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Directional Overcurrent Relays Coordination Restoration by Reducing Minimum Fault Current Limiter Impedance

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Abstract: FCL (fault current limiter) is used to solve relays miscoordination problem arises from DG (distributed generation) installation. In most published researches, different optimization methods are developed to obtain optimal relay settings to achieve coordination in case of not installing DG, then depending on the achieved optimal obtained relay settings, FCL impedance is deduced to ensure relays coordination restoration in case of installing DG. Based on original optimal relay settings, obtained FCL impedance is not the minimum one required to achieve relay coordination. The contribution of this paper is the generation of multi sets of original relay settings that increase the possibility of finding FCL impedance of minimum value which is lower than the calculated value based on original optimal relay settings. The proposed method achieves better economic target by reducing FCL impedance. The proposed approach is implemented and tested on IEEE-39 bus test system.

Key words: FCL (fault current limiter), IP (pickup current setting), relays coordination, TDS (time-dial setting).

1. Introduction

The advantageous applications of DG (distributed generation) can be summarized as: backup generation, loss reduction, power quality improvement, grid expansion postponement, rural and remote application, combined heat and power generation, and financial and trading purposes [1]. These advantages can be achieved if the relevant issues are deliberately taken into account. One of the most influential issues is the coordination of protective devices.

The presence of DG tends to affect negatively the protective relays coordination. The unacceptable operation of protective devices may occur, since the protection coordination will be lost if the fault current characteristic flowing through any protective device is changed, especially in case of DOCRs (directional overcurrent relays). In power delivery systems without DGs, several methods are proposed for the coordination of these relays. Traditionally, a trial and error procedure was employed for setting relays in multi-loop networks. In a trial to minimize the number of iterations needed for coordination process, a technique is proposed to break all the loops at the breakpoints and locate the relays for which to start the coordination procedure [2]. A systematic approach for determining the relative sequence setting of the relays in a multi-loop network based on a linear graph theory approach is suggested in Ref. [3]. The graph theoretic concepts are extended by proposing a systematic algorithm for determining a relative sequence matrix corresponding to a set of sequential pairs which reduced the number of iterations [4]. A functional dependency concept for topological analysis of the protection scheme is proposed by expressing the

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constraints on the relay settings through a set of functional dependencies [5]. Both the graph theoretic and functional dependency approaches provide a solution which is the best setting, but not necessarily an optimal solution. The coordination of DOCRs in optimization frame is presented in Ref. [6] by using generalized reduced gradient nonlinear optimization technique. Another method is proposed to consider the dynamic changes in the networks topology for DOCRs using linear programming [7].

In some other researches, coordination problem has been solved in the frame of optimization frame based on applying AI (artificial intelligence) such as, GA (genetic algorithm), EA (evolutionary algorithm), and PSO (particle swarm optimization). A modified particle swarm optimization method is proposed for optimal DOCRs settings taking into account the discrete values for the pickup current settings by formulating coordination problem as a mixed integer nonlinear problem [8]. A method based on GA was developed to solve the problems of miscoordination and continuous or discrete time setting multipliers [9].

In Ref. [10], an approach to solve DOCRs coordination problem arises from installing DG is presented. This approach involved the implementation of FCL to locally limit the DG fault current and thus restore the original relay coordination without altering the original relay settings. This approach basically centered on the selection of optimal original relay settings using two phase optimization technique in case of without DG installation, FCL impedances (resistive and inductive) have been calculated based on these relay settings. The same main idea has been developed based on (GA) technique [11]. Both El-Khattam and Agheli [10, 11] concerned only with optimal original relays setting, then centered on these relays setting, FCL impedance has been calculated.

The coordination scheme is normally determined according to specific considerations of the distribution system as each utility has its own criteria and required constraints. The main philosophy is that the protection devices are coordinated such that the primary protection operates before the backup protection can take its action. Miscoordination situations result in nuisance tripping to some of the loads and false tripping for healthy feeders. In addition, it may cause long delay for tripping of faulty feeders, resulting in increasing fault currents causing significant overstress on power system equipment, and finally replacement of equipment may be required.

The main contribution of this paper is to deduce FCL impedance based on multi sets of original relay settings, therefore, increasing the possibility of finding FCL of optimal minimum value. Procedure of selecting relay settings sets is developed in optimization frame using linear programming technique. The proposed approach is examined on IEEE-39 bus test system.

2. Overview on Linear Programming

LP (linear programming) is a technique for solving optimization problems. In such problems, a linear objective function is subject to linear equality and inequality constraints. A linear programming problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints. Not all linear programming problems can so easily solved.

DOCRs coordination problem can be defined as linear programming problem with constraints that can be solved using one of the linear programming techniques, namely: simplex, dual simplex, or two phase simplex technique.

