



A New Optimal Algorithm for Coordination of Over Current Relays in Interconnected Power System

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ABSTRACT: This paper presents maximum path, dual simplex and a new proposed method based on linear and non linear programming model for coordination of overcurrent (OC) relays. OC relays are the major protection devices in a distribution system. OC relays are usually employed as backup protection. To reduce the power outage, mal-operation of the backup relays should be avoided and for that coordination of OC relays in distribution network is major concern. The OC relay coordination in radial and parallel network is by conventional maximum path, dual simplex and proposed methods is given. Also coordination of OC in radial and parallel network is a constrained optimization problem. The purpose is to find optimum relay setting to minimize the time of operation of relays by dual simplex method is given. A brief comparison of all three methods is also given.

KEYWORDS: Maximum path Method, Dual simplex method, Overcurrent relay coordination, Constrained optimization.

I.INTRODUCTION

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. Directional overcurrent relays are commonly used as an economical means for protecting power distribution systems. The selection of appropriate settings of these relays under various systems conditions plays an important role in timely removal of the faulty section of power systems. Two methods have been proposed for the coordination of these relays. Ordinary coordination algorithms named Maximum path method considered [4]-[6]. However, the solutions found by this method are not optimal in any strict sense. In other words, relay time multiplier settings (TMS) are relatively high shown in this paper.

The coordination problem of relays in system can be defined as constrained optimization problem. It is a linear programming problem (LPP) and can be solved by dual simplex method [13]. In all of the above optimal techniques, the objective function and auxiliary variables must be defined so that the total number of auxiliary variables becomes equal to the number of constraints [14]. The introduction of auxiliary variables requires a complicated solution. As a result, the use of the conventional optimal techniques imposes limitations in terms of the low numbers of constraints to be used in the problem. In these methods convergence is difficult and needs many computer programming iterations, else, it may never converge.

In this paper, a new method for optimal coordination of over-current relays is proposed in which there is no need for introducing additional auxiliary variables and an objective function. It is a simple method and the number of iterations for the program to converge is low. It also considers both relays of the characteristics of which are linearly proportional to TMS (L.P) of TMS itself is the abbreviation of time dial setting of the relay under consideration. The new optimal coordination method together with its advantage is outlined. Finally, the performance of the new method is evaluated by comparing its results with the conventional optimal methods.



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II. LITERATURE SURVEY

From [1]-[6] method implementation of maximum path method is observed. From [13],[14] method implementation of dual simplex method is observed. From [1] proposed method is implied.

III. COORDINATION OF OC RELAYS IN DISTRIBUTION SYSTEM

A. Maximum Path Method

Assuming that the plug and time-multiple settings of a relay are stipulated, its operating time and time multiplier setting (TMS) can be calculated, provided that its operating (fault) current and current transformer rating are known, by mathematical analysis as shown below. The basic equations used are as follows:

$$RSI = CT \times PS / 100 \text{ amperes} \quad (1)$$

$$PSM = FC/RSI \quad (2)$$

$$RCOT = f(PSM) \text{ seconds} \quad (3)$$

$$ROT = RCOT \times TMS \text{ seconds} \quad (4)$$

$$RjOT = RnOT + DI \text{ seconds} \quad (5)$$

Where, CT = current transformer primary rating, A

FC = fault current

RSI = relay setting current in primary, A

PS = relay plug setting

PSM = relay plug setting multiple

TMS = relay time multiplier setting

RCOT = relay characteristic operating time, s

ROT = relay operating time, s

RjOT = major relay operating time, s

RnOT = minor relay operating time, s

DI = discriminating interval, s

B. Dual Simplex Method

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, for near end fault, is to be minimized [13],

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

where $t_{i,i}$ indicates the operating time of the primary relay at i , for near end fault. This objective is to be achieved under the following constraints :

(a) Coordination criteria :

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

where

$t_{i,i}$ is the operating time of the primary relay at i , for near end fault

$t_{bi,i}$ is the operating time for the backup relay for the same near end fault

Δt is the coordination time interval (CTI)

(b) Bounds on the relay operating time :

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

where

$t_{i,i, \min}$ is the minimum operating time of relay at i for near end fault (fault at i)

$t_{i,i, \max}$ is the maximum operating time of relay at i for near end fault (fault at i)



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(c) Relay characteristics :

