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Efficient Dimensionality Reduction of Directional Overcurrent Relays Optimal Coordination Problem

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Abstract**—**Directional over current relays (DOCR) are commonly used in power system protection as a primary protection in distribution and sub-transmission electrical systems and as a secondary protection in transmission systems. Coordination of protective relays is necessary to obtain selective tripping. In this paper, an approach for efficiency reduction of DOCRs nonlinear optimum coordination (OC) is proposed. This was achieved by modifying the objective function and relaxing several constraints depending on the four constraints classification, non-valid, redundant, pre-obtained and valid constraints. According to this classification, the far end fault effect on the objective function and constraints, and in consequently on relay operating time, was studied. The study was carried out, firstly by taking into account the near-end and far-end faults in DOCRs coordination problem formulation; and then faults very close to the primary relays (near-end faults). The optimal coordination (OC) was achieved by simultaneously optimizing all variables (TDS and Ip) in nonlinear environment by using of Genetic algorithm nonlinear programming techniques. The results application of the above two approaches on 6-bus and 26-bus system verify that the far-end faults consideration on OC problem formulation don't lose the optimality.

Keywords**—**Backup/Primary relay, Coordination time interval (CTI), directional over current relays, Genetic algorithm, time dial setting (TDS), pickup current setting (Ip), nonlinear programming.

I. INTRODUCTION

THE main function of relay protection on power systems is to detect faulted parts and to remove them selectively as fast as possible. Directional overcurrent relaying is commonly used in power system protection as a primary protection in distribution and sub-transmission systems and as a secondary protection in transmission systems as an economical protection system [1][2]. These simple and economic relays, which are and used in the modern complex interconnected power system networks, are standalone devices and strategically placed throughout the system. Coordination of protective relays is necessary to obtain selective tripping. Thus, directional overcurrent relays coordination has been achieved by means of three approaches: trial and error approach [3], topological analysis approach [4][5], and optimization approach. For overcurrent relays coordinated by the third approach, due to the complexity of nonlinear optimal programming techniques, the optimal coordination has been performed using linear programming techniques, including simplex, two-phase simplex and dual simplex methods. The disadvantage of these last optimization techniques is that they are based on an initial guess and may be trapped in the local minimum values [6]. In these methods the current setting of the relays are assumed to be determined prior, and only find the time dial setting of the relays. Generally this is not the global optimum solution of the problem [7].

These above mentioned difficulties for adjusting the setting of the relays don't appear when the intelligent optimization techniques, such as genetic algorithm and interior point non-linear programming, are used. By using of these intelligent optimization techniques, we can determine both two variables of DOCR, time dial settings (TDS) and pickup current (I_p).

The optimal coordination in reference [8] has been done by a method based on genetic algorithm, and in reference [9] by an evolutionary algorithm and in [10] by particle swarm optimization, and in [11] by Sequential Quadratic Programming technique (SPQ).

The constraints reduction in the DOCR coordination has been widely studied in several researches. The authors in [12] consider that the constraints which make the optimal problem feasible are not taken into account. This will increase the feasibility of the optimal problem and decrease the run-time of the program.

This paper presents an approach for reduction of problem dimension, in constraints number and objective function. Two cases have been adopted in order to solving the DOCR coordination problem. The first one, which is the general optimizing method, assumes an objective function constituted as summation of the primary operating times of relays, which would respond to the near-end and the far-end fault currents. The other, takes into account problem reduction and it is based on only a near-end fault with objective function consists of the summation of operating time of primary relays calculated for near-end faults. The current setting and time dial setting of all relays are considered as optimization parameters.

This paper is divided into three main sections. Section II describes the optimal problem formulation. In section III, the new approach depending on constrains reduction will be presented. Finally, the results will be presented for an application of this approach on genetic algorithm nonlinear optimization techniques, on 6-bus and 26-bus electrical system.

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II. OPTIMAL COORDINATION PROBLEM FORMULATION

A. Modeling of Overcurrent Relay

Generally, the typical over current relay consists of two elements, an instantaneous unit (time independent), and an inverse overcurrent unit (time dependent). The time dependent unit has two values to be set, the pickup current value (Ip), and the time dial setting (TDS). The pickup current value is the minimum current value for which the relay operates (on the secondary of current transformer). The time dial setting defines the operation time (T) of the device for each current value, and is normally given as a curve of T versus M, where is the ratio of the relay fault current I_{rf}, to the pickup current value, i.e. $M = I_{rf} / I_p$. In general, over current relays respond to a characteristics function of the type:

$$T = f\left(TDS, I_p, I_{rf}\right) \quad (1)$$

Where T is the relay operation time, TDS is time dial setting; I_p is the pickup current and I_{rf} is the current flowing through the relay. Under simplistic assumption, the above equation can be approximated by the following equation:

$$T = \frac{k_1 . TDS}{\left[\left(\frac{I_{rf}}{CT\_reatio * I_p}\right)^{k_2} - k_3\right]} \quad (2)$$

Where: k_1, k_2 and k_3 are constants which depend on the relay characteristic (inverse, very inverse, extremely inverse, and so on …). CT_reatio is the current transformer ratio.