The simplex algorithm, invented by George Dantzig in 1947, is one of the earliest and one of the best known optimization algorithms for obtaining a basic feasible solution; if the solution is not optimal; the method provides a neighboring basic feasible solution that has a lower or equal value of function. The process is repeated until, in a finite number of steps, an optimum is found. Dual simplex method is a variant of regular simplex method, developed by Lemke, to solve a linear programming problem. It starts from infeasible solution to the primal. The method works in an iterative manner such that it forces the solution to become feasible as well as optimal at some stage. This method has some important characteristics; it does not require the first phase calculations of the two phase simplex method. This is a desirable feature, as the starting point obtained at the end of first phase, may not be near optimal. In addition, it works towards feasibility and optimality simultaneously; the solution is expected to be achieved in less number of iterations [10].

Many software have been developed for the mentioned various linear programming techniques, optimization toolbox included in Matlab environment is considered an easy and powerful tool to implement different linear programming techniques.

3. Proposed Approach Formulation

3.1 Conventional Coordination Problem

The problem of DOCRs coordination is stated as a parametric optimization problem. Solving this problem implies finding the coordinated setting TDS and pickup current settings for all the directional overcurrent relays in the system so that the sum of operating times of the primary relays for near end faults is minimized and the coordination constraints are satisfied. Therefore:

(1) The objective function is that the total time for N primary relays for near end faults is minimized as follows:

$$\sum_{i=1}^{N} t_i \quad (1)$$

(2) To ensure relay coordination, the operating time of the backup relay has to be greater than that of the primary relay for the same fault location by a CTI (coordination time interval) as:

$$t_{j,i} - t_i \geq CTI_{j,i} \quad (2)$$

where, $t_{j,i}$ is the operating time of the first back up j-th relay for a near end fault at the i-th relay, $CTI_{j,i}$ is the coordination time interval for backup-primary relay pair (*j,i*). Based on the local distribution company practice, coordination interval value can be taken between 0.2 s and 0.5 s which includes relay overtravel time, breaker operating time, and safety margin for relay error.

(3) The boundary conditions on relay settings can be written as linear inequalities of two sets as follows:

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

$$Ip_{i,\min} \leq Ip_i \leq Ip_{i,\max} \quad (4)$$

where,

$TDS_{i,\min}$, $TDS_{i,\max}$ is the minimum and maximum value of *TDS* of relay R_i, respectively. $TDS_{i,\min}$, $TDS_{i,\max}$ values are taken 0.05 and 1.1, respectively. Ip_i is the pickup current setting of relay R_i. Limits of Ip_i are chosen between 1.25 and 2 times the maximum load current seen by the relay.

(4) Relays characteristics under simplistic assumptions are assumed identical and their functions are approximated by:

$$t_{j,i} = \frac{0.14\,TDS}{\left(\left(\frac{I_{f\,j,i}}{I_{P\,j}}\right)^{0.02} - 1\right)} \quad (5)$$

where,

$I_{f\,j,i}$ is the short circuit current passing through the relay R_j for fault at *i*, $t_{j,i}$ is the operating time of the relay R_j, for a fault at *i* .

3.2 DOCRs Coordination for a System Not Including DG Using Multi Sets of Original Relay Settings

From the above subsection, it can be seen that for previously predefined value of $Ip_i = Ip_{Fixed}$, Eq. (5), can be reduced to :

$$t_{j,i} = a_{j,i} \times TDS_j \quad (6)$$

Therefore, the problem of DOCRs coordination could be treated as a LP problem.

Considering x_i , x_j as (TDS) of relay *Ri* and *Rj* respectively, a simplified relay coordination problem for the general case shown in Fig. 1 can be represented as follows:

(1) Objective function:

$$\text{Minimize} \quad \sum_i^j a_{i,i} x_i + \sum_i^j a'_{i,i} x_i \quad (7)$$

(2) Subject to constraints without network topology:

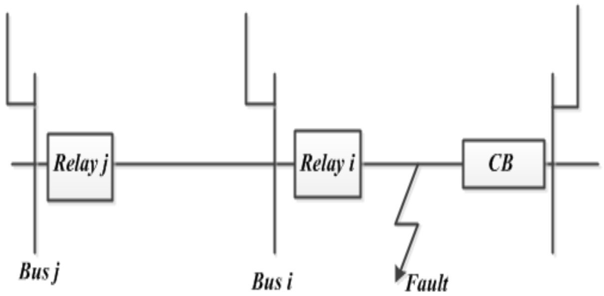

Fig. 1 A typical primary and backup relays on a part of a power system.

$$a_{j,i}x_j - a_{i,i}x_i \geq k \quad (8a)$$

where,

$a_{j,i}$, $a_{i,i}$are the coefficient of the j^{th}, i^{th} relays given by "(6)," for a near end fault at *Ri* respectively.

