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Two approaches for directional overcurrent relays coordination in interconnected power systems with distributed generation

By

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Abstract:

Connection of distributed generation (DGs) powered by renewable energy resources in power systems has numerous benefits. However the presence of these (DGs) increase the fault current levels in different points, and disturb the protection coordination of the existing relays. Two approaches are proposed for coordination of directional overcurrent relays (DOCRs) in power systems with (DGs), depending on the types of system relays either adaptive or non adaptive.

For adaptive protection system, the first proposed approach is based on linear programming technique which used to calculate the relay settings in case of DGs existing or not. For non-adaptive protection system, the second proposed approach is introduced, in which minimum impedance of fault current limiter is calculated to restore the coordination of relays without altering the original relay settings. The two proposed approaches are implemented and tested on IEEE-39 bus test system.

Keywords: Distributed Generation, Fault Current Limiter, Relay Setting, Relays Coordination.

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1. Introduction:

The advantageous applications of DG 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 negatively affect 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 directional overcurrent relays (DOCRs). 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 [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 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 [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 techniques such as, Genetic algorithm (GA), Evolutionary algorithm (EA), and particle swarm optimization. A modified particle swarm optimization method is proposed for optimal DOCRs settings taking into account the discrete values for the pick-up 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 this paper, the problems of DOCRs coordination in power system network including DG in case of either adaptive or non adaptive protection system relays types are solved using two proposed solutions. DOCRs coordination is stated as a linear programming optimization problem using the first proposed approach. However the second approach involves the implementation of a fault current limiter to locally limit the DG fault current, and thus restore the original relay coordination. The implementation of the two approaches based on IEEE-39 bus case study is carried out.

2.Overview on Linear Programming:

Linear programming (LP) is a technique for 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 are so easily solved. There may be many variables and many constraints. Some variables may be constrained to be nonnegative and others unconstrained. Some of the main constraints may be equalities and others inequalities.
DOCRs coordination problem can be defined as linear programming problem with constraints and 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 best known optimization algorithms for obtaining a basic feasible solution; if the solution is not optimal, the method provides for finding 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 phase I calculations of the two phase simplex method. This is a desirable feature, as the starting point obtained at the end of phase I, 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- Overview on Relay Characteristics:

A typical inverse time overcurrent has two values to be set, the pick-up current value (*Ip*) which is the minimum current value for which the relay operates, and the time dial setting (*TDS*) which defines the operation time of the device for each current value. Under simplistic assumptions, the relay characteristics are assumed identical and with characteristic functions approximated by:

$$t_{i,k} = \frac{0.14 \times TDS_i}{(\frac{I_{i,k}}{I_{Pi}})^{0.02} - 1} \qquad (1)$$

Where:

$I_{i,k}$ is the short circuit current passing through the relay R_i ,for fault at k ,

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

4. First Proposed Approach Programming:

4.A. Coordination Problem Formulation:

The problem of DOCRs coordination is stated here as a linear programming optimization problem using the first proposed approach. Solving this problem implies finding the coordinated settings *TDS* and pick-up current setting 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:

- The objective function is that the total time for N primary relays for near end fault is minimized ($\sum_{i=1}^{N} t_i$ is minimum).
- 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 coordination time interval as : $t_{j,i} - t_i \geq CTI_{j,i}$

  Where: $t_{j,i}$ is the operation 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). It can be chosen based on the local distribution company practice, which consists of: relay overtravel time, the breaker operating time, and safety margin for relay error. It can take a value between 0.2 and 0.5 s. In this paper, a coordination time interval of 0.2 s was adopted.

- The boundary conditions on relay settings can be written as linear inequalities, of two sets as follows:

  $TDS_{i,\min} \le TDS_i \le TDS_{i,\max}$, $Ip_{i,\min} \le Ip_i \le Ip_{i,\max}$

  Where:

  $TDS_{i,\min}, TDS_{i,\max}$ is minimum and maximum value of *TDS* of relay R_i respectively. $TDS_{i,\min}, TDS_{i,\max}$ are taken 0.05 and 1.1 respectively.

  Ip_i is the pickup current settings of relay R_i. Limits of Ip_i are chosen between 1.25 and 2 times the maximum load current seen by each relay.

  For previously predefined value of $Ip_i = Ip_{Fixed}$, Equation (1) can be reduced to:

$$t_{i,k} = a_{i,k} * TDS_i \qquad (2)$$

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

4.B. DOCRs Coordination for a Power System Configuration Without DG:

To test the first proposed method, the case study of IEEE-39 bus system that shown in Figure (1) is simulated. This case study system has 345, 230 & 22 kV buses, with 34 lines, 10 generators, 12 transformers and 84 OC relays.

Firstly, load flow and near-end fault primary and backup relays currents are calculated.

Then, the optimization model is formulated as a linear programming (LP) problem considering previously predetermined values of *Ip* which varies between 1.25 and 2 times the maximum load current seen by each relay and *TDS* lies between 0.05 and 1.1.

