i for the fault at point in the zone of operation.
 $t_{i,\max}$ = maximum operating time of relay at location i for the fault at point in the zone of operation.

Constraint Set III-Bounds on the TMS of Relays

The TMS of relays directly affect the operating time of relays, which puts bounds on TMS of relays. It can be stated as [1][2][3].

$$TMS_{i,\min} \leq TMS_i \leq TMS_{i,\max} \quad (1.4)$$

Where

$TMS_{i,\min}$ = minimum value of TMS of R_i relay;
 $TMS_{i,\max}$ = maximum value of TMS of R_i relay;
 $TMS_{i,\min}$ and $TMS_{i,\max}$ were taken as 0.025 and 1.2 [4].

Constraint Set IV-Bounds on the PS of Relays

The bounds on PS of relays can be stated as

$$PS_{i,\min} \leq PS_i \leq PS_{i,\max} \quad (1.5)$$

where

$PS_{i,\min}$ = minimum value of PS of relay R_i ;
 $PS_{i,\max}$ = maximum value of PS of relay R_i ;

As a rule of thumb, the minimum pickup current setting is equal to or greater than 1.25 times the maximum load current. This is to ensure that the relays will not mal-operate under normal load and small amount of overload conditions. Similarly maximum pickup current setting is less than or equal to 2/3rd of the minimum fault current. This ensures that the relay is sensitive to the smallest fault current [1][2][3].

Constraint Set V-Relay Characteristics

In this paper, a nonlinear and popular OCRs characteristic function (which has been reported in most of the literature) as shown in (6.6), has been considered. The values of λ and γ are detailed in Table I [1][2][3].

$$top = \frac{\lambda(TMS)}{(I_{relay}/PS)^{\gamma-1}} \quad (1.6)$$

where

top = relay operating time
 I_{relay} = current through the relay operating coil
 PS = plug setting
 TMS = time multiplier setting.

Table :I.Values of λ and γ for different types of OCRs.

OCR Type	λ	γ
Instantaneous	Operating time is fixed. No intentional time delay is added.	
Definite Time	Operating time is pre-decided and fixed. Intentional time delay may be added.	
Inverse Definite Minimum Time (IDMT)	0.14	0.02
Very Inverse	13.5	1

Extremely Inverse	80	2
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3. GENETIC ALGORITHM

The genetic algorithm (GA) is a randomized search and optimization technique guided by the principle of natural genetic systems. Genetic algorithms use vocabulary borrowed from natural genetics. A genetic algorithm starts with an initial set of random solutions, the population. Each individual in the population is a chromosome, representing a solution to the problem. A chromosome is a string structure, typically a concatenated list of binary digits representing a coding of the control parameters of a given problem. The chromosomes evolve through successive iterations called generations[7].

Genetic operators

- **Reproduction:** In this process the individuals are selected based on their fitness values relative to that of the population. Thus individuals (chromosomes) with higher fitness values have a greater chance of being selected for mating and subsequent genetic action. Consequently, highly fit individuals live and reproduce, and less fit chromosomes die.
- **Crossover:** After reproduction, "crossover" operation is implemented. Crossover is an operator that forms a new chromosome, called "offspring", from two "parent" chromosomes by combining part of the information from each. Crossover is implemented in two steps. First, two individuals strings are selected from the mating pool generated by the reproduction operator. Next, a crossover site is selected at random along the string length, and the binary digits are swapped between the two strings following the crossover site. The offspring obtained from crossover are placed in the new population.
- **Mutation:** This process is applied after crossover. A mutation is the occasional, random alteration of a binary digit in a string. Thus in mutation a 0 is changed to 1, and vice versa, at a random location[5][7].

4. NONLINEAR PROGRAMMING PROBLEM

In an optimization problem, if the objective function and/or constraint/s are nonlinear, the problem is called nonlinear programming problem (NLPP). In case of OCR coordination problem the relay characteristic, described by (1.6), is nonlinear in nature because of which the objective function, the operating time constraints, and the coordination constraints become nonlinear.

Various methods are available to solve the constrained NLPP. In this paper, the function available in MATLAB optimization toolbox has been used to find the global optimum solution of the relay coordination problem.

5. SIMULATION AND RESULTS.

The Hybrid GA -NLP method was tested for Nine bus system as shown in figure 1. In this twenty four relays have been considered as numerical relay with standard IDMT characteristics. A multi loop distribution system with 9-buses, and 24 relays, as shown in figure 1.

