The Inter-tie Protection Schemes of the Utility Interactive Dispersed Generation Units for Distribution Automatic Reclosing

Joon-Ho Choi*, Jae-Chul Kim and Seung-Il Moon*****

Abstract - *Dispersed Generation* (DG) units significantly effect the existing distribution protection practices. Therefore, new protection practices of the distribution system interconnected with DG units should be reevaluated and developed. In this paper, a new inter-tie protection scheme of DG units for distribution automatic reclosing is proposed. The impact of DG units on existing recloser-sectionaliser coordination is analyzed. And the effects of the distribution reclosing type (radial and passive reclosing) on DG dynamics are analyzed and classified. From the results of the DG dynamic responses by the reclosing type, i.e. radial and passive reclosing, the inter-tie protection schemes of DG are introduced to improve the reliability and availability of utility interactive DG. The proposed schemes are proved and evaluated by a case study using PSCAD/EMTDC simulation.

Keywords: Dispersed Generation(DG), recloser, sectionaliser, inter-tie protection schemes, distribution protection practices, radial reclosing, passive reclosing.

1. Introduction

It is expected that unexpected protective coordination problems will occur with the introduction of *Dispersed Generation* (DG) in distribution systems. In general, distribution systems adopt automatic reclosing to improve reliability, i.e. *System Average Interruption Frequency Index* (SAIFI). With the introduction of DG in distribution networks, the fault contributions of DG will affect existing distribution coordination practices, i.e. recloser - sectionaliser coordination and recloser - fuse coordination. In addition, distribution automatic reclosing can result in DG islanding, and damage DG units if the system and the DG devices are operating out-of-phase.

Previous works on the protection issue with DG, the protection problems and over voltage considerations are discussed well in [1-3], the grounding considerations of cogeneration systems are discussed well in [4, 6-7], and relay performance and inter-tie protection of DG units are discussed well in [8-10, 12]. In general, the utility interactive DG units are disconnected from utility networks as soon as possible when a fault occurs in distribution systems.

Two types of reclosing can be seen in the power systems namely; "radial reclosing" and "passive reclosing". These reclosing types must be considered in protection schemes of the DG units. Since the passive reclosing does not occur on a branch, which directly provides a link between the source and DG units, it is not as dangerous as radial reclosing as shown in Fig. 1.

The DG units cannot be greatly damaged during the passive reclosing because fault contributions of the DG unit are relatively small and voltage angle differences of DG should be close to the utility source. Thus, if a fault occurred in a nearby feeder, DG should not be immediately disconnected from the utility grid.

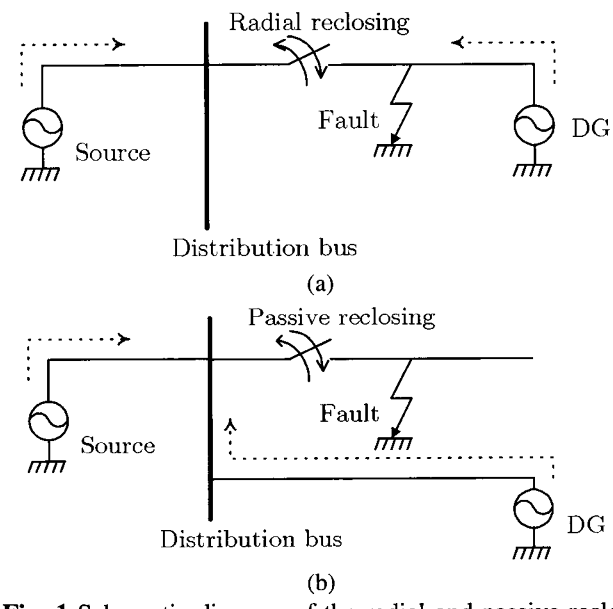

Fig. 1 Schematic diagram of the radial and passive reclosing of the distribution systems with DG: (a) radial reclosing, (b) passive reclosing

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In this paper, new inter-tie protection schemes of DG for distribution reclosing types are proposed in view of the reliability and the availability of utility interactive DG units.

