Scientific Journal Impact Factor (SJIF): 5.278
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745 ISSN (PRINT) : 2393 - 8161

Optimul Coordination of over current Relays using Linear Programming Method

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Abstract— Over current (OC) relays are the major protection devices in a distribution system. The operating time of the OC relays are to be coordinated properly to avoid the mal-operation of the backup relays. The OC relay time coordination in distribution networks is a highly constrained optimization problem which can be stated as a linear programming problem (LPP). The purpose is to find an optimum relay setting to minimize the time of operation of relays and at the same time, to keep the relays properly coordinated to avoid the mal-operation of relays. This paper presents linear programming method for optimum time coordination of OC relays. The method is used to find optimum values of Time Multiplier Setting (TMS) and Plug setting (PS) which is used to find optimum coordination of Over current Relays. The method minimizes the original objective function and gives the optimum time coordination of OC relays.

Keywords—Interconnected Network, Over current relay, Linear Programming.

I. INTRODUCTION

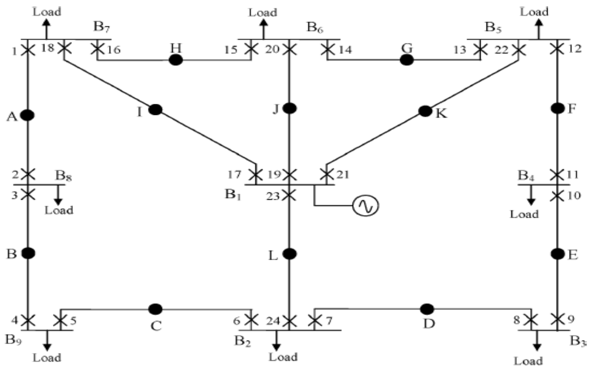
Over current relays are usually employed as backup protection. In distribution feeders, they play a more important role and there it may be the only protection provided [1,2]. The problem of coordinating protective relays consists of selecting their suitable settings such that their fundamental protective function is met under the requirements of sensitivity, selectivity, reliability, and speed [3,4]. If backup protections are not well coordinated, mal-operation can occur and, therefore, OC relay coordination is a major concern of power system protection [5]. Each protection relay in the power system needs to be coordinated with the relays protecting the adjacent equipment. The overall protection coordination is thus very complicated. The OC relay coordination problem in distribution system can be defined as constrained optimization problem. The objective is to minimize the operating time of relay for fault at any point. The problem can be defined as a LPP and can be solved using simplex technique. A protective relay should trip for a fault in its zone and should not, for a fault outside its zone, except to backup a failed relay or circuit breaker traditionally; a trial and error procedure is employed for setting relays in multi loop networks. In the past few years, several mathematical techniques have been reported. Warakanath and Noritz [2] suggested a systematic approach for determining the relative sequence setting of the relays in a multiloop network. They used a linear graph theory approach which provided a directional loop matrix. A minimal set of break points spanning all loops of the system graph were obtained from this matrix.Damborg et al. [3] extended the graph theoretic concepts and proposed a systematic algorithm for determining a relative sequence matrix corresponding to a set of sequential pairs which reduced the number of iterations. Jenkins et al. [4] proposed a functional dependency concept for topological analysis of the protection scheme. They expressed the constraints on the relay settings through a set of functional dependencies. A parametric optimization approach was reported by Urdeanneta et al. [5] that optimized the time multiplier settings (TMS) using the Simplex method. Optimal values of the pick-up currents for selected TMS were then determined by using a generalized reduced gradient technique. The objective of this paper is to present some of the optimization concepts and their use in the project. The objective of this paper is to find optimum value of Time Multiplier Setting (TMS) and Plug Setting (PS) for optimum relay coordination by linear programming. In this paper linear programming is done using TORA software. By using linear programming non-linearity of the problem is converted into liner problem which is easy to solve and less time consuming.

II. COORDINATION OF OC RELAYS IN SYSTEM

As soon as the fault takes place it is sensed by both primary and backup protection. The primary protection is the first to operate as its operating time being less than that of the backup relay. If the operating time of primary relay is set to 0.1 s, the backup relay should wait for 0.1 s plus, a time equal to the operating time of circuit breaker (CB), associated with primary relay, plus the overshoot time of primary relay [1,6]. This is necessary for maintaining the selectivity of primary and backup relays. A system is shown in Fig. 1. A Single end fed, ring main system with nine buses (B1 to B9) and 24 relays as shown in Fig. 1, was considered. All of the relays were considered as digital directional OCR with standard IDMT characteristics, and have their tripping direction away from the bus System Information: Bus 1 is receiving the power, which has been represented by a source of 100 MVA, 33 KV with a source impedance of p.u. Base MVA is 100 and base kV is 33. Each line has an impedance of p.u. The load currents are shown in Table II. The OCRs are numbered as 1 to 24. The CT ratio for each relay is500:1. Twelve fault points (one on each line), marked as A to L, were considered. The primary-backup relationship of relays for these fault points is shown in Table I. The maximum load current, and minimum and maximum fault current through the relays is shown in Table II.

