Coordination of Overcurrent Relays in Distribution System using Linear Programming Technique

Prashant P. Bedekar, Sudhir R. Bhide, and Vijay S. Kale

Abstract— A power system consists of many number of equipment. Much more number of circuit breakers and relays are required to protect the system. The relays in the power system are to be coordinated properly so as to avoid mal-operation and hence to avoid the unnecessary outage of healthy part of the system. The overcurrent relays are the major protection devices in a distribution system. Overcurrent relay is usually employed as backup protection. But in some situations it may be the only protection provided. 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 back-up protection should initiate tripping, and therefore, overcurrent relay coordination in power distribution network is a major concern of protection engineer. The overcurrent relay coordination in ring fed distribution networks is a highly constrained optimization problem. The purpose is to find an optimum relay setting to minimize the time of interruption of the power supply and to avoid the mal-operation of relays. This paper discusses linear programming technique for optimum coordination of overcurrent relays in a ring fed distribution system.

Index Terms— Linear programming Overcurrent relay coordination, simplex method.

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1 INTRODUCTION

THE most obvious effect of a shunt fault is a sudden built up of current. So it is natural that the magnitude tude of current be utilised as positive indication of existence of a fault. Therefore the over-current protection is the most widely used form of protection [1-3]. Overcurrent (OC) relay is usually employed as backup protection. But in some situations it may be the only protection provided.

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 back-up protection should initiate tripping. A typical power system may consist of hundreds of equipment and even more protection relays to protect the system. Each relay in the system needs to be coordinated with the relay protecting the adjacent equipment. If backup protections are not well coordinated, mal-operation can occur and, therefore, OC relay coordination is a major concern of power system protection [4,5]. 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

In a system where there is a source at more than one of the line terminals, fault and load current can flow in either direction. Relays protecting the lines are, therefore, subject to fault currents flowing in both the directions. If non directional OC relays were used in such system, they would have to be coordinated with, not only the relays at the remote end of the line, but also with relays behind them. Since directional relays operate only when the fault current flows in the specified tripping direction, they avoid coordination with the relays behind them.

The directional OC relay coordination problem in distribution system can be defined as linear programming problem with constraints and can be solved using one of the linear programming techniques, namely, simplex, dual simplex, or two phase simplex technique.

2 COORDINATION OF DIRECTIONAL OC RELAYS IN RING FED 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 that that of the backup relay.

A simple radial feeder with two sections is shown in figure 1. For fault at point F, relay R_B is first to operate. Let the operating time of R_B is set to 0.1 s. The relay R_A should wait for 0.1 s plus, a time equal to the operating time of circuit breaker (CB) at bus B, plus the overshoot time of relay A [1]. This is necessary for maintaining the selectivity of relays at A and B.
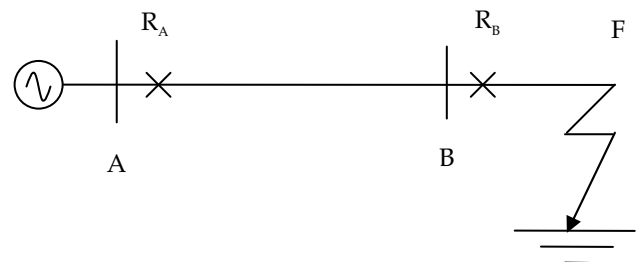

Fig. 1 A radial feeder

A ring main feeder system is shown in figure 2. It allows supply to be maintained to all the loads in spite of fault on any section. Relays 1, and 8 are non directional whereas all other relays (2, 3, 4, 5, 6, and 7) are directional OC relays. All directional relays have their tripping direction away from the concerned bus.

