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Evaluating the Impact of DG Presence on Reclosers, Fuses and Over-current Relays Coordination in Distribution System

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Using distributed generator is growing due to their advantages in distribution networks recently. But these advantages will be realized when the consequences of their presence in distribution system are fully checked and their disadvantages are eliminated. One of their major impacts is on the protection of the distribution systems. Presence of distributed generator in distribution system makes the grid become non-radial which makes the coordination between protections devices lost. The reason for doing this is to look at the network of events and changes in the DG entrance, so that we can solve the problems. In the subsequent research, we present a solution to this problem. Therefore, it is necessary to provide a new plan to address the problem. In this paper, the problems of DG presence on the traditional protection systems of distribution network is investigated and the DIgSILENT platform is used to simulate the problems of DG presence on protection devices coordination on a test distribution grid as a case study.

Keywords: distributed generators; protection systems; DG presence; reclosers; coordination.

1. Introduction

Distributed generators are electrical power resources that are connected to distribution grids. In other words, the distributed sources of production are located close to consumers, including power plants, wind turbines, micro turbines, fuel cells, solar cells, power storage systems, and so on. This type of resource is also referred to as local or decentralized resources. These resources' capacities and start-up costs are much lower than regular power plant unit generators. Also the usage of these resources brings much more advantages for distribution companies (DISCOs). Loss reduction, congestion management, voltage profile correction and lower environmental pollution are some of these advantages.

Hydroelectric, wind, fuel cells, solar cells, micro-turbines, geothermal systems and pumped storage power plants can be pointed as the main types of distributed generator resources [1]. In general, the purpose of using distributed generator sources in distribution networks is to provide all or part of the power consumption of the network on a full-time or part-time basis, among which the main goal is to generate active power. Increasing demand for power over the last few years, in many countries, the sources of electricity production are not able to respond effectively to this high demand. As a result, prices rose sharply during peak periods. However, with the economic growth of countries that led to an increase in the amount of energy they needed, the issue of quality and reliability was also important. The use of scattered products in the system of distribution of enormous environmental, economic

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and technical benefits looking for achieving these benefits, dispersed products should be of suitable size and fitted in suitable locations.

Conventional distribution networks are exploited radially, thus the protection schemes of these networks are very complex. But today, due to the numerous numbers of installed DGs in distribution systems, the distribution grids radial nature is changing to non-radial which directly causes major issues on existing network protection schemes [2].

Wrong feeder trips, wrong generator unit trips, changing short-circuit levels, unwanted islanding, preventing on auto-reclosing, and etc. are some of the protection problems that caused by the presence of DG in the distribution network [3-4].

In general, distribution systems protection schemes are designed without considering DGs. Also as mentioned above, installation of DGs in distribution grids causes a change in short-circuit level of the grid [5]. The severity of these changes depends on the capacity of DG, DG location, and type and technology of used DG. In [6] the impact of used DG type and technology on the protection systems is investigated. This reference has been shown that the greatest impact on the short-circuit currents and protection inconsistency is caused by synchronous generators.

This paper consists of five sections; section 2 investigates the impact of distributed generator on short-circuit. In section 3, coordination rules for different protection elements in the conventional distribution networks are investigated. In section 4, the impact of installing DGs on over-current protection devices is investigated. And section 5 contains an example of a typical distribution network that simulated in DIgSILENT software and in this section the consequences of distributed generator units' entry on protection devices coordination are shown for the case study grid.

2. The Impact of Distributed generator on the Short-circuit Level

When a fault occurs in a DG containing network, the failure is supplied through both paths, i.e. the gird and the DG units. The contribution of each of these two sources depends on the size of DG, network topology and network equivalent impedance [7].

In its simplest form, each DG unit can be considered as a voltage source in series with constant impedance. With the installation of DG, the impedance seen from the fault location is changed and thus the level of short-circuit is changed. Also with the installation of DG, the grid fault current is reduced, while the fault current is increased at the fault location. Consequently, the DG contribution of the short-circuit flow increases and the main feeder contribution decreases which may cause some inconsistency in protection devices.

3. Protection Devices Coordination Rules

Convectional distribution systems protection schemes are very simple, they usually use fuses, reclosers, over-current relays and sectionalizers but they must be properly coordinated. Protection rules should be so that:

1. Cut the short-circuit current as less as possible.
2. Keep the consequences of blackout that happens because of protection devices operation, as low as possible.

