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Bayati, Navid; Aghaee, Fateme; Sadeghi, S. H.H.

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The Adaptive and Robust Power System Protection Schemes in the Presence of DGs

Navid Bayati*‡, Fateme Aghaee**, S. H. H. Sadeghi***

* Department of Energy Technology, Aalborg University, Esbjerg, Denmark

**Department of Electrical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran

*** Department of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran

(nab@et.aau.dk, fateme.aghaei@sru.ac.ir, Sadeghi@aut.ac.it)

‡ Department of Energy Technology, Aalborg University, Esbjerg, Denmark,

nab@et.aau.dk

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Abstract- In recent years, using distributed generations (DGs) has increased in order to compensate the load and consumption growth. Although connecting DG resources to power system has many advantages, it might cause some protective problems such as mis-coordination between network protection devices, due to the changing in the short circuit level of power system. In this paper, two method for restoring the coordination of relays in the presence of DGs by using FCLs are proposed. In both methods, different criteria, such as considering the variation of network topology, optimizing the value and number of FCLs are considered to propose a comprehensive and adaptive protection method. In the first method, an adaptive protection scheme by using FCLs is proposed to active and deactivate FCLs in different topologies to restore the coordination of relays. In addition, the second method proposes a robust method which considers all possible situations and topologies of the power system to maintain the coordination of power system during fault. Finally, the proposed robust and adaptive protection scheme has been compared in terms of cost, the operation time of relays and computation time, and based on the aims of operators in a power system one of these method can be implemented, The proposed methods are implemented on IEEE 14-bus standard network, and all possible topologies of the mentioned network are considered. Simulation results show that the proposed method can maintain the coordination of overcurrent relay protection in the presence of DGs and topology changes. In other words, the proposed method is robust against topologies changes.

Keywords Relay; protection; power system; optimization; robust.

1. Introduction

Due to the economic and environmental advantages of renewable energy resources, using DGs has increased in recent years [1-2]. Despite these advantages, installing DGs in the power systems change the direction and magnitude of short-circuit currents (SCs) [3]. One of the most important parameter in selecting protection devices such as Circuit Breaker (C.B), fuse, CT and relay is SC, hence, installing DGs in the power system change the operation and coordination of protection devices [4]. An undeniable challenge caused by the presence of DGs in the power system is Directional Over-Current Relay (DOCR) mis-coordination [5]. In the power systems, settings of relays must be set chronologically, during fault, the primary relay must detect fault first, then, if the primary relay fails, the backup relay must operate after a coordination time interval (CTI), this process is known as DOCR protection coordination. But, installing DGs change the SC level, and it causes mis-coordination between DOCRs in the power system.

A few researches have been published in the context of improving the coordination of DOCRs. In [6], a numerical method has been used to optimize the operation time of DOCRs. But, due to the complexity of the power systems, optimization methods are widely used for coordinating DOCRs to improve DOCR coordination. The Linear Programming (LP) technique for adjusting the DOCR settings was used in [7]. However, since LP only optimizes linear variables, this method cannot adjust the current setting of DOCRs. Thus, Genetic Algorithm (GA) [8], Particle Swarm Optimization (PSO) [9] and Firefly algorithm [10] have been used for optimizing time and current settings of DOCRs. For increasing the computational speed of optimization algorithms, a hybrid algorithm based on the LP and GA has been used in [11] for DOCR coordination. In this method, linear and nonlinear variables have been optimized using LP and GA, respectively. Hence, Due to the decreasing number of GA variables, the computational speed and convergence of the optimization algorithm have increased.

Usually, in the protection studies the topology of the power systems are considered as a fixed network, but, in real situations, DGs and network topology can be changed. Hence, it modifies the SC level and causes mis-coordination in the DOCRs. In [7], coordination of DOCRs has been solved using LP through considering the absence and presence of DGs.