(3) Subject to constraints with network topology:

$$a'_{j,i}x_j - a'_{i,i}x_i \geq k \quad (8b)$$

where,

$a'_{j,i}$, $a'_{i,i}$ are as the same of $a_{j,i}$, $a_{i,i}$ but taking into consideration any network topology.

$a_{j,j}$, $a'_{j,j}$ are as the same of $a_{i,i}$, $a'_{i,i}$ but for the j-th relay for a near end fault at R_j.

(4) Boundary conditions can be written as linear inequalities of:

$$l_i \leq x_i \leq u_i$$
$$l_j \leq x_j \leq u_j$$

where,

$l_i = l_j$ = minimum value of TDS;

$u_i = u_j$= maximum value of TDS.

In case that the pickup current values of the relays are known previously, $a_{i,i}$, $a'_{i,i}$, $a_{j,i}$, $a'_{j,i}$ will be constants and the problem is solved in terms of variable (TDS).

The graphical presentation of this problem is shown in Fig. 2. The procedure shown in Fig. 3 to obtain multi sets of relays, TDS is as follows:

(5) For primary and backup relays, load flow and near-end fault currents are calculated. For fixed *Ip* , TDS values are calculated and constrains are checked. If the constrains are violated, another values of *Ip* are chosen until all constrains are satisfied, thus TDS set that corresponding to point "*A*" is obtained.

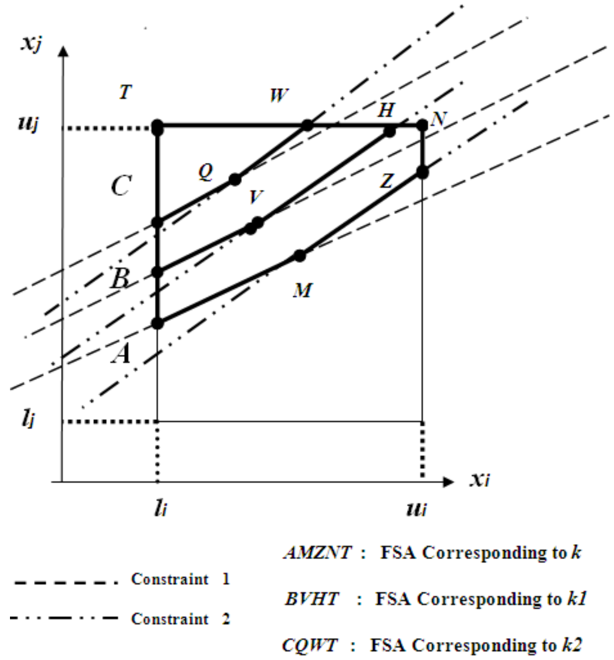

Fig. 2 Three sets of relays TDS for a simplified example.

(6) Resolving the problem using the correct *Ip* set, however in this time the value of *k* is replaced by kk_1 where $k_1 > 1$. If constraints are satisfied, therefore a new set of *TDS* is obtained that corresponding to point "*B*". Repeating step (3) by replacing *k* with kk_2 where $k_2>k_1$, thus a new set of TDS is obtained that corresponding to point "*C*".

(7) The process should be stopped at the step at which the constraints are violated. If the assumed value of *k* in this step equals to kk_n, the possible number of relays TDS sets for relay coordination will be n sets. AMZNT shape represents FSA (feasible solution area) that contains "*A*", "*B*" and "*C*". Thus, for the simplified example, the points "*B*" and "*C*" achieve relay coordination but not the optimal one when compared with "*A*" .

Where: *k* is the coordination time interval, kk_1, ..., kk_n are the assumed values of coordination time intervals.

3.3 FCL Selection Based on Multi Sets of Relay Settings

In most published researches, the minimum fault current limiter is developed only based on optimal