Protection devices coordination rules are mentioned in table 1 [8], and the used parameters in table 1 are defined in table 2.

To cut the short-circuit current for any type of faults in distribution grids, the protection devices settings should be coordinated for all pairs of main and backup protection devices. Also it is important to note that sectionalizers don't have separate protection curve and therefore they are not participated in coordination calculation.

Table 1. Distribution systems protection devices coordination rules

Coordination Type	Coordination Rules
Fuse-Fuse	$TCT_{fuse}(P,I_{MF})<0.75\times MMT_{fuse}(B,I_{MF})$
Relay-Fuse	$OT_{Rel}(B,I_{MF})>TCT_{fuse}(P,I_{MF})+0.3$
Recloser-Fuse	$OT_{Rec}(B, F,I_{MF})<MMT_{fuse}(P,I_{MF})$ $OT_{Rec}(B,D,I_{MF})>TCT_{fuse}(P,I_{MF})+0.3$
Relay-Relay	$OT_{Rel}(B,I_{MF})>OT_{Rel}(P,I_{MF})+0.3$
Relay-Recloser	$OT_{Rel}(B,I_{MF})>OT_{Rec}(P,D,I_{MF})+0.3$
Recloser-Recloser	$OT_{Rec}(B,F,I_{MF})>OT_{Rec}(P,F,I_{MF})$ $OT_{Rec}(B,D,I_{MF})>OT_{Rec}(P,D,I_{MF})+0.3$

Table 2. Used parameters definition of table 1

Fuse	Fuse	Maximum Short-circuit Current	IMF
Recloser	Rec	Minimum Melting Time	MMTfuse
Relay	Rel	Total Clearing Time	TCTfuse
Backup Protection	B	Fast Performance	F
Main Protection	P	Performance with delay (slow performance)	D
Operation Time	OT	Minimum of Fault Current	Imf

4. Impact of distributed generator on protection coordination

Impact of DG on protection coordination has a direct has a direct relation with type, capacity and the connection point of the DG. Due to usage of fuses, over-current relays and reclosers as the routine protection devices in distribution networks, this section of paper is discussed about the impact of DG on fuses-fuses, fuse-recloser-relays and relay-relay coordination.

4.1. Fuse-Fuse Coordination

Two coordinated relays are shown in Fig.1, the protection device coordination for this scenario is reached when Fuse1 operated before Fuse2 for any fault on the load feeder. In the other words, the TCT characteristics curve of the Fuse1 should be located below the MMT characteristics curve of the Fuse2.

This characteristics curves are shown in Fig. 2. This curve shows that for all fault currents between IF, min and IF, max the protection coordination is reached [10]. This means for any fault on load feeder that the short-circuit current limited between IF, min and IF, max the protection devices are coordinated, Thus, this area of the curves is called coordinating area (CA) [9].

In the first case, if the distributed generator units connected to the system at "A" point, the minimum and maximum values of fault current for a fault at the "DE" section will increase. Consequently, Fuse1 and Fuse2 will detected more fault current. However, if the fuses with new currents can be coordinated, coordination of the fuses is not very impressed. But if the fault current become too high, the coordination area is demolished.

In the latter case, if the distributed generator units are connected to the system between "D" and "E" points, for faults at "DE" section, Fuse1 and Fuse2 detect the fault current directly while the faults at "A" point, fuses detect the fault current in reverse. It should be noted that for any faults in the "DE" section or at "A" point, Fuse1 and Fuse2 detect same fault currents. In this case for a fault at "DE" section, Fuse1 should operate before Fuse2 and for a fault at "A" point, Fuse2 should operate before Fuse1; but due to different direction detections these will not happen.

In the third case, if the DG units are connected to the "BC" area, Fuse1 detects more fault current than the Fuse2 for any faults at "DE" section. While for every fault at "A" point, Fuse2 detects more current than the Fuse1. All these unbalanced detection cause protection inconsistencies.