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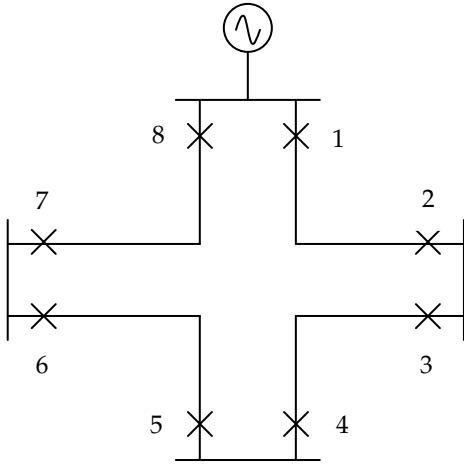
Fig. 2 A ring main feeder

For coordination purpose relays 2,4,6, and 8 will form one group and relays 1,3,5, and 7 will form other group. For group one, setting is to be started from relay 2. The relay operating times will be related as

$$T_{R8} > T_{R6} > T_{R4} > T_{R2}$$

For group two, setting is to started from relay 7. The relay operating times will be related as

$$T_{R1} > T_{R3} > T_{R5} > T_{R7}$$

The actual operating time for each relay can be decided again considering the operating time of preceding relay, operating time CB associated with preceding relay, and the overshoot time of the relay under consideration.

As the size and complexity of the system goes on increasing it becomes more and more difficult to coordinate the relays. Keeping the same concept of coordination (as explained above) in view, the problem can be stated as optimization problem which can be solved by linear programming technique.

3   RELAY COORDINATION PROBLEM

Directional OC relays have two types of settings : time dial setting (TDS) and pickup current setting (I_{pu}). Directional OC relays allow for continuous time dial setting and discrete pickup current setting. If pickup currents are taken to be fixed, the problem becomes a linear programming problem and is solved to calculate the optimal TDS of the relays [6].

The coordination of directional OC relays in a power system can be stated as follows [6-9] :

$$\min \sum W_i T_{ik} \qquad \qquad …(1)$$

where T_{ik} indicates the operation time of relay R_i for a fault in zone k, and W_i is a coefficient and is usually set to 1 [6,10]. Thus the coordination problem of directional OC relays in interconnected power systems, can be stated as an optimization problem, where the sum of the operating times of the relays of the system is minimized, under the following constraints [7,8]:

Coordination criteria

$$T_{nk} – T_{ik} \geq \bullet T \qquad \qquad …(2)$$

where T_{nk} is the operation time of the first backup of relay R_i for a given fault in zone k. •T is coordination time interval which is necessary for maintaining the selectivity of relays. It is taken to be 0.2 second.

Bounds on the settings

$$TDS_{imin} \leq TDS_i \leq TDS_{imax} \qquad …(3)$$
$$T_{imin} \leq T_i \leq T_{imax} \qquad …(4)$$

where TDS_i is the time dial setting of relay R_i and T_i is the operating time of relay R_i .

Relay characteristics

All relays are assumed to be identical and are assumed to have normal IDMT characteristic as [7-11] :

$$T_i = (\lambda . TDS_i) / [(I/I_s)^\gamma - 1] \qquad …(5)$$

where I is input current, and I_s is setting current. For normal IDMT relay γ is 0.02 and λ is 0.14. As the pickup currents of the relays are pre determined from the system requirements, equation (5) becomes

$$T_i = (\alpha_i . TDS_i) \qquad …(6)$$

where α is $\lambda / [(I/I_s)^\gamma - 1]$.
Making substitution from equation (6) in equation (1), the objective function becomes

$$\min \sum (\alpha_i . TDS_i) \qquad …(7)$$

In this equation α_i's are known. Values of TDS_i can be determined by simplex method, which is one of the linear programming methods.

4   THE SIMPLEX ALGORITHM

The simplex method of Dantzig is a powerful scheme for obtaining a basic feasible solution; if the solution is not optimal, the method provides for finding a neighboring basic feasible solution that has a lower or equal value of function [12]. The process is repeated until, in a finite number of steps, an optimum is found.

The algorithm is given below [12,13] –

Step 1 : Obtain an initial basic feasible solution and form first simplex table.

Step 2 : If all the cost coefficients are nonnegative, optimum solution has been obtained, go to step 8 , otherwise go to step 3.