As seen from the above equation, overcurrent relay operating time is a function to two variables; the first is *TDS* and the second *Ip*. In many researches, and due to the complexity of nonlinear optimal programming techniques, the coordination of overcurrent relays was commonly performed by linear programming techniques. In this method the current setting of the relays are assumed to be determined prior, and only find the time multiplier setting of the relays. In this paper, this is not applied, but the nonlinear programming technique solves this problem and the two variables will be simultaneously calculated.

B. Problem Formulation

The main principle for DOCRs coordination is that the objective function of primary relays operating times has to be optimized and subjected to keeping the operation of the backup relays coordinated. One possible approach to achieve minimum shock to the system due to faults would be to minimize a sum of the operating times of all primary relays hoping that the operating times of individual primary relays would be close to the minimum individual operating times that might be possible 0. Generally, the simulated fault occurred near the relay on the line is called by near-end fault. The same fault is a far-end fault for the relay situated at the other end of the line. The near-end fault and far-end fault for relay are shown in Fig. 1.

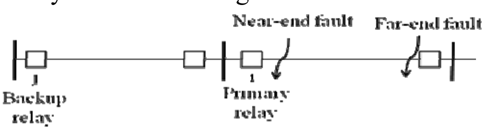

Fig. 1 near-end and far-end faults for relay

The near-end fault level is used to coordinate relay operations for high fault currents very close to relay. The far-end fault level coordinates for the minimum fault current at the end of the line [11]. Typically, the objective function for the directional overcurrent relays coordination is formulated as summation of the primary operating times of relays, which would respond to the near-end fault currents and the far-end fault currents. Thus the next equation presents this function:

$$J = \sum_{m=1}^{N_{near}} T_{i\_near}^{m} + \sum_{n=1}^{N_{far}} T_{i\_far}^{n} \quad (3)$$

Where:

N_{near} Number of relays responding to near-end fault;

N_{far} Number of relays responding to far-end faults;

$T_{i\_near}^{m}$ Primary operating-time of mth relay for near-end fault;

$T_{i\_far}^{n}$ Primary operating-time of n[th] relay for far-end fault;

This objective function is subjected to the constraints for both near-end and far-end faults. Typically, the operating time of the backup relay must be greater than the sum of the operating time of its primary relay and the coordination margin (CTI). This can be depicted by these two inequalities:

$$T_{i\_near} - T_{j\_near} \geq CTI$$
$$f(I_f, I_p)TDS_i - f(I_f, I_p)TDS_i \geq CTI \quad (4)$$

$$T'_{i\_far} - T'_{j\_far} \geq CTI \quad (5)$$

Eq. (5) refers to the primary operating times for far-end faults.

The other constraints in this optimization problem are the limitation of the variables as follows

$$TMS_{i\,\min} \leq TMS_i \leq TMS_{i\,\max} \quad (6)$$

$$I_{pi_{\min}} \leq I_{pi} \leq I_{pi_{\max}} \quad (7)$$

For this general case, two constraints reduction has to be relaxed in order to simplify the problem. Firstly, when the DOCR fault currents fall below their pick-up current, then it must relaxed. On the other hand, several constraints are relaxed when directions of fault currents for associated relays in a selectivity constraint are opposite to each other 0.

C. Problem statement

When the obtained solutions satisfy all constraints, then the optimization is feasible. But, if any constraint is in conflict, then the optimal problem becomes infeasible. In order to simplify the problem without affecting the results quality, then it is necessary to recognize these conflicting constraints before performing the optimal programming process. The possible solutions of the optimization process are situated on an area called possible solution area (PSA) for each relay pair, i.e. primary and backup relays. The PSA is a square, which is bounded by the maximum and minimum values of the time dial setting (TDS) for each primary and backup relays (see Fig. 2). The constraint representing by Eq. 5 can be drawn as line in the plane (TDS_i,TDS_j). The intersection points with PSA and the slope of the line represented the constraint for a relay pair depend on the coefficient of its variable and CTI value. So, according to (5) This line divides the (TDS_i,TDS_j) plane into two sections, the upper and the lower one. The upper section contains any possible optimal settings of a P/B pair satisfying and it is called feasible solutions area (FSA).