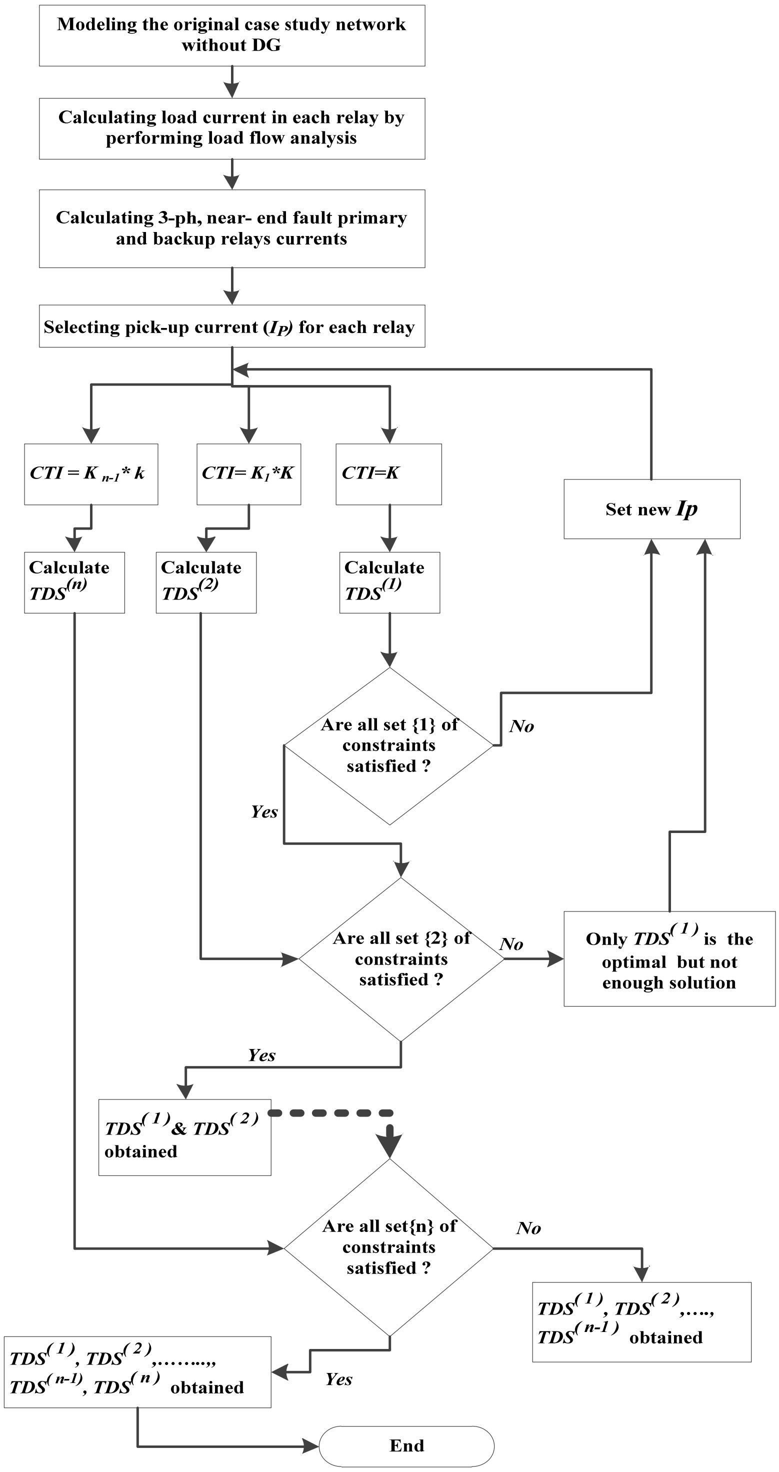

Fig. 3 DOCRs coordination procedure using multi sets of relays settings.

relay settings. However in this paper, different values of FCL are generated based on multi sets of original relay settings. The minimum obtained value of FCL impedance is lower than the developed by other traditional techniques.

The step by step process for determining FCL impedance for each relay settings will be briefly discussed as follows:

(1) Calculating optimal original relays settings set (not including DG) as mentioned before in the previous subsection.

(2) Starting with a low value of FCL impedance and then fault calculations are carried out to improve relays coordination.

(3) Increasing the value of FCL impedance step by step and calculating CTI of all relay pairs based on fault calculations, taking into account that the value of FCL will be inserted only during fault and has no effect during normal power flow.

(4) Repeating the above steps until the lowest value of CTI for miscoordinated relay pairs are achieved at new RCTI (revised coordination time interval), which is near to or lower than the original value of CTI.

The above procedure is repeated by replacing the optimal original relay settings set in the first step by another new set that developed in the previous subsection. Finally, different values of FCL impedances are obtained.

4. Analysis and Results

The complete system under study is the 39-bus IEEE system that shown in Fig. 4. It has 345, 230 and 22 kV buses, with 34 lines, 10 generators, 12 transformers and 84 directional overcurrent relays.

4.1 Optimal & Non-Optimal Relay Coordination Results for System Not Including DG

In this study, continuous TDS & *Ip* values are allowed, a fixed *Ip* value corresponding to 1.5 times maximum load current is firstly chosen and shown in Table 1. Consequently, by applying the steps in Section *3.2*, three different sets of relays TDS are generated to achieve relays coordination. The results are given in Tables 2-4 where CTI = 0.2 s, k_1 = 1.1, and k_2 = 1.25.

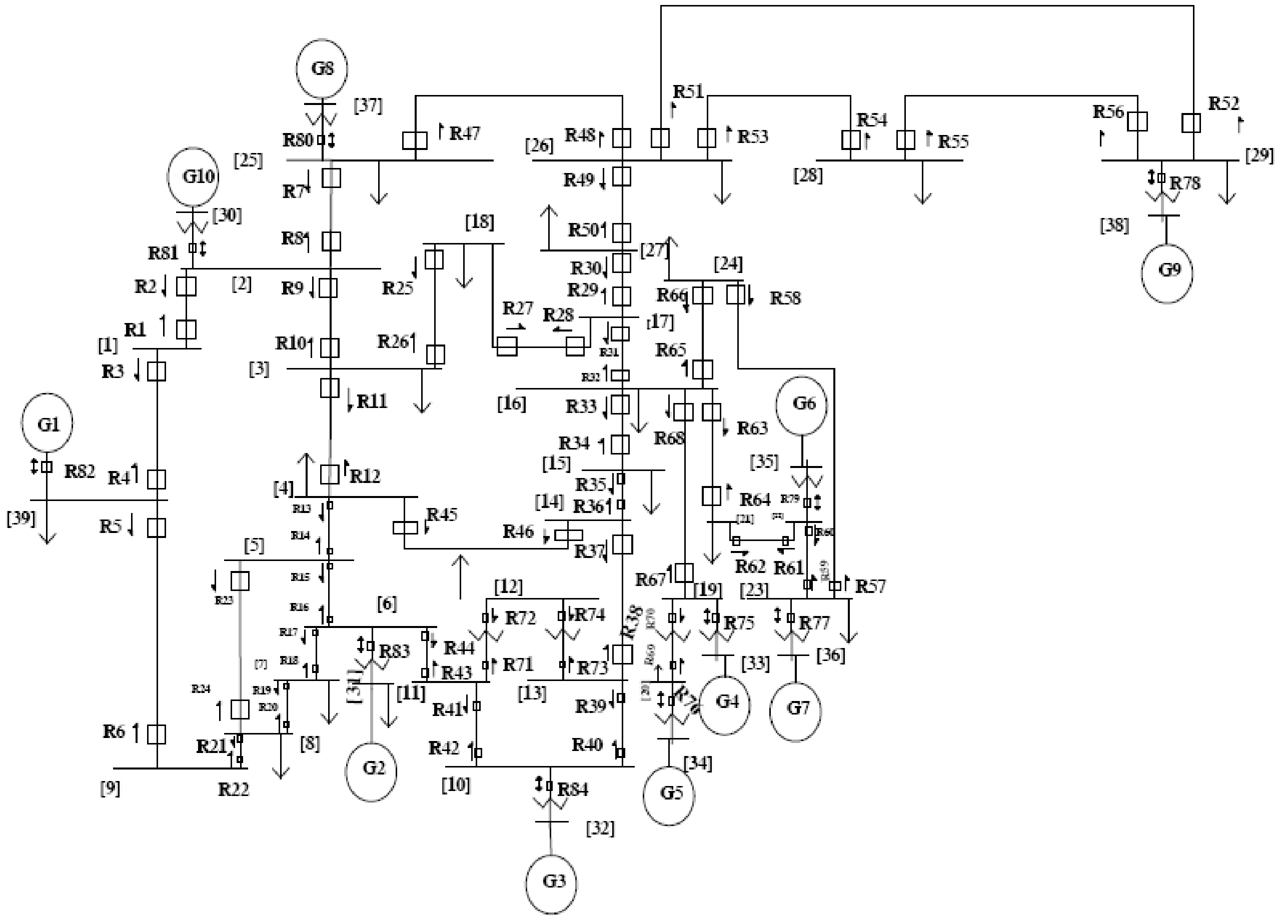

Fig. 4 IEEE-39 bus system.

Table 1 I_p**s for relays in power system configuration not including DG.**

I_p	Value	I_p	Value	I_p	Value	I_p	Value	I_p	Value	I_p	Value
I_p1	1.5	I_p15	1.5	I_p29	1.3445	I_p43	10.721	I_p57	10.625	I_p71	1.333
I_p2	3.78	I_p16	6.0	I_p30	1.5	I_p44	1.5	I_p58	1.5	I_p72	1.5
I_p3	3.66	I_p17	5.427	I_p31	1.5	I_p45	1.5	I_p59	1.5	I_p73	1.460
I_p4	1.5	I_p18	1.5	I_p32	6.395	I_p46	8.257	I_p60	1.79	I_p74	1.5
I_p5	1.77	I_p19	6.013	I_p33	9.843	I_p47	2.334	I_p61	7.374	I_p75	7.545
I_p6	1.5	I_p20	1.5	I_p34	1.5	I_p48	1.5	I_p62	1.5	I_p76	9.857
I_p7	7.57	I_p21	1.5	I_p35	1.5	I_p49	8.255	I_p63	1.5	I_p77	6.715
I_p8	1.5	I_p22	2.203	I_p36	1.601	I_p50	1.5	I_p64	10.08	I_p78	9.904
I_p9	11.251	I_p23	10.087	I_p37	1.5	I_p51	1.5	I_p65	1.5	I_p79	7.976
I_p10	1.5	I_p24	1.5	I_p38	9.163	I_p52	6.083	I_p66	3.033	I_p80	6.433
I_p11	4.129	I_p25	1.063	I_p39	1.5	I_p53	1.5	I_p67	5.478	I_p81	8.446
I_p12	1.5	I_P26	1.5	I_p40	9.412	I_p54	4.537	I_p68	1.5	I_p82	12.233
I_p13	1.5	I_P27	1.5	I_p41	1.5	I_p55	1.5	I_p69	1.5	I_p83	7.154
I_p14	5.1	I_p28	5.848	I_p42	10.94	I_p56	10.5	I_p70	5.229	I_p84	8.135

Table 2 Optimal *TDS* for relays in power system configuration not including DG.

TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value
TDS1	0.529	TDS15	0.334	TDS29	0.679	TDS43	0.232	TDS57	0.169	TDS71	0.05
TDS2	0.309	TDS16	0.247	TDS30	0.566	TDS44	0.73	TDS58	0.363	TDS72	0.272
TDS3	0.248	TDS17	0.213	TDS31	0.637	TDS45	0.657	TDS59	0.348	TDS73	0.05
TDS4	0.641	TDS18	0.312	TDS32	0.468	TDS46	0.305	TDS60	0.381	TDS74	0.277
TDS5	0.57	TDS19	0.274	TDS33	0.394	TDS47	0.5292	TDS61	0.107	TDS75	0.109
TDS6	0.376	TDS20	0.53	TDS34	0.575	TDS48	0.52	TDS62	0.304	TDS76	0.05
TDS7	0.293	TDS21	0.466	TDS35	0.64	TDS49	0.316	TDS63	0.517	TDS77	0.075
TDS8	0.665	TDS22	0.435	TDS36	0.657	TDS50	0.551	TDS64	0.133	TDS78	0.05
TDS9	0.34	TDS23	0.236	TDS37	0.67	TDS51	0.285	TDS65	0.487	TDS79	0.081
TDS10	0.614	TDS24	0.473	TDS38	0.28	TDS52	0.1097	TDS66	0.35	TDS80	0.092
TDS11	0.452	TDS25	0.673	TDS39	0.579	TDS53	0.286	TDS67	0.186	TDS81	0.296
TDS12	0.675	TDS26	0.752	TDS40	0.32	TDS54	0.168	TDS68	0.05	TDS82	0.345
TDS13	0.497	TDS27	0.646	TDS41	0.635	TDS55	0.206	TDS69	0.484	TDS83	0.065
TDS14	0.414	TDS28	0.464	TDS42	0.267	TDS56	0.13	TDS70	0.05	TDS84	0.073

Table 3 Second SET of relays *TDS* for relays in power system configuration not including DG.

TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value
TDS1	0.583	TDS15	0.367	TDS29	0.747	TDS43	0.256	TDS57	0.186	TDS71	0.05
TDS2	0.34	TDS16	0.272	TDS30	0.623	TDS44	0.804	TDS58	0.399	TDS72	0.3
TDS3	0.273	TDS17	0.234	TDS31	0.701	TDS45	0.723	TDS59	0.383	TDS73	0.05
TDS4	0.706	TDS18	0.344	TDS32	0.514	TDS46	0.335	TDS60	0.42	TDS74	0.304
TDS5	0.627	TDS19	0.301	TDS33	0.433	TDS47	0.582	TDS61	0.118	TDS75	0.12
TDS6	0.414	TDS20	0.583	TDS34	0.632	TDS48	0.572	TDS62	0.334	TDS76	0.05
TDS7	0.323	TDS21	0.513	TDS35	0.704	TDS49	0.348	TDS63	0.568	TDS77	0.082
TDS8	0.731	TDS22	0.479	TDS36	0.723	TDS50	0.606	TDS64	0.146	TDS78	0.05
TDS9	0.374	TDS23	0.259	TDS37	0.737	TDS51	0.313	TDS65	0.536	TDS79	0.089
TDS10	0.676	TDS24	0.52	TDS38	0.309	TDS52	0.121	TDS66	0.386	TDS80	0.102
TDS11	0.497	TDS25	0.74	TDS39	0.637	TDS53	0.315	TDS67	0.205	TDS81	0.326
TDS12	0.743	TDS26	0.827	TDS40	0.352	TDS54	0.184	TDS68	0.05	TDS82	0.38
TDS13	0.547	TDS27	0.71	TDS41	0.698	TDS55	0.226	TDS69	0.533	TDS83	0.071
TDS14	0.455	TDS28	0.51	TDS42	0.294	TDS56	0.143	TDS70	0.05	TDS84	0.081

Table 4 Third SET of relays *TDS* for relays in power system configuration not including DG.

TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value	TDS	Value
TDS1	0.662	TDS15	0.417	TDS29	0.849	TDS43	0.2905	TDS57	0.2117	TDS71	0.05
TDS2	0.3867	TDS16	0.3092	TDS30	0.707	TDS44	0.9136	TDS58	0.4537	TDS72	0.341
TDS3	0.31	TDS17	0.2658	TDS31	0.796	TDS45	0.8212	TDS59	0.4351	TDS73	0.05
TDS4	0.8018	TDS18	0.3903	TDS32	0.585	TDS46	0.3811	TDS60	0.4769	TDS74	0.346
TDS5	0.7128	TDS19	0.342	TDS33	0.492	TDS47	0.6616	TDS61	0.1343	TDS75	0.137
TDS6	0.4704	TDS20	0.6623	TDS34	0.718	TDS48	0.6496	TDS62	0.3799	TDS76	0.05
TDS7	0.3666	TDS21	0.5829	TDS35	0.8	TDS49	0.3951	TDS63	0.646	TDS77	0.094
TDS8	0.8311	TDS22	0.544	TDS36	0.821	TDS50	0.6891	TDS64	0.166	TDS78	0.05
TDS9	0.4252	TDS23	0.295	TDS37	0.837	TDS51	0.3559	TDS65	0.609	TDS79	0.102
TDS10	0.7679	TDS24	0.591	TDS38	0.351	TDS52	0.1372	TDS66	0.438	TDS80	0.116
TDS11	0.5651	TDS25	0.841	TDS39	0.724	TDS53	0.3576	TDS67	0.233	TDS81	0.37
TDS12	0.844	TDS26	0.94	TDS40	0.4	TDS54	0.2091	TDS68	0.05	TDS82	0.432
TDS13	0.6211	TDS27	0.807	TDS41	0.793	TDS55	0.2572	TDS69	0.605	TDS83	0.081
TDS14	0.5174	TDS28	0.579	TDS42	0.334	TDS56	0.1626	TDS70	0.05	TDS84	0.092

4.2 DOCRs Miscoordination in a Power System Configuration with DG

DG is assumed to be added at bus 28, the transient reactance and capacity of the DG are 0.02 pu and 10 MVA, respectively. The DG is connected to the network through a transformer of 10 MVA capacity and 0.01 pu reactance. The near-end fault primary and backup relays current are calculated in the presence of DG. Table 5 shows the miscoordination occurrence cases for 19 pairs of relays based on optimal set of relays TDS. Tables 6 and 7 depicted the miscoordination occurrence cases for 5 and 3 pairs of relays based on the second and third sets of relays *TDS* respectively.

Table 5 Miscoordinated relays pairs in presence of DG based on optimal relays TDS.

CTI	Value	CTI	Value
CTI 10,8	0.1984	CTI 49,30	0.1795
CTI 48,7	0.1926	CTI 28,25	0.1979
CTI 54,48	0.1485	CTI 9,26	0.1961
CTI 52,48	0.1901	CTI 46,12	0.1989
CTI 54,49	**0.0159**	CTI 11,45	0.1983
CTI 52,49	0.0543	CTI 72,41	0.1988
CTI 7,9	0.1903	CTI 33,35	0.1989
CTI 25,10	0.1984	CTI 30,31	0.1883
CTI 51,56	0.1961	CTI 31,33	0.1963
CTI 55,52	0.1642		

Table 6 Miscoordinated relays pairs in presence of DG based on second set of relays TDS.

CTI	Value	CTI	Value
CTI 54,48	0.1628	CTI 55,52	0.1806
CTI 54,49	**0.0170**	CTI 49,30	0.1974
CTI 52,49	0.05976		

Table 7 Miscoordinated relays pairs in presence of DG based on third set of relays TDS.

CTI	Value
CTI 54,48	0.185
CTI 54,49	**0.0193**
CTI 52,49	0.0679

4.3 FCL Implementation

As illustrated from miscoordination cases shown in Table 5, the lowest value of CTI, based on optimal relays TDS, which equals to 0.0159 s, is occurred for relays pair 49 and 54. However based on the second and third sets of relays, TDS values are 0.0170 and 0.0193, respectively.

(1) As shown in Fig. 5, the CTI 54,49 is nearly improved to 0.1922 s (0.96% of the original (CTI) by introducing X-FCL of 35 pu. This value is calculated based on optimal relays TDS. The total optimal operating time in such case equals to 76.6 s.

(2) From Fig. 6, the CTI 54,49 is nearly improved to 0.1917 s by introducing X-FCL of 4 pu. This value is calculated based on the second set of relays TDS, and the total operating time equals to 83.5044 s.

(3) Moreover, based on the third set of relays TDS,

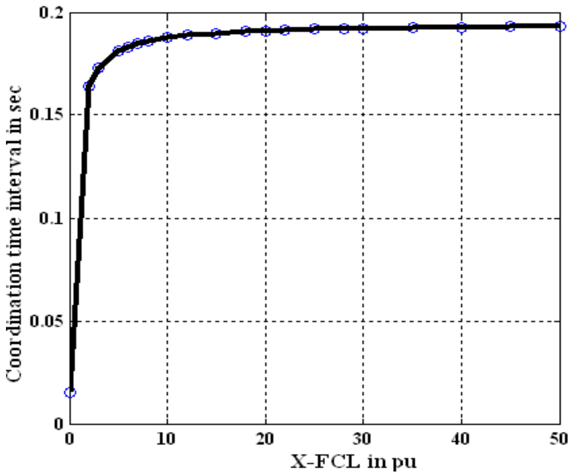

Fig. 5 Coordination time interval CTI 54,49 based on optimal relays TDS.

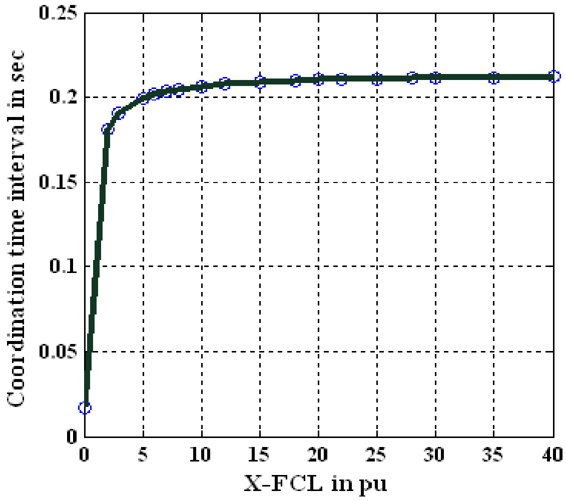

Fig. 6 Coordination time interval CTI 54,49 based on second set of relays TDS.

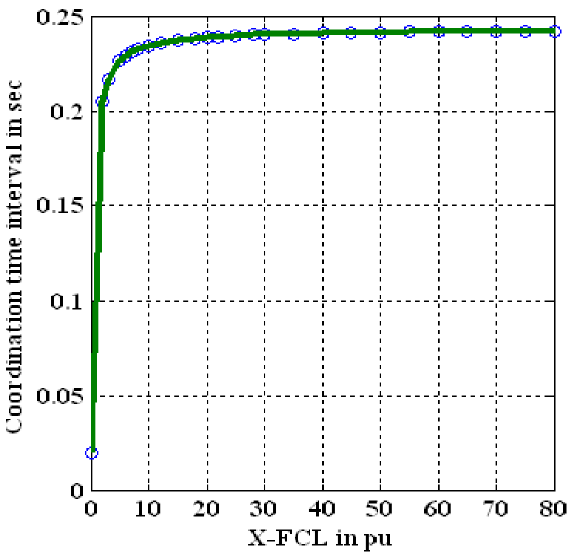

Fig. 7 Coordination time interval CTI 54,49 based on third set of relays TDS.

the corresponding value of X-FCL equals to 2 pu as illustrated in Fig. 7.

As clearly shown, FCL has a large value of 35 pu based on the traditional method of optimal relays TDS, while FCL of minimum impedance value equals to 2 pu is developed based on the selection of a new relay settings for original network. These achieved results ensure the effectiveness of the proposed method in restoring relay coordination with a lower value of FCL impedance.

5. Conclusions

This paper outlines one of the economic challenges to interconnect DG into utility system. It highlights the importance of choosing relay settings to reduce the FCL impedance to the possible lowest value thus, achieve better economic target. An integrated model, using linear programming based on Matlab optimization toolbox function linprog, is introduced to generate multi sets of original relay settings that required for relays coordination. These sets are used to implement FCL impedances. The results ensure the capability of the proposed method to obtain FCL impedance of lower value than the other calculated based on traditional method that only depends on optimal relay settings.

The achieved results are based on near end, 3-ph faults at each relay of IEEE-39 bus test system.

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