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EFFECT OF ADDING DISTRIBUTED GENERATION TO DISTRIBUTION NETWORKS

CASE STUDY 3:

Protection coordination considerations with inverter and machine based DG

Canada

EFFECT OF ADDING DISTRIBUTED GENERATION TO DISTRIBUTION NETWORKS

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Protection coordination considerations with inverter and machine based DG

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Financial support for this research project was provided by Natural Resources Canada through the Program on Energy Research and Development. The first edition of this report was prepared by C. Kwok and A. S. Morched in April 2006 [1].

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Summary

This report details the third of a series of case studies with the intent of disseminating knowledge about the impact of distributed generation on distribution planning and operation. This third case study is based on the investigation of the protection coordination of a 25 kV weak system with both inverter and machine-based distributed generation interconnected. The second edition for this series of case studies is meant to update the information in the first edition and facilitate the study of the integration of DG into distribution networks. This case study is meant to be accompanied by the corresponding CYMDIST case study files; however, it also serves as a self-contained and informative report.

Sommaire

Ce document est le troisième d'une série d'études de cas qui ont comme but de diffuser la connaissance sur le sujet de l'impact de l'intégration de la production distribuée sur l'opération et la planification des réseaux électriques. Cette étude de cas 3 est basée sur le problème de coordination des appareils de protection dans un système faible de 25kV avec production éolienne et hydro. Cette deuxième édition vise à mettre à jour les études de cas de la première édition, toujours avec l'intention de faciliter l'étude de la production décentralisée et son intégration. Ce document décrit l'étude de cas, incluant les étapes suivies et les résultats. Il a été conçu pour accompagner les fichiers de simulation de CYME mais peut aussi servir de référence utile et informative.

1 Introduction

The incorporation of distributed generation into power systems can offer many major advantages. However, besides its various benefits, distributed generation can cause various negative impacts; careful investigation is required to insure that system reliability and security are conserved following DG integration.

Among these issues, protection coordination is a major concern since it directly affects continuity of service, as well as safety of equipment and personnel. Therefore it is essential to conduct thorough analyses in order to determine if protective devices installed on the network are properly coordinated, following the addition of distributed generators. Furthermore, mitigation strategies can then be identified to alleviate any potential problems.

As will be demonstrated hereafter, the addition of DG to the distribution network may prevent the protective device from detecting a fault, which is supposed to be within its protection zone. It may also result in the loss of coordination between two protective devices. A potential loss of coordination within the system depends strongly on the DG type, size and location in the network.

1.1 Description of Assignment

The objective of this assignment is to create a tutorial in order to demonstrate the impact of implementing distributed generation sources of different technologies, in a typical distribution circuit, on:

1. The proper operation of protective devices based on their settings prior to the addition of distributed generation resources.

2. The effect of adding distributed generation on the coordination of operation between two protective devices.

1.2 Distributed Generation

Each of the above cases is examined taking into consideration the impact of using:

- Distributed generation sources composed of directly connected synchronous machines.

- Distributed generation sources composed of electronically coupled units, where the inverter control mode is set such that, during short circuits, the contribution of the source is limited to its rated current.

2 Distribution System Investigated

The distribution system selected for this tutorial is a 25 kV (nominal) multi-grounded distribution circuit with several laterals (single-phase) feeding multiple loads, which operates at 25.83 kV.

The circuit had to be reduced to a representative equivalent circuit maintaining the main generation and load feeding points, for better observation of the impact of DG sources on the circuit. The equivalent circuit is shown in Figure 1. The total load in the circuit is concentrated at the locations L1 – L6. The total demand of the equivalent concentrated loads, in MVA, and their corresponding power factor, are given in Table 1.

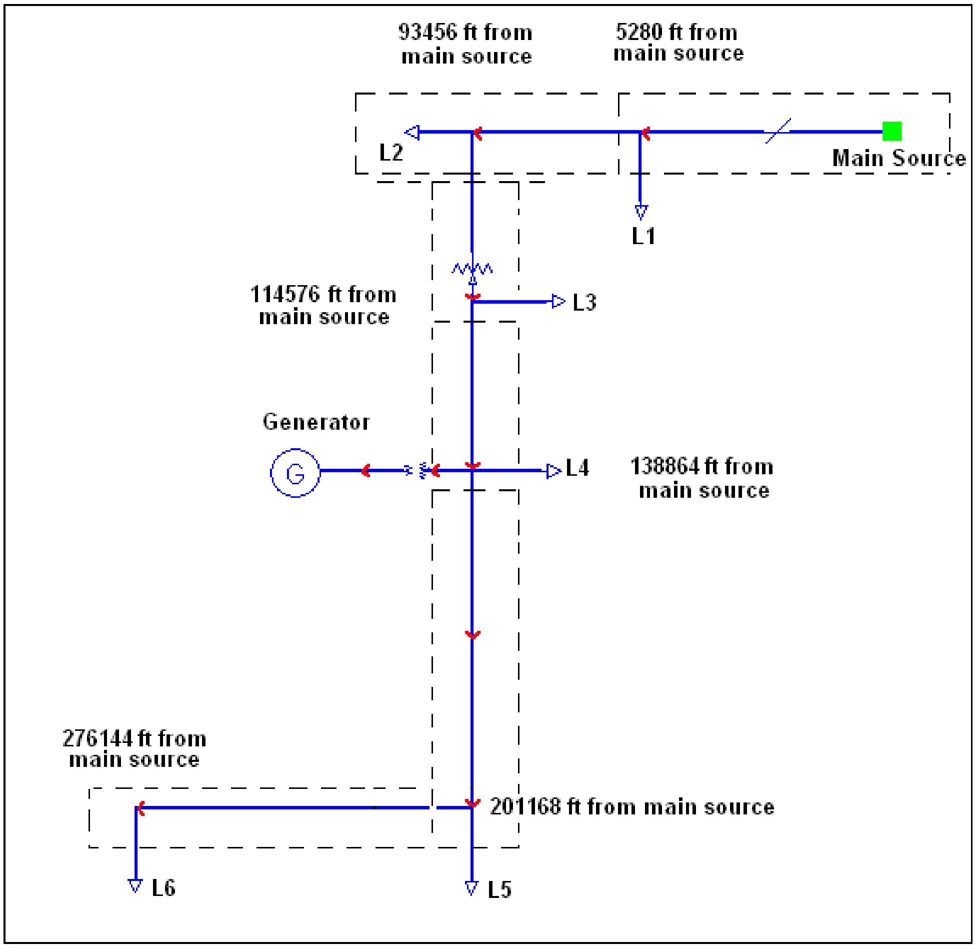


Figure 1 - System Configuration

	LOAD (in MVA)		
	Peak (100%)	Normal (60%)	Light (30%)
L1	0.50 (pf = 95)	0.30	0.15
L2	1.59 (pf = 94.6)	0.95	0.48
L3	0.58 (pf = 96.8)	0.34	0.17
L4	0.71 (pf = 96.6)	0.43	0.21
L5	0.32 (pf = 98.3)	0.19	0.09
L6	0.56 (pf = 97.5)	0.34	0.17
Total	4.27	2.56	1.28