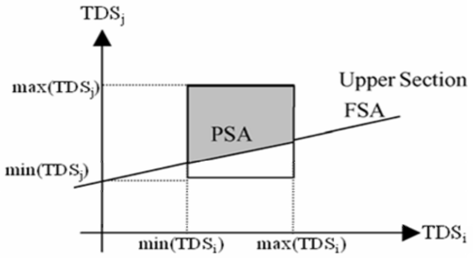

Fig. 2 Possible solutions area (PSA) and feasible solutions area

The possible solutions of the optimizing process must be in the upper section of the constraint line and in the same time within the PSA which is bounded by the maximum and minimum values. Fig. 3, depicts the various possible positions for the constraints representing the optimization process.

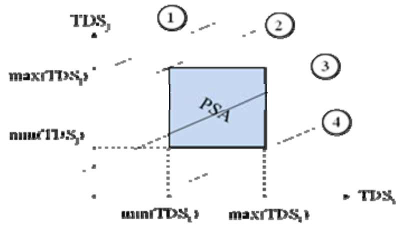

Fig. 3 Constraints classification (1-non valid, 2-pre-determained, 3-activ, 4-redundant constraints)

By regarding Fig. 3, when the upper section of a constraint line does not have any common area with PSA, it is classified as a non-valid constraint (Fig. 3-line 1).
In addition, a constraint line crosses the PSA on the upper-left-corner point, then the optimal solutions for two variables are *min* TDS_i and *max* TDS_j. we call this type of constraints is known as the pre-obtained one (Fig. 3 line 2). In fact, the line 4 has not any intersection with PSA but lies under this area. This line represents the redundant constraint. In this case, any arbitrary point within the PSA is an optimal solution. Therefore, this constraint can be excluded from the constraints set too, because the constraint line does not have any effect on optimal solutions [12]. The constraint which has two intersection points with PSA is the valid constraint (Fig. 3-line 3). In this type of constraints, and as depicted in Fig. 2, the upper area which is bounded between the valid line (line 3 in Fig. 3) and the PSA is the FSA where the optimal solutions of TDS_i and TDS_j exist.

III. PROPOSED APPROACH AND PROBLEM REFORMULATION

Actually, if more than one valid constraint for each relay pair (P/B) exists, then two FSA areas have to be formulated (see Fig. 4). In this figure, FSA1 and FSA2 are the two feasible areas formulated upon the two lines belong to two different constraints (1&2). As it is mentioned in the item (C) of the previous section, the optimal solution for every constraint exist on the upper section of the line, therefore, all solutions of the constraint 1 are valid for constraint 2. Hence, constraint 2 can be removed from the constraints set.

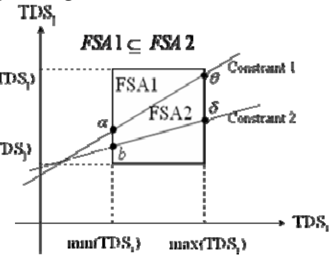

Fig. 4 comparing two valid constraints

The line representing the first constraint is above that representing the second constraint if we can proof that the intersection points of the first constraint line with the PSA left and right limits are above those resulting from the intersection of the second constraint line. Then we can remove the constraint number 2 from the constraints set. The previous approach can be presented by the next inequalities:

$$TDS_j(\alpha) \ge TDS_j(b)$$
$$TDS_j\left(\min\left(TDS_i\right)\right) \ge TDS_j\left(\min\left(TDS_i\right)\right) \tag{8}$$

For the constraint N°1 and for the point (α), we can write the constraint condition corresponding to line 1as next:

$$\frac{k_1 .TDS_j}{\left[\left(\frac{I_{rf\ j}}{I_{pj}}\right)^{k_2} - k_3\right]} - \frac{k_1 . \min(TDS_i)}{\left[\left(\frac{I_{rfi}}{I_{pi}}\right)^{k_2} - k_3\right]} = CTI \tag{9}$$

In case of a very close fault to the primary relay (near-end fault), the Eq. (9) can

$$TDS_j = (CTI + \frac{k_1 . \min(TDS_i)}{\left[\left(\frac{I_{rfi}}{I_{pi}}\right)^{k_2} - k_3\right]}).(\frac{\left[\left(\frac{I_{rf\ j}}{I_{pj}}\right)^{k_2} - k_3\right]}{k_1}) \tag{10}$$

We notice, according to (10) that with the increasing values of relay fault current $\left(I_{rf}\right)$, the relay time dial setting will increase. This means, the intersection point of the constraint line will go up on the vertical line representing $\min(TDS_i)$. Typically, the fault current level at the end of a feeder is much smaller than that at the beginning of the same feeder, because of the increasing feeder impedance with its length. Therefore, the far-end fault current is smaller than the near-end fault current $I_{f\_near} \ge I_{f\_far}$. So, and due to the previous discussion, the near-end constraint line position is always found above the far-end constraint line for the same DOCR (see Fig. 5).