One of the most efficient methods for decreasing the impact of DGs in power system protection is using a fault current limiters (FCLs). During normal conditions, FCLs behave as a zero impedance, but during fault, it adds an impedance to the power system to limit the fault current. This characteristics of FCLs decrease the SC level to the desired value. Using FCLs has a few advantages, such as, decreasing SC level and voltage sag in fault conditions, increasing stability and reliability of the power system. In radial networks, placement of FCLs is simple, but in the ring networks, placement and sizing of FCLs faced with a complexity due to the bidirectional flow of current during fault. In other words, fault current is injected to the fault point from two different sides of the fault. Hence, a single FCL cannot decrease SC level to the desired value, then, placement and sizing of FCLs are a challenging task.

Using FCL in power systems requires an optimized placement and sizing. In [12], the value of FCLs have been increased step by step until it has reached to an appropriate impedance and when these FCLs restore the coordination of DOCRs, the increasing trend of FCL impedances will stop. This method cannot be used in complex power systems with a large number of constraints. Hence, optimization methods can be used for solving FCLs placement in power systems with a lot of buses. Several methods have been proposed for optimal placement and sizing of FCLs in [13-14]. And in [15], the sensitivity factor has been used for the placement of FCLs, in this method, the number of search space has been decreased. Hence, the computational speed and accuracy of the proposed method have been improved. Also, in [16], Hashing-Integrated Generic Algorithm has been used for sizing FCLs in order to restore DOCR coordination in the presence of DGs, and the operation time of DOCRs has been reduced by using FCLs.

Two different models are defined for FCLs, Resistance and Impedance model. A comprehensive comparison between these two models has been performed in [17]. In the impedance model, the number of variables are twice the resistance model. Hence, the optimum fitness value would be closer to the desired values in impedance models. But, the cost of the resistance model is lower than the impedance models.

In [13], a protection method by using FCLs is presented and it used GA for optimizing multi-objective fitness function for calculating the FCL placements to restore DOCR coordinations. The fitness function in [13] includes different objectives, such as, restoring DOCR coordination, reducing operation time, reducing cost issues and power loss. But, in this paper, the presence of DGs and changing network topology did not considered and they can eliminate the coordination of DOCRs. Changing the connections of transmission lines and DGs modify the network topology. Hence, it changes the SC level of the power system and thus causes some challenges in power system protection. For this reason, all network topologies must be considered in the coordination of DOCRs and protection studies.

On the other hand, considering all network topologies in optimizing size and place of FCL increases the number of constraints and computational time. This problem can be solved through adaptive protection, which includes the Central Protection Unit (CPU) and can detect the topology and decide according to the current topology of the power system. In [18], FCLs and adaptive protection have been applied to a Microgrid. In this paper, adaptive protection uses the current of each transmission line for the protection of Microgrid. Authors of [19] have used adaptive protection for adjusting DOCR settings. In the mentioned paper, all DOCRs are connected to a CPU which adjusts DOCR settings according to new topology while changing topology. But, these methods cannot be fast in complex power systems, and it needs infrastructures. Thus it is more expensive than traditional protection schemes.

In most of the researches, placement, and sizing of FCLs has been optimized for restoring DOCR coordination without considering network topology variations. In practical power systems, transmission lines and power resources can change during normal operation of power systems, then SC level changes and DOCR coordination is eliminated. Hence, considering all topologies of the power system is very pivotal. This paper proposes a new adaptive and robust method for placement and sizing of FCLs in the power system to restore the coordination of DOCRs by considering the variation of network topologies and DGs. In the adaptive protection method, the miscoordination problems of DOCRs is solved by using an CPU and also deactivate the unnecessary FCLs during fault, and the operation time of the DOCRs is decreased. Moreover, by using robust method, the size and value of FCLs are determined by considering all situations, and this method active all FCLs during fault to ensure that the coordination of DOCRs are maintained. Then, both of the proposed methods are applied to a case study to compare the features of each method. Simulation results show that both methods maintain and restore DOCR coordination and reduce their operation time.