Fig. 1. Fuse-fuse coordination

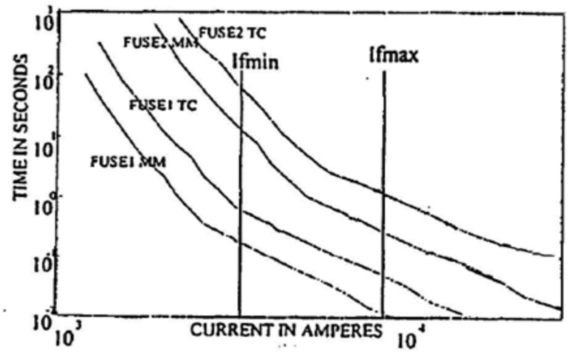

Fig. 2. Fuse-fuse coordination area (CA) [10]

4.2. Fuse-Relay-Recloser Coordination

Fuse must be coordinated with the recloser installed at the beginning or middle of feeders. The coordination between the recloser and fuse means that fuse should operate only for persistent faults. For transient faults, recloser by its fast performance should operate and make an opportunity for fault to eliminate. Fuse is allowed to operate only for persistent faults. If the fuse fails for any reason to act for a permanent fault, the slow mode of reclosers should operate as the backup protection and if both of fuse and recloser have failed to operate, the relay should operate to cut the defective part.

The classic protection scheme of reclosers, fuses and relays in a distribution grid are shown in Fig. 3. For all fault currents between the IF, min and IF, max, the fast performance curve of recloser is located below the MMT curve of fuse and slow performance curve of the recloser are located above the TCT curve (the curves are explained in the Appendix). Transient faults are eliminated by fast performance of reclosers. Permanent faults are eliminated by fuse, if fuse fails, slow operation on recloser and relay are cut the fault current as the backup protections, respectively [11].

With the addition of a DG unit downstream of the recloser and relay, the minimum and maximum fault current (IF, min and IF, max) will change and also for all the faults on the load feeder, the fuse detects more current than the recloser. This deference depends on the DG capacity, type and location. Fig. 3 shows that for a certain IF, if the deference between IF and IR is become greater than CA. the fuse melts before the fast performance of recloser, and the consistency lost.

4.3. Relay-Relay Coordination

Consider the radial grid depicted in Fig. 4. The coordination between ith and jth relays is shown in Fig. 5. In this type of coordination, for all faults in the protection area of ith relay, the jth relay should operate as the backup protection and the coordination time between these two should be lower than the CTI. Phase and ground settings are different for these relays [12].

In the first case, a DG unit is installed at B bus, which cause an increase in minimum and maximum fault current in "CD" section. With the increase of fault current passing through both relays, the coordination time of these relay reduce. This particular problem does not cause any problem, because reverse over-current relays have different setting taps.

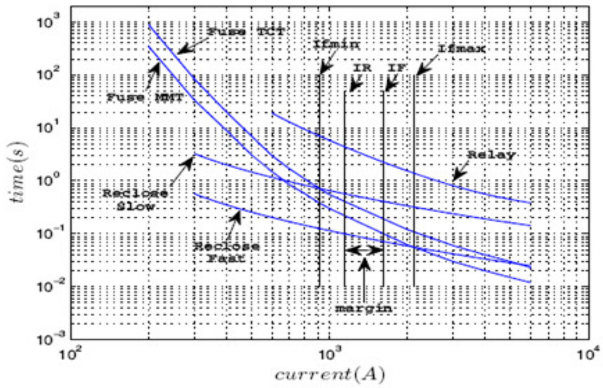

Fig 3. Recloser-fuse-relay CA

In the second case, a DG unit is installed on the C bus. In this case, for a fault on "CD" section, the fault current passing through the ith relay increase but he faults current passing through the jth relay decrease. Increase of fault current passing through the ith relay, cause an increases in operation speed of this relay but the decrease of fault current passing through the jth may cause a protection inconsistency.