For a fixed *Ip* corresponding to 1.5 times maximum load current and 1.5A for relays in the opposite direction, *TDS* values are calculated for each relay and coordination time interval (*CTI*) constraints are checked, if the constraints are violated, another values of *Ip* is chosen. The above steps are shown in Figure (2).

By applying the above procedure, all constraints are satisfied. Tables (1) and (2) demonstrate the obtained results for testing the first approach.

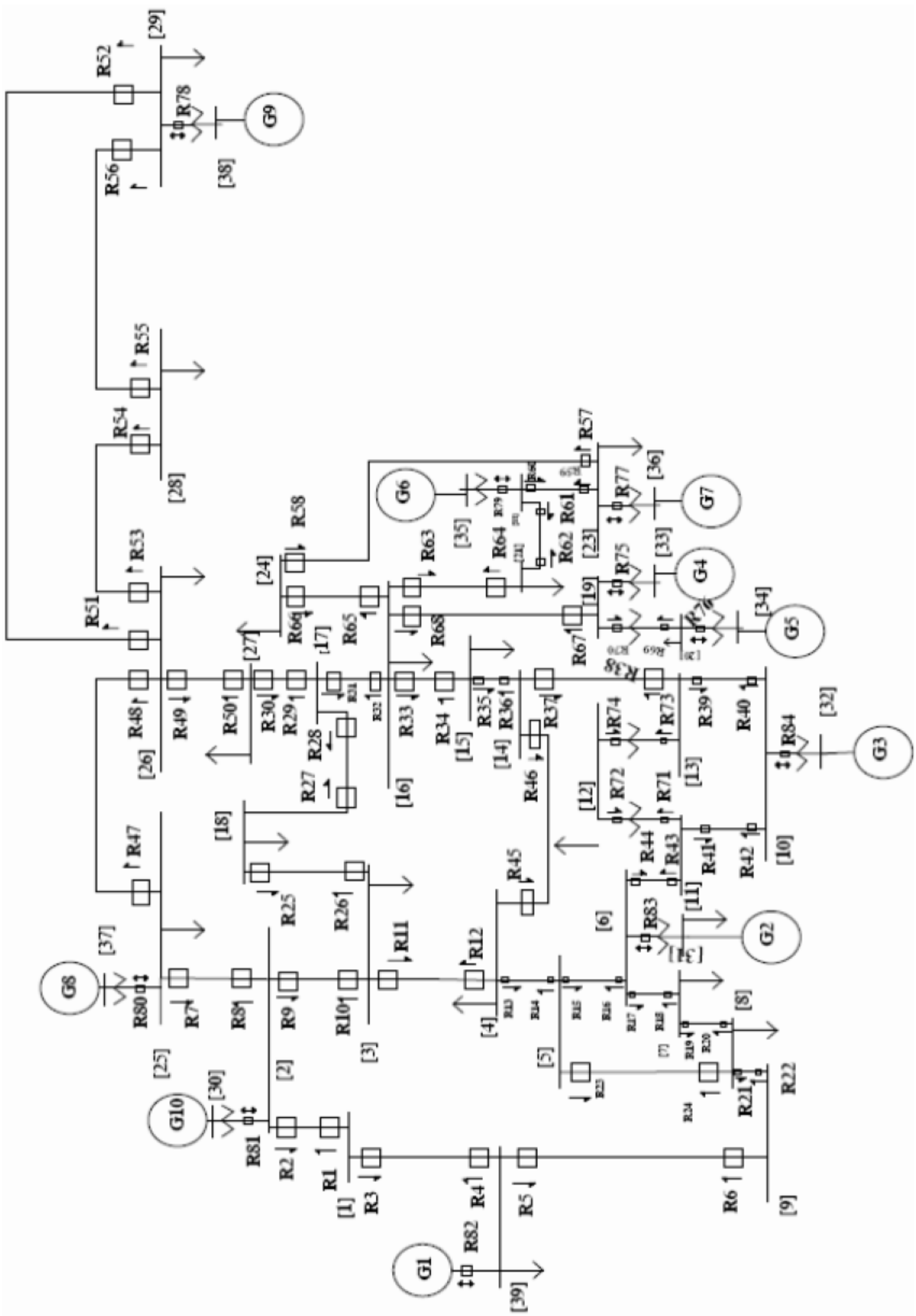

Figure (1): *IEEE-39 bus system*

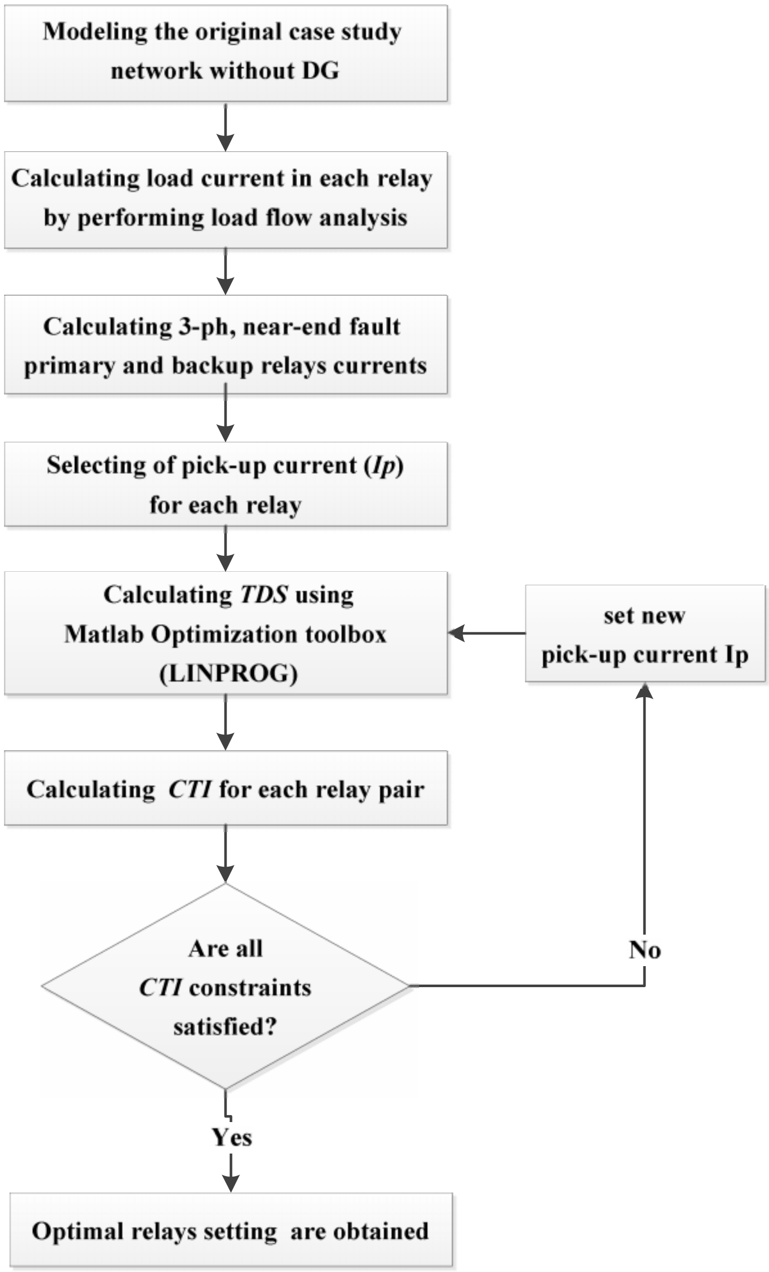

Figure (2): *Flow chart of DOCRs coordination in a power system configuration without DG using first approach*

Table (1): *Ips for relays in power system configuration without DG*

Ip	Value	*Ip*	Value	*Ip*	Value	*Ip*	Value
Ip1	1.5	*Ip22*	2.203125	*Ip43*	10.72125	*Ip64*	10.08
Ip2	3.78	*Ip23*	10.0875	*Ip44*	1.5	*Ip65*	1.5