Table 1 - Load Distribution along the Feeder

3 Overview of Solution

The simulations of the different case-studies of this tutorial are conducted in a pre-released version 5.0 of the CYMDIST software. The short-circuit current in each section, resulting from applying a fault at a specific location of the network, is obtained through Fault Flow analysis. Every case has been saved as a self-contained study file, as specified in Annex A.

CYMTCC was used to check the fault current magnitude against the characteristics of the relay, which is supposed to clear it for different operating conditions. It was also used to check the coordination of two separate relays under different fault conditions, for different operating scenarios.

3.1 Study Procedure

The procedure followed in this study is described below:

1. Simulation of the distribution network selected for the study using CYMDIST, including the embedded distributed generation source.
2. Conduction of a fault flow analysis for a selected fault location, without the inclusion of distributed generator.
3. Conduction of a fault flow analysis for a selected fault location, with the inclusion of a directly connected synchronous distributed generator.
4. Conduction of a fault flow analysis for a selected fault location, with the inclusion of electronically connected distributed generator.
5. Comparison of the current seen by the relay against its assumed time current characteristic using CYMTCC.
6. Replacement of the single-device protection scheme by a different scheme with two protective devices with different characteristics, in order to improve the protection scheme selectivity.
7. The above steps are repeated for the two protective devices scheme of point 6.

4 Investigated Scenarios

4.1 Case A - One Breaker Feeder Protection - DG synchronous Generator

The feeder configuration is shown in Figure 2. One breaker (B1) situated at the source end of the feeder protects the total length of the feeder. The fault detection is provided by a constant time over current relay that trips the whole feeder after 0.2 seconds if the current seen by the relay exceeds 250 amperes.

A.1 In the absence of the distributed generation source, this current setting allows the relay to cover the total length of the feeder, with a good margin. The fault current seen by the relay for a fault at the end of the feeder is 315 amperes for these operating conditions.

A.2 A distributed generation source composed of a 5000 kW synchronous generator is added at L4, as shown in Figure 2. The current seen by the relay for a fault at the end of the feeder decreases to 197 amperes under these conditions. This current is much less than the relay triggering current. Thus the relay will not see the fault and consequently, it will not operate. The comparison between the cases A.1 and A.2 is shown in Figure 3.

A.3 A much smaller distributed generation source composed of a 1000 kW synchronous generator is added at L4, as shown in Figure 2. The current seen by the relay for a fault at the end of the feeder is 287 amperes, which is barely enough to operate the relay under these conditions. Case A.3 demonstrates a marginal condition for the detection of the fault. The comparison between cases A.1 and A.3 is shown in Figure 4.