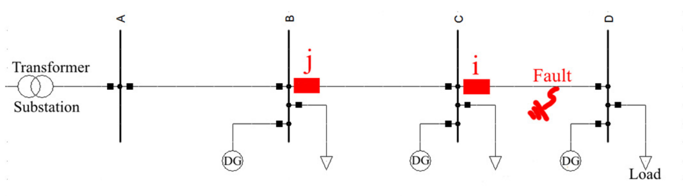

Fig 4. Different DG unit installation in a radial grid

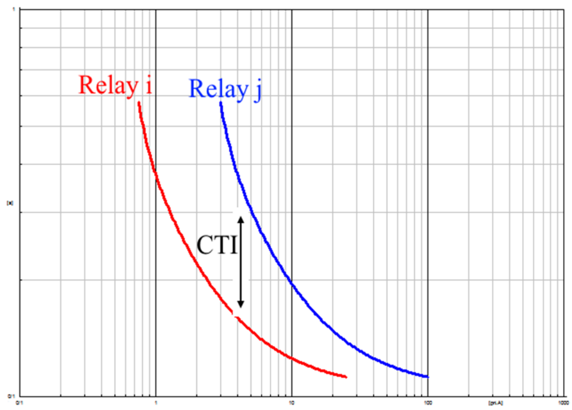

Fig 5. Relay-relay coordination

In the third case, a DG unit is installed on the D bus. In this case, for a fault on "CD" section, ith and jth relays detect fault current directly; and for a fault on "AB" section, ith and jth relays detect fault current reverse.

It should be noted that for faults on "CD" section, ith relay should operate before jth relay and for faults on "AB" section, jth relay should operate before ith relay but this will happen only if both relays can detect fault current direction correctly.

5. Simulation and Results

5.1. Network Data

To assess the impact of distributed generator on protection devices coordination, a typical test network is used that is shown in Fig. 6. The selected network, is a modified in version of network that used in [13] that has 14 buses, 13 lines, 2 over-current relays, 2 reclosers, 5 fuses and 4 distributed generator units.

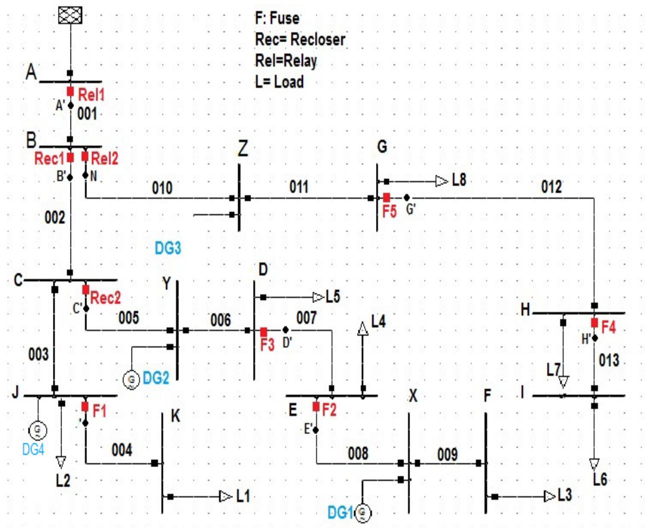

Fig 6. Single line diagram of the typical test network.

It should be noted that the modeled relays and reclosers are CO type manufactured by ABB, also characteristic curve of relays and slow operation of reclosers are "CO8 Inverse" and fast operation of recloser is "Extremely Inverse" [14-17].

The TSM for discrete relays is considered from 0.025 up to 1.5 with 0.025 steps and current setting for these elements is considered from 0.1 up to 10 with 0.01 steps.

Reclosers and relays setting are selected as described in table 1 and also in [13]. Table 3 and 4 contain these setting. Also the characteristics of used fuses are shown in table 5.

Table 3. Relays setting

Relay name	TDS time setting	Setting current (pri. A)
Rel1	0.15	500
Rel2	0.1	232

Table 4. Reclosers setting

Relay name	Delayed setting current	Delayed time setting	Instantaneous setting current	Instantaneous time setting
Rec1	300	0.15	300	0.175
Rec2	200	0.1	200	0.075

Table 5. fuses selection

Fuse name	Nominal current of the fuse
F1	50E
F2	20E
F3	50E
F4	30E
F5	65E

It is worth noting that the purpose of this paper is to carefully examine the events that will be observed in the distribution network with increasing scattered generator resources. In most of the papers that have been done, this issue has not been properly evaluated and is still one of the fundamental problems in designing a system optimally and efficiently. Thus, in this paper, main goal of simulation is to identify the underlying problems in the presence of several distributed production sources and approaching a final solution in the next steps of research. On the other hand, calculations and design drawings are based on two pairs of short-circuit current, but in this project, the design of protective devices is based on six pairs of short circuit current [18].

5.2. Results

As it mentioned before, the DIgSILENT platform is used to implement the grid and protection devices. Table 6 and 7 (F: Reclose Fast and D: Reclose Slow) contains the simulation results for a balanced three phase short circuit of protection area of each protection pairs. These results are minimum and maximum of short circuit current and trip times of all main and backup protection pairs. Table 6 shows the result for the case study network before DG unit installation, and table 7 shows the results after DG unit installation. The detected fault currents that measured by each protection device for a three phase short-circuit on middle of "Line 013" are depicted in table 8 for both scenarios (with and without DG unit installation).