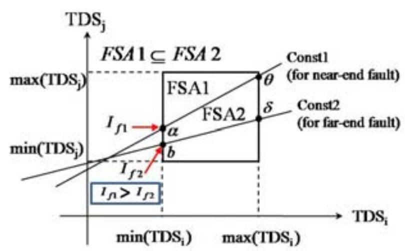

Fig. 5 near-end and far-end fault constraints

Thus, the far-end constraints can be removed from the constraints according to their own FSA2 covered by near-end fault constraints FSA1 (see Fig. 5). As demonstrated on (3), the objective function consists of two parts, one for the near-end faults and the other for the far-end faults. It means that for every primary relay time dial setting, we have two summation parts as mentioned below:

$$T_i = \left(\frac{k_1}{\left[\left(\frac{I_{rf\_near}}{CT\_rat.I_p} \right)^{k_2} - k_3 \right]} + \frac{k_1}{\left[\left(\frac{I_{rf\_far}}{CT\_reat.I_p} \right)^{k_2} - k_3 \right]} \right) .TDS_i \quad (11)$$

The proposed approach depends on the fact that the weight factors of the objective function don't affect its optimal solution. In fact, the optimal solution will not change if the weight factors changed from a zero to infinity 0. The optimal solution will change only if the weight factors get negative values, but this case is unacceptable because, the weight factors are positive real numbers, and if negative values of the weight factors are accepted, some of the operating times will be maximized rather than minimized. So, we can find that relays operating time for the close-in faults will necessarily lead to the reduction of the operating times for any fault location, just as middle-line and far-end faults, but it is important to notice that the case of vice versa is not true. So, by neglecting the objective function part concerning the far end fault, we obtain the new formulation of this function:

$$T_i = \frac{k_1}{\left[\left(\frac{I_{rf\_near}}{CT\_rat.I_p} \right)^{k_2} - k_3 \right]} .TDS_i \quad (12)$$

IV. CASES STUDY

The proposed algorithm was tested on the 6-bus system and 26-bus system. The normal inverse characteristic for directional overcurrent relays applied for the lines protection are (k1 = 0.14, k2 = 0.02, k3=1). TDS is taken in the range of (0.01–1.1). The pick-up setting is determined by allowing a margin for overload above the nominal current. So the minimum values of the pick-up currents were set to 1.3 of the nominal current. Using the topological tracking we have determined the entire primary/backup relay. Newton-Raphson load flow technique is used in this application to determine the voltages at each bus and the line currents. Finally the backup and primary relays short circuit currents are calculated for the fault located near and far every primary relay for every associated relays pairs. The current transformer was selected according to the maximum load current and it must not saturate at high fault currents.

A. 6-bus system

In this section the proposed method will be applied on 6-bus network shown in figure 6. This figure also specifies the location of 10 directional overcurrent relays. Table 1 and 2 present the line and load data respectively. Using graph theory, the primary/backup relay pairs are identified and depicted in table 2. In this case study, there are 20 parameters for the nonlinear optimization problem; ten TDS and 10 for $I_{p.}$ Twenty seven selectivity constraints are generated for the faults simulated at near-ends and far-ends for 6-bus system, these constraints are expected to be valid constraints in this study after relaxing 6 constraints based on the following criteria.

1) If the DOCR fault currents fall below their pick-up current, then the concerning constraints will be relaxed.
2) Many constraints are also relaxed when the fault currents directions for associated relays are opposite to each other.

