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Research Article

THE EFFECT OF DISTRIBUTED GENERATION SOURCES PRESENCE ON PROTECTION SYSTEM PERFORMANCE AND REDUCING THE IMPACT OF THEIR PRESENCE ON PROTECTIVE DEVICES COORDINATION OF THE DISTRIBUTION NETWORK

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ABSTRACT
Conventional distribution systems are normally radial fed by a downstream feeder**.** In the past, protective system was designed based on being radial. In recent years, the use of distributed generation power plants has been developed. If these power plants are to be connected to global networks, they would influence protective system of distribution networks and therefore, the coordination among protective devices will not be accessible anymore. Considered in this article, is the problems caused by the presence of distributed generation sources in distribution network with conventional protective systems. Later in this study, the importance and the use of fault current limiters (FCL) in protective devices coordination resulted from distributed generation resources connection to distribution systems will be surveyed. The sample distribution network containing distributed generation is simulated in Digsilent software.

Keywords: *Distributed Production, Radial System, Distributing Network, Protective Coordinating, FCL*

INTRODUCTION
Traditional distribution networks are exploited radially. Therefore, protective system designing for these networks is not such complex. However, great attention in drawn to DG units in the previous year and existence of these networks has obliterated the radial nature of distribution networks. Presence of distributed generation sources has brought numerous problems to designing of these networks (Javadian and Haghifam, 2007; Girgis and Brahma, 2001). In comparison with big generators and power plants, these sources have lower production rate and can be implanted with lower costs. In addition, connecting of these resources to distribution networks has got so many benefits such as reducing production cost, energy loss, environment pollution and improving voltage profile, production efficiency, and wattage quality (Chang, 2001).
In order to achieve this goal, fuel cells, micro turbines, diesel generators, small wind and water power plants, and solar cells can be used (Rezaie, 2008). Because of various philosophies existed for protective system designing, problems due to presence of DG sources in distribution networks with traditional systems are considered in this article. These problems can be wrong twipping of feeders and production units, changing the levels of short circuit, unwanted islanding, avoiding automatic reclosing and production coring. In this article, fault current limiting method is used with F.C.L utilization after connecting the distributed generation sources to distribution system (Ghomi, 2009). This method has a great advantage over the others which is not having requirement to change or replace the network lateral components. Finally, a sample distribution network containing DG has been simulated in Digsilent software in order to clarify the problems mentioned.

The Effect of Distributed Generation (DG) on Protective Devices Coordination
The effect of DG on coordination of protective devices is related to the size, type, and place of DG. In this study the effect of DG on coordination of some devices such as fuse-fuse, fuse-reclosing, and relay-relay is considered.

Fuse-fuse Coordination
A fuse has two characteristics which are melting margin [threshold] (MM) and total cut (Tc). The MM shows a time that after that fuse will be burnt (For a particular current) and Tc shows the exact time of troubleshooting or fault current cut**.** Figure 1 shows how fuse-fuse coordination is done in traditional

networks. Figure 1-A shows two fuses coordinated together. For coordination between the first and second fuses, for each fault in feeding-time fuse the first fuse should perform before the second one. This coordination happens when Tc trait of the first fuse is lower than the second one mm trait. Figure 1-B represents the coordination curve. The curve shows that this coordination is existed for all fault currents between $I_{F\ min}$ and $I_{F\ max}$. Therefore, these fuses are coordinated with each other. Figure 1 shows a part of this extensive distribution network. In this state concerning that DG is not existed, couple fuses of F_1-F_2, F_2-F_3, F_3-F_4, F_4-F_5 will be coordinated as demonstrated in figure 1-B. If DG_1, DG_2, and DG_3 are connected to the system, the following changes would happen in network.