A comparison on these tables clearly shows that DG presence caused some changes on fault currents. Results from table 8 show changes for measured currents of some protection devices. It should be noted that the minus sign defines a direction change in current flows. All these changes caused that the conventional protection schemes become insufficient for distribution grids with DG units

Some reasons of protection devices incoordination that mentioned in table 6, 7 and 8 are described below:

- After DG installation, the current of F2-F3 and F4-F5 fuses (main-backup) increased. In the first case, F4 and F5 fuses maintained coordinated but the coordination between F2 and F3 fuses lost.
- For a three phase fault on X bus, the pass through currents of F2 and F3 are IF2= IF3=1377 (A) while for a three phase fault on Y bus, the pass through currents of F2 and F3 are IF2= IF3=-156 (A). For the first mode, F2 fuse should operate before F3 fuse and for the second mode, F3 fuse should operate before F2. But these would not happen if both relays detect same currents for direct and reverse directions.
- The DG presence caused some changes on minimum and maximum of short-circuit currents of F3-Rec2 and F1-Rec1 protection pair devices in a way that fuses detect more current than the reclosers. As it mentioned before the deference between detected current of fuse and recloser is depended on place, capacity and size of DG units. For the first case, coordination between the F3 and Rec2 remains but in the second case the coordination between F3 and Rec1 is lost. Thus if the difference is lower than the CA, coordination remains otherwise it is lost.
- After DG installation, detected fault current by Rel1 reduces, this reduction causes an incoordination for Rel1-Rec1 and Rel2-Rel1 protection devices pair by insufficiency of Rel1 as the backup protection.
- After DG installation, the coordination between Rel1-Rel2 is not lost due to incensement of coordination time delay. Also due to a same reason, the coordination of Rec1-Rec2 protection pair is not lost.

Table 6. Maximum and Minimum fault current of protection devices pair (main and back-up element) for three-phase short circuit without distributed generator presence

Equipment		Coordination Range									
Main	Backup	Maximum three-phase short circuit					Minimum three-phase short circuit				
		fault location	short circuit current (A)		operating times (sec)		fault location	short circuit current (A)		operating times (sec)	
			Main	backup	Main	backup		Main	Backup	Main	backup
F4	F5	H'	868	868	0.043	0.122	I	747	747	0.056	0.182
F2	F3	E'	875	875	0.022	0.044	F	728	728	0.029	0.071
F1	Rec1	J'	1031	1031	0.029	0.015(F)	K	948	948	0.036	0.018(F)
					0.070	0.835(D)				0.082	0.888(D)
F3	Rec2	D'	985	985	0.033	0.003(F)	F	775	775	0.060	0.005(F)
					0.076	0.432(D)				0.119	0.504(D)
F5	Rel2	G'	980	980	0.158	0.478	I	796	796	0.253	0.555
Rel2	Rel1	N	1108	1108	0.441	1.275	G	957	957	0.487	1.502
Rec2	Rec1	C'	1114	1114	0.003(F)	0.013(F)	F	787	787	0.005(F)	0.027(F)
					0.400(D)	0.790(D)				0.504(D)	1.046(D)
Rec1	Rel1	B'	1262	1262	0.720(D)	1.123	F, K	810	810	1.046(D)	1.956

Table 7. Maximum and Minimum fault current of protection devices pair (main and back-up element) for three-phase short circuit with distributed generator presence.

