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Optimum Coordination of Overcurrent Relays using Dual Simplex and Improved Harmony Search Algorithms

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Abstract—**Relays in a distribution system are used to clear the fault in the least possible time and prevent it from travelling upstream. Excessive current caused due to these faults damages equipments and harm personnel. Overcurrent (OC) relays operate when the current in the system exceeds a threshold level. Hence proper coordination of OC relays is necessary to minimize discontinuity of supply for consumers. Different algorithms are used to optimize the time of operation of these OC relays. This paper compares two algorithms namely, Dual Simplex and Improved Harmony Search Algorithm (IHSA) on three radial networks to identify the time multiplier setting (TMS) of the relay. This eventually assists in fixing the time of operation of the relays.**

Keywords-optimum coordination; directional overcurrent relays; dual simplex; improved harmony search algorithm

I. Introduction

Relay coordination is an important protection criterion in power distribution systems. Usually relay settings are calculated using the relay’s characteristic curve which takes into consideration the maximum fault current, current transformer (CT) ratio, load current, minimum fault clearance time and relay coordination time interval (CTI) [1]. It is time consuming and as the system size increases, it becomes very cumbersome and complex. This method may not always yield the optimal solution. So, there is a chance of mal-operation of the relays in a large system.

Because of the above mentioned disadvantages of the conventional method, optimization techniques are now employed [2]. Optimization algorithms may be iterative, adaptive or evolutionary. In this paper, we compare an iterative method – dual simplex, with an evolutionary method – improved harmony search algorithm (IHSA) to obtain directional overcurrent (DOC) relay coordination [2,3].

During fault condition, current in the system increases. To protect the system from damages due to this, overcurrent (OC) relays are employed. OC relays are of two types – directional and non-directional. Non-directional OC relays have to be coordinated with both the relays and with the relays at the remote end of the line. In DOC relays, tripping direction is specified so coordination with the relays behind them is not necessary [2]. Due to DOC relays are usually preferred over non-directional OC relays.

II. Coordination of OC Relays in a Radial System

The two bus radial system is considered as shown in Fig.1. R1 and R2 are the DOC relays. Fault is considered in two locations: just after R2 and just after R1. Primary and backup relays are selected according to the fault location. Primary protection always acts first and incase it fails to clear the fault within the stipulated time then the backup protection comes into play.

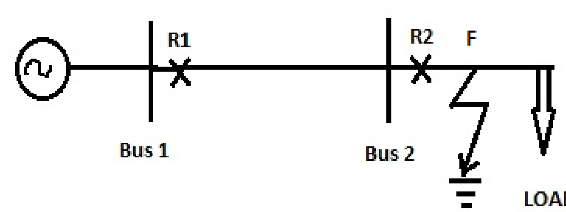

Fig. 1. The radial two bus system in consideration

When the fault occurs at F, R2 operates first i.e. it is the primary relay. Let R2 operate 0.2 s after the fault inception. This is done to allow the fault to clear on its own, failing

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which primary protection will operate. This time is allotted to ensure that relay does not operate for current surges in feeder. Relay R1 should operate after a fixed time, known as the CTI, which equals to the sum of operating time of circuit breaker (CB) at bus 2, overshoot time of relay R1 and 0.2 s [2,4].

Using this concept, constraints are formulated and are solved by dual simplex and IHSA to obtain the time multiplier setting (TMS) of the relays, and consequently the time of operation (t_{opi}).

III. Problem Formulation

DOC relays require two main parameters to operate namely relay current settings and the time TMS [4]. Relay settings depend on the maximum load current in the feeder. TMS is obtained by minimizing the objective function [2]:

$$\text{Min } z = \sum_{i=1}^{n} t_{opi} \tag{1}$$

where,

t_{opi} is the operating time of the primary relay i, for a fault at i under the following constraints [2]:

A. Bounds on Operating Time –

$$t_{opimin} \le t_{opi} \le t_{opimax} \tag{2}$$

where

t_{opimin} - the minimum time required for operation of the relay at i for fault at ‘i’.

t_{opimax} - time required for operation of the relay at i for a fault at ‘i’.

B. Coordination Time Criteria –

Coordination time is the minimum time required between operation of two relays [2].

$$t_{bopi} - t_{opi} \ge \Delta t \tag{3}$$

where

t_{bopi} - the operating time of the backup relay i, for a fault at ‘i’.

Δt - the coordination time interval (CTI) [2].

C. Relay Characteristics –

Normal inverse definite minimum time (IDMT) charcteristics are assumed for all relays [2,5].

$$\alpha = \frac{\lambda}{(PSM)^{\gamma} - 1} \tag{4}$$

where

λ is 0.14and is 0.02.