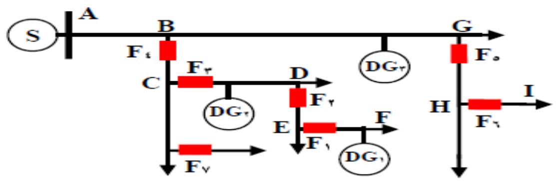

Figure 1: Extensive distribution network

1- The minimum and maximum number of fault currents will increase in HI part for each fault happening and F5 and F6 will received more fault currents as well. However, you will never see a reverse fault current.
2- With fault happening in CD part, F3 and F4 fuses will experience direct current fault while as fault happens in AB part these fuses will experience reverse fault current. Furthermore, the fault current experienced by these fuses in accordance to fault happened in AB and CD is equal. F_1 and F_2 fuses will experience exactly the same situation.
3- In accordance to fault happening in DE part, F_2 fuse will experience higher current compared to F_3, while F_3 fuse will see more current than F_2 as fault happens in BC part. In the first situation the current is downward and in the second situation it is upward. In the first situation if the fuses can coordinate with the new current, fuses coordination will not be influenced so much and it is due to direct current experience of the fuses. The only alternation in coordination curve of F_5-F_6 will be in coordinating area of the fuses. However, if fault current increase is about to be very high, coordination area will destroyed and fuses will not be able to maintain coordination. Concerning the second situation, a polarity would occur. One of the main targets of the protective designs is deleting the fault part only. According to this reason, in accordance to fault occurrence in CD region, F_3 should perform before F_4, however; for fault in AB region it is vice versa. This work is not achievable as these fuses experience the same current in direct and reverse mode. This is the same for F_2 and F_3.

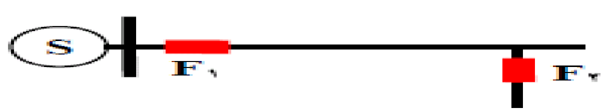

Figure 1-A: Coordination of the two fuses

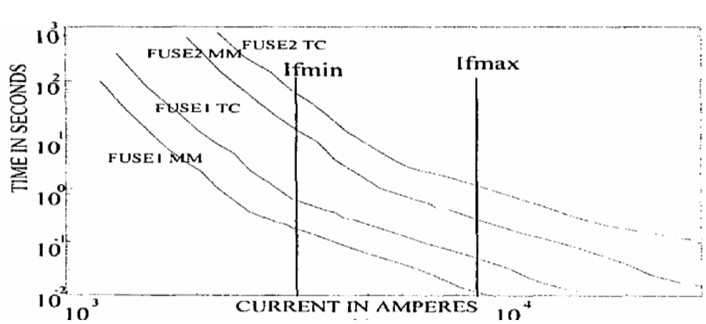

Figure 1-B: Coordination curve of the two fuses

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Based on figure 2, there would be a coordinating region for the third situation. This figure shows F_2 and F_3 traits without presence of DG. In this case F_2 will receive a higher current in comparison with F_3 for a downstream fault. It is clear that as long as I_{F3} is greater than I_{F2}, relays coordination will not be disrupted. It is because F_2 always performs before the demolition of F_3. As it can be seen in figure 2, the difference of I_{F2} and I_{F3} is greater than the coordination range since F_3 will perform before F_2 is melted and therefore, the coordination will not be disrupted. However, if the currents difference is less than the coordination range, F2 starts to melt before F3 cuts and thus, coordination will be disrupted.