<table>
<tr><th colspan="2">Equipment</th><th colspan="14">Coordination Range</th></tr>
<tr><th rowspan="3">Main</th><th rowspan="3">Backup</th><th colspan="7">Maximum three-phase short circuit</th><th colspan="7">Minimum three-phase short circuit</th></tr>
<tr><th rowspan="2">location of fault</th><th colspan="2">short circuit current (A)</th><th colspan="2">operating times (sec)</th><th rowspan="2">location of fault</th><th colspan="2">short circuit current (A)</th><th colspan="2">operating times (sec)</th></tr>
<tr><th>Main</th><th>backup</th><th>Main</th><th>backup</th><th>Main</th><th>Backup</th><th>Main</th><th>backup</th></tr>
<tr><td>F4</td><td>F5</td><td>H'</td><td>1503</td><td>1503</td><td>0.018</td><td>0.032</td><td>I</td><td>1222</td><td>1222</td><td>0.028</td><td>0.052</td></tr>
<tr><td>F2</td><td>F3</td><td>E'</td><td>1540</td><td>1540</td><td>0.01</td><td>0.011</td><td>F</td><td>1163</td><td>1163</td><td>0.014</td><td>0.022</td></tr>
<tr><td rowspan="2">F1</td><td rowspan="2">Rec1</td><td rowspan="2">J'</td><td rowspan="2">2177</td><td rowspan="2">1299</td><td>0.01</td><td>0.011(F)</td><td rowspan="2">K</td><td rowspan="2">1879</td><td rowspan="2">1123</td><td>0.012</td><td>0.015(F)</td></tr>
<tr><td>0.021</td><td>0.706(D)</td><td>0.027</td><td>0.785(D)</td></tr>
<tr><td rowspan="2">F3</td><td rowspan="2">Rec2</td><td rowspan="2">D'</td><td rowspan="2">1762</td><td rowspan="2">1580</td><td>0.01</td><td>0.002(F)</td><td rowspan="2">F</td><td rowspan="2">1168</td><td rowspan="2">1063</td><td>0.022</td><td>0.003(F)</td></tr>
<tr><td>0.029</td><td>0.332(D)</td><td>0.057</td><td>0.412(D)</td></tr>
<tr><td>F5</td><td>Rel2</td><td>G'</td><td>1744</td><td>1290</td><td>0.052</td><td>0.401</td><td>I</td><td>1125</td><td>895</td><td>0.1</td><td>0.511</td></tr>
<tr><td>Re l2</td><td>Rel1</td><td>N</td><td>1651</td><td>1032</td><td>0.35</td><td>1.438</td><td>G</td><td>1235</td><td>809</td><td>0.412</td><td>2.168</td></tr>
<tr><td rowspan="2">Re c2</td><td rowspan="2">Rec1</td><td rowspan="2">C'</td><td rowspan="2">1983</td><td rowspan="2">1470</td><td>0.002(F)</td><td>0.007(F)</td><td rowspan="2">F</td><td rowspan="2">1603</td><td rowspan="2">819</td><td>0.003(F)</td><td>0.019(F)</td></tr>
<tr><td>0.298(D)</td><td>0.650(D)</td><td>0.412(D)</td><td>1.035(D)</td></tr>
<tr><td>Re c1</td><td>Rel1</td><td>B'</td><td>1754</td><td>1242</td><td>0.584(D)</td><td>1.143</td><td>F,K</td><td>819</td><td>618</td><td>1.035(D)</td><td>inf</td></tr>
</table>

Table 8. Comparison of short circuit level for a three phase balanced fault on the middle of line 013

<table>
<tr><th rowspan="2">Device Name</th><th colspan="2">Current (A)</th><th rowspan="2">Device Name</th><th colspan="2">Current (A)</th></tr>
<tr><th>Without DG</th><th>With DG</th><th>Without DG</th><th>With DG</th></tr>
<tr><td>F1</td><td>0</td><td>0</td><td>Rec1</td><td>0</td><td>-428</td></tr>
<tr><td>F2</td><td>0</td><td>-76</td><td>Rec2</td><td>0</td><td>-194</td></tr>
<tr><td>F3</td><td>0</td><td>-76</td><td>Rel1</td><td>840</td><td>1062</td></tr>
<tr><td>F4</td><td>840</td><td>1382</td><td>Rel2</td><td>840</td><td>637</td></tr>
<tr><td>F5</td><td>840</td><td>1382</td><td>-</td><td>-</td><td>-</td></tr>
</table>

According to these results, it is clear that after DG installation in a distribution grid, conventional protection devices coordination may become insufficient.

6. Conclusion

The impacts of DG unit installation on protection devices coordination is discussed in this paper. Simulation results show that DG installation on distribution grids may cause some incoordination on protection devices. As the results show, in DG installed grid, downstream protection devices cannot detect reverse fault current, and upstream protection devices cannot detect direct fault currents. These may cause some protection incoordination in the distribution system.