All relays are assumed to be identical and are assumed to have normal IDMT characteristic as

$$t_{op} = \frac{\lambda (TMS)}{(PSM)^\gamma - 1} \quad (4)$$

where

$$\text{Plug Setting Multiple (PSM)} = \frac{\text{Fault Current}}{RSI}$$

t_{op} is relay operating time,

TMS is time multiplier setting, and

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, above equation becomes

$$t_{op} = a (TMS) \quad (5)$$

where

$$a = \frac{\lambda}{(PSM)^\gamma - 1}$$

Making substitution from above equation (5) in equation (1), the objective function become

$$\min z = \sum_{i=1}^m a_i (TMS)_i \quad (6)$$

The algorithm of dual simplex method to solve a maximization problem is given below (the minimization problem can easily be converted into maximization problem) :

01. Start

02. State the problem in maximization form.

03. Convert all the constraints into \leq type.

04. Convert all the constraints into equality constraints by adding slack variables.

05. Form first dual simplex table by taking slack variables as basics and original variables as non-basics.

06. Form cost coefficient ($C_j - \sum C_i e_{ij}$) row.

07. (a) If any element in this row is positive, then the method fails. Go to step 14

(b) If all the elements in this row are non positive and all the elements in the column of 'b' (i.e. RHS of constraints) are non negative then optimal solution is reached .Go to step 13.

(c) If all the elements in this row are non positive and at least one element in the column of 'b' is negative then further optimization is possible. Go to step 08.

08. Identify key row. It is the row having maximum negative value of b.

09. (a) If all the coefficient values (a_{ij}) in key row are non negative then there is no feasible solution for problem. Go to step 14.

(b) If some a_{ij} in key row are negative then find the ratio for those columns where $a_{ij} < 0$.

$$\text{Ratio} = (C_j - \sum C_i e_{ij}) / (a_{ij})$$

10. Decide key column. It is the column having smallest (positive) ratio.

11. Identify the pivot element (element corresponding to key column and key row) and proceed for formation of next dual simplex table.

12. Go to step 06.

13. Print results.

14. Stop.

C. NEW METHOD

Proposed Methodology

In the coordination program, two types of tap settings, The current setting for each relay is determined by two parameters, namely the minimum fault current and the maximum load current [4], [15].

To find TMS by new method, consider (1)



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$$\text{Min}(Obj) = \sum_i W_i * f(I_{pi}, I_i) * TDS_i \quad (1)$$

subject to

$$T_i = f(I_{pi}, I_i) * TDS_i \quad (2)$$

$$TDS_{min} \leq TDS_i \leq TDS_{max} \quad (3)$$

$$f(I_{pi}, I_i) * TDS_i(br) - f(I_{pj}, I_j) * TDS_j(pr) \geq CTI \quad (4)$$

Therefore the equations of the proposed method, i.e., constraints are constructed from (3) and (4). Equation (4) is formed for close-in and far end faults under various lines outages. In other words, for each primary and back up relay and for each fault location, outage of the lines connected to the feeders, on which the primary and back up relays exist, is made sequentially. Equation (5) expresses the relevant constraints, whereas, (6) illustrates (5) in detail

$$A * X \geq B \quad (5)$$

The lower part of matrix A relates to the other constraints being $f(I_{pi}, I_i)$ on the back up and primary equations. Here, it is assumed that the first constraint set of the optimal problem is related to relays i and j , where relay i is the back up for relay j .

Matrix A is shown in (6). As mentioned before, (6) expresses (5) in detail

$$\begin{bmatrix} 1 & 0 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & 0 & \dots & 0 \\ 0 & 0 & 1 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ 0 & 0 & 0 & 1 & \dots & 1 \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ A_{ij} & & & & & \end{bmatrix} * \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \\ \vdots \\ X_{m+1} \\ X_n \end{bmatrix} \geq \begin{bmatrix} TMS_{min} \\ TMS_{min} \\ \vdots \\ \dots \\ TMS_{min} \\ \vdots \\ CTI \\ CTI \end{bmatrix} \quad (6)$$

The lower part of matrix A can be rewritten as (7)

$$A_1 * X - A_2 * X \geq CTI \quad (7)$$

Where A_1 and A_2 are positive and negative parts of the lower section of matrix A. The systematic procedure of the new method to find TMS of the relays is described below.