2. DOCR Coordination Problem

In the ring power systems, due to the nonlinear part of relay characteristic and constraints, coordination of DOCRs is a complex optimization problem. In the defining the optimization problem, the difference of operation times between backup and primary relays are considered as constraints and variables are defined through minimizing fitness function.

The first step of protection studies is designing DOCR coordinations. The DOCR coordination means that the difference of operation time between backup and primary relays must be more than CTI. CTI is the minimum time that requires preventing primary relay interference with other protection devices. The CTI is usually between 0.2 and 0.5; in this paper the CTI is considered 0.3.

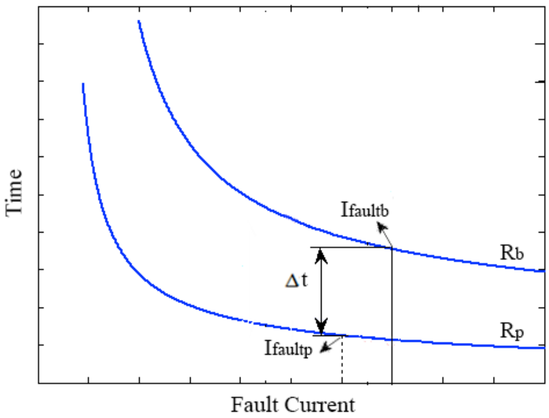

Fig. 1. The curves of a DOCR pair

The characteristic curves of R_b and R_P, backup and primary relays, respectively, are shown in fig. 1. The operation time of each DOCR depends on the fault current, and the difference between two DOCRs, Δt, must be more than CTI. The characteristic curves of relays have two settings, time multiplier setting (TMS) and pickup current. Hence, for calculating these settings in the ring power systems, an optimization algorithm must be used.

The main purpose of DOCR coordination is obtaining TMS and pickup current by minimizing fitness function and satisfying constraints. The fitness function of this problem is determined by Equation (1) [13]:

$$\text{minimize } \sum t_i \tag{1}$$

Such that:

$$\text{subject to: } t_j - t_i \geq CTI \quad (i,j)\in\Omega \tag{2}$$

$$TMS_i^{\min} \leq TMS_i \leq TMS_i^{\max} \tag{3}$$

$$I_{set_{\min}} \leq I_{set_i} \leq I_{set_{\max}} \tag{4}$$

$$I_{set_{\min}} = \max(I_{load}^{\max}, I_{set_i}^{\min}) \tag{5}$$

$$I_{set_{\max}} = \min(I_{fault}^{\min}, I_{set_i}^{\max}) \tag{6}$$

Where n is the number of relays, Ω is the number of relay pairs, t_j and t_i are the backup and primary operation times of relays, respectively. TMS_i^{min} and TMS_i^{max} are the minimum and maximum TMS of the i^{th} relay, respectively. On the other hand, the minimum value of I_{set} must be between the maximum value of load current and minimum value of allowed I_{set}, and the maximum value of I_{set} must be between the minimum value of fault current and the maximum value of allowed I_{set}. The operation time of the relay is calculated using equation (7):

$$t_j = \left(\frac{A}{\left(\frac{I_{scij}}{I_{pi}}\right)^B - 1} + C\right) TMS_i \tag{7}$$

The I_{scij} is the current passing through i^{th} relay for fault in location j, I_{Pj} and TMS_j are the pickup current, and TMS for the i^{th} relay, respectively; A, B and C are constant values of characteristic of relays, these can be determined using standards, which are shown in table 1 [20]. In this paper, the characteristic of DOCRs is chosen from IEC 255-3 [21].