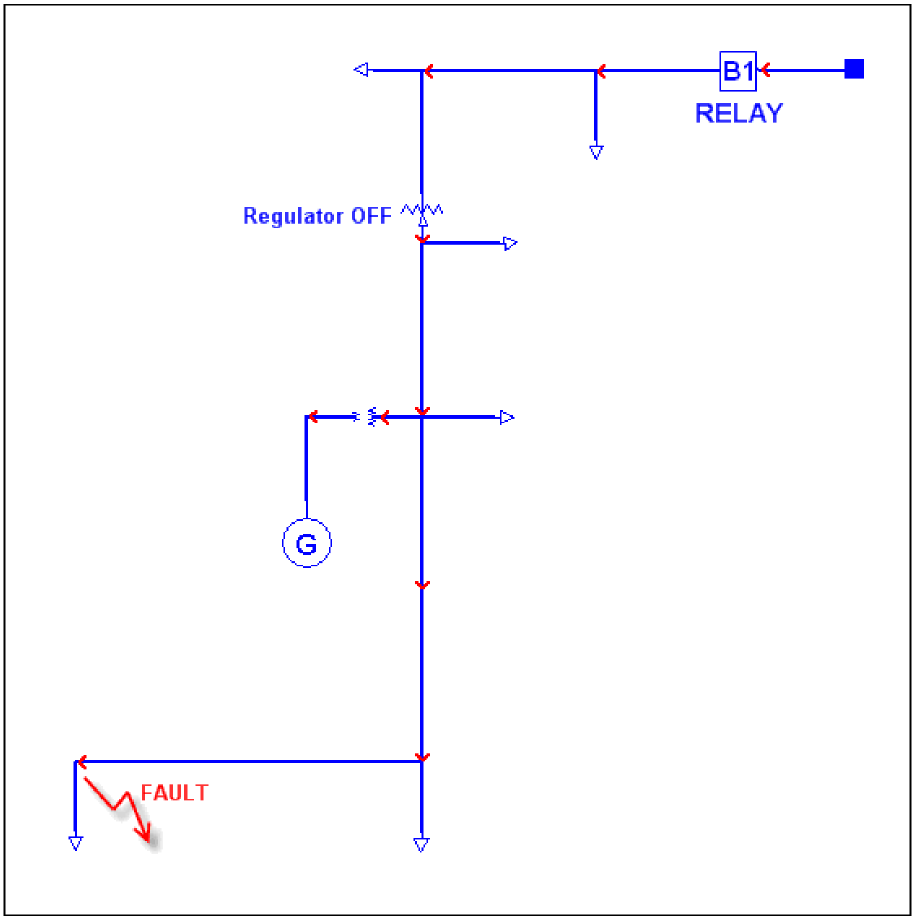


Figure 2 - The Protection Scheme for Case A

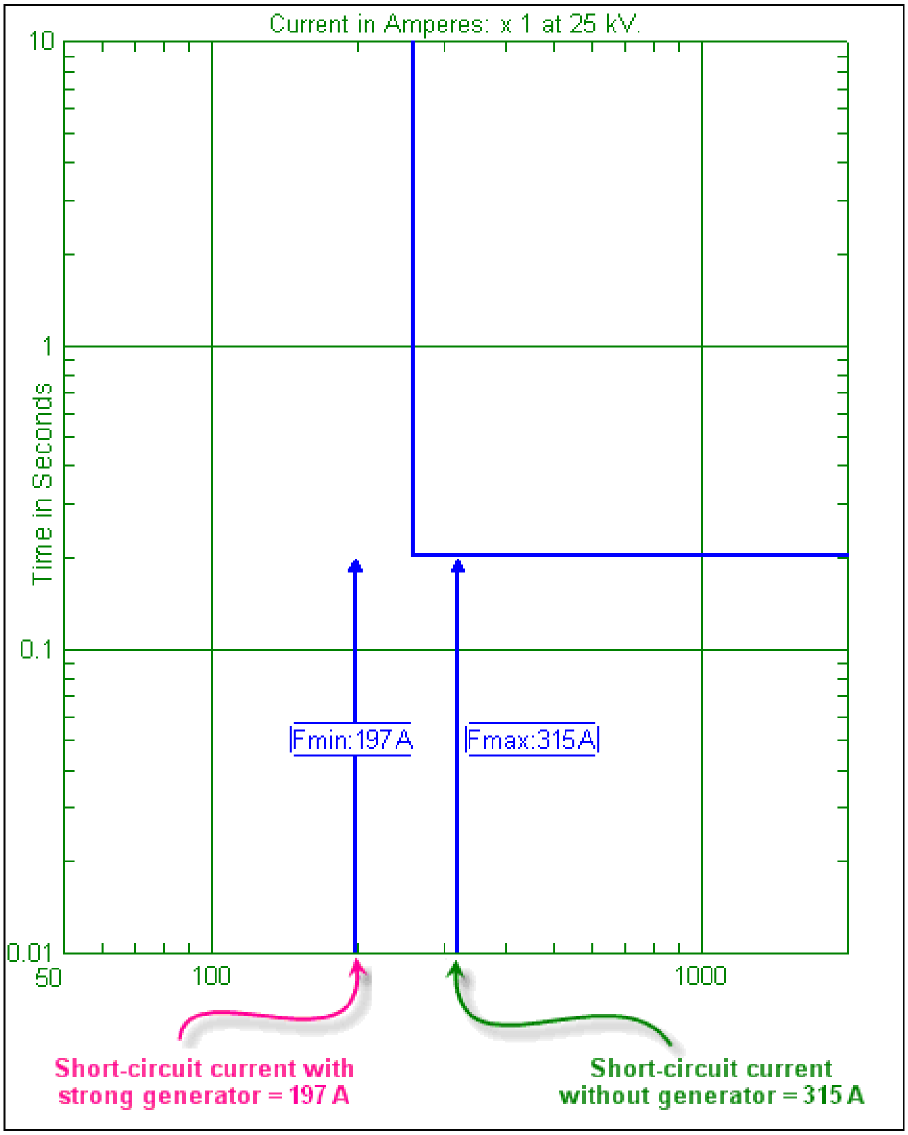


Figure 3 - Relay Current versus Relay Characteristics for Cases A.1 and A.2

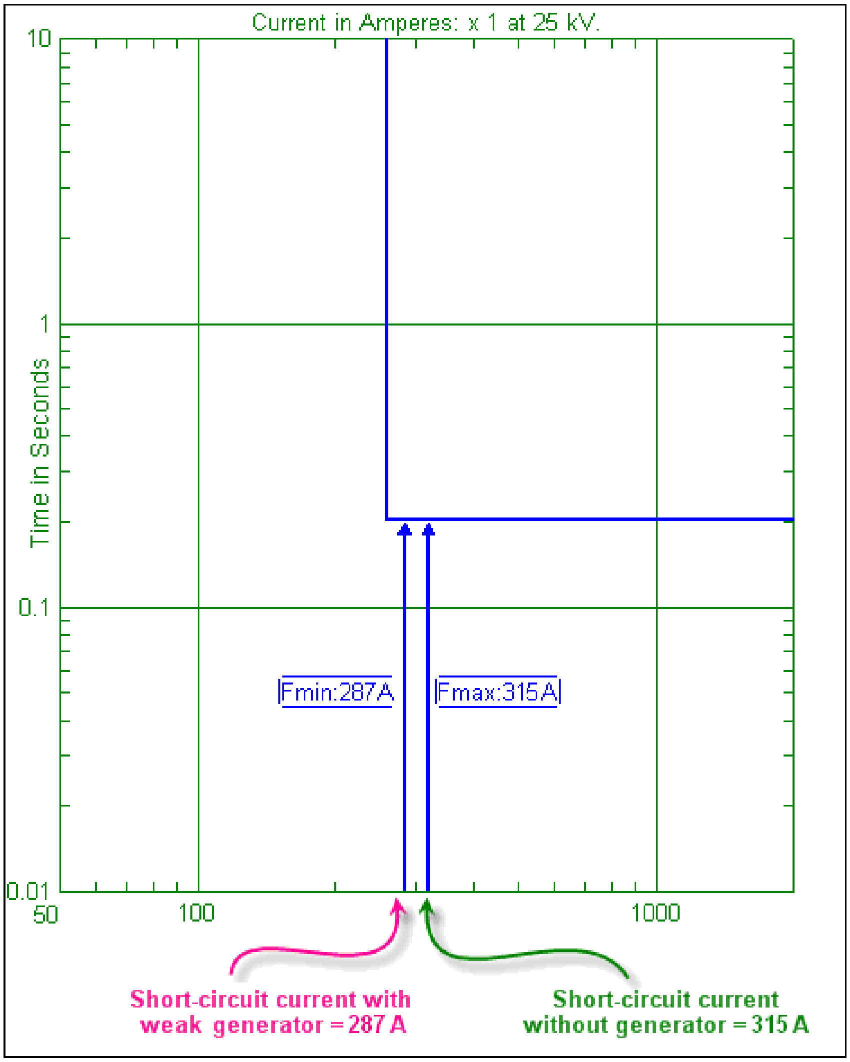


Figure 4 - Relay Current versus Relay Characteristics for Cases A.1 and A.3

4.2 Case B - One Breaker Feeder Protection - DG Electronically Coupled Generator

The feeder configuration and the protection scheme in this case are similar to those of Case A. The distributed generation in this case is an electronically coupled unit that contributes 100% of its rated current during short circuit conditions.