- 1) Determine A and B matrices of (5) and (6).
- 2) Eliminate the negative value of each row in such a way that all elements of matrix A are positive or zero. This can be achieved by eliminating each negative element. It should be noted that the maximum two elements of each row of matrix A are nonzero. The above could be found from (3) and (4). Any negative value of row i is changed to zero. To achieve this, multiplication of a positive value to a row relevant to the relay is made first. The multiplication value should be such that the absolute value result becomes exactly the same as negative element of row i . adding the resulted value to the negative element makes this element zero.
- 3) Solve (6) and find each element of X (i.e., TMS).
- 4) It is possible to get some different values for TMS for a given relay. In this case, the one with higher value is chosen.
- 5) Check whether all elements of X in (5) and (7) are fulfilled.
If this is the case, the obtained TMS values are the final results. If not, the upper part of matrix B is replaced by the new TMS, and the whole process is repeated. In the new iteration, the minimum amounts are increased. Some of the advantages of this approach are simplicity and speed convergence, compared to the ordinary optimization technique such as the dual simplex.

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IV.METHOD APPLICATION OPTIMUM COORDINATION OF OC RELAYS

A. Illustration I-

To test the algorithm, initially a simple radial system, shown in figure 1, is considered. The maximum fault current just beyond bus A and bus B are 4000 A and 3000 A respectively, the plug setting of both the relays are 1, the CT ratio for R_A is 300:1 and for R_B is 100:1. Minimum operating time for each relay is considered as 0.2 s and the CTI is taken as 0.57 s. let operating time of R_B is set to 0.1 s.

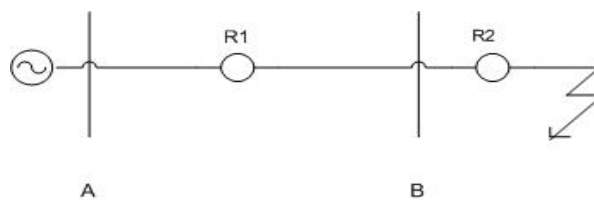


Fig 1 A radial feeder (both relays are non-directional)

I. Maximum Path Method

$$\begin{aligned} \text{Top of } R_2 &= 0.1 \text{ s}, \quad \text{PSM}=4000/100=40 \\ \text{RCOT of } R_2 &= \frac{0.14}{(\text{PSM of } R_2)^{0.02}-1} = 1.828 \text{ s} \quad \text{Top of } R_2 = \text{RCOT} \times \text{TMS of } R_2 \\ \text{TSM of } R_2 &= 0.05 \\ R_1 &\text{ will backup } R_2 \\ \text{Top of } R_1 &= 0.1 + \text{CTI} = 0.67 \text{ s}, \quad \text{PSM}=4000/300=10 \\ \text{RCOT of } R_1 &= \frac{0.14}{(\text{PSM of } R_1)^{0.02}-1} = 2.63 \text{ s} \\ \text{Top of } R_1 &= \text{RCOT} \times \text{TMS of } R_1 \\ \text{TSM of } R_1 &= 0.254 \end{aligned}$$

II. Dual Simplex Method

Calculation of value of a_i (mentioned in equation 6) for relays is shown in table 1

Where

$$\text{Relay current} = \frac{\text{Fault current}}{\text{Pick up current}} \quad \text{and}$$

$$a_i \text{ constant} = \frac{0.14}{(\text{Relay Current})^{0.02}-1}$$

Table 1 (a_i constant calculation)

Fault Point		Relay	
		1	2
A	Relay Current	13.33	—
	a_i constant	2.63	—
B	Relay Current	10	30
	a_i constant	2.97	2

Considering X_1 and X_2 as TMS of Relay R_A and R_B respectively, the problem can be stated as :

$$\text{Min } Z = 2.63X_1 \tag{8}$$

$$\text{subjected to } 2.63 X_1 - 2. X_2 \geq 0.57 \tag{9}$$

$$2.97 X_1 \geq 0.2 \tag{10}$$



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$$2 X_2 \geq 0.2$$

(11)

The optimum solution to this problem is obtained in three iterations. The iterations are shown in table 2, 3 and 4.