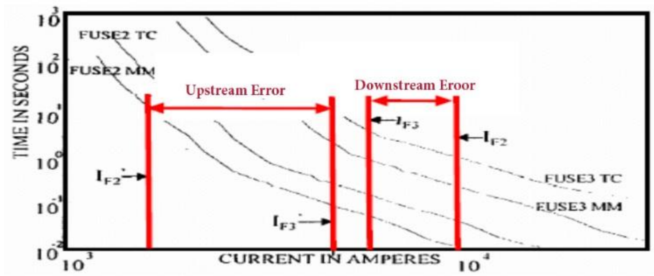

Figure 2: Coordination range

Reclosing-fuse Coordination

Figure 3 shows a distribution line connected to the load. Load-feeding fuse is protected by a fuse. The method of coordination without the presence of DG is represented in figure 4. The philosophy of performance is that the fuse should only function for permanent faults. For transient faults, the fuse should cut the circuit through its fast performance and let the error to be corrected. The fuse has only allowed to be cut for permanent faults. Consequently, load-feeding fuse will not be cut for all transient faults. In addition, the performance of slow reclosing mode protects the backup fuse. It is seen in figure 4 that between $I_{F\ min}$ and $I_{F\ max}$ the performance curve of fast reclosing is placed under the MM fuse curve. Therefore, reclosing occur in shorter time compared to fuse melting time. One type of fast-reclosing performance sequences is F-F-S-S (F means fast performance and S means performance with delay). If the error is transient, it would be corrected in closing of reclosing in its second fast performance otherwise, the fault is permanent and the fuse should function in this mode. Furthermore, it is obvious in figure 4 that the fuse Tc curve is under the slow-reclosing performance curve between I_{Fmin} and I_{Fmax}. Thus, for permanent faults the fuse should function before the slow-reclosing performance. If the fuse did not function, the reclosing will perform the backup and cut the circuit. Concerning the presence of DG on seasonal feeders and under the reclosing level, following changes will occur.

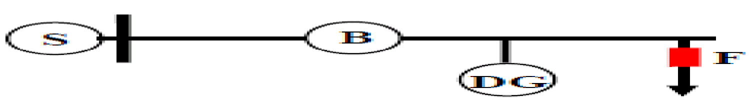

Figure 3: One-line network

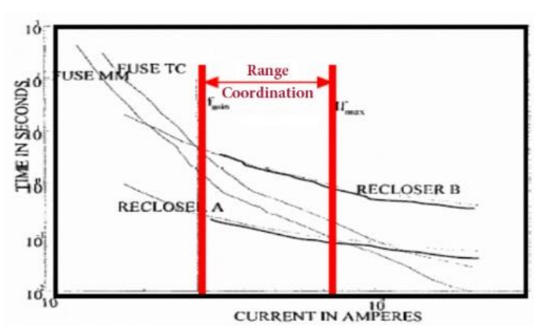

Figure 4: Coordination range without the presence of DG

1- The quantity of MAX and MIN current will change for all faults on load feeder.
2- In accordance to all faults on the load feeder, the fuse will find more currents than the reclosing does. As previously pointed, the maximum and minimum of fault current should be between I_{Fmin} and I_{Fmax} otherwise, the coordination will be lost. As shown in figure 5, there would be a coordinating region if the fault currents are still in the allowed distance. The difference of fuse and reclosing currents will be related to the place, type, and size of the DG. As represented in figure 5, if the difference between I_F and I_R for determined current of I_F is more than the coordinating range, the fuse will be melted before reclosing functions in its fast mode and coordination will be lost. So, if DG injects more current or becomes closer to load feeder, coordination is highly likely to be lost.

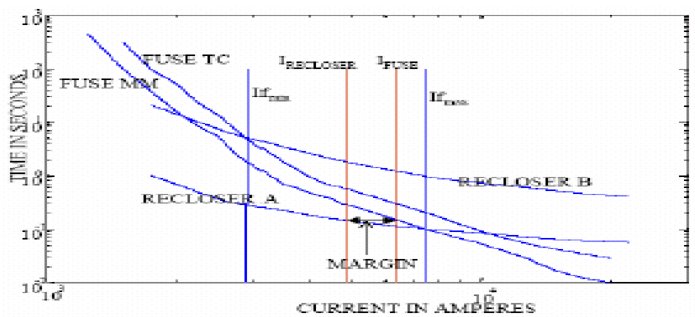

Figure 5: Coordinating range of fuse reclosing

Relay-relay Coordination
Shown is Figure 6-A, is a main distribution feeder supplied by S source and protected by reverse high current relays of R_1, R_2 and R_3. The coordination among these relays is shown in figure 6-b. The protection philosophy used here is that in accordance to maximum fault current in bus 3 which is coordinated in accordance to maximum fault current in bus 2, the nature of the reverse current relay curve is in a way that if they are coordinated for the maximum current, they would be the same for lower currents. As demonstrated in figure 6, R_1 is a backup for R_2 and so, R_2 is a backup for R_3.