Table 1. Characteristic types of DOCRs

Characteristic type	Standard	A	B	C
Standard inverse	IEC	0/14	0/02	0
Very inverse	IEC	13/5	1	0
Extremely inverse	IEC	80	2	0
Moderate inverse	ANSI/IEEE	0/0515	0/02	0/114
Very inverse	ANSI/IEEE	19/61	2	0/491
Extremely inverse	ANSI/IEEE	28/2	2	0/1217

3. Placement and Sizing of FCLs

The second step of the proposed approach is placement and sizing of FCLs, the optimum place, size and number of FCLs must be calculated by minimizing the fitness function and satisfying all constraints, hence, it restores coordination of all DOCRs by lowest cost and operation time. Fitness function of the FCL sizing is considered based on restoring DOCR coordination, reducing operation time of relays, size and number of FCLs. Reducing size and number of FCLs reduces the cost of power system protection system.

$$fitnessfunction = \alpha \sum_{i=1}^{N} t_i + b \sum_{j=1}^{M} Z_{FCL_j} + M \tag{8}$$

Where *a* and *b* are weighting factors, t_i is operation time of DOCRs, Z_{FCLj} is FCLs impedance and *M* is the number of FCLs. The constraints of this problem can be defined according to equation (9):

$$t_{backup} - t_{primary} - 0.3 \geq 0 \tag{9}$$

$$Z_{FCL\min} \le Z_{FCL_j} \le Z_{FCL\max}, j = 1,...,M \quad (10)$$

Two different methods are defined in the next sections, Robust Placement and Adaptive Placement.

4. Adaptive Placement and Sizing Method

Due to topology variations in the power systems, the FCL optimization must consider all topologies of the system to restore DOCR coordination while changing the power system. By considering all topologies, the number of constraints will increase, thus, obtaining an optimum value can be difficult for optimization algorithms. For this reason, if for a specific topology only a limited number of FCLs are required, therefore, only the necessary FCLs are used to restore the coordination of DOCRs. Researchers have proposed various approaches for adaptive protection, but, usually, the proposed approaches need PMU and a central processing unit with the capability to process currents fast and send commands to protection devices. Hence, these protection schemes are expensive. However, in this method, the protection calculation is offline, thus, it does not require calculations during fault, and this characteristics increases the operation speed of this method.

During topology variations, by outage of the transmission lines, the state of C.Bs are changed, and therefore, the topology of the power system can be defined by the state of C.Bs. For this reason, in the proposed method, only the state of C.Bs and a CPU are required which is independent to measuring fault currents. The states of C.Bs are sent to the CPU, and it uses recorded information of each topology and the required FCLs are calculated before fault, therefore, for the current topology, CPU only sends signal for necessary FCLs to active during fault for the fault limiting.

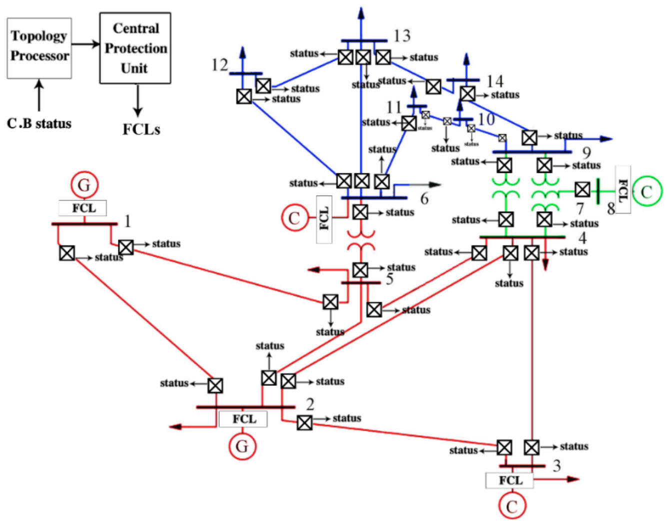

Fig. 2. Adaptive protection scheme of FCLs

Fig. 2 shows the proposed adaptive protection scheme and the case study. As can be seen in this figure, topology processor (TP) receives the states of C.Bs through communication links, then the output of TP will be sent to CPU. Therefore, CPU detects the required FCLs; then, the activation signal will be sent to the required FCLs to participate in the fault current limiting.

Table 2. An example of proposed Adaptive scheme

Group number	Topology number	Active FCLs
1	1, 2, 3, 4, 5	FCL_1, FCL_2, FCL_3
2	6,7,8	FCL_1, FCL_2, FCL_4
3	9,10,11,12	FCL_1, FCL_2, FCL_3, FCL_4

An example for introducing more about the proposed adaptive protection method is shown in table 2. The first column is the group number, and each group includes a number of topologies, the second column is the topology numbers, and the third column shows active FCLs which must participate in the fault limiting according to the group number. For instance, if the current topology of the power system is 1, TP sends this topology to the CPU and then, FCL_1, FCL_2, and FCL_3 participate in the fault limiting. Hence, this method is robust, and DOCR coordination can be maintained. More discussions on the calculating the FCLs parameters are presented in section 6.

5. Robust Placement and Sizing Method

The fitness function and constraints for this method are similar to the adaptive method as indicated in equations (8), (9) and (10), but, in this method constraints are considered for all topologies, hence, the number of constraints are determined using equation (11):

$$\text{Number of Constraints} = \sum_{S=1}^{a} N_S \quad (11)$$

Where α is the number of all topologies, S is the number of topology and N_S is the number of DOCR pairs in each topology. In this paper, FCLs are impedance type, hence, they can be divided into resistance and inductance parts, and range of values are between 0 and 2 Pu.

Due to the presence of many number of constraints, a penalized fitness function is useful. In the proposed fitness function, if each constraint exceeds an allowed value, a large constant must be added to the fitness function, hence, because the aim of optimization algorithms is to minimize the fitness function, the optimization algorithm tries to reduce the amount of fitness function through satisfying constraints. The penalized fitness function is defined using equation (12):

$$j = \sum_{i=1}^{N} t_i + \sum_{j=1}^{M} Z_{FCL_j} + M + \sum_{i=1}^{N} K_1 + \sum_{j=1}^{L} K_2 \quad (12)$$

Where, K_1 and K_2 are penalty factors, and the value of penalty factors are assumed 500.

$$\begin{cases} if \ \ t_{backup} - t_{primary} - 0.3 \ge 0 \\ K_1 = 0 \\ if \ \ t_{backup} - t_{primary} - 0.3 < 0 \\ K_1 = 500 \end{cases} \quad (13)$$

In this paper, placement and sizing of FCLs are optimized by GA, which is discussed in the next section. In addition, this paper proposes a new method for the placement of FCLs. Installing FCLs is expensive, hence, reducing the number of FCLs can be more affordable for power system protection costs. The structure of the proposed method includes 4 different stages, first, all DGs and power resources can be a candidate for FCL installation, and then, after optimization and obtaining the value of FCL impedances, the low impact FCLs are eliminated. To this end, a threshold is assumed for the impact of FCLs, for instance in this paper 0.1 p.u is the threshold, if the the impedance values of FCLs are lower than this threshold, these FCLs will be eliminated. Then, after removing the low impact FCL, the optimization method calculate and obtain FCLs' values again. This method is repeated until all FCLs' values become more than the threshold.

6. Genetic Algorithm

Optimization methods are widely used in different applications in recent years [22-23], and one of the practical optimization approaches is GA [24]. And, GA can be optimize nonlinear and mixed integer problems, therefore this method is suitable for using in relay coordination problems. GA uses three rules to generate next generation, mutation, crossover, and selection. The first step of FCL sizing and placement by GA is developing a fitness function, therefore, the equations (8) and (12) are the fitness functions of adaptive and robust FCL sizing and placement, respectively. Then, the second step is evaluating constraints, which defined by equations (9) and (10). In the robust method, for neglecting the unnecessary FCLs, another constraints added to the method, which shows if any FCL impedance was calculated and was less than a threshold it would be an unnecessary FCL. In this paper the threshold is 0.1 p.u. In addition, for both methods, equation (9) is defined for all situations. Therefore, the constraints of the optimization are given by:

$$\begin{cases} t_{b1} - t_{p1} - 0.3 \geq 0 \\ t_{b2} - t_{p2} - 0.3 \geq 0 \\ \\ t_{bn} - t_{pn} - 0.3 \geq 0 \end{cases} \quad (14)$$

Which t_{p1}, t_{p2},.., t_{pn} are the primary operation times for each situations or topologies, and t_{b1}, t_{b2},.., t_{bn} are the backup operation times for mentioned topology.

7. Flowcharts of the Proposed Methods

The proposed methods restore DOCR coordination and reduce the operation time of DOCRs as in the following steps:

6.1. Adaptive Protection scheme

Step 1) Check the coordinations, if there are any mis-coordinations, FCLs will be installed

Step 2) Divide all topologies into several groups for FCL placement and sizing

Step 3) optimize fitness function for finding size and place of FCLs for all groups

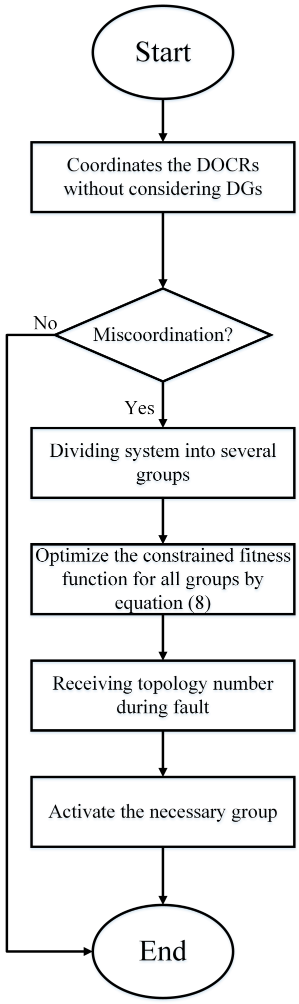

Fig. 3. The flowchart of Adaptive protection

6.2. Robust Protection Scheme

Step 1) Check the DOCR coordination, if there are any mis-coordinations, the system needs FCLs

Step 2) Optimize fitness function for finding FCLs size and place in all topologies

Step 3) check the value of FCLs, remove FCLs which its value is less than the threshold, then, repeat step 2 without the low impact FCL

Detailed flowcharts of robust and adaptive protection are shown in fig. 3 and 4.

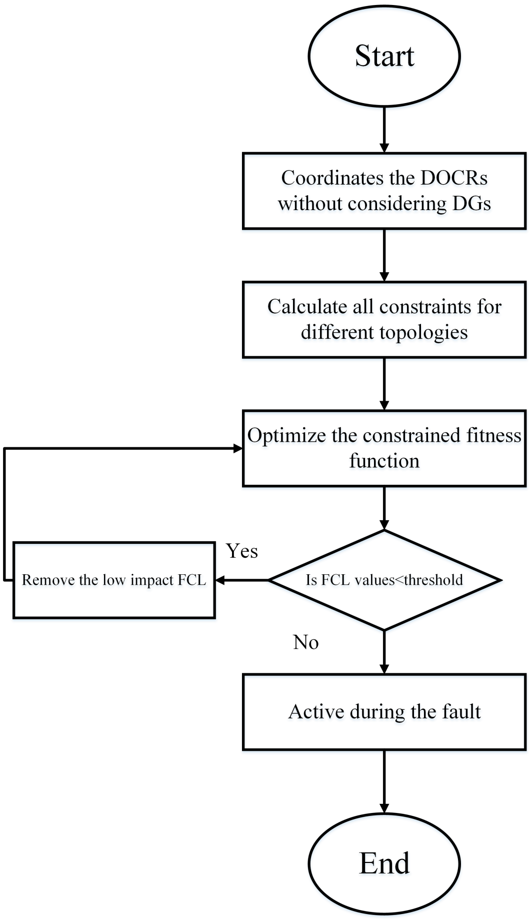

Fig. 4. The flowchart of Robust protection

8. Simulation Results

In this paper, the proposed methods are applied to IEEE 14-bus as a case study, which is shown in fig. 2. This system includes 14 buses, 39 DOCR, 18 lines, 5 power resources, and 39 C.Bs. All lines of this system have two C.Bs and two DOCRs. MATLAB is used for the simulation and optimization of the proposed method and case study. More detailed information of the IEEE-14 bus has been provided in [25]. In this network, the buses 6, 12 and 14 are the candidate places for installing DGs.

Due to the installation of DGs on the power system, the SC level in all parts of the system are changed. The presence of DGs in the system makes another path for SC current in the power system, and it increases the SC level. Thus, it can cause problems in the coordination of DOCRs, and this depends on the place and size of DGs. For evaluating the impact of DGs in mis-coordination problem, at the first stage, DOCRs are coordinated in the absence of DGs, then after installing DGs, constraints of DOCRs based on equation (9) show mis-coordination of DOCRs. Values of some of the relays are shown in Table 3. And, after installing DGs on the power systems, the value of constraint is changed. Therefore, some of the DOCRs are mis-coordinated. The constraints values are calculated using equation (9), DOCRs are coordinated for positive constraint values.

Table 3. mis-coordination in DOCRs

Backup Relay	Primary Relay	Constraint= t_b-t_p-0.3
6	1	-0.0423
6	3	-0.0525
12	9	-0.1130
12	7	-0.1158
14	8	-1.0760

7.1 .Adaptive

Coordination of DOCRs are restored by installing FCLs in series with power resources. Hence, the minimum values of FCLs are determined to reduce the SC level, and ensure to operation time difference of backup and primary relays are more than CTI.

The first stage of adaptive protection is calculating the optimum value of FCLs. For this reason, by using GA the fitness function is optimized and value and place of FCLs are calculated, these impedances are shown in table 4. In addition, in the proposed method, all topologies are considered by calculating the constraints for all situations. After finding the FCL's values, all FCLs which can restore the DOCR coordination are selected as a group. Therefore, after detecting topology of the system by TP, signals will be sent to the CPU for activating and deactivating necessary FCLs. Because the proposed method only requires C.B states, and do not need any additional equipment, for example, PMU, and the cost of the proposed method is lower than other methods. Table 5 shows the operation time of DOCRs using adaptive protection. As can be seen in table 5, all coordinations of DOCRs after installing DGs and changing topologies are restored by installing FCLs. As can be seen in the table 4, the values of the FCLs are shown in two different terms, the coefficient of the *j* is the inductance of FCL.

Table 4. FCL's values for adaptive protection

	First Group	second Group	third Group
FCL 1	1.04	1.04	1.04
FCL 2	1.08+0.01j	1.08+0.01j	1.08+0.01j
FCL 3	0	0	1.13+0.09j
FCL 4	0.93+1.57j	0.93+1.57j	0.93+1.57j
FCL 5	0	0	0.05+0.14j
FCL 6	0.93+0.2j	0.93+0.2j	0.93+0.2j
FCL 7	0	0.27+0.01j	0.27+0.01j
FCL 8	0	0.08+0.04j	0.08+0.04j

Table 5. operation times for adaptive protection

Backup relay	Primary Relay	Operation time
1	6	0.7515
3	6	0.2439
7	10	0.0137
4	10	0.1799
11	10	0.7556

7.2. Robust

In real power systems, transmission lines and power resources can be changed which can change the SC level, therefore, a robust protection scheme maintains coordination of DOCRs. Hence, robust placement and sizing of FCLs is applied to the case study. In the proposed method, the value of FCLs are optimized by considering all network topologies using GA. Thus, the value of FCLs restore and maintain coordination of DOCRs while changing topologies and installing DGs. The impedance of FCLs is shown in table 6. And, the values of FCL_1, FCL_2, and FCL_3 are neglected, because they are low impact FCLs and the value of them are less than the threshold. Thus, after the first optimization, the value of these FCLs are neglected and the optimization method calculates the size of FCLs again. In table 7, values of constraints are shown, when the power system is protected by robust scheme, changing the topologies cannot mis-coordinate the DOCRs.

Table 6. Values of FCLs for robust protection

FCL number	FCL value (Ohm)
FCL 1	0
FCL 2	0
FCL 3	0
FCL 4	0.26
FCL 5	1.7478
FCL 6	0.51+0.25j
FCL 7	1.5652
FCL 8	1.6+0.88j

Table 7. Values of operation times of relays in robust protection

Backup relay	Primary Relay	Operation time
1	6	0.6421
3	6	0.1232
7	10	0.0001
4	10	0.1543
11	10	0.5178

7.3. Comparing Adaptive and Robust Schemes

In this paper, two separate schemes have been proposed for protecting power systems by considering topology variations and DG installation. Therefore, both schemes restore the coordination of DOCRs, but each one has its own advantages.

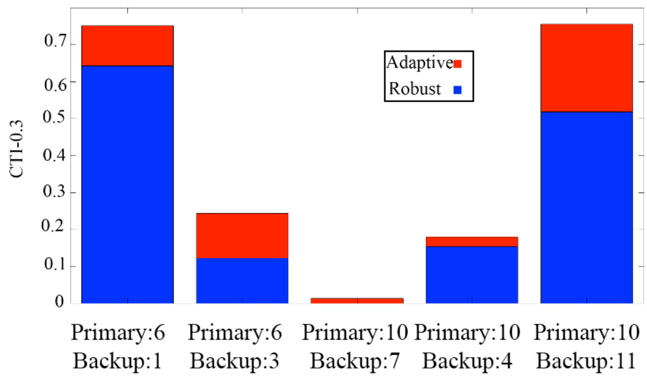

Fig. 5. CTI comparison

As can be seen in tables 5 and 7, the operation time of relays in the robust method is lower than the adaptive method.

Coordination of DOCRs in both robust and adaptive protection schemes are restored, but the adaptive protection scheme needs some infrastructures and communication facilities, hence, it increases the cost of the protection method compared to the robust scheme.

Since the number of constraints in the robust method is more than adaptive method, the computation time will increase and the probability of convergence will decrease in the robust method.

The closer is the operation time error between DOCR pairs to the CTI results in better protection. As can be seen in Fig. 5, the difference between operation times of DOCR pairs in adaptive protection is close to the CTI.

Also, in the table 8, the characteristics of the proposed methods with other reported methods are compared in terms of cost, computational speed, complexity, and considering DGs or network variations. The results show that the cost and complexity of the proposed methods is much lower than other methods, and the novelty of the proposed methods is considering the variation of the power system structure in sizing and placement of the FCLs.

Table 8. Values of operation times of relays in robust protection

Method	Cost	Computational Speed	Considering DGs network variations
Adaptive method	L	H	Yes
Robust method	M	H	Yes
[26]	H	M	No
[27]	H	H	No
[28]	H	M	No

L: Low, M: Moderate, H: High

9. Conclusion

One of the main challenging problems of DGs in the power system is mis-coordination of DOCRs. In this paper, the coordination of DOCRs has been restored by FCLs by considering the DGs and topology variation. Due to the importance of determining size and place of FCLs, two robust and adaptive protection schemes have been proposed for FCL placement and sizing. The cost of FCL protection schemes depends on the number and size of FCLs, thus, the proposed methods minimize these criterions, and also the operation time of DOCRs is minimized by minimizing fitness function. In practical power systems, the power system topology changes, hence, in this paper, the variation of the power system topology has been considered. Therefore, both of the proposed methods restore the coordination of DOCRs during the variation of the topology and the presence of DGs. The efficiency of the proposed methods was also proved through applying both protection schemes on a case study. The results show that the coordination of DOCRs is restored, and cost and operation times are minimized. For evaluating the advantages of each method, a comprehensive comparison is performed between these methods.

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