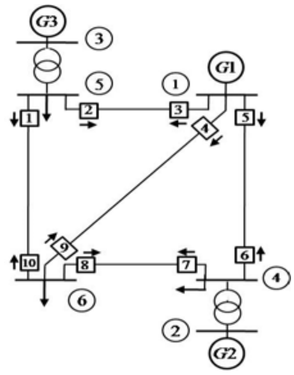

Fig. 6 Single line diagram of 6-bus system

TABLE I
LINE, TRANSFORMER AND LOAD DATA FOR 6-BUS SYSTEM

Line and Transformer Data					Load DATA		
Bus No.	Bus No.	R pu	X pu	Y pu	Bus No.	Load MW	Load Mvar
1	4	0.035	0.225	0.0	1	0	0
1	5	0.025	0.105	0.0	2	0	0
1	6	0.040	0.215	0.0	3	0	0
2	4	0.000	0.035	0.0	4	100	70
3	5	0.000	0.042	0.0	5	90	30
4	6	0.028	0.125	0.0	6	160	110
5	6	0.026	0.175	0.0			

TABLE II
PRIMARY/BACKUP RELAY PAIRS AND CURRENT TRANSFORMER

Primary relays No	Primary relays CT	Backup relays	Primary relays No	Primary relays CT	Backup relays
1	800/5	3	6	600/5	8
2	800/5	10	7	1200/5	5
3	1000/5	6-9	8	1000/5	4-1
4	1000/5	6-2	9	900/5	1-7
5	600/5	2-9	10	900/5	7-4

TABLE III
GENERATION DATA FOR 6-BUS SYSTEM

Generation data				
Bus No.	Voltage Mag.	Generation MW	Mvar Limits Min	Mvar Limits Max
1	1.06			
2	1.04	150	0	140
3	1.03	100	0	90

There are 28 selectivity constraints generated for the faults calculated at near-ends and far-ends for sample 6-bus system. Depending on the criteria described, 7 constraints are relaxed. Out of the 21 remaining valid constraints, 16 constraints belong to near-end faults and 5 constraints belong to far-end faults. The problem has been solved by three cases.

1. Case I: based on both far-end and near-end faults in constraints and Ob-Fun.
2. Case II: based on far-end and near-end faults consideration in Ob-Fun and only near-end faults was taken in constraints (Eq. 12).
3. Case III: based on the proposed approach, which depends on only near-end faults consideration in constraints and Ob-Fun.

Table 4 shows the results for the application of genetic algorithm optimization technique in order to finding the optimal values of pickup and Time Dial Settings for each DOCR. The optimization was realized for the three approaches explained above. Optimal points of objective functions obtained with approach I, approach II and approach III are 10.1486, 9.0390, and 3.1713, respectively. Significant reductions in time delays were obtained when the proposed method solves the problem.

TABLE IV

TIME DIAL SETTINGS AND PICKUP RELAYS CURRENTS RESULTING FROM GENETIC ALGORITHM OPTIMIZATION TECHNIQUE FOR 6-BUS SYSTEM.

	Genetic Algorithm Optimization technique (far-end and near end faults-Case -I)		Genetic Algorithm Optimization technique (far-end and near-end faults-Case -II)		Genetic.A Optimization technique (near end faults Case -III)	
Rel N°	TDS(s) (.01-1.1)	I_0 (A)	TDS (s) (.01-1.1)	I_P (A)	TDS (s) (.01-1.1)	I_P (A)
1	0.0845	4.1518	0.0722	4.1305	0.0905	4.3686
2	0.0549	5.7820	0.0538	5.8559	0.0509	6.4834
3	0.1079	4.6091	0.1120	4.6369	0.1225	4.6130
4	0.1137	4.2436	0.0913	4.2634	0.1000	4.3810
5	0.1518	3.7135	0.1625	2.4779	0.1341	5.0920
6	0.2017	2.4803	0.1452	2.5390	0.2077	2.5123
7	0.1241	3.9370	0.1066	3.9324	0.1409	3.8777
8	0.0725	4.9802	0.0594	5.1891	0.0333	6.9933
9	0.0295	4.7255	0.0260	4.7193	0.0322	4.6952
10	0.1180	3.6731	0.1213	3.8330	0.1055	3.7263
	Objective function 10.1486 (s)		Objective function 9.0390 (s)		Objective function 3.1713 (s)	

Case I (far-end and near-end faults consideration in constraints and Ob-Fun). Case II (far-end and near-end faults consideration in Ob-Fun and only near-end faults was taken in constraints). Case III (near-end faults consideration in constraints and Ob-Fun).

