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Optimal Relay Coordination Using Two Phase Simplex Method

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***Abstract* — The time of operation of Overcurrent (OC) relays can be reduced, and at the same time, coordination can be maintained, by selecting optimum values of Time Multiplier Setting (TMS) of OC relays. This paper presents two phase simplex method for optimal time coordination of Overcurrent (OC) relays. The method is based on the simplex algorithm which is used to find optimum solution of Linear programming problem (LPP). The technique introduces artificial variables to get Initial basic feasible solution (IBFS). Artificial variables are removed using iterative technique of first phase which minimizes the auxiliary objective function. The second phase minimizes the original objective function & gives the optimum time coordination of OC relays.**

Keywords- Backup Protection, Constrained optimization, LPP, IDMT relay coordination, Two-phase simplex method.

I. INTRODUCTION

The most common effect of a shunt fault is a sudden built up of current. So it is natural that the magnitude of current be utilized as positive indication of existence of a fault. Therefore the over-current protection is the most widely used form of protection [1-2].Overcurrent (OC) relay is usually used as backup protection. But in some situations it is employed as primary protection. Each protection relay in the power technique needs to be coordinated with the relays defending the adjoining equipment. The general protection coordination is thus complicated.

The OC relay coordination problem in distributed network can be defined as constrained optimization problem. The aim 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 two phase simplex method.

In two-phase simplex method, phase-I minimizes the auxiliary objective function which is sum of all artificial variables. Phase-II uses the optimum solution of phase-I as the starting solution. Using the iterative process the optimum solution to the original objective function is obtained.

II. PROBLEM FORMULATION

The coordination problem of directional OC relay 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 method, is to be minimized [3],

$$\text{i.e.,}\quad \min z = \sum_{i=1}^{m} W_i t_{i,k} \tag{1}$$

where,

m is the number of relays,

$t_{i,k}$, is the operating time of the relay R_i , for fault at k, and

W_i is weight assigned for operating time of the relay R_i

In distribution network since the lines are short and are of about equal length, equal weight (=1) is assigned for operating times of all the relays [3, 4, 5].

The objective of minimizing the total operating time of relays is to be achieved under following set of constraints, as discussed in the following section.

A. Constraint Set I - Coordination Criteria

Fault is sensed by both primary as well as back relay simultaneously. To avoid mal-operation, the backup relay should take over the tripping action only after primary relay fails to operate. If R_j 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:

$$t_{i,k} - t_{j,k} \geq \Delta t \quad (2)$$

where,

$t_{j,k}$, is the operating time of the primary relay R_j , for fault at k

$t_{i,k}$, is the operating time of the backup relay R_i , for the same fault (at k)

Δt is the coordination time interval (CTI)

B. Constraint Set II - Bounds on the relay setting and operating time

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

$$t_{i,min} \leq t_{i,k} \leq t_{i,max} \quad (3)$$

where,

$t_{i,min}$ is the minimum operating time of relay at location i for fault at any point in the zone of operation

$t_{i,max}$ is the maximum operating time of relay at location i for fault at any point in the zone of operation

The bounds on time multiplier setting (TMS) of relays can be stated as:

$$TMS_{i,min} \leq TMS_i \leq TMS_{i,max} \quad (4)$$

where,

$TMS_{i,min}$ is the minimum value of TMS of relay R_i

$TMS_{i,max}$ is the maximum value of TMS of relay R_i

C. Constraint Set III - Relay Characteristics

All relays are assumed to be identical and are assumed to have normal IDMT characteristic as [1, 3, 4, 6]:

$$t_{op} = \frac{\lambda(TMS)}{(PSM)^{\gamma} - 1} \quad (5)$$

where,
t_{op} is relay operating time, and
PSM is plug setting multiplier.

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, equation (5) becomes

$$t_{op} = a(TMS) \quad (6)$$

where, $$a = \frac{\lambda}{(PSM)^{\gamma} - 1} \quad (7)$$

Substituting equation (6) in equation (1), the objective function becomes:

$$\min z = \sum_{i=1}^{m} a_{i,k}(TMS)_i \quad (8)$$

where, $a_{i,k}$, is constant of relay R_i for fault at k.

Thus the relay characteristic constraint is incorporated in the objective function itself. The values of $a_{i,k}$, for relay R_i for different fault locations (k) are predetermined. Here, the value of TMS for each relay is to be determined using two-phase simplex method.

III. PROPOSED METHOD

After incorporating the relay characteristic in the objective function, the relay coordination problem have two set of constraints. Generally, the upper bound on the relay operating time need not be taken care of, because when optimum solution is obtained the operating time of relays do not exceed the upper bound. So, the remaining constraints are coordination criteria constraint and relay operating time constraint (lower bound). Both the set of constraints are inequalities of ≥ type. To convert these constraints to equality type, non-negative variable (surplus variable) is subtracted from left hand side. If surplus variables are taken as basics for the initial (starting) solution it will give infeasible solution as the coefficient of surplus variables is -1. Thus surplus variables can't become starting basic variables. In order to obtain an IBFS, artificial variable is added to the left hand side of the constraints [7-10].

Artificial variables have no meaning in a physical sense and are only used as a tool for generating an IBFS. Before the final solution is reached, all artificial variables must be eliminated from the solution. If at all an artificial variable becomes a basic variable in the final solution, its value must be zero [8, 10].