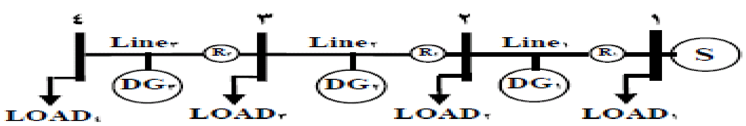

Figure 6-A: Main feeder with relay presence

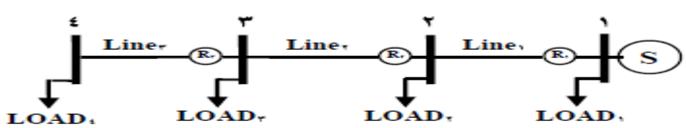

Figure 6-B: Relays coordination

Now with assumption that DGs are placed in the circuit, based on the placing shape of DGs on the feeder following feasibilities may occur.
1) If DG_1 and DG_2 are connected only, MAX and MIN of fault current will be changed by fault in line 1. However, R_3 will never experience the recursive fault current. It is required that R_2 and R_3 relays can be coordinated in various currents. This current is usually a greater one. Various setting tips of reverse high current relays will not considered as a problem.
2) If DG_3 is connected only, R_2 and R_3 relays will experience direct fault current in accordance to fault in line 3. Important to be considered, is that relays do not consider any differences between direct and reverse currents. Therefore, this issue leads to an antithesis since the purpose is to delete the damaged

part. In accordance to any fault in line 1, R_2 relay should perform before R_3 and it is not achievable unless they distinguish a difference in current's direction.

3) If all of the three DGs are connected to the network, in accordance to any fault occurrence in line 3 or any other downstream point, R_3 will experience the maximum fault current and then in accordance to any fault happening in line 1 or any other upstream point, R_2 will receive more currents than R_3.

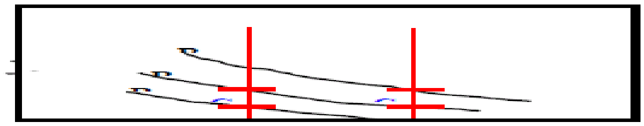

Figure 7: DG placing in circuit

Simulation of Sample Distribution Network

Figure 8 shows the simulated distribution network in Digsilent software. In order to depict all the effects of DG presence in protection system, 3 levels of 20, 63, and 0.4 KV voltages are considered in the network. 5 generation sources are given throughout the network which one of them is connected in 20KV part and the four remaining are connected in 400V part. As the first step, experienced currents by protective devices in accordance to a 3-phase symmetrical fault on bus 13 is compared in two states of concerning and without concerning the DGs. The comparison results are shown in table 1. It should be said that the negative mark for some protective devices' current means current direction change compared to normal direction in traditional structure in accordance to simulation fault.

As shown in table 1, short-circuit sources will be severely changed as distributed generation sources are added to the network. These changes happen in both quantity and direction of the fault current. As a result, protective system is not able to have a correct performance. Some of the network protective systems' wrong performances are as followings.

Table 1: Short-circuit level comparison

Device Name	**Current (A)**		**Device Name**	**Current (A)**	
	With DG	**Without DG**		**With DG**	**Without DG**
R_3	**603**	**931**	F_3	**0**	**0**
R_4	**-174**	**0**	F_4	**-167**	**0**
B_1	**603**	**931**	F_5	**-167**	**0**
B_2	**-174**	**0**	F_6	**1074**	**931**
F_1	**-279**	**0**	F_7	**1074**	**931**
F_2	**-279**	**0**	F_8	**0**	**0**