B. 26-bus system

This system (see Fig.7) consists of 26 bus bars, 8 lines, 6 generators, 7 transformers and 78 directional OC relays. All data related to this system are given in [15]. Primary and back up relays for this system and relays current transformer ratio were presented in Table 6. There are 156 optimizing parameters; 78 pick-up current and 78 time dial setting. The same approaches have been applied on this system in order to achieve the nonlinear optimization algorithm for determining relays parameters values. There are 338 selectivity constraints generated for the faults calculated at near-ends and far-ends for sample 26-bus system. Depending on the criteria described, 73 constraints are relaxed. Out of the 265 remaining valid constraints, 196 constraints belong to near-end faults and 69 constraints belong to far-end faults. The precedent cases I and III were applied in order to solve the optimization problem. The lines power flows were calculated by the Newton-Raphson technique to obtain line current and bus voltage. And then the short circuit currents have been calculated. Results were presented in Table 5.

V. RESULTS DISCUSSION

Depending on the results presented on TABLES 4,5, for the two studied cases , we find that there are no big change on problem parameters before and after applying the approach of problem reduction. In fact, the efficiency reduction of the objective function value, when applying the proposed approach on the optimization problem, didn't affect the optimization parameters values. In addition, the enormous relaxing of constraints number abbreviates the optimization time operation.

TABLE V

TIME DIAL SETTINGS AND PICKUP RELAYS CURRENTS RESULTING FROM GENETIC ALGORITHM OPTIMIZATION TECHNIQUE FOR 26-BUS SYSTEM

	Genetic Algorithm Optimization technique (far-end and near end faults-Case -I)		Genetic Algorithm Optimization technique (far-end and near-end faults-Case -II)	
Rel N°	TDS(s) (.01-1.1)	I_p (A)	TDS (s) (.01-1.1)	I_p (A)
1	0.2654	7.4556	0.5338	7.4539
2	0.3577	8.3097	0.6136	8.3043
3	0.5822	1.4278	0.7282	1.4206
4	0.2530	8.3458	0.4915	8.3298
5	0.3618	2.4639	0.3729	3.4606
6	0.7161	1.6249	0.7419	1.6154
7	0.2398	5.2005	0.2911	5.1982
8	0.2679	2.5053	0.3758	3.5049
9	0.7790	1.2143	0.8026	1.3176
10	0.3828	1.3085	0.9755	1.2119
11	0.0710	5.1798	0.0491	6.1169
12	0.1605	6.1469	0.5284	6.1463
13	0.8101	2.0645	0.8643	2.0964
14	0.3185	1.5297	0.7957	1.5476
15	0.4172	0.8920	0.6995	0.7339
16	0.2374	1.5500	0.2004	2.5876
17	0.2869	2.2315	0.3600	2.9657
18	0.2390	7.5681	0.3651	7.5615
19	0.9119	0.7179	0.8482	0.7166
20	0.4396	0.3689	1.0615	0.1885
21	0.3342	0.8866	0.6350	0.7418
22	0.8183	0.7744	0.3463	1.4773
23	0.3863	0.8049	0.6181	0.8281
24	0.5117	0.5848	0.4696	0.5298
25	0.6247	0.2881	0.5010	0.2871
26	0.9302	0.0897	0.9635	0.0888
27	0.5212	0.4511	0.6144	0.3261
28	0.4387	0.5590	0.5818	0.5408
29	0.4855	0.5516	0.4308	0.5882
30	0.2499	0.7865	0.2952	0.8050
31	0.2149	1.5972	0.4533	1.0618
32	0.3453	0.4230	0.3214	0.4471
33	0.3381	0.6406	0.3146	0.6077
34	0.2913	0.9779	0.3403	0.9668
35	0.2499	1.3615	0.2324	1.3567
36	0.5981	0.2163	0.7894	0.2150
37	0.3394	1.1297	0.3604	1.1320
38	0.4442	0.2828	0.5015	0.7766
39	0.5316	0.9464	0.7556	0.9430
40	0.2252	3.5906	0.2283	3.6022
41	0.3836	1.9152	0.3522	2.9080
42	0.4829	2.0962	0.5260	2.1068
43	0.1787	2.9476	0.2492	2.9039
44	0.3258	0.8289	0.3638	0.8350
45	0.2232	1.7298	0.2656	1.7858
46	0.7851	0.2851	0.8096	0.1459
47	0.5988	0.3684	0.5680	0.2674
48	0.5217	0.4497	0.4742	0.4493
49	0.8750	0.1780	0.5145	0.9226
50	0.5072	0.5037	0.7814	0.4458
51	0.2746	0.7129	0.3017	0.9530
52	0.2712	0.8951	0.4904	0.2487
53	0.1992	2.0776	0.1983	2.0704
54	0.3012	3.3888	0.2379	3.4515
55	0.3993	0.0894	0.4097	0.1001
56	0.4034	0.5660	0.6063	0.3250
57	0.4594	0.5816	0.4844	0.5576
58	0.3640	0.7351	0.4455	0.7901
59	0.2388	1.1431	0.3647	1.1251
60	0.4961	0.9689	0.4425	0.9483