Table-1 Primary and Backup Relay Pair

Primary Relay	Back up Relay
1	15,17
2	4
3	1
4	6
5	3
6	8,23
7	5,23
8	10
9	7
10	12
11	9
12	14,21
13	11
14	21
15	13,19
16	2,17
17	-
18	2,15
19	-
20	13,16
21	-
22	11,14
23	-
24	5,8



III. PROBLEM FORMULATION

The coordination problem of directional OC relays 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, for different fault points, is to be minimized[5,7,8],

$$\min z = \sum_{i=1}^{m} w_i \, t_{i,k}$$

where
m is the number of relays,
ti,k, is the operating time of the relay i R , for fault at k, and
Wi is weight assigned for operating time of the relay R i
In 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 [5,9,10] The objective of minimizing the total operating time of relays is to be achieved under three sets of constraints [5,10]as mentioned below.
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A. Coordination Criteria

Fault is sensed by both primary as well as secondary relay simultaneously. To avoid mal-operation, the backup relay should takeover the tripping action only after primary relay fails to operate. If j R is the primary relay for fault at k, and Ri is backup relay for the same fault, then the coordination constraint can be stated as

$$t_{i,k} - t_{j,k} \geq \Delta t$$

where,
tj,k , is the operating time of the primary relay j R , for fault at k
t i,k , is the operating time for the backup relay i R , for the same fault (at k)
Δ t is the coordination time interval (CTI)

B. Bounds on the relay setting and operating time

Constraint imposed because of restriction on the operating time of relays can be mathematically stated as

$$t_{i,min} \leq t_{i,k} \leq t_{i,max}$$

where,
t i,min is the minimum operating time of relay at i for fault at any point
ti,max is the maximum operating time of relay at i for fault at any point
The bounds on time multiplier setting (TMS) of relays can be stated as

$$TMS_{i,min} \leq TMS_i \leq TMS_{i,max}$$

where,
TMS i ,min is the minimum value of TMS of relay Ri
TMS i ,max is the maximum value of TMS of relay Ri
Instead of taking these two constraints for each relay, one is taken and other, which is redundant, is not considered. TMSi ,min and TMS i,max are taken as 0.025 and 1.2 respectively [11].

C. Relay Characteristics

All relays are assumed to be identical and are assumed to have normal IDMT characteristic as [1,5,9,12]

$$[\![t]\!]_{\downarrow op} = (\lambda)(TMS)/([\![((I_{\downarrow}relay/PS)]\!]^{\uparrow}\gamma - 1)))$$

where, top is relay operating time, and PSM is plug setting multiplier. For normal IDMT relay is 0.02 and is 0.14. As the pickup currents of the relays are pre determined from the system requirements, equation (5) becomes

$$t_{op} = a(TMS)$$

where,

$$a = (\lambda/(([\![I_{\downarrow}relay/PS)]\!]^{\uparrow}\gamma - 1)))$$

Making substitution of above equation in equation (1), the objective function becomes

$$\min z = \sum_{i=1}^{m} a_{i,k}\,(TMS)_i$$

where, ai k , is constant of relay Ri for fault at k.
Thus the relay characteristic constraint is incorporated in the objective function itself. The values of a i k , for relay Ri for different fault locations (k) are predetermined. Value of TMS for each relay is to be determined using simplex method.

Table-II
Load Current and Fault Current

Relay	I_{Lmax} (A)	I_{fmin} (A)
1	105	1300
2	105	8300
3	70	7600
4	70	2200
5	245	18700
6	245	1900
7	141	4100
8	141	13400
9	19	8700
10	19	8600
11	156	13200
12	156	4300
13	45	7400
14	45	6700
15	20	6000
16	20	8500
17	436	12000
18	436	2200
19	416	2100
20	416	9500
21	461	2400
22	461	10400
23	737	3700
24	737	16100

IV. RESULT AND DISCUSSION

Coordination of OC relays is basically an LPP, in which the aim is to find out the optimum value of TMS for all relays, hence TMS of the relays are taken as variables. The optimum values of TMS will ensure optimum time of operation of relays. Out of the three sets of constraints, the relay characteristic constraint is already incorporated in the objective function. The bounds on TMS and the coordination criteria are included in the problem as constraints. In case of optimum time coordination of OC relays the objective function will always be of minimization type and all the constraints will be inequality constraints of ≥ type. Results of Linear Programming Method are shown in Table initially a simple radial system, shown in Fig. 1, was considered. The maximum fault current and Load current found by Load Flow Analysis and Short Circuit Analysis. The CT ratio for all Relay is 500:1 Minimum operating time for each relay was considered as 0.2 second and the CTI was taken as 0.57 s. Calculation of value of i a for relays is shown in Table III The fault current in relay coil 1 beyond bus 1 is 1300 Amp. As the PSM in this case is 12.38. The values of a can be calculated by equation given in table. These values are used in calculation of TMS by Linear Programming. The Results are shown in table. In this way we can get optimum value of TMS which can be used to calculate time of operation of relay and so coordination of relay can be optimized.

Table-III Value of TMS and PS

RELAY	TMS	a= $\frac{0.14}{\left(\left(\frac{I_f}{I_1}\right)^{0.02}\right)}$
1	0.04	2.8
2	0.02	1.5
3	0.07	1.5
4	0.05	2.00
5	0.07	1.5
6	0.03	1.5
7	0.04	2.34
8	0.07	1.5
9	0.09	1.07
10	0.09	1.07
11	0.07	1.50
12	0.04	2.34
13	0.07	1.4
14	0.07	1.4
15	0.02	1.16
16	0.09	1.16
17	0.04	2.34
18	0.04	4.67
19	0.04	4.67
20	0.04	2.34
21	0.03	4.67
22	0.02	2.34
23	0.02	4.67
24	0.04	2.34

V.CONCLUSION

Linear Programming Method for optimum time coordination of over current relays in distribution system is presented in this paper. The optimum relay coordination problem is basically a highly constrained optimization problem. Formation of this problem as an LPP is explained in this paper. A program has been solved in TORA for finding the optimum time coordination of relays using simplex method. The resulted optimum values of TMS and PS can be used for optimum time coordination of relays in a system with any number of relay and any number of primary-backup relationships. The problem has been successfully tested for various systems, including multi loop systems and was found to give satisfactory results in all the cases.

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