Ip3	3.658125	*Ip24*	1.5	*Ip45*	1.5	*Ip66*	3.03375
Ip4	1.5	*Ip25*	1.063125	*Ip46*	8.2575	*Ip67*	5.478
Ip5	1.771875	*IP26*	1.5	*Ip47*	2.334375	*Ip68*	1.5
Ip6	1.5	*IP27*	1.5	*Ip48*	1.5	*Ip69*	1.5
Ip7	7.57125	*Ip28*	5.848125	*Ip49*	8.255625	*Ip70*	5.229375
Ip8	1.5	*Ip29*	1.344375	*Ip50*	1.5	*Ip71*	1.333125
Ip9	11.25188	*Ip30*	1.5	*Ip51*	1.5	*Ip72*	1.5
Ip10	1.5	*Ip31*	1.5	*Ip52*	6.0825	*Ip73*	1.460625
Ip11	4.12875	*Ip32*	6.395625	*Ip53*	1.5	*Ip74*	1.5
Ip12	1.5	*Ip33*	9.84375	*Ip54*	4.5375	*Ip75*	7.545
Ip13	1.5	*Ip34*	1.5	*Ip55*	1.5	*Ip76*	9.85725
Ip14	5.098125	*Ip35*	1.5	*Ip56*	10.5	*Ip77*	6.71475
Ip15	1.5	*Ip36*	1.60125	*Ip57*	10.62563	*Ip78*	9.9045
Ip16	6.036	*Ip37*	1.5	*Ip58*	1.5	*Ip79*	7.97625
Ip17	5.42775	*Ip38*	9.163125	*Ip59*	1.5	*Ip80*	6.4335
Ip18	1.5	*Ip39*	1.5	*Ip60*	1.790625	*Ip81*	8.446875
Ip19	6.013125	*Ip40*	9.4125	*Ip61*	7.374	*Ip82*	12.23303
Ip20	1.5	*Ip41*	1.5	*Ip62*	1.5	*Ip83*	7.15425
Ip21	1.5	*Ip42*	10.9425	*Ip63*	1.5	*Ip84*	8.13525