B.1 A distributed generation source composed of a 5000 kW electronically coupled generator is added at L4. The current seen by the relay for a fault at the end of the feeder is 278 amperes under these conditions. This current is within the relay triggering current and no problem would be anticipated for these conditions. The comparison between cases A.1 and B.1 is shown in Figure 5.

B.2 A much smaller distributed generation source composed of a 1000 kW electronically coupled unit is added at L4. The current seen by the relay for a fault at the end of the feeder is 307 amperes under these conditions. This current is not much lower than the conditions without distributed generation and is well within the relay triggering current. No problem would be anticipated for these conditions. The comparison between cases A.1 and B.2 is shown in Figure 6.

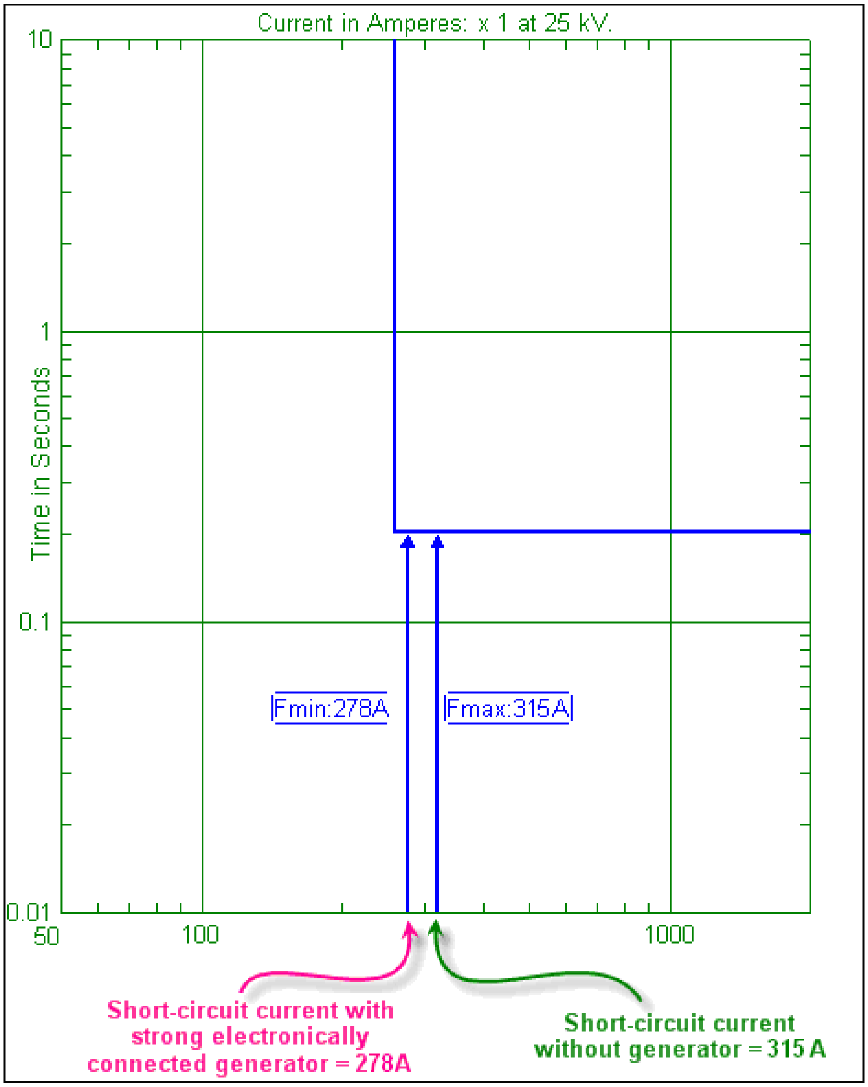
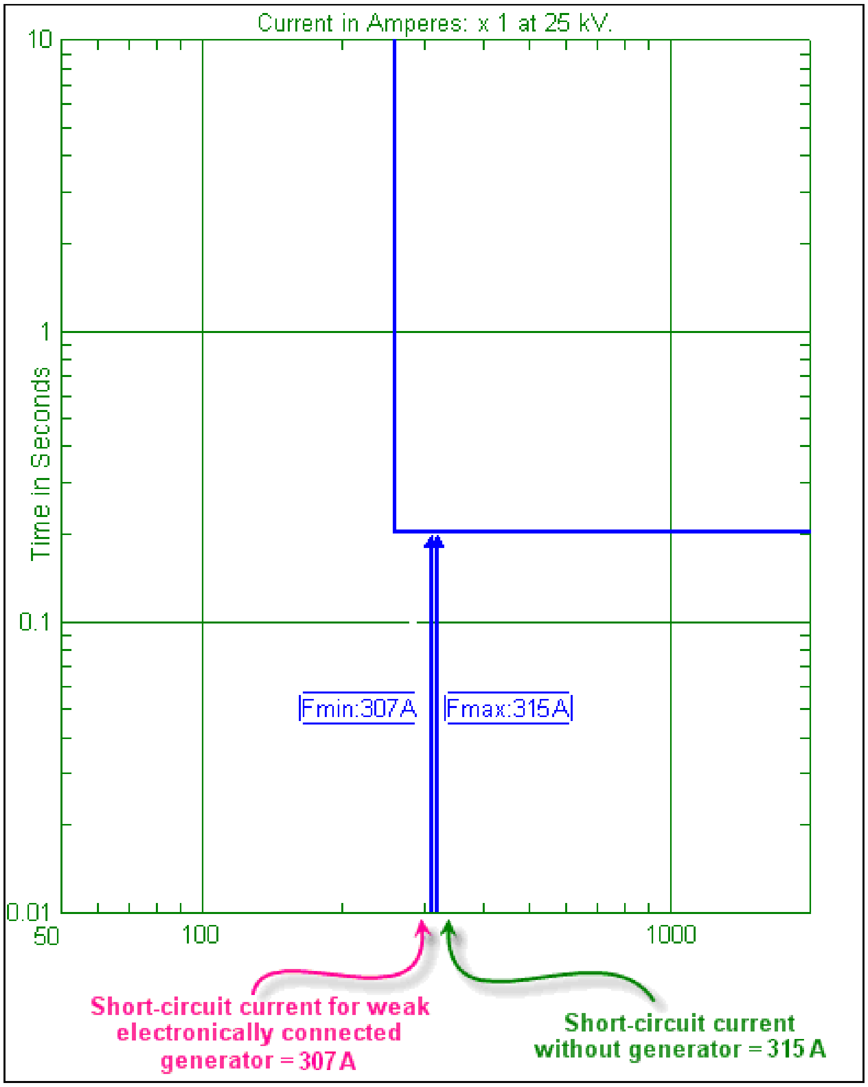