61	0.4118	0.4846	0.4345	0.7050
62	0.4345	0.7601	0.3956	0.7499
63	0.6407	0.2761	0.6213	0.4050
64	0.6188	0.7751	0.6388	0.3284
65	0.4421	0.2574	0.7002	0.2573
66	0.4987	0.3247	0.4730	0.2987
67	0.5123	0.5711	0.4595	0.5688
68	0.3887	3.6069	0.4882	3.6002
69	0.1039	1.4402	0.1552	1.4557
70	0.3177	1.0546	0.4838	1.0279
71	0.2965	4.2227	0.3033	4.2054
72	0.4257	1.0437	0.7194	1.0210
73	0.3519	1.1234	0.3113	3.6601
74	0.3751	1.4493	0.7276	1.4465
75	0.3021	0.5539	0.3549	0.4211
76	0.2881	2.2099	0.3246	2.1756
77	0.1975	4.5806	0.3006	4.5195
78	0.3504	4.4398	0.4882	4.4337
	Objective function 188.3718 (s)		Objective function 89.4829 (s)	

Case I (far-end and near-end faults consideration in constraints and Ob-Fun). **Case** II (near-end faults consideration in constraints and Ob-Fun).

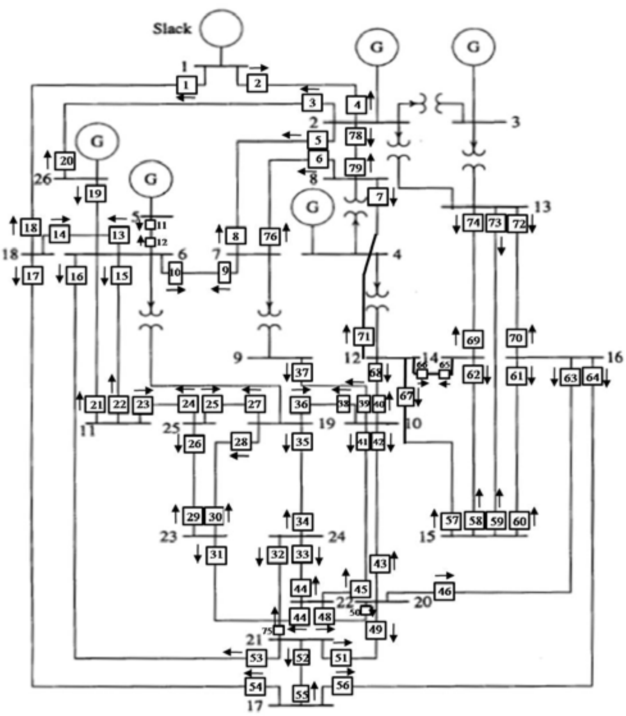

Fig. 7 Single line diagram of 26-bus system

VI. CONCULSION

This paper has presented an enhanced reformulation of the overcurrent relays coordination. An approach for constraints number reduction and reduction of the dimensions of objective function were also presented. In this paper, the constraints concerning the far end faults and their part on the objective function were relaxed. Genetic algorithm optimization technique was applied to the 6-bus and 26-bus systems in order to obtain the optimal values of overcurrent relays time dial setting (TDS) and pickup currents.

REFERENCES

[1] D. Birla, R.P. Maheshwari, HariOmGupta "Time-overcurrent relay coordination: a review, International Journal of Emerging Electric Power Systems 2 (2) (2005).

[2] H. Askarian Abyaneh, M. Al-Dabbagh, H. Kazemi Karegar, S.H.H. Sadeghi, R.A. Jabbar Khan, "A new optimal approach for coordination of overcurrent relays in interconnected power systems" IEEE Transactions on Power Delivery 18 (April (2)) (2003).

[3] Li Yinhong, Shi Dongyuan, and Dum Xianzhong "A Study on Optimal Coordination of Definitetime Relay Based'on Genetic Algorithm" 0-7803-81 10-6/03/2003 IEEE

[4] R. E. Albrecht et al. 'Digital Computer Protective Device Coordination program –Igeneral Program Description', IEEE Trans on PAS, Vol. 83, No 4, April 1964, pp. 402-410.

[5] L. Jenkines, H. Khincha, S. Shivakumar and P. Dash. "An Application of Functional Dependencies to the Topological Analysis of Protection Schemes", IEEE Transaction on Power Delivery, Vol. 7, No. 1, January 1992, pp. 77-83.