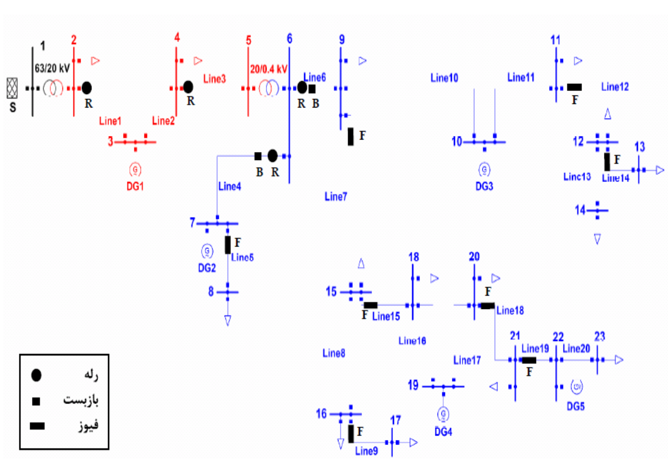

Figure 8: Simulated sample network

1. Before connection of DGs, the current of F_7 and F_6 fuses is 931 amperes and they are coordinated by this current. While after connection of the DGs, fuses current increases to 1074 amperes which leads to loss of coordination.
2. Current experienced by R_3 is decreased from 931 to 603 amperes. This phenomenon leads R_3 recognition power to be lost. Thus, it cannot function as a backup for F_6 fuse.
3. Due to presence of DG_2, R_4 current will be heightened from 0 to 173 amperes. As result of current direction unrecognition in R_4, this relay will mistakenly twip to its neighboring feeder's fault and cut its under-protection feeder.
4. After twipping R_4, due to DG_2 performance persistence the relating feeder continues to work in islanding way. In addition to power quality destruction in the existed island due to synchronization lost in the time of B_2 reclosing reconnection, this phenomenon leads to severe current placing and damages in the network.
5. In accordance to 3-phase fault on line 17, $I_{F1} = I_{F2} = 964$ while in accordance to the same fault on line 6, the quantities will be $I_{F1} = I_{F2} = -793$. In the first mode, F_2 should perform before F_1. However, for the second mode F_1 should perform before F_2 and it is not achievable unless fuses experience different currents in direct and reverse mode.
6. For every 3-phase fault on line 18, $I_{F1} = 1441, I_{F2} = 675$ while for the same fault occurrence on line 7, the quantities will be $I_{F1} = -382, I_{F2} = -1071$. In these conditions, coordination range of F_2 and F_4 fuses changes just like figure 2.
7. After connecting the DG, in accordance to every 3-phase fault on line 5 the quantities will be $I_{F8} = 3594, IB2=2812$. This difference in fuse and reclosing crossing current existed due to DG injection, leads to F_8 and B_2 coordination decrease.
8. In accordance to 3-phase fault on line 3, the currents of R_1 and R_2 relays will be 8578 and 8454 amperes, respectively. These two currents' difference is due to fault current injected by DG_1 which leads to coordination loss of the two relays. As a result, R_1 cannot perform well as the backup protecting for R_2.

According to presented details and the performance comparison of simulated distribution network's protection system, it can be concluded that after connecting the distributed generations, conventional protecting system has lost its performance completely.

Using FCL and its Impact on the Performance of Distribution System in Presence of DG

Using FCL in distribution system leads to fault current supply avoiding by DG and its flowing towards the main feeder. The suitable place of power keys' FCL should have the ability to cut great currents. This work needs lots of costs to be spent. Toward this goal, expected characteristics for FCLs are as the followings:

1. Very low losses.
2. No impact on system stability.
3. Low need for changing and maintaining.
4. FCL does not have an impact on fault current in the branch that does not have a DG.
5. Numerous performance capabilities and the ability to retrieve it again.
6. Fault current limiting.
7. Desired impact on sustainability angle of the distributed generation unit.

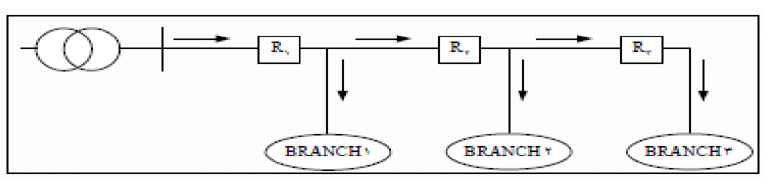

Figure 9: Distribution system

In order to perform the simulation, only a part of previous distribution network which its one-line diagram is as shown in figure 10 will be used with following features.

1. Fault protection through 3 coordinated relays. BRK_1, BRK_2, and BRK_3 are done at first of the line, the first 1/3 of line length, and the second 1/3 of the line length, respectively.
2. Loads are distributed at 1/3, 2/3, and end of the line.
3. The loads power is 1/7MVaR, 5/8mw.
4. Distributed generation units with nominal power of 6mva KV connected through a transformer to the local load. In addition, DG and load are connected to the bus placed on the main feeder using FCL.