Figure 5 - Relay Current versus Relay Characteristics for Cases A.1 and B.1



Short-circuit current for weak electronically connected generator = 307 A

Short-circuit current without generator = 315 A

Figure 6 - Relay Current versus Relay Characteristics for Cases A.1 and B.2

4.3 Case C - Coordination between Two Protective Devices – Directly Coupled Synchronous Generators

To improve the selectivity of the protection system and to minimize interruptions of loads connected to an un-faulted portion of the feeder, two protective devices strategically located and well coordinated can be used.

An example of this is the scheme shown in Figure 7, where a breaker (B2) is inserted at the beginning of the section L4 to L5. The breaker operation is initiated by an inverse current characteristics relay that would operate within 0.04 second if the current seen by the relay exceeds 400 amperes. A fuse (F1) is installed at the beginning of the L5-L6 section to isolate faults on this portion of the feeders before the upstream breaker operates.

The coordination of these two devices is examined in this section for conditions of the system with and without distributed generation for different fault location on the L5-L6 line section. The distributed generation examined in this section is assumed to be directly coupled synchronous units of two different sizes.

C.1 This section shows the short circuit current seen by the fuse F1 as well as the relay B2 for a fault (Fault 1) at the end of the feeder (L6) for the three different situations of:

C.1.1 No distributed generation added

C.1.2 A relatively large synchronous unit of 5000 kW is added at L4

C.1.3 A small synchronous unit of 1000 kW is added at L4

The resulting currents for each of these cases, superimposed on the relay and fuse characteristics, are shown in Figure 8. Figure 8 shows that the coordination between the two devices is maintained in all three cases. However, it should be noticed that proper coordination is marginally maintained, since the resulting current for the case-study which includes a large synchronous unit is very close to the tripping current of the relay B2.

C.2 This section shows the short circuit current seen by the fuse F1 as well as the relay B2 for a fault (Fault 2) at the entrance of the feeder (L5) for the three different situations of:

C.2.1 No distributed generation added

C.2.2 A relatively large synchronous unit of 5000 kW is added at L4

C.2.3 A small synchronous unit of 1000 kW is added at L4

The resulting currents for each of these cases, superimposed on the relay and fuse characteristics are shown in Figure 9. The figure shows that the coordination between the two devices is lost for the cases where DG is involved and the relay B2 will trip both sections, i.e., sections L4-L5 and L5-L6, for a fault in the later section. This would result in an outage for all customers downstream of relay B2, one that normally would have been limited to customers downstream of the fuse F1.