Table (2): *Optimal TDS for relays in power system configuration without DG*

TDS	Value	*TDS*	Value	*TDS*	Value	*TDS*	Value
TDS1	0.529579	*TDS22*	0.435473	*TDS43*	0.232433	*TDS64*	0.132519
TDS2	0.3093571	*TDS23*	0.235767	*TDS44*	0.730852	*TDS65*	0.486888
TDS3	0.2479933	*TDS24*	0.472817	*TDS45*	0.656957	*TDS66*	0.35082
TDS4	0.6414664	*TDS25*	0.672985	*TDS46*	0.304848	*TDS67*	0.186422
TDS5	0.5701535	*TDS26*	0.752233	*TDS47*	0.529214	*TDS68*	0.05
TDS6	0.3763307	*TDS27*	0.645655	*TDS48*	0.519719	*TDS69*	0.484394
TDS7	0.2933137	*TDS28*	0.463591	*TDS49*	0.31609	*TDS70*	0.05
TDS8	0.664837	*TDS29*	0.678976	*TDS50*	0.551281	*TDS71*	0.05
TDS9	0.3401322	*TDS30*	0.565973	*TDS51*	0.284946	*TDS72*	0.272794
TDS10	0.6142968	*TDS31*	0.637003	*TDS52*	0.109759	*TDS73*	0.05
TDS11	0.4520729	*TDS32*	0.467611	*TDS53*	0.286098	*TDS74*	0.27674
TDS12	0.6751627	*TDS33*	0.393544	*TDS54*	0.167761	*TDS75*	0.109318
TDS13	0.4968642	*TDS34*	0.574515	*TDS55*	0.205804	*TDS76*	0.05
TDS14	0.4139164	*TDS35*	0.639737	*TDS56*	0.130258	*TDS77*	0.074992
TDS15	0.3335647	*TDS36*	0.657129	*TDS57*	0.169382	*TDS78*	0.05
TDS16	0.2473283	*TDS37*	0.669728	*TDS58*	0.362934	*TDS79*	0.081285
TDS17	0.2126053	*TDS38*	0.28067	*TDS59*	0.348031	*TDS80*	0.092618
TDS18	0.3122686	*TDS39*	0.579341	*TDS60*	0.381494	*TDS81*	0.29632
TDS19	0.2736297	*TDS40*	0.319667	*TDS61*	0.107456	*TDS82*	0.345324
TDS20	0.5298683	*TDS41*	0.634601	*TDS62*	0.303883	*TDS83*	0.064807
TDS21	0.466287	*TDS42*	0.267072	*TDS63*	0.516804	*TDS84*	0.073465

4.C. 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 (3) shows miscoordination occurrence cases for 19 pair of relays as the coordination time intervals are less than 0.2 sec

Table (3): *Miscoordination in a power system configuration with DG*

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		

4.D. DOCRs Coordination in a Power System Configuration with DG:

Load flow and near-end fault primary and backup relays current are calculated in the presence of DG using (LP) technique. For a fixed *Ip*, *TDS* values are calculated for each relay, then coordination time interval (*CTI*) constraints are checked, if the constraints are violated, another value of *Ip* is chosen till all constraints satisfied.
The above steps are the same as described in Figure (2). Therefore, by applying the above procedure, the all constraints (143) for the studied network with DG are satisfied.

Tables (4) and (5) demonstrate the obtained results for testing the first approach.

Table (4): *Optimal TDS for relays in power system configuration with DG using first proposed approach*