Load flow and short circuit analysis results shown in table II. Load flow study is necessary to find out plug setting of relay and short circuit study is essential to find plug setting multiplier (PSM) of relay. Then using this PSM, Time multiplier setting of relay is obtained. therefore, load flow and short circuit analysis is necessary in relay coordination.

6. SIMULATION AND RESULTS

Load flow and short circuit analysis results

Table II Load flow and short circuit analysis

Relay	IL,max(A)	If,min(kA)	If,max(kA)
1	121.8	0.85	2.65
2	--	3.9	9.31
3	21.7	2.26	5.73
4	--	2.48	6.13
5	--	3.67	8.88
6	78.3	1.08	3.06
7	78.3	1.08	3.06
8	--	3.67	8.88
9	--	2.48	6.13
10	21.7	2.26	5.73
11	--	3.9	9.31
12	121.8	0.85	2.65
13	--	2.02	5.03
14	30.4	1.64	4.3
15	30.4	1.64	4.3

16	--	2.02	5.03
17	441.4	1.73	14.7
18	--	3.38	6.92
19	411	1.61	14.82
20	--	3.0	6.08
21	441.4	1.73	14.7
22	--	3.38	6.92
23	506.7	1.98	14.45
24	--	4.07	8.39

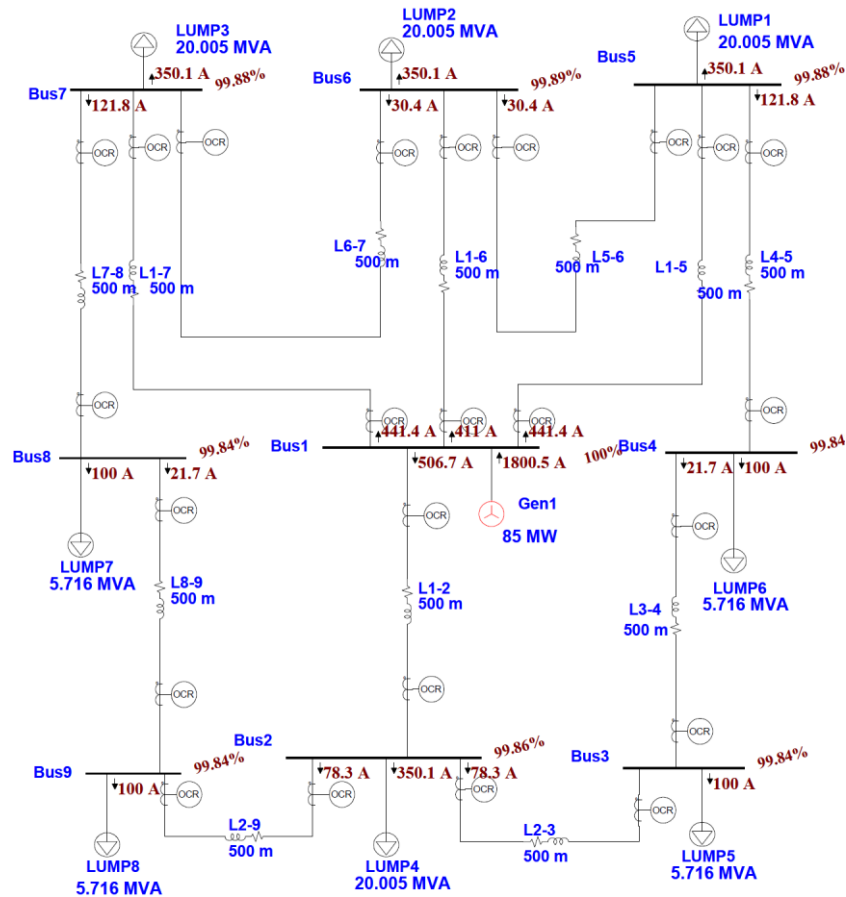


Fig.1 Nine bus system.

System Data^[1]:

Base MVA: 100 MVA, Base KV: 33Kv.

Generator : 100MVA, 33kV, impedance (0+j0.1)p.u.

Line: impedance (0+j0.2)p.u.