[6] D. Vijayakumar, R. K. Nema "A Novel Optimal Setting for Directional over Current Relay Coordination using Particle Swarm Optimization" International Journal of Electrical Power and Energy Systems Engineering 1;4 © www.waset.org Fall 2008

[7] J. Sadeh "Optimal Coordination of Overcurrent Relays in an Interconnected Power System" 15th PSCC, Liege, 22-26 August 2005.

[8] M. J. Damborg, et al. 'Computer Aided Transmission Protection System Design, Part I: Algorithms', IEEE Trans on PAS, Vol. 103, No 4, 1984.

[9] C. W. So, K. K. Li, K. T. Lai, and K. Y. Fung, "application of genetic algorithm for overcurrent relay coordination," in: Proc. 1997 IEE Conf.Developments in Power System Protection, pp. 66–69, 1997.

[10] C. W. So and K. K. Li, "Time coordination method for power system protection by evolutionary algorithm", IEEE Trans. on Industry Applications, vol. 36, no. 5, pp. 1235-1240,September-October2000.

[11] D.Birla, R.P. Maheshwari, and H. O. Gupta, "A New Nonlinear Directional Overcurrent Relay Coordination Technique, and Banes and Boons of Near-End Faults Based Approach". IEEE transactions on power delivery, vol. 21, no. 3, july 2006 pittsburg,20-24-july 2008.

[12] H. A. Abyaneh, H. K. Karegar, A. Zahedi, M. Al-Dabbagh, and M. Ahamadi, "Constraints reduction of the optimal Coordination of Overcurrent relays," in Proc. Australian Universities Power Engineering Conf. (AUPEC), Melbourne, Australia,Sep.–Oct.29–02,2002.

[13] F. Razavi, H. Askarian. Abyaneh, M. Al-Dabbagh, R. Mohammadi and H. Torkaman, "A new comprehensive genetic algorithm method for overcurrent relays coordination", Electr .PowerSyst.Res.May2007.

[14] H.K. Karegar, H. A. Abyaneh, V. Ohis, M. Meshkin "Pre-processing of the optimal coordination of overcurrent relays" Electric Power Systems Research 75 (2005) 134–141

[15] H.Saadat. "power system analysis". NewYork 1999.

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APPENDIX I

TABLE VI
PRIMARY AND BACKUP RELAYS FOR 26-BUS SYSTEM

Prim No	CT Ratio (./5)	Backup Relays	Prim No	CT Ratio (./5)	Backup Relays
1	1200	4	38	1000	37-68-43-45
2	1200	18	39	1200	36-45-43-68
3	1000	8-77-2	40	900	36-37-43-45
4	1200	8-77-20	41	900	43-36-37-68
5	900	20-77-2	42	900	45-36-37-68
6	900	78-71	43	1100	63-51-48
7	900	78-76-	44	1000	41-31-50
8	900	6-10-	45	1000	31-33-50
9	900	5-6	46	1200	42-48-51
10	900	11-22-53-14	47	1200	33-41-50
11	1400		48	1200	31-33-41
12	1200	9-22-53-14	49	1200	63-42-48
13	900	9-22-53-11	50	1200	42-63-51
14	1200	1-54	51	1200	55-16-32
15	1200	11-14-9-53	52	1200	49-16-32
16	1200	22-9-11-14	53	900	32-49-55
17	1200	13-1	54	800	52-64
18	1200	13-54	55	1200	17-64
19	1200	3	56	1200	17-52
20	1200	21	57	1200	61-62-73
21	1200	15-24	58	1200	61-67-73
22	1200	19-24	59	1200	67-62-61
23	1200	15-19	60	1200	73-62-67
24	1200	29-27	61	1200	72-46-56
25	1200	23-29	62	1200	74-66
26	1200	23-27	63	1200	60-72-56
27	1200	30-34-38	64	1200	60-72-46
28	1200	25-34-38	65	1200	58-74
29	1200	28-47	66	1200	7-57-40
30	1200	47-26	67	1200	7-40
31	1200	26-28	68	900	7-57
32	1200	44-35	69	1200	58-66
33	900	35-75	69	1200	58-66
34	900	44-75	70	900	60-46-56
35	900	30-25-38	71	1200	40-57-65
36	1200	25-30-34	72	1200	59-69
37	1000		73	1200	70-69
74	1200	59-70	75	1200	16-55-49
76	1200	10-5	77	900	71-76
			78	900	8-20-2

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