Plug multiplier setting (PSM) is given by

$$\text{PSM} = \frac{\text{If}}{\text{CT ratio x Relay Setting}} \tag{5}$$

where

I_f is the fault current (in A).

$$\text{topi} = \lambda * (\text{TMS}) * \left((\text{PSM})^{\gamma} - 1\right)^{-1} \tag{6}$$

i.e. $$t_{opi} = \alpha(\text{TMS}) \tag{7}$$

Substituting (7) in (1) gives the objective function as:

$$\text{Min } z = \sum_{i=1}^{n} \alpha_i (\text{TMS})_i \tag{8}$$

The value of TMS is hence determined.

IV. Dual Simplex Method

It is one of the methods used for solving a linear programming problem (LPP) and was developed by C. E. Lemke [6]. It is a more economical approach when compared with simplex method as it requires less number of iterations to converge [6].

This method only solves maximization functions. So, the minimization function should be converted to maximize. Since objective function is minimizing, the constraints should be ≤ type.

The algorithm is [2,7]:

1. Start
2. Initialize the objective function and constraints.
3. Convert all inequality constraints to equality by adding slack variable. Add slack variable in objective function.
4. Form the Simplex table with basics and non-basics
5. Find cost coefficient $C_j - \sum C_i e_{ij}$
6. If cost coefficient is positive the method fails. Go to step 11.
   Else
   i. If at least one number in B column is negative then proceed to Step 6.
   ii. Else if all B’s are positive optimal solution is achieved.
7. Leaving variable is the one with most negative B. Find the leaving row.
8. If all coefficients in leaving row are positive then there is no solution. Go to Step 11.
   i. Else, max [($\sum c_i e_{ij} - C_j$) / a_{ij}] containing column is entering column
9. Find the pivot element and make necessary changes in the entering row or column. Write the updated table.
10. Go back to Step 5.
11. Stop.

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V. Harmony Search Algorithm

A. Improved Harmony Search Algorithm

Harmony Search Algorithm, originally developed by Z. W. Geem in 2001, was improvised by many other researchers in order to check if a better solution was possible [8]. In 2007, Mahadevi M., Fesanghary M. and Damangir E succeeded in making the harmony search algorithm slightly better, thus developing IHSA[8,9].

The basic steps in IHSA are as follows:

The above steps are described in detail below.

1) Step 1: Initialize the problem and IHSA parameters.

The optimization problem is,

$$\text{Minimize } Z=f(x) \tag{9}$$

$$\text{Subject to } x=X_i,\ i=1,2,3,..n \tag{10}$$

where f(x)is the objective function, x is the set of decision variable X_i, n is the number of decision variables, X_i is all the possible values for each decision variable.

The constraints limit the range of these decision variables [3,9].

The IHSA parameters to be initialized are as follows:

1. Harmony memory size (HMS) : A 2-D matrix which stores the solution vector for the set of decision variables
2. Harmony Memory Considering Rate ($HMCR_{min}$, $HMCR_{max}$) : A probability range that shows the rate of choosing values from Harmony Memory (HM) [8].
3. Pitch Adjusting Rate (PAR_{mim}, PAR_{max}) : Values chosen from the memory will be checked for pitch adjustment within the specified range.
4. NI : Number of Iteration
5. PVB : Range of each decision variable

2) Step 2: Initialize Harmony Memory

HMS and the number of decision variables limit the size of HM. This HM matrix is filled with random values within the specified range (PVB) [10].

$$HM=\begin{bmatrix} x_1^1 & x2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \dots & x_{N-1}^2 & x^2 \\ | & | & | & | & | \\ x_1^{HMS-1} & x_2^{HMS-1} & \dots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \dots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{11}$$

3) Step 3: Improvise a new Harmony Memory

Improvisation is the process of generating New Harmony. This is done based on memory consideration, pitch adjustment rate and random selection. HMCR, PAR and band width (bw) updates with generation number. The formula for the updating is :

$$HMCR = HMCR_{min} + \frac{[HMCR_{max} - HMCR_{min}]}{\exp^{\left(\frac{1}{gn^2}\right)}} \tag{12}$$

$$PAR(gn) = PAR_{min} + gn\,\frac{[PAR_{max} - PAR_{min}]}{NI} \tag{13}$$

$$bw(gn) = bw_{max} * e^{(C.gn)} \tag{14}$$

$$C = \frac{\left[\ln\left(\frac{bw_{max}}{bw_{min}}\right)\right]}{NI} \tag{15}$$

gn : Generation number i.e. Current iteration

For any decision variable x_i, the values are picked at the rate of HMCR from HM or randomly (rand) generated at the rate of (1-HMCR). Every value obtained should be considered for pitch adjustment depending on PAR value. (1-PAR) is the rate of no change with respect to pitch adjustment. Pitch adjustment is done using the following formula:

$$x_i = x_i \pm rand*bw \tag{16}$$

4) Step 4: Update HM

The generated vector is checked if it is better than the worst value in the HM. If true, then this value replaces the worst value in HM.