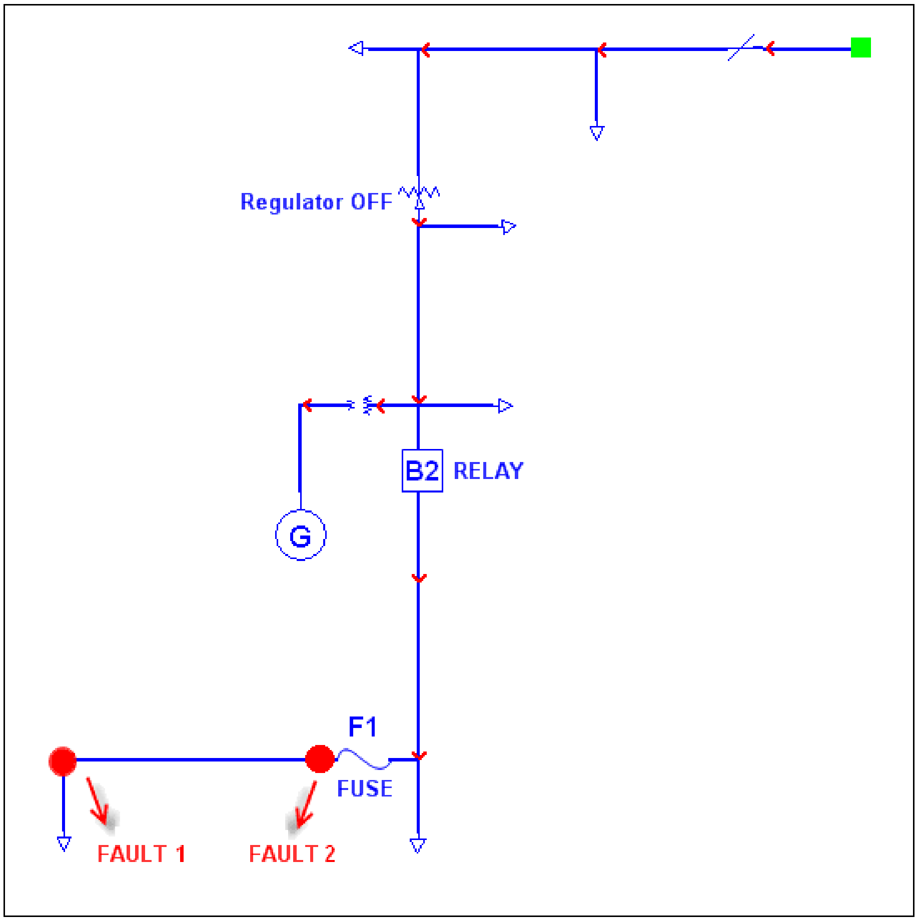
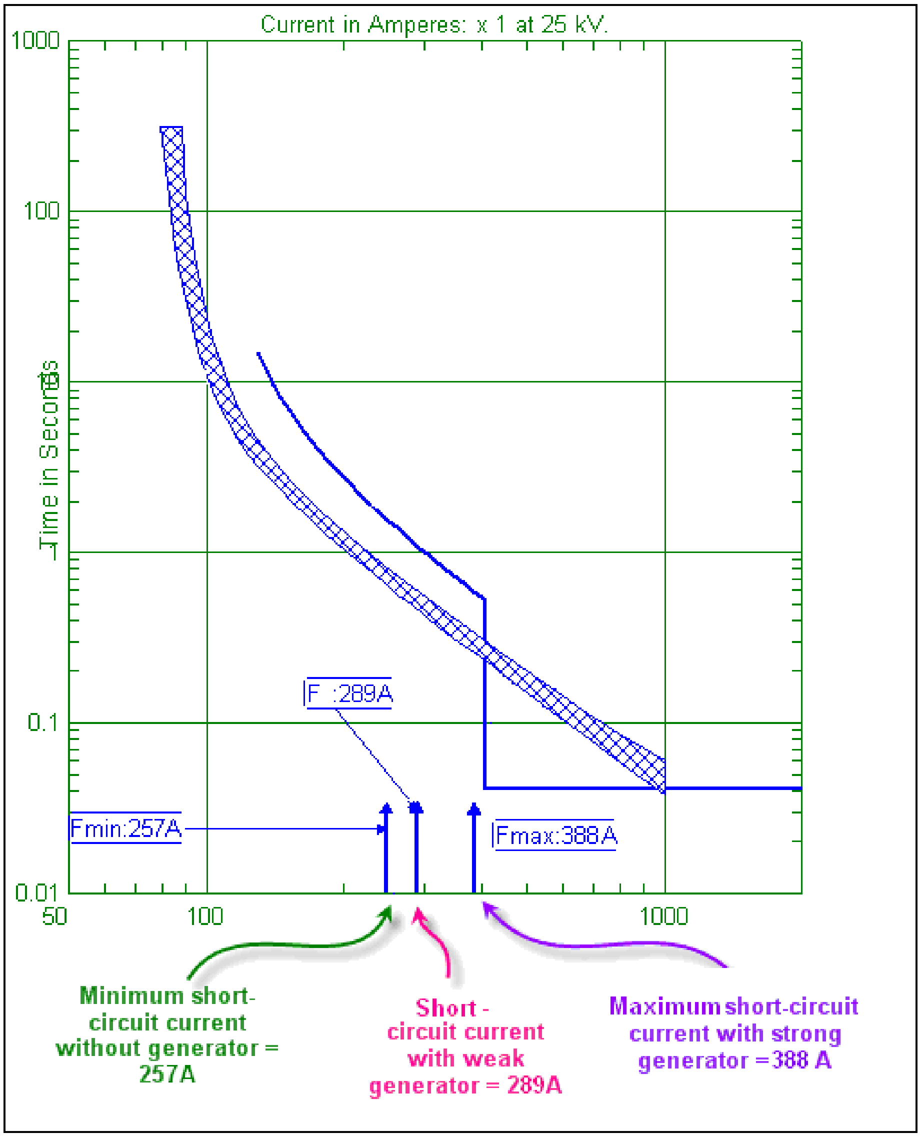


Figure 7 - Two Protection Devices Scheme



Minimum short-circuit current without generator = 257A

Short - circuit current with weak generator = 289A

Maximum short-circuit current with strong generator = 388 A

Figure 8 - Coordination between Two Protective Devices for a Fault at L6, Without and With a Synchronous DG, Cases C.1.1, C.1.2, and C.1.3.