2. Impacts of DG Units on Recloser-Sectionaliser Coordination

The coordination of the recloser-sectionaliser is very simple and widely used in protection practices in distribution systems. The sectionaliser (backup protection device of recloser) must only count a number of deadline checks when it has experienced a fault current. The counter of the sectionaliser can be programmable. It is determined and coordinated with the sequence of an up-line recloser operation. A typical operation sequence of the automatic reclosing is shown in Fig. 2.

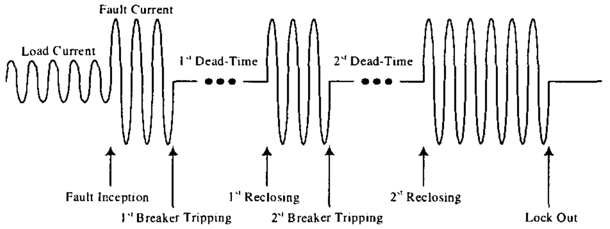

Fig. 2 Typical fault current and operation sequence of automatic reclosing

2.1 Impacts of DG fault contribution on reclosersectionaliser coordination

When a fault occurred between a recloser and a sectionaliser, the fault contribution of DG could have an effect on the deadline check of the sectionaliser due to the fault contribution of the interconnected DG. Hence, it is possible that the fault contributions of DG can cause a recloser-sectionaliser miscoordination. For example, this situation is expected when a DG is interconnected between the up-line recloser and down-line sectionaliser and a fault occurred in the downward of the sectionaliser.

The sectionaliser counts operation sequences of the up-line recloser and opens the distribution line. The line open operation of the sectionaliser must be executed during the open status of the recloser because it is not able to block a fault current. If DG contributes a fault current until the first reclosing operation, i.e. separately excited synchronous machine and induction machine with an external reactive power source, this interferes with the deadline check of the sectionaliser. Thus, the sectionaliser does not accurately cognize the predefined reclosing sequence of an up-line recloser. In the case of a temporally fault, the recloser is locked out unnecessarily due to the failure of backup protection devices (sectionaliser). In the case of a permanent fault, it is possible that the out-of-phase operation occurred between the utility source and DG units. The out-of-phase operation greatly impacts the DG unit, i.e. mechanical stress on the generator and turbine shaft. Thus, it is necessary that the DG unit be disconnected from the utility grid before the first reclosing operation as soon as possible when it experiences a fault to ensure proper coordination of the recloser-sectionaliser.

2.2 Reevaluation of DG-recloser and DG-sectionaliser coordination

DG units are mechanically damaged and stressed due to the successive contribution of a fault current and out-of-phase operation. Therefore, DG must be disconnected from the utility grid before the first reclosing operation as soon as possible when it experiences a fault to ensure proper coordination of the recloser-sectionaliser. Generally, the 10 cycles or faster disconnection from the utility grid for utility interactive DG is recommended [11]. Thus, a relaying time of the DG units should be about 5 cycles or less. Therefore, it can be seen that DG could be disconnected from the utility grid before the first (instantaneous) reclosing operation regardless of the reclosing type (radial and passive). Furthermore, DG cannot maintain interconnection operation during the successive reclosing sequence.

The relay of DG must be properly recoordinated and reevaluated in this criterion considering the reclosing sequence of the up-line recloser of the interconnected feeder. The same protection criterion of DG-recloser coordination is also applied to DG-sectionaliser coordination. This is an important protective coordination criterion of a utility interactive DG in the distribution system adopting recloser-sectionaliser coordination.

However, most DG units are disconnected from the utility grid unnecessarily when a fault occurs in the distribution system under this protection criterion. If DG units are not seriously damaged during a passive reclosing, it is proper for DG to maintain an interconnection operation when a fault occurs in nearby feeders. Thus, proper inter-tie protection schemes of utility interactive DG units must be developed to ensure their reliable and secure operation.

3. Dynamic response of DG by the fault conditions

3.1 A test system model

The basic protection practices of a test system model are the recloser-sectionaliser coordination that is widely adopted in the *Multi-Grounded Neutral* (MGN) distribution systems. A test system model is shown in Fig. 3. The

DG unit is connected to the downward part of the sectionaliser (S_1). The specifications of distribution systems and recloser sequences are shown in Tables 1 and 2.