In the first phase of this method IBFS to the original problem is found out. For this all the artificial variables are driven to zero. To do this an auxiliary objective function (w) is defined which is the sum of all artificial variables. This function is minimized subject to the given constraints to get a basic feasible solution of the LPP. In phase I, the iterations are stopped as soon as the value of auxiliary objective function becomes zero. There is no need to continue till the optimality is reached, if the auxiliary function becomes zero earlier. At the end of phase I, one of the two cases arise:

1) Min $w > 0$, and at least one artificial variable appears in the basis with a positive value. In this case the LPP does not possess any feasible solution. The procedure is terminated.
2) Min $w = 0$, and no artificial variable appears in the basis then basic feasible solution to the problem is obtained. Proceed for phase II.

The second phase finds the optimum solution of the original objective function. In this phase the optimum solution of phase- I is taken as the starting solution. The actual costs are assigned to the objective variables. The simplex algorithm is then applied to find the optimum solution.

If at the end of phase I, min $w = 0$, and one or more artificial variable appears in the basis at zero level then basic feasible solution to the problem is obtained. In this case, care should be taken that this artificial variable never becomes positive in phase II.

IV. RESULTS AND DISCUSSION

A single end fed, multi loop distribution system with 3-buses, and 8 relays, as shown in Fig. 1, was considered.

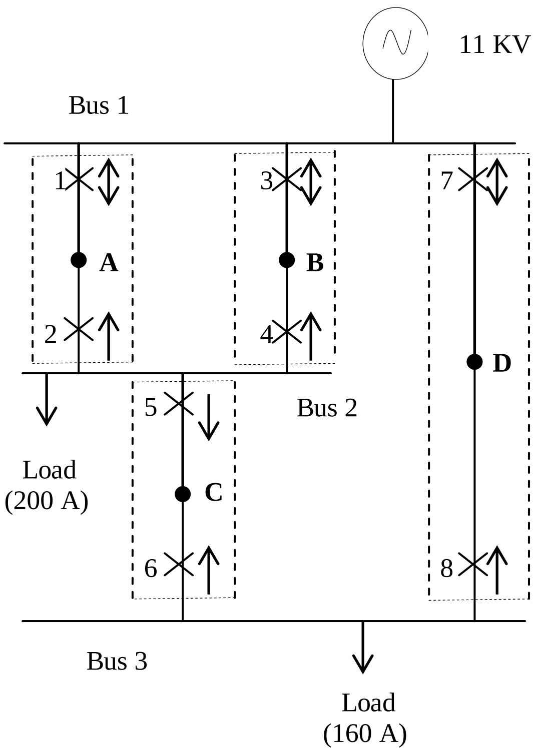

Fig.1. A single-end-fed distribution system

Bus 1 is receiving the power, which has been represented by a source of 25 MVA, 11 kV with a source impedance of (0+j0.25) pu. Base MVA is 25 and base kV is 11. Lines between bus-1 and bus-2, and line between bus-2 and bus-3 have an impedance of (0.6+j0.3) pu. Line between bus-1 and bus-3 has an impedance of (1.2+j0.6) pu. The primary-backup relationships of relays for the four fault points are given in Table 1 and the CT ratios and plug settings are given in Table 2. Four different points were considered [11].

Table 1. Primary-backup relationship of relays

Fault Point	Primary relay	Backup relay
A	1 2	-- 3,6
B	3 4	-- 1,6
C	5 6	1,3 8
D	7 8	5 --

Table 2. CT ratios and plug settings of relays

Relay	CT ratio (A/A)	Plug setting
1	200:1	1
2	100:1	1
3	200:1	1
4	100:1	1
5	300:1	1
6	100:1	1
7	100:1	1
8	300:1	1

The current seen by the relays and the a_i constants (for different fault points) is shown in Table 3.

Table 3. Current seen by relays and a_i constants

Fault point		Relay							
		1	2	3	4	5	6	7	8
A	I_{relay}	16.622	13.298	4.986	--	--	3.324	--	1.108
	a_i	2.422	2.636	4.294	--	--	5.761	--	68.192
B	I_{relay}	4.986	--	16.622	13.298	--	3.324	--	1.108
	a_i	4.294	--	2.422	2.636	--	5.761	--	68.192
C	I_{relay}	7.278	--	7.278	--	9.704	11.645	--	3.881
	a_i	3.465	--	3.465	--	3.017	2.783	--	5.092
D	I_{relay}	2.911	--	2.911	--	3.881	--	11.645	9.704
	a_i	6.484	--	6.484	--	5.092	--	2.783	3.017

In this case there are eight variables (TMS of eight relays), eight constraints due to bounds on relay operating time and eight constraints due to coordination criteria. Thus the total number of constraints is sixteen. Value of CTI is taken as 0.2 s and minimum operating time of relay is taken as 0.1 s.

The optimum values of TMS obtained are as under (the subscripts indicate the relay number)-

$TMS_1 = 0.11$	$TMS_2 = 0.04$	$TMS_3 = 0.11$	$TMS_4 = 0.04$
$TMS_5 = 0.06$	$TMS_6 = 0.05$	$TMS_7 = 0.04$	$TMS_8 = 0.07$

V. CONCLUSION

Two phase simplex method for optimum time coordination of overcurrent 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 a LPP is explained in this paper. The minimum operating time for each relay is considered as 0.1 s and the CTI is taken as 0.2 s for the distribution system. The optimum time coordination of relays has been found out in TORA software using two phase simplex method.

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