Value of TMS and PS for Relay Using GA

Table III Value of TMS and PS using GA

Relay	TMS	PS
1	0.42856681	0.3045
2	0.22843018	0.79206292
3	0.41170231	0.37423044
4	0.25420445	0.45091937
5	0.20047607	0.57773404
6	0.44669954	0.1957
7	0.69659217	0.34251338
8	0.24887618	1.1957
9	1.025	0.1957

10	0.31378115	0.77542573
11	0.85083926	0.42765951
12	0.28712232	0.41591235
13	0.26947223	1.242
14	0.37625599	0.076
15	0.64021519	0.09787578
16	0.74315728	0.076
17	0.04581303	2.1092373
18	0.14841309	2.30721115
19	0.12374224	1.0275
20	0.13432428	1.88637651
21	0.05296006	1.49964654
22	0.275	1.9652095
23	0.14927677	1.2667
24	0.17153939	1.26767656

Value of TMS and PS for Relay using Non linear Programming

Table IV Value of TMS and PS using NLP

Relay	TMS	PS
1	0.14218	0.292967
2	0.244061	0.307023
3	0.266857	0.111876
4	0.271037	0.113228
5	0.305874	0.119627
6	0.176873	0.193896
7	0.177401	0.193973
8	0.270853	0.207967
9	0.237724	0.208825
10	0.269324	0.111873
11	0.317637	0.123943
12	0.147803	0.294239
13	0.214765	0.296363
14	0.273899	0.088835
15	0.241363	0.089632
16	0.222187	0.100992
17	0.054903	1.098766
18	0.106743	1.104091
19	0.047693	1.02476
20	0.10256	1.027923
21	0.057931	1.098846
22	0.113139	1.10455
23	0.055947	1.26251
24	0.114962	1.267666

The result obtained at from GA was taken as the initial value of variables while applying NLP method. The function available in MATLAB optimization toolbox, for optimization of constrained NLPP, was used to find the global optimum solution of the relay coordination problem.

Final value of TMS and PS for Relay using Hybrid GA- NLP

Table V Final value of TMS and PS for Relay using Hybrid GA-NLP.

Relay	TMS	PS
1	0.106142	0.600792
2	0.145575	1.545481
3	0.234514	0.191739
4	0.1647	0.675457
5	0.167534	1.079432
6	0.134319	0.435427
7	0.130944	0.468174
8	0.164171	1.143834
9	0.179314	0.551069
10	0.230251	0.21336
11	0.227739	0.486956
12	0.129128	0.420143
13	0.134926	1.067474
14	0.192292	0.332301
15	0.145678	0.520851
16	0.111579	0.946447
17	0.038386	1.547301
18	0.085838	1.793618
19	0.035491	1.370096
20	0.080027	1.750627
21	0.042646	1.48343
22	0.083757	2.103909
23	0.046976	1.513817
24	0.089999	2.196411

Operating time of Primary and Back up relay

Table VI Operating time of Primary and Back up relay.

PRIMARY RELAY	Top(sec.)	BACK UP RELAY	Top(sec.)
1	0.3339	15	0.5536
1	0.3339	17	0.6312
2	0.3993	4	0.5863
3	0.3851	1	0.5339
4	0.3863	6	0.6464
5	0.4071	3	0.6851
6	0.3464	8	0.6076
6	0.3464	23	0.6387
7	0.3475	5	0.5071
7	0.3475	23	0.6387
8	0.4076	10	0.7887
9	0.3922	7	0.6475
10	0.3887	12	0.6476
11	0.4218	9	0.7922
12	0.3476	14	0.7004
12	0.3476	21	0.5495
13	0.4117	11	0.6218

14	0.4004	21	0.7495
15	0.3536	13	0.6117
15	0.3536	19	0.7883
16	0.3227	2	0.6993
16	0.3227	17	0.5312
17	0.3312	--	
18	0.2881	2	0.5993
18	0.2881	15	0.5536
19	0.2883	--	
20	0.2835	13	0.4917
20	0.2835	16	0.4927
21	0.3495	--	
22	0.3054	11	0.5218
22	0.3054	14	0.6004
23	0.3387	--	
24	0.3036	5	0.7071
24	0.3036	8	0.7076

7. CONCLUSION

The values of TMS and PS for each relay of the Nine bus distribution system without DG using only genetic algorithm technique were not optimal. Optimization terminated and no feasible solution found using NLP method for the same system. By using hybrid GA method a feasible solution is achieved with minimum objective function value. The optimal values of TMS and PS for 9-bus distribution system found using hybrid GA-NLP approach.

8. REFERENCES

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