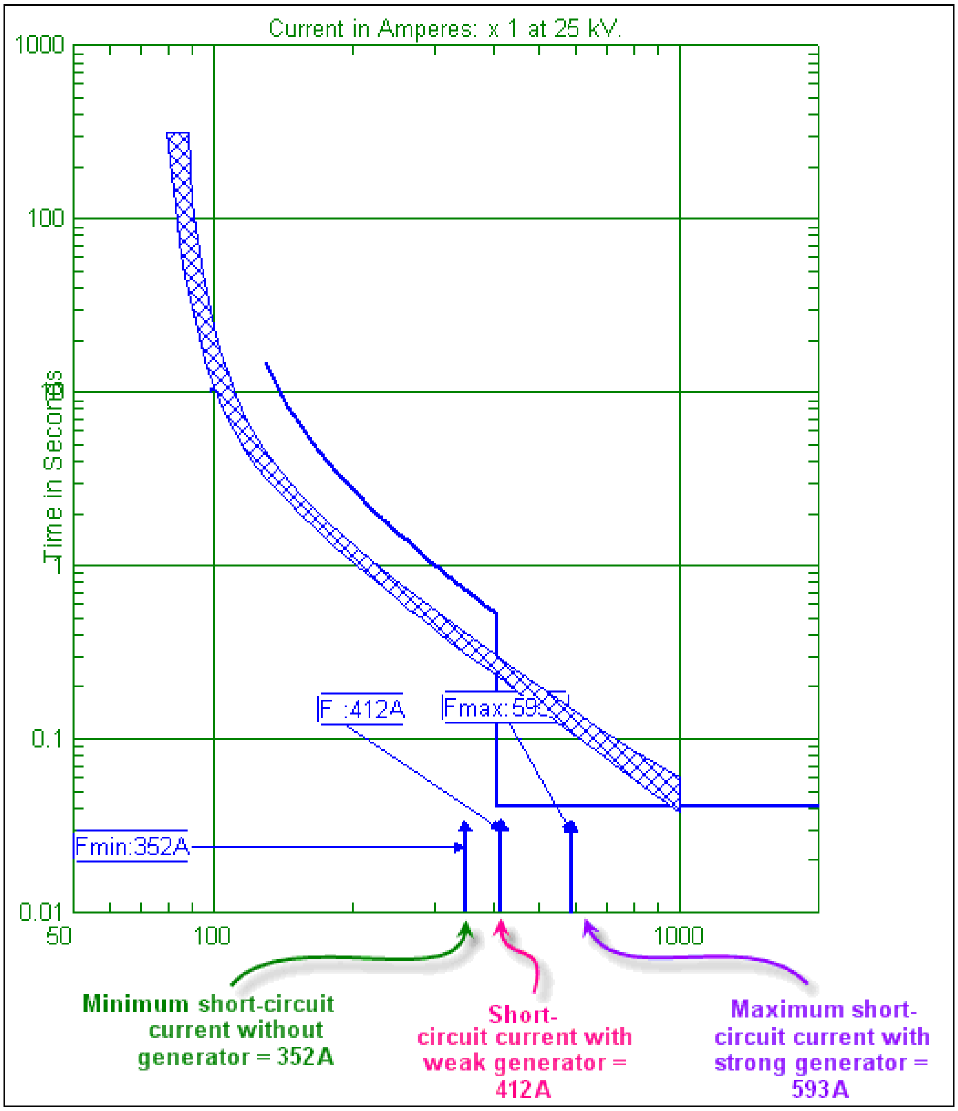


Figure 9 - Coordination between Two Protective Devices for a Fault at L5, Without and With a Synchronous DG, Cases C.2.1, C.2.2, and C.2.3.

4.4 Case D - Coordination between Two Protective Device - Electronically Coupled DG Units

This case assumes the same protection scheme used in case C and shown in Figure 7.

The coordination of the two devices is examined in this section for conditions of the system with and without distributed generation for different fault location on the L5-L6 line section. The distributed generation examined in this section is assumed to be electronically coupled units, of two different sizes, that contribute a maximum of their rated current under fault conditions.

D.1 This section shows the short circuit current seen by the fuse F1 as well as the relay B2 for a fault (Fault 1) at the end of the feeder (L6) for the three different situations of:

- D.1.1 No distributed generation added
- D.1.2 A relatively large electronically coupled unit of 5000 kW is added at L4
- D.1.3 A small electronically coupled unit of 1000 kW is added at L4

The resulting currents for each of these cases, superimposed on the relay and fuse characteristics are shown in Figure 10. Figure 10 shows that the coordination between the two devices is maintained in all three cases and the fuse F1 will eliminate the faulted section before the relay B2 operates.

D.2 This section shows the short circuit current seen by the fuse F1 as well as the relay B2 for a fault (Fault 2) at the beginning of the feeder (L5) for the three different situations of:

- D.2.1 No distributed generation added
- D.2.2 A relatively large electronically coupled unit of 5000 kW is added at L4
- D.2.3 A small electronically coupled unit of 1000 kW is added at L4

The resulting currents for each of these cases, superimposed on the relay B2 and fuse F1 characteristics are shown in Figure 11. The figure shows that the coordination between the two devices is lost for the case which involves a large electronically interfaced DG unit. This results in the operation of relay B2 prior to the operation of fuse F, i.e., in an outage for all customers downstream of relay B2, one that normally would have been limited only to customers downstream of the fuse F1.

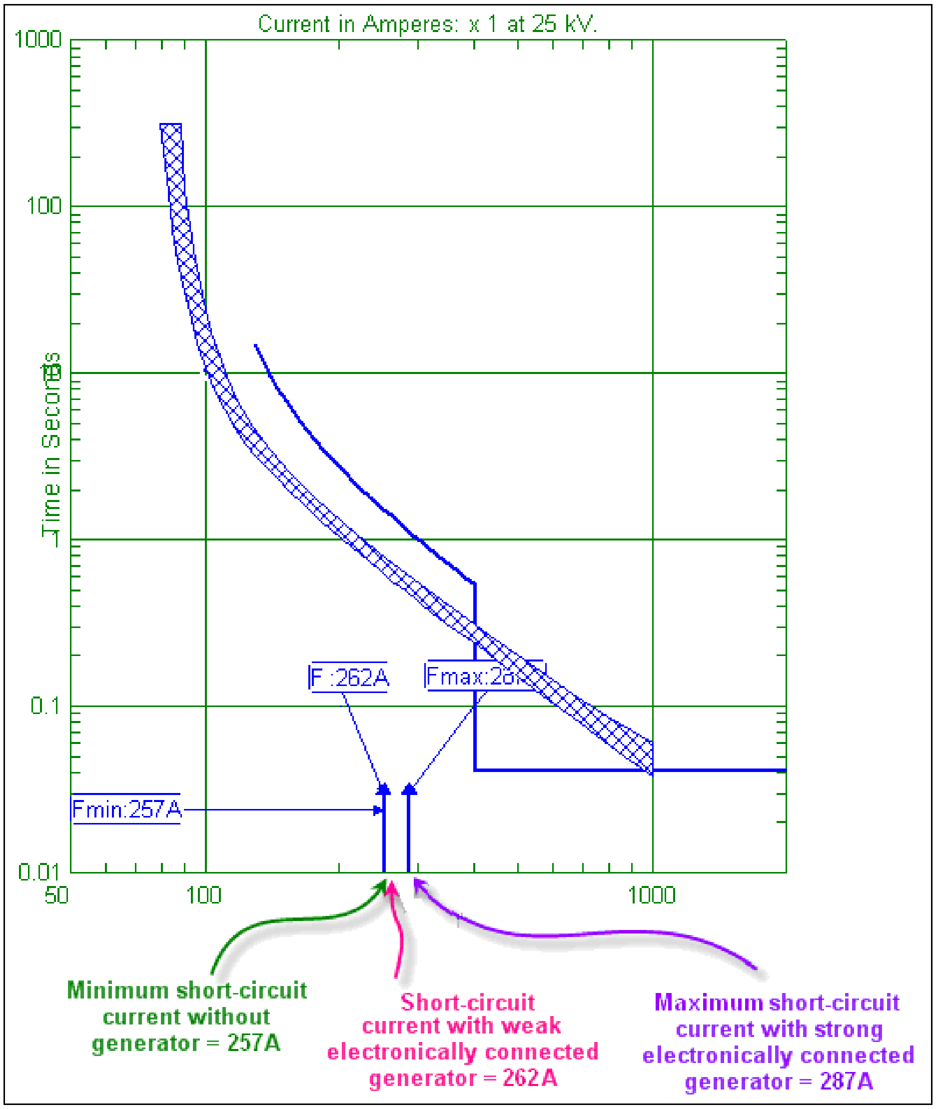


Figure 10 - Coordination between Two Protective Devices for a Fault at L6, Without and With Electronically Coupled DG Units, Cases D.1.1, D.1.2, and D.1.3.