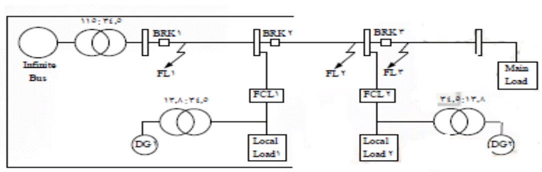

Figure 10: One-line diagram

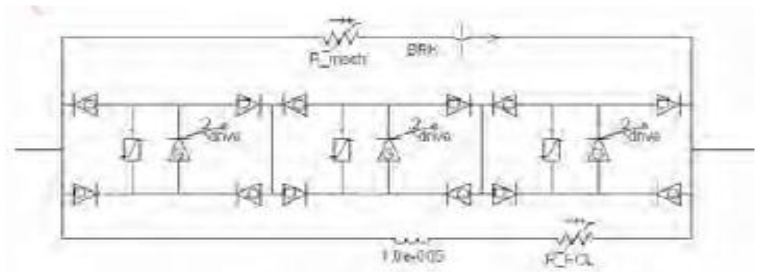

Figure 11: Proposed FCL model

Figure 11 shows the simulated model of FCL in this article. In order to make sure whether the GTOs work properly or not, a lightening arrester is installed parallel to any of the GTOs.

Done Simulations and Results Recording

Concerning the relays existed in the network, three places can be distinguished for fault in network:

A. Fault occurrence in protective region of the first relay (FL_1).
B. Fault occurrence in non-protective region of the third relay (FL_4).
C. Fault occurrence in protective region of the third relay (FL_5).

Fault Occurrence in Protective Region of the First Relay

Figure 12 shows the results of 3-phase fault to ground simulation when DG is not connected. In these conditions, the most portion of the fault current is supplied by infinite bus. Therefore, the fault current flows toward FL_1 point.

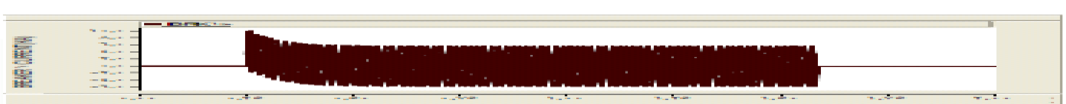

Figure 12: The first relay current for fault occurrence in the place of FL1 without the presence of DG

When DG units are connected to distribution system, the most portion of 3-phase fault to ground is supplied by infinite bus. Simulation results are brought in figure 13. Figure 14 shows the simulation results of 3-phase fault to ground with connection of DG in presence of FCL in the distribution system.

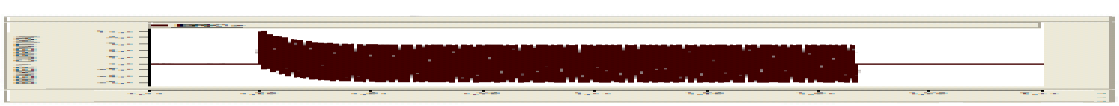

Figure 13: The first relay current for fault occurrence in place of FL1 in existence of DG

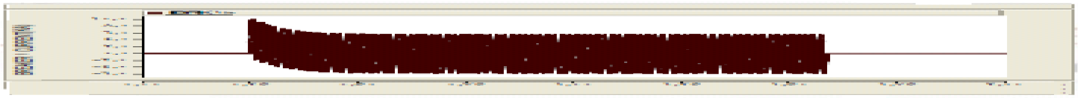

Figure 14: The first relay current for fault occurrence in place of FL1 in existence of DG and FCL

Figures of 15 and 16 shows current flown from distributed generation units to the main feeder.

Figure 15-A: Flown current of DG1 without FCL

Figure 15-B: Flown current of DG1 with FCL

Figure 16-A: Flown current of DG2 without FCL

Figure 16-B: Flown current of DG2 with FCL

Fault Occurrence in Non-protective Region of the Third Relay (FL_4)
In this situation, three states are considered for the distribution system as follows:
DG connection, DG connection without FCL, DG connection in presence of FCL.
Simulations results are shown in figures of 17, 18, and 19.