Step 3 : The nonbasic variable with most negative cost coefficient is choosen to enter as a basic variable in the next basic feasible solution.

Step 4 : Examine the ratio of constants (right hand side of constraints) to the corresponding coefficient of entering variable in each equation. If at least one positive ratio exists go to step 5, otherwise the objective function is unbounded, so go to step 9.

Step 5 : The current basic variable in the equation corresponding to the smallest nonnegative ratio from step 4 is chosen as the variable to leave the set of basic variable in the current basic feasible solution.

Element corresponding to entering variable column and leaving variable row is the pivot element.

Step 6 : Form new simplex table. For this perform elementary transformations on rows such that the pivot element (obtained in step 5) becomes 1, and the coefficient of entering variable in other rows become zero.

Step 7 : With the new simplex table formed, go to step 2.

Step 8 : An optimal solution for the problem has been obtained. Print the result and stop.

Step 9 : The objective function is unbounded, so stop.

Since there are finite number of choosing m basic variables out of n variables, the iterative process of the simple algorithm will terminate in a finite number of cycles.

5 RESULTS

MATLAB is a commonly used programming language for computer modeling. Its code is relatively straight forward. A program has been developed in MATLAB for optimization using simplex method. This program is used to solve the coordination problem of directional overcurrent relays.

The program is tested for various systems and it is found that it gives correct results. Two different systems are presented here for illustration.

A   System I

The system shown in figure 2 is considered. As discussed in section II, for coordination purpose relays 2,4,6, and 8 will form one group and relays 1,3,5, and 7 will form other group. The results obtained are shown in table 1.

Table 1 : Relay coordination results (system I)

Relays	TDS
2 and 7	0.04
4 and 5	0.15
3 and 6	0.26
1 and 8	0.39

It can be seen that the results obtained give proper coordination for fault at any point in the system.

B   System II

The second system under study is shown in figure 2. The results obtained are shown in table 2.
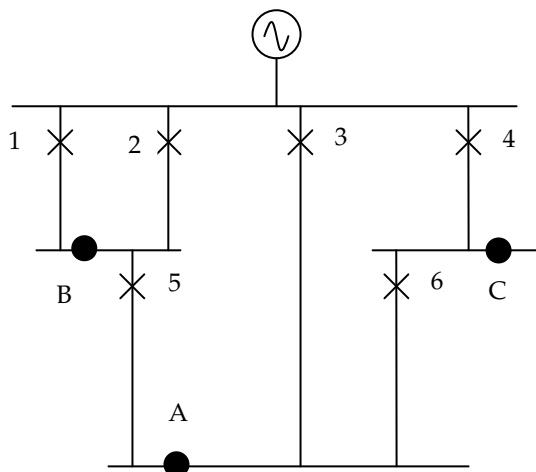

Fig. 3 A Sample system

Table 2 : Relay coordination results (system II)

Relays	TDS
3, 5 and 6	0.13
1, 2 and 4	0.28

Depending upon the location of fault, three configurations are possible. Each configuration (corresponding to location of fault) is shown in table 3.

Table 3 : Possible configurations (system II)

Fault Point	Primary Relay	Corresponding Backup Relay
A	3	--
	5	1 and 2
	6	4
B	1	--
	2	--
	3	--
	6	4
C	3	--
	4	--
	5	1 and 2

The results show that for any configuration the coordination obtained is correct.

6 CONCLUSION

The overcurrent relays are the major protection devices in a distribution system. The relays in the power system are to be coordinated properly so as to provide primary as well as back up protection, and at the same time avoid mal-operation and hence avoid the unnecessary outage of healthy part of the system.

The overcurrent relay coordination in ring fed distribution networks is a highly constrained optimization problem. As the pickup currents of the relays are pre determined from the system requirements, the optimization can be treated as linear program problem.

In this paper simplex method is presented to solve the optimization problem. Two sample systems are considered for illustration. It is shown that simplex method provides an efficient tool to solve the coordination problem of directional overcurrent relays in ring fed distribution system.

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