5) Step 5: Stopping Criteria

If the number of iterations reaches the maximum number of iteration (stopping criteria), the computation is terminated. The best value from HM is the solution for the given problem.

B. Traditional Harmony Search Algorithm

This meta-heuristic algorithm was initially developed by Geem Zong Woo in 2001 and is based on the music improvisation process [10]. Like musicians play different tunes in different instruments to find the best possible combination that blends well, the algorithm finds the best solutions considering the constraints for a given problem [9].

The parameters-HMS, HMCR, PAR, bw and NI are assumed at the starting of each problem. The algorithm considers these parameters and continues its iterations till it reaches NI, after which it stops. All the steps in IHSA and harmony search algorithm are the same except that in IHSA, the parameters HMCR, PAR and bw are improvised after each iteration. This allows small adjustments in the solution vectors generated, thus allowing the possibility of obtaining better solutions. In harmony search algorithm, these parameters remain constant throughout the program.

VI. Application of Algorithm

A. CASE I –

The two algorithms were applied to the radial two bus system shown in Fig.1. The source is a 220 kV, 100 MVA

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(these were also considered as the base kV and base MVA of the system respectively). CTI for the relay is assumed to be 0.57 s. The maximum fault currents just beyond relays R1 and R2 were found to be 2108 A and 1703 A respectively. These values of fault currents are used to calculate PMS and α using (5) and (4) respectively. This is shown in Table I.

TABLE I. PSM AND A VALUES

Fault Position	Relay	
	R1	R2
1)Just beyond R1		
PSM	8.432	-
α	3.21	-
2) Just beyond R2		
PSM	2.556	6.812
α	7.38	5.57

The problem can be formulated by considering TMS of relay R1 as x_1 and that of relay R2 as x_2.

Min z = $3.21\, x_1 + 5.57\, x_2$ (17)

Subject to $7.38\, x1 - 3.57\, x2 \geq 0.57$ (18)

$3.21\, x1 \geq 0.2$ (19)

and $3.57\, x2 \geq 0.2$ (20)

Here we assume the upper limit of the TMS of both relays as 1.2 and the lower limit as 0.1. We use the lower bound of the TMS to form (19) and (20). (16) gives the coordination criteria. The result of the above formed LPP using dual simplex & IHSA is as shown in Table II.

TABLE II. TWO BUS RADIAL SYSTEM RESULT

Method		Relays		
		x_1	x_2	z
Dual Simplex	TMS	0.1043	0.056	-
	t_{opi}(in sec)	0.3349	0.2	0.5349
IHSA	TMS	0.0994	0.0477	-
	t_{opi}(in sec)	0.3190	0.17028	0.4893

t_{opi} (in sec) in both cases is obtained by (7).The maximum time in which the fault will be cleared by both relays using dual simplex method is 0.535 sec and using IHSA, it is 0.489 sec

B. CASE II –

Here, a four bus radial system is considered for two cases – without a distributed generation (DG) source and with a DG source. The main source is of 66 kV, 100 MVA (also considered as base kV and MVA respectively). The CT ratio at all the buses is taken as 200:5.

1) Four bus radial system without DG

The system is shown in fig 2. There are four directional OC relays.

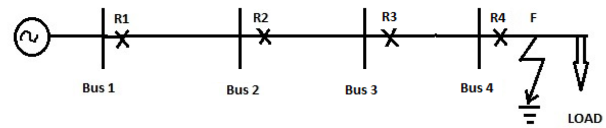

Fig. 2. The radial four bus system without a DG source

A three phase to ground fault is simulated at all of the buses, the details of which are given in Table III.

TABLE III. PSM AND A VALUES (WITHOUT DG SOURCE)

Fault Position	Relays			
	R1	R2	R3	R4
1)Just beyond R1				
PSM	14.924	-		
α	2.504	-		
2) Just beyond R2				
PSM	11.376	12.052	-	-
α	2.773	2.7427	-	-
3) Just beyond R3				
PSM	-	7.14	7.276	-
α	-	3.4915	3.4577	-
4) Just beyond R4				
PSM	-	-	6.708	6.74
α	-	-	3.6083	3.5991

The optimization problem is formulated in the same way as explained in case 1. There will be three constraints due to CTI and four constraints due to bounds on relay operating time. The values of TMS obtained are shown in Table IV.