Table 2 Iteration 2 (slack variables are basic)

	C _j	-2.63	-2.	0	0	0	
C _i	Basic	x1	x2	s1	s2	s3	b
0	s1	-2.97	2	1	0	0	-0.57
0	s2	-2.63	0	0	1	0	-0.02
0	s3	0	-2	0	0	1	-0.2
$\sum C_i a_{ij}$		0	0	0	0	0	
C _j - $\sum C_i a_{ij}$		-2.63	-2	0	0	0	
Ratio		0.8855					

Table 3 Iteration 3 (s1 comes out x1 enters)

	C _j	-2.63	-2	0	0	0	
C _i	Basic	x1	x2	s1	s2	s3	b
-2.63	x1	1	-0.3367	-0.336	0	0	0.1919
0	s2	0	-1.771	-0.885	1	0	0.3047
0	s3	0	-2	0	0	1	-0.2
$\sum C_i a_{ij}$		-2.97	1.771	0.885	0	0	
C _j - $\sum C_i a_{ij}$		0	-3.771	-0.885	0	0	
Ratio			1.8855				

Table 4 Iteration 4 (s3 comes out x2 enters)

	C _j	-2.97	-2.26	0	0	0	
C _i	Basic	x1	x2	s1	s2	s3	b
-2.63	x1	1	0	-0.336	0	-0.336	0.2592
0	s2	0	0	-0.885	1	-0.885	0.4818
-2	x2	0	1	0	0	-0.5	0.1
$\sum C_i a_{ij}$		-2.63	-2	0.885	0	1.885	
C _j - $\sum C_i a_{ij}$		0	0	-0.885	0	-1.885	
Ratio		Optimum Solution is reached					

As, at the end of third iteration, all the values in the C_j - $\sum C_i a_{ij}$ row are non positive, the optimal solution reached.

From above table

$$X_1(\text{TMS of } R_1)=0.2592 \quad \text{and} \quad X_2(\text{TMS of } R_2)=0.1$$

III. Proposed Method

L.P Model : We can get a Matrix from the equation (6) for finding the TMS of the relay show below,

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$$\begin{bmatrix} 2.63 & 0 \\ 0 & 2 \\ 2.97 & -2 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \geq \begin{bmatrix} 0.2 \\ 0.2 \\ 0.57 \end{bmatrix}$$

From solving the above matrix,

$$X_1(\text{TMS of } R_1)=0.259 \quad X_2(\text{TMS of } R_2)=0.1$$

From section [I] , [II] and [III] we can compare the results in table 5 shown below,

Table 5 comparison results

	Maximum Path Method	Dual simplex Method	New Method L.P
R1	0.254	0.259	0.259
R2	0.05	0.1	0.1

B. Illustration II-

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 7 and 2 are non directional whereas all other relays (1, 3, 4, 5, 6, and 8) are directional OC relays. All directional relays have their tripping direction away from the concerned bus. Operating time is 0.2 s taken .CTI is 0.25 s taken .TMS of R_1 and R_8 is 0.1 taken. Shown in figure 2 and the breaking capacity of the circuit breakers are given in table 6 below,

Table 6 Breaking Capacity Of Circuit Breakers

Circuit brakers	MVA
R_2, R_7	5000
R_3, R_6	2000
R_1, R_4, R_5, R_8	3000

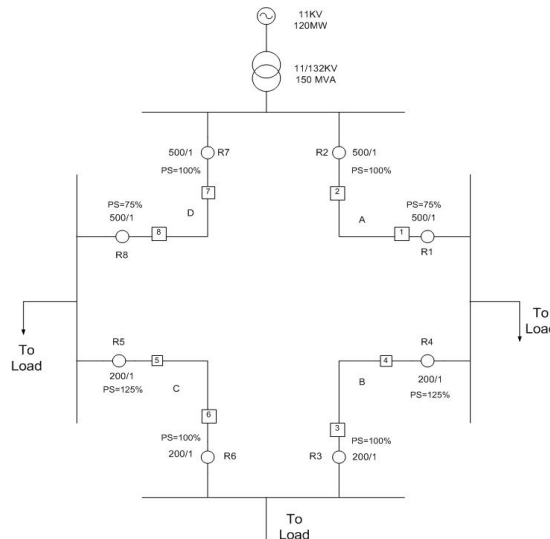


Fig 2 4-Bus ring main system



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The calculation of relay current and i_a constant for the system shown in figure 2 is shown in table 7 below,

Table 7 current seen by the relays and i_a constant for relays are

Fault Point		Relay							
		1	2	3	4	5	6	7	8
A	Relay Current	8.74	6.5	16.4	-	-	-	-	-
	i_a constant	3.15	3.67	2.43	-	-	-	-	-
B	Relay Current	-	-	21.86	17.49	17.49	-	-	-
	i_a constant	-	-	2.3	2.3	2.3	-	-	-
C	Relay Current	-	-	-	-	39.36	49.2	19.68	-
	i_a constant	-	-	-	-	2.3	2.3	2.28	-
D	Relay Current	26.2	-	-	-	-	-	26.24	34.99
	i_a constant	2.3	-	-	-	-	-	2.3	2.3