TDS	Value	*TDS*	Value	*TDS*	Value	*TDS*	Value
TDS1	0.5289336	*TDS22*	0.4358532	*TDS43*	0.2320537	*TDS64*	0.1324828
TDS2	0.3082957	*TDS23*	0.2363354	*TDS44*	0.7324193	*TDS65*	0.4873489
TDS3	0.2471482	*TDS24*	0.4737728	*TDS45*	0.6579499	*TDS66*	0.3504673
TDS4	0.6408254	*TDS25*	0.6665916	*TDS46*	0.3050039	*TDS67*	0.1862339
TDS5	0.5694809	*TDS26*	0.7528269	*TDS47*	0.5342886	*TDS68*	0.05
TDS6	0.376151	*TDS27*	0.6461303	*TDS48*	0.5269608	*TDS69*	0.483984
TDS7	0.2941975	*TDS28*	0.4630452	*TDS49*	0.3217389	*TDS70*	0.05
TDS8	0.6642149	*TDS29*	0.6828945	*TDS50*	0.5495256	*TDS71*	0.05
TDS9	0.3403531	*TDS30*	0.5731229	*TDS51*	0.2985431	*TDS72*	0.2736158
TDS10	0.6146338	*TDS31*	0.6397358	*TDS52*	0.1243865	*TDS73*	0.05
TDS11	0.4512626	*TDS32*	0.4690496	*TDS53*	0.298911	*TDS74*	0.2770615
TDS12	0.6752644	*TDS33*	0.3931753	*TDS54*	0.1951805	*TDS75*	0.109225
TDS13	0.4979912	*TDS34*	0.5743806	*TDS55*	0.239716	*TDS76*	0.05
TDS14	0.4182135	*TDS35*	0.640649	*TDS56*	0.1383463	*TDS77*	0.0749863
TDS15	0.3344074	*TDS36*	0.6643197	*TDS57*	0.169308	*TDS78*	0.05
TDS16	0.2492072	*TDS37*	0.6705945	*TDS58*	0.3632686	*TDS79*	0.0812488
TDS17	0.2134017	*TDS38*	0.2825611	*TDS59*	0.3481035	*TDS80*	0.092531
TDS18	0.3129088	*TDS39*	0.5801126	*TDS60*	0.3814084	*TDS81*	0.2958481
TDS19	0.2748826	*TDS40*	0.3215791	*TDS61*	0.1074561	*TDS82*	0.3450451
TDS20	0.5307297	*TDS41*	0.636165	*TDS62*	0.3041644	*TDS83*	0.0668114
TDS21	0.4661235	*TDS42*	0.2666553	*TDS63*	0.517168	*TDS84*	0.0736228

Table (5): *CTI of all relay pairs in power system configuration with DG using first approach*

CTI j,i	*CTI*	*CTI j,i*	*CTI*	*CTI j,i*	*CTI*	*CTI j,i*	*CTI*
CTI 4,1	0.2	*CTI 27,29*	0.304798	*CTI 72,41*	0.2	*CTI 67,33*	0.274007
CTI 7,2	0.651483	*CTI 26,27*	0.2	*CTI 39,42*	0.2	*CTI 36,34*	0.2
CTI 10,2	0.62814	*CTI 21,6*	0.2	*CTI 84,42*	0.270574	*CTI 17,19*	0.2
CTI 81,2	0.634968	*CTI 28,25*	0.2	*CTI 18,44*	0.2	*CTI 22,20*	0.2
CTI 1,8	0.2	*CTI 9,26*	0.2	*CTI 83,44*	0.2	*CTI 23,20*	0.2
CTI 10,8	0.2	*CTI 12,26*	0.2	*CTI 43,17*	0.524621	*CTI 19,21*	0.248228
CTI 81,8	0.2	*CTI 82,4*	0.2	*CTI 15,17*	0.2	*CTI 23,21*	0.331628
CTI 48,7	0.2	*CTI 6,4*	0.2	*CTI 83,17*	0.717138	*CTI 19,24*	0.2
CTI 80,7	0.2	*CTI 82,5*	0.263332	*CTI 20,18*	0.2	*CTI 22,24*	0.278113
CTI 8,47	0.2	*CTI 3,5*	0.2	*CTI 83,18*	2.685191	*CTI 66,63*	0.54714
CTI 80,47	0.311377	*CTI 25,11*	0.279803	*CTI 24,15*	0.421268	*CTI 67,63*	0.542556
CTI 54,48	0.347152	*CTI 9,11*	0.451505	*CTI 13,15*	0.2	*CTI 31,63*	0.465819
CTI 52,48	0.350639	*CTI 14,12*	0.2	*CTI 18,16*	0.392743	*CTI 34,63*	0.538951
CTI 50,48	0.2	*CTI 46,12*	0.2	*CTI 43,16*	0.2	*CTI 61,64*	0.2
CTI 54,49	0.2	*CTI 41,40*	0.2	*CTI 83,16*	0.382981	*CTI 62,60*	0.2
CTI 52,49	0.2	*CTI 84,40*	0.2	*CTI 35,37*	0.2	*CTI 79,60*	0.2
CTI 47,49	0.2	*CTI 74,39*	0.2	*CTI 45,37*	0.200313	*CTI 59,61*	0.2
CTI 7,9	0.2	*CTI 37,39*	0.2	*CTI 74,38*	0.284815	*CTI 79,61*	0.378606
CTI 1,9	0.203566	*CTI 84,39*	0.555264	*CTI 40,38*	0.2	*CTI 63,62*	0.2
CTI 12,10	0.369995	*CTI 43,71*	2.045112	*CTI 33,35*	0.2	*CTI 60,57*	0.2
CTI 25,10	0.2	*CTI 38,73*	2.297199	*CTI 38,36*	0.2	*CTI 77,57*	0.286552
CTI 29,50	0.2	*CTI 40,73*	294.3489	*CTI 45,36*	0.2	*CTI 65,58*	0.2
CTI 52,53	0.865944	*CTI 76,69*	3.379582	*CTI 30,31*	0.2	*CTI 77,59*	0.2
CTI 47,53	0.803113	*CTI 75,70*	3.022053	*CTI 27,31*	0.2	*CTI 58,59*	0.2
CTI 50,53	0.658855	*CTI 67,70*	1.224457	*CTI 34,32*	0.2	*CTI 64,65*	0.2
CTI 56,54	0.2	*CTI 75,67*	0.2	*CTI 66,32*	0.2	*CTI 67,65*	0.592518
CTI 53,55	0.2	*CTI 69,67*	0.2	*CTI 67,32*	0.2	*CTI 31,65*	0.519684
CTI 51,56	0.2	*CTI 38,46*	0.401976	*CTI 46,13*	0.504952	*CTI 34,65*	0.592202
CTI 78,56	0.765093	*CTI 35,46*	0.401015	*CTI 11,13*	0.455664	*CTI 57,66*	0.2
CTI 54,51	0.857363	*CTI 14,45*	0.249702	*CTI 16,14*	0.2	*CTI 66,68*	1.217027
CTI 47,51	0.80777	*CTI 11,45*	0.2	*CTI 24,14*	0.2	*CTI 64,68*	0.823188
CTI 50,51	0.662925	*CTI 2,3*	0.2	*CTI 5,22*	0.2	*CTI 34,68*	1.215165
CTI 55,52	0.2	*CTI 42,43*	0.2	*CTI 13,23*	0.305892	*CTI 31,68*	1.141606
CTI 78,52	1.04383	*CTI 83,43*	1.968492	*CTI 16,23*	0.530224	*CTI 30,28*	0.221987
CTI 4,1	0.2	*CTI 72,43*	0.412337	*CTI 31,33*	0.2	*CTI 32,28*	0.2
CTI 7,2	0.651483	*CTI 44,41*	0.2	*CTI 66,33*	0.273376		