Appendix

Similarly, relays and reclosers can be characterized by inverse-time characteristic curve. Such curves are generally represented by the following equation:

$$t_{op}(I) = TD\left[\frac{A}{\left(\frac{I}{I_{Pick-up}}\right)^{p} - 1} + B\right] \quad (1)$$

Where t_{op} is the device operating time, I am the device current, TD is the time dial setting, $I_{Pick\text{-}up}$ is the device current set point, and A, B and p are constant parameters [11].

References

[1] A. Girgis, and S. Brahma. (2004). Development of adaptive protection scheme for distribution systems with high penetration of distributed generation. IEEE Transactions on Power Delivery. Vol. 19. No. 1. 56-63

[2] H. Wan, K. K. Li, and K. P. Wong. (2005). A multi-agent approach to protection relay coordination with distributed generators in industrial power distribution system. Industry Applications Conference, Fourtieth IAS Annual Meeting Conference. Vol. 2. 830-836

[3] K. Kauhaniemi and L. Kumpulainen. (2004). Impact of distributed generation on the protection of distribution network. Eighth IEE International Conference on Developments in Power System Protection. Vol. 1. 315-31

[4] K. Maki, S. Repo, and P. Jarventausta. (2008). Methods for assessing the protection impacts of distributed generation in network planning activities. IET, 9th International Conference on Developments in Power System Protection (DPSP). 484-489

[5] F. A. Viawan. Steady State Operation and Control of Power Distribution Systems in the Presence of Distributed Generation. Thesis for the Degree of Licentiate Engineering.

[6] M. Khederzadeh, H. Javadi, and S. M. A. Mousavi. (2010). Source type impact of distributed generation (DG) on the distribution protection. 10th IET International Conference on Developments in Power System Protection (DPSP). Manchester. UK

[7] E. Coster and J. Myrzik, Wil Kling. (2007). Effect of distributed generation on protection of medium voltage cable grids. 19th International Conference on Electricity Distribution Vienna. 21-24

[8] F. Razavi, H.A. Abyaneh, M. Al-dabbagh, R. Mohammadi, and H. Torkaman. (2008). A new comprehensive genetic algorithm method for optimal overcurrent relays coordination. Electric Power Systems Research. Vol. 78. No. 4. 713-720

[9] W. J. Ruschel and A. W. Ashley. (1989). Coordination of relays, reclosers, and sectionalizing fuses for overhead lines in the oil patch. IEEE Transactions on Industry Applications. Vol.25. No.6. 1041-1048

[10] A. Girgis and S, Brahma. (2001). Effect of distributed generation on protective device coordination in distribution system. Conference on Large Engineering Systems. 115-119

[11] A. Zamani, T. Sidhu, and A. Yazdani. (2010). A strategy for protection coordination in radial distribution networks with distributed generators. IEEE, Power and Energy Society General Meeting. Vol. 10. 263-270

[12] D. Birla, R. P. Maheshwari, and H. O. Gupta. (2005). Time-overcurrent relay coordination: a review. International Journal of Emerging Electric Power Systems. Vol. 2, No. 2

[13] K. Tuitemwong and S. Premrudeepreechacharn. (2009). Expert system for protective devices coordination in radial distribution network with small power producers. International Conference: Electrical Energy and Industrial Electronic Systems, Penang, Malaysia, 7-8 December.

[14] H. M. Soheilipour, H. Askarian-Abianeh, R. Mohammadi, F. Razavi. A Genetic Algorithm optimized setting for optimal coordination of protection devices in distribution grids. 23rd international conference on electrical engineering, Tehran, Iran.

[15] Amini A.R., Derakhshan-Barjoei P." Evaluation and Optimization of power transformer differential protection using amplitude and phase angle difference between the first and second harmonics current based on fuzzy logic" ICEEE Conf. 2013.

[16] Khashayar A., Derakhshan-Barjoei P. (2018), " Optimization of static inter-phase controller using joint particle swarm and neural network algorithm for damping power system fluctuations", International Journal of Advanced Science and Research. Vol. 3, Issue 2.

[17] Zakariapour A., Derakhshan-Barjoei P. (2018), " Sub-harmonics fluctuations cancellation in LED resonant-switching driver controller using imperialistic competitive algorithm", International Journal of Multidisciplinary Research and Development. Vol. 5, Issue 1.

[18] Mohammadi, R., Abyaneh, H.A., Razavi, F., "Optimal relays coordination efficient method in interconnected power systems", Journal of Electrical Engineering, vol. 61, no. 2, pp. 75–83, June 2010.