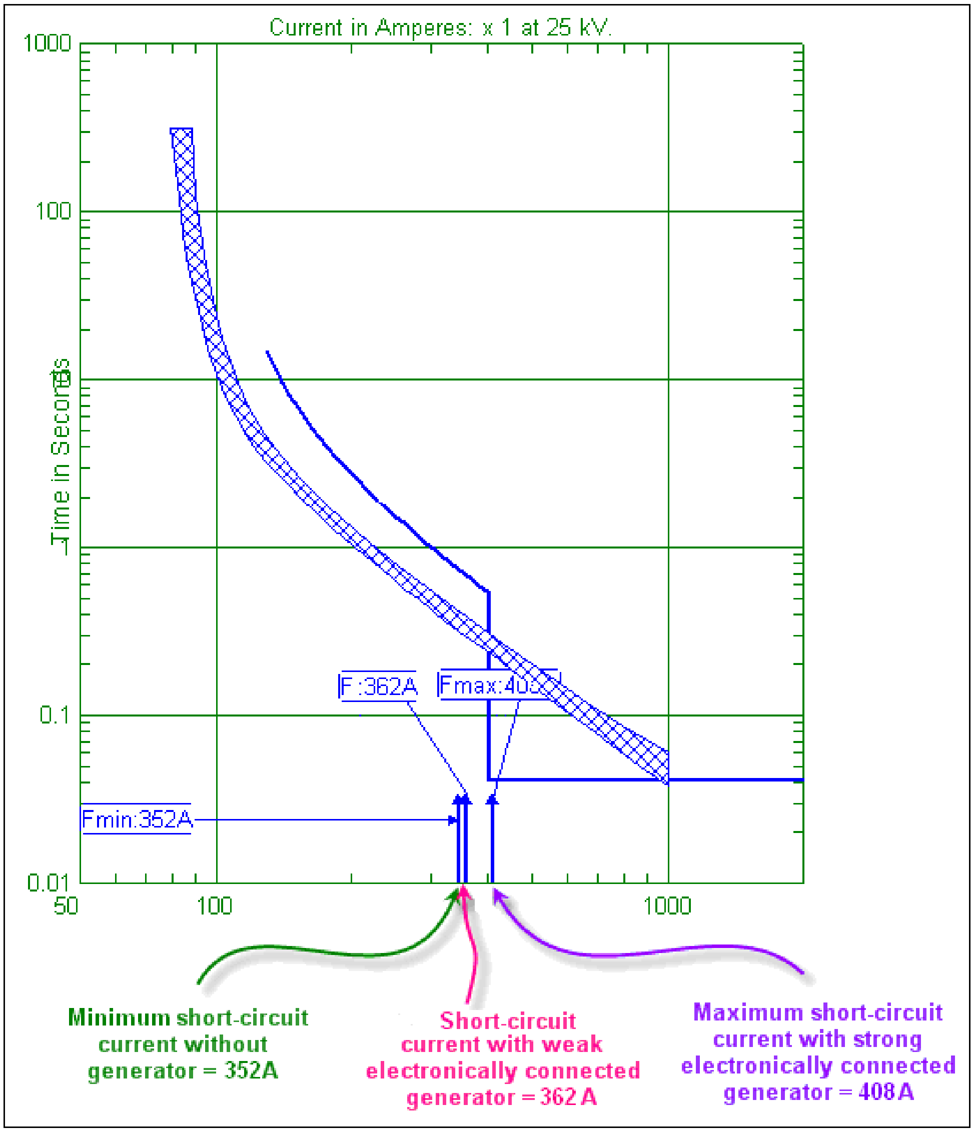


Figure 11 - Coordination between Two Protective Devices for a Fault at L5, Without and With Electronically Coupled DG Units, Cases D.2.1, D.2.2, and D.2.3.

5 Conclusions

The incorporation of distributed generation in power systems introduces several interfacing issues that need careful investigation to insure system reliability and security.

Among these issues, protection coordination is a major concern since it directly affects continuity of service as well as safety of equipment and personnel. Therefore it is essential to conduct thorough analyses in order to determine if protective devices installed on the network are coordinated properly after the addition of distributed generators and to identify corrective means to alleviate potential problems.

Simulation studies included in this report indicate that:

1. The addition of distributed generation units within a feeder results in a reduction of the source contribution to faults downstream of the DG while increasing the fault current itself.
2. This effect is more pronounced for DG units controlling their terminal voltage such as directly coupled synchronous units.
3. This effect is almost negligible for electronically coupled DG units acting as a constant current source, when their contribution to the fault is modeled by their rated current.
4. The effect of adding DG units, particularly large synchronous generators, to a distribution feeder can produce blind zones for protection devices or alter the coordination between two (or more) protective devices and should be studied carefully.

It should be noted that most utilities will require that DG trips during these types of disturbances, in most cases circumventing the potential problems discussed in this report. However, the potential impact of DG on the protection scheme should be analyzed with care.

6 References

[1] Kwok, C. and Morched, A.S., Effects of Adding Distributed Generation to Distribution Networks Case Study 3: Protection coordination considerations with inverter and machine based DG, report # CETC 2006-147 (INT), CANMET Energy Technology Centre – Varennes, Natural Resources Canada, April 2006, 18 pp.

[2] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/renewables/integration_der.html

ANNEX A
CYME file references

ANNEX A
CYME file references

The CYMDIST software and the CYMDIST files corresponding to the case studies of this report can be obtained from CYME International (www.cyme.com). Interested users should contact CYME International directly.

Section		CYMDIST Files
4.1, 4.3	Synchronous Generator	FaultFlow_NonElectronicallyConnectedMachine_Strong.sxst FaultFlow_NonElectronicallyConnectedMachine_Weak.sxst
4.2, 4.4	Electronically Interfaced Units	FaultFlow_ElectronicallyConnectedMachine_Strong.sxst FaultFlow_ElectronicallyConnectedMachine_Weak.sxst