From table 7 and methods explained in illustration I, the Result Comparison between maximum path method, dual simplex method and proposed method for system shown in figure 2 shown in table 8 below,

Table 8 Comparison results all three method for ring system

Relay	TMS		
	Maximum Path Method	Dual simplex Method	New Method L.P
R1	0.1	0.1	0.1
R2	0.5	0.08	0.08
R3	0.25	0.32	0.3
R4	0.35	0.43	0.41
R5	0.35	0.43	0.41
R6	0.25	0.32	0.3
R7	0.5	0.08	0.08
R8	0.1	0.1	0.1

V. CONCLUSION

The new proposed method in this paper is superior to previous technique and provides flexibility due to the possibility to incorporate different network configurations and fast convergence due to smaller matrix dimension. In the coordination, higher speeds could be achieved for the relays employed. Other capabilities are different relay characteristics L.P.

REFERENCES

- [1] Hossein Askarian Abyaneh, Majid Al-Dabbagh, Hossein Kazemi Karegar, Seyed Hesameddin Hossein Sadeghi, and Rana Abul Jabbar Khan, "A New Optimal Approach for Coordination of overcurrent Relays in interconnected Power Systems", IEEE Transactions On Power Delivery, vol.18, No.2, APRIL 2003.
- [2] Paithankar Y. G., and Bhide S. R., "Fundamentals of Power System Protection", Prentice Hall of India Private Limited, New Delhi, 2007.
- [3] Badri Ram, and Vishwakarma D. N., "Power System Protection and Switchgear", Tata McGraw Hill Publishing Company Limited, New Delhi, 2008.



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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- [4] J. P. Whiting and D. Lidgate, "Computer prediction of IDMT relay settings and performance for interconnected power systems", IEE Gen., Transmiss., Distrib., vol. 130, no. 3, pp. 139–147, 1983
- [5] R. Ramswami and P. F. McGuire, "Integrated coordination and short circuit analysis for system protection", IEEE Trans. Power Delivery, vol. 7, pp. 1112–1119, July 1992.
- [6] P. E. Sutherland, "Protective device co-ordination in an industrial power system with multiple sources", IEEE Trans. Ind. Applicat., vol. 33, pp. 1096–1103, July/Aug. 1997.
- [7] Chattopadhyay B., Sachdev M.S., and Sidhu T.S., "An Online Relay Coordination algorithm for Adaptive Protection using Linear Programming Technique", IEEE Trans. on Power Delivery, vol 111, pp. 165-173, Jan 1996.
- [8] Lemke C.E., "The dual method of solving the linear programming problem", Naval research and logistics quarterly, vol. 1, no. 1, pp 36- 47, 1954.
- [9] Rao S.S., "Engineering optimization – theory and practice, third edition", New Age International (P) Limited, Publisher New Delhi, 1998.
- [10] Taha H., "Operations research – an introduction, eighth edition", Dorling Kindersley (India) Pvt.Ltd., New Delhi, 2009.
- [11] Bhavesh Bhalja , R . P . Maheshwari , Nilesh G. Chothani, "Protection and Switchgear", Oxford University Press.
- [12] Pradeep Prabhakar Pai , "Operation Research Principles and Practice ", Oxford University Press.
- [13] P. Bedekar, Sudhir R. Bhide , Vijay S. Kale , "Optimum coordination of overcurrent relays in distribution system using dual simplex method", Conference on Emerging Trends in Engineering and Technology, ICETET-09.
- [14] S. S. Rao, Optimization (Theory and Application), 2nd ed. New Delhi.
- [15] A. S. Braga and J. T. Saraiva, "Co-ordination of directional overcurrent relays in meshed networks using simplex method", Proc. IEEE MELECON Conf., vol. 3, pp. 1535-1538, 1996.
- [16] A. J. Urdaneta, R. Nadira, and L. prez, "Optimal co-ordination of directional overcurrent relay in interconnected power systems", IEEE Trans. Power Delivery, vol. 3, pp. 903–911, July 1988.
- [17] Bhuvanesh A. Oza , Nirmal Kumar C Nair , Rashesh P Mehta , Vijay H Makwana, "Power System Protection and Switchgear" , McGraw Hill Education.