TABLE IV. FOUR BUS RADIAL SYSTEM (WITHOUT DG) RESULT

	TMS of relays			
	x1	x2	x3	x4
Dual Simplex	0.1142	0.1	0.0897	0.0413
IHSA	0.0988	0.0986	0.0774	0.0326

It can be seen that IHSA gives a more optimal solution than dual simplex method.

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2) Four bus radial system with DG

In the four bus system used above, a DG source is added at bus 3. The DG source is a wind generator of 60MW. This system is shown in fig 3.

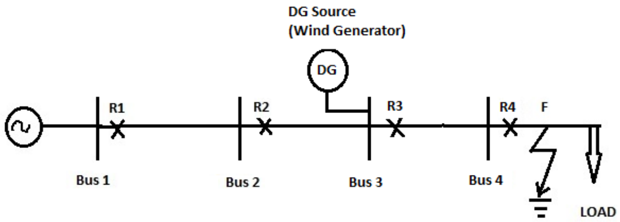

Fig. 3. The radial four bus system with a DG source at bus 3

A three phase to ground fault is simulated at all the buses and the fault current is used to calculate PSM and α. Due to the addition of a DG source, it is observed that the magnitude of fault current increased. Table V gives the values for PSM and α for this case.

TABLE V. PSM AND A VALUES (WITH DG SOURCE)

Fault Position	Relay			
	R1	R2	R3	R4
1)Just beyond R1				
PSM	20.888	-		
α	2.2339	-		
2) Just beyond R2				
PSM	12.052	18.372	-	-
α	2.7427	2.3355	-	-
3) Just beyond R3				
PSM	-	7.276	17.08	-
α	-	3.4576	2.3972	-
4) Just beyond R4				
PSM	-	-	14.84	14.872
α	-	-	2.5258	2.523

The objective function and constraints are formulated using the values in Table VI. The procedure remains the same as explained in Case 1. There will be three constraints due to CTI and four constraints due to bounds on relay operation. The results are summarized in Table VI.

TABLE VI. FOUR BUS RADIAL SYSTEM (WITH DG) RESULT

	TMS of relays			
	x1	x2	x3	x4
Dual Simplex	0.1219	0.1135	0.0492	0.1109
IHSA	0.0993	0.0967	0.0325	0.0963

It is necessary that the relay at bus 3 should operate first as the fault current will be higher at this bus due to the DG source. It is clear from Table VII that IHSA always gives a better solution than dual simplex method.

VII. CONCLUSION

In a distribution network, it is necessary that the fault be cleared in the least time possible. This paper employs two algorithms on three radial networks to facilitate identification of TMS of the DOC relay. This aids in computing t_{opi} (time of operation). Both the methods give a feasible value of t_{opi}. It is evident that IHSA gives a lesser value of t_{opi} and so it is a better optimizing algorithm than dual simplex.

REFERENCES

[1] Chao-Rong Chen, Cheng-Hung Lee, Chi-Juin Chang, “Optimal Overcurrent Rel;ay Coordination in Power Distribution System Using a New Approach”, Elsevier, October 2012

[2] Prashant P. Bedekar, Sudhir R. Bhide, Vijay S. Kale, “Optimum Coordiantion of Overcurrent relays in Distribution system using Dual Simplex Method”, ICETET-09.

[3] Mostafa Barzegari, S. M. T. Bathaee, Mohsen Alizadeh, “Optimal Coordination of Directional Overcurrent Relays using Harmony Search Algorithm”.

[4] Paithankar Y. G. and Bhide S. R., “Fundamentals of Power System Protection”, Prentice Hall of India Private Limited, New Delhi, 2007.

[5] Urdaneta A. J., Nadira Ramon and Luis G. P. Jimenez, “Optimal Coordiantion of Directional Relays in Interconnected Power Syatem”, July 1988.

[6] Manohar Singh, B. K. Panigrahi and A. R. Abhyankar, “Optimal Overcurrent Relay Coordination in Distribution System”.

[7] Vasek Chvatel, “Linear Programming”, W. H. Freeman & Co. Ltd., 1983.

[8] Mahdavi M., Fesanghary M., Damangir E., “An improved harmony search algorithm for solving optimization problems”, Applied Mathematics and Computation, 2007.

[9] Geem Zong Woo, Joong Hoon Kim, Loganathan G. V., “A New Heuristic Optimization Algorithm: Harmony Search”, SIMULATION 76:2, 2001.

[10] Sachin A. Patil, D. A. Patel, “An Overview: Improved Harmony Search Algorithm and its Applications in Mechanical Engineering:, IJESIT Volume 2, Issue 1, Januoary 2013.

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