Figure 17: The third relay current for fault occurrence in place of FL4 without DG

Figure 18: The third relay current for fault occurrence in place of FL4 with DG

Figure 19: The third relay current for fault occurrence in place of FL4 with connection of DG and FCL

Fault Occurrence in Protective Region of the Third Relay (FL_5)
The results of three states of without DG connection, DG connection without FCL and in presence of FCL are shown in figures of 20, 21, and 22, respectively.

Figure 20: The third relay current for fault occurrence in place of FL5 without DG

Figure 21: The third relay current for fault occurrence in place of FL5 with DG

Figure 22: The third relay current for fault occurrence in place of FL5 in presence of DG and FCL

RESULTS AND DISCUSSION

For comparative analysis influence of FCL on relay settings as the result of DG connection to the distribution system, three diverse places are considered. In the first place of fault occurrence in position of FL_1, the quantities of current peak and fault correction time are approximately the same in three studies of DG disconnection, DG connection without FCL, and DG connection in presence of FCL. In the study of DG without the presence of FCL the currents peak flown from DG_1 and DG_2 to the main feeder are about 509 and 41 amperes, respectively.

However, in DG connection in presence of FCL these quantities are decreased by 165 and 198. This shows the FCL concerning benefit. In the second place, fault occurrence in the place of FL4, the current peak of the second relay in studies of DG disconnection, DG connection without FCL, and DG connection in presence of FCL is approximately 2.2, 2 and 2 KA and fault cut time is roughly 0.415, 0.501, and 0.482 second after its start, respectively. Compared to DG disconnection without presence of FCL which has fault correction time changes of 42.97%, DG connection in presence of FCL has changes of 7.8% which is dramatically increased. In the third place of fault occurrence in position of FL_5, the third relay current peak in studies of DG disconnection, DG connection without FCL, and DG connection in presence of FCL is almost 2, 4.2, and 2 KA and fault cut time is 0.162, 0.093, 0.151 second after its start, respectively.

Compared to DG disconnection without presence of FCL which has fault correction time changes of 15.98%, DG connection in presence of FCL has changes of 1,82% which is well improved. The simulated results are depicted in table 2.

According to the results obtained from simulations performed in this study with connection of DGs to distribution system, FCLs using will lead DGs' impact on protective devices time settings to be decreased. Consequently, their resetting is considered.

Table 2: The impact of FCL and DG on relays timing

FL_3 BRK_3 DG with F.C.L	**FL_3 BRK_3 DG without F.C.L**	**FL_3 BRK_3 Without DG**	**FL_2 BRK_2 DG with F.C.L**	**FL_2 BRK_2 DG without F.C.L**	**FL_2 BRK_2 Without DG**	**FL_1 BRK_1 DG with F.C.L**	**FL_1 BRK_1 DG without F.C.L**	**FL_1 BRK_1 Without DG**	**Fault place Breaker State**
9/18	**5/3**	**10/12**	**29/1**	**25/19**	**29/91**	**79/9**	**79/9**	**79/9**	Fault correction time (cycle)
0/91	**4/39**	**-**	**0/89**	**5/02**	**-**	**0**	**0**	**-**	Fault correction time changes
8/7	**43/59**	**-**	**2/92**	**16/57**	**-**	**0**	**0**	**-**	Fault correction time changes (Percentage)

Conclusion

In this survey, effects of distributed generation resources presence on the performance of distribution networks' protection systems are analyzed. Furthermore, FCL using for better controlling of protection in presence of DG is discussed and the following results are obtained.

1. Downstream devices placed at lower levels compared to DG, will never experience reverse fault current. As a result, if these devices can perform correctly in accordance to fault current increase caused by DG presence, their coordination will not be lost.

2. If protective devices experience reverse fault current, two possibilities may come to existence:

A. The coordination will not be lost, if no difference is existed between reverse and direct current.

B. If there is a difference between reverse and direct current, there would be a range which coordinating will not be lost for that. However, if currents difference is greater than this range coordination will be removed.

3. Using FCLs in distribution systems in presence of distributed generation resources leads to fault current limitation after fault occurrence in different places as well as maintaining system stability at fault occurrence mode in different places.

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