5. Second Proposed Approach:

The proposed approach considers the idea to negate or, at the very least, minimize the contribution of the DG during a fault, while adding no adverse effects to the network during normal steady state non-fault operation. It introduces the use of fault current limiter (FCL) in series with DG to limit the current of the DG during a fault, and therefore to restore the original relay coordination. The advantage of this solution over others is that it does not require the existing relay protection scheme in a distribution system to be changed adaptively [11]-[12].
Therefore, using this solution, the miscoordination of relays can be solved without the need to change the relay settings or DG disconnecting during fault. The process of determining FCL type whether resistive, inductive or combined and calculating its minimum impedance will be briefly discussed in the following steps:

- The first step in this approach is to calculate original relays settings (without DG) as mentioned before in Section *4.B.*
- The second step is to start with low value of FCL and then fault calculation is carried out to improve relays coordination.
- Then, the value of FCL is increased step by step and *CTI* of each relay pair is calculated based on fault calculations, taking into account the new value of FCL during fault only and therefore prevent any effect during power flow.
- The above steps are repeated until the lowest value of the *CTI* of miscoordination relay pairs is achieved to a new revised coordination time interval (*RCTI*) , Which is near to or lower than the original value of *CTI.*

The steps of the second proposed approach are explained briefly in Fig (3).
As previously shown in Table (3), the lowest value of *CTI* is occurred for relays pair 49 and 54 which equals to 0.0159 s.
As shown in Table (6), the *CTI 54,49* is improved nearly to 0.1922 sec (0.96% of the original (*CTI*) by introducing the resistive FCL of 28 pu or by introducing X-FCL of 35 pu. Finally combined FCL of :(30+30 j pu) improves the *CTI54,49* to the same value. Therefore, the resistive FCL is considered more effective than the inductive one.
It is obviously shown from Figs (4), (5) and (6) that any increase of FCL above theses values has no improvement on *CTI54,49.*

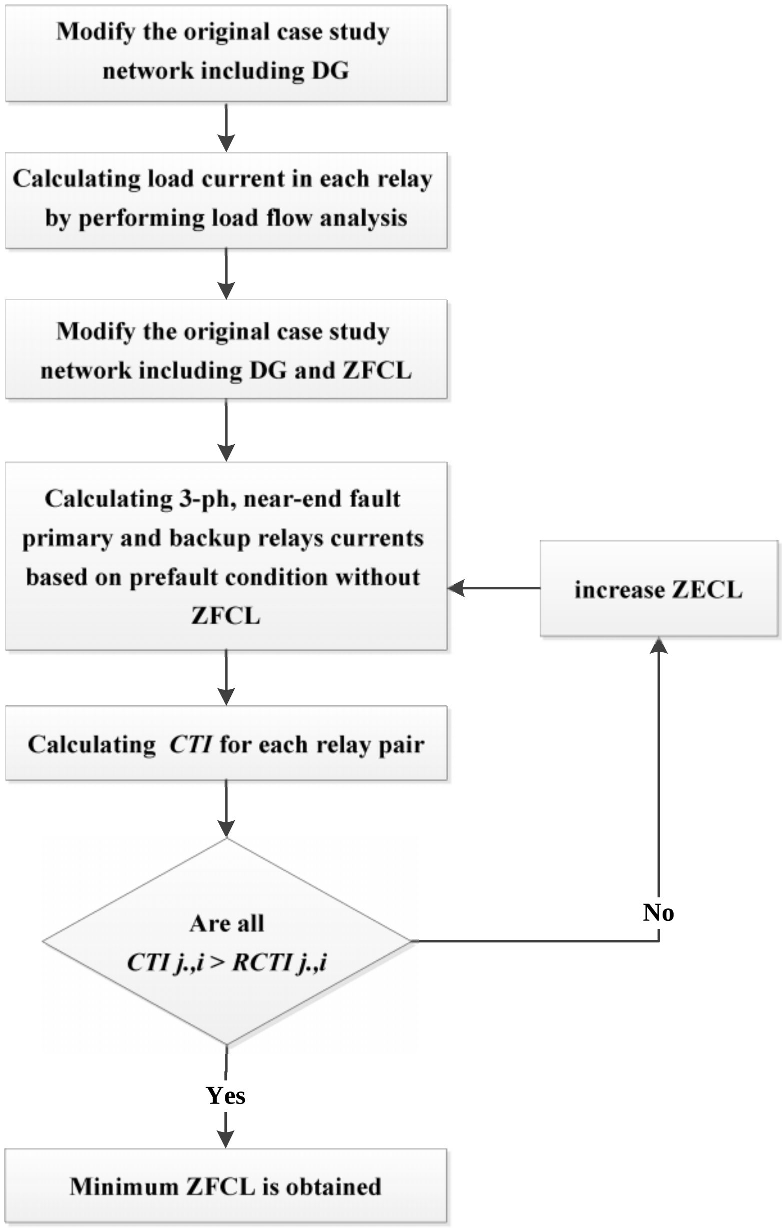

Figure (3): *Flow chart of the second proposed approach for DOCRs coordination in a power system configuration with DG*

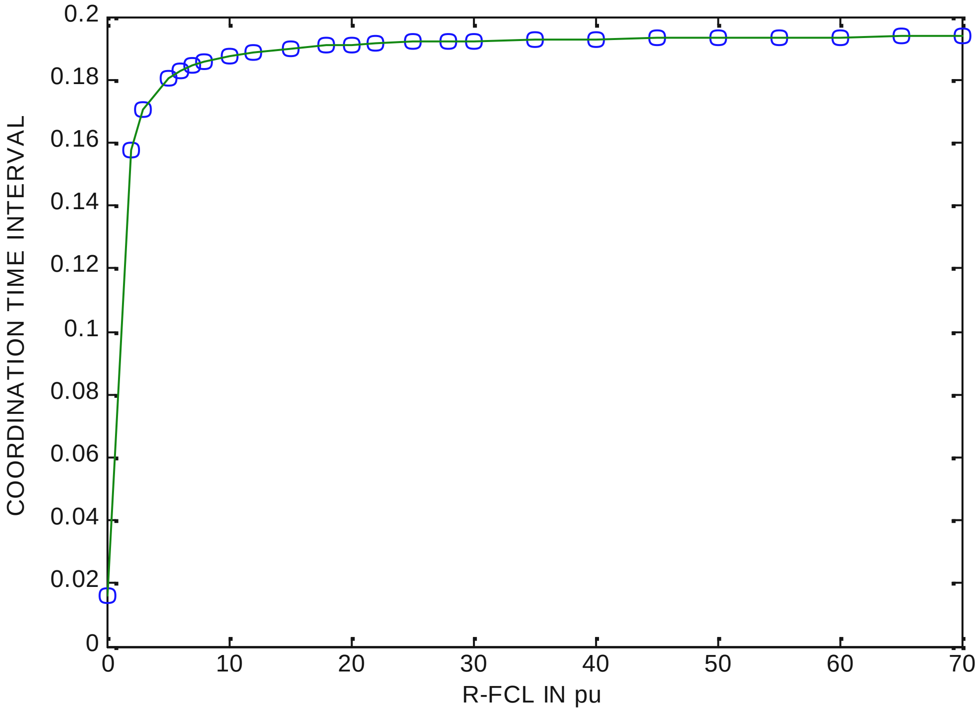

Figure (4): *Coordination time interval CTI 54,49 using R-FCL*

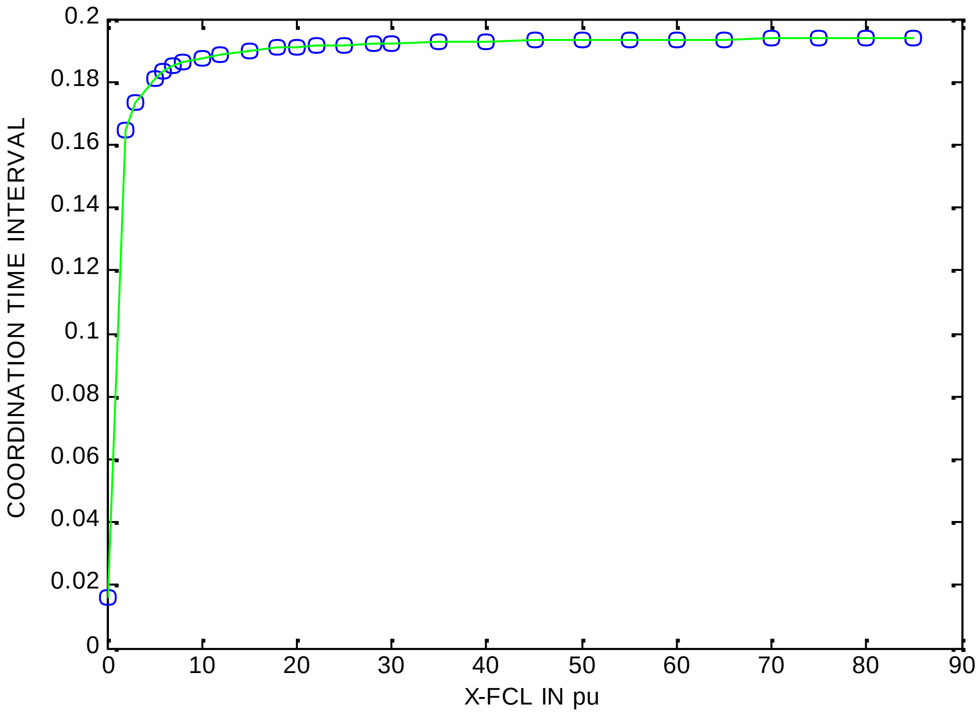

Figure (5): *Coordination time interval CTI 54,49 using X-FCL*

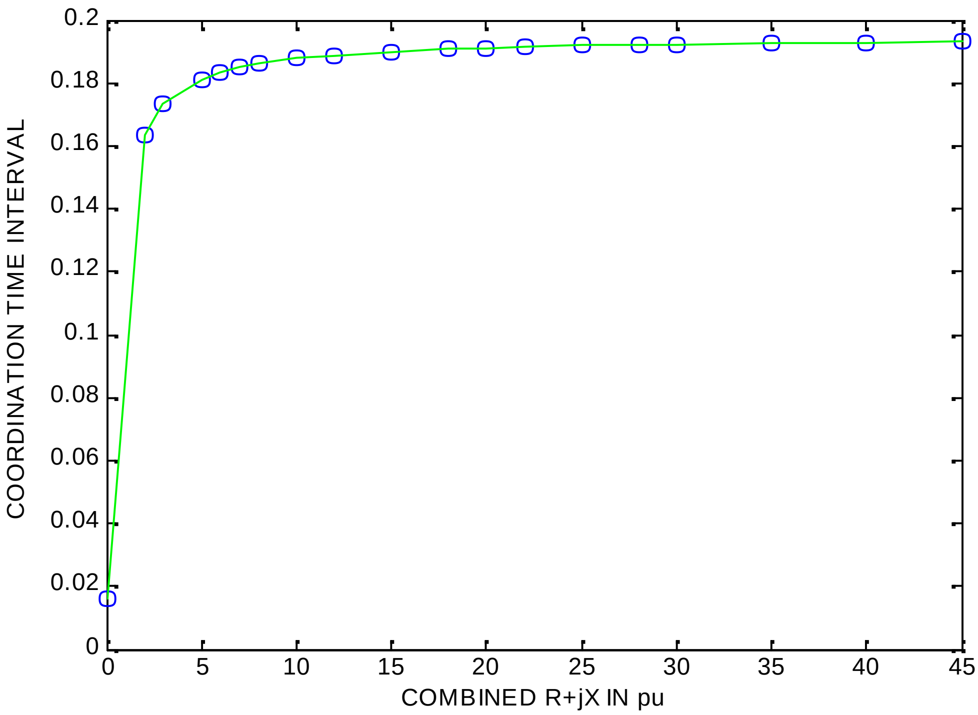

Figure (6): *Coordination time interval CTI 54,49 using Combined Z- FCL*

6. Conclusion :

Coordination of DOCRs in presence of DG is introduced using two approaches. The first one is suitable for adaptive relays, relay settings in case of no existing and existing DG have been calculated using (LP) technique based on Matlab optimization toolbox. The second approach is suitable for non adaptive relays, in which, FCL is introduced to restore the coordination of relays without changing of relay settings. The results show that the R-FCL with lower impedance than X-FCL and combined Z–FCL is chosen for the case study. The results given are based on near end, 3-Ø faults at each relay of IEEE-39 bus case study for the two approaches.

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Nomenclatures:

TDS_i	Time dial setting of relay R_i
Ip_i	Pick-up current of relay R_i
t_i	Operating time of the *i th* primary relay for a near end fault at *i* (in seconds)
$t_{j,i}$	Operating time of the first back up *j th* relay for a near end fault at the *i th* relay
$CTI_{j,i}$	Coordination time interval for backup-primary relay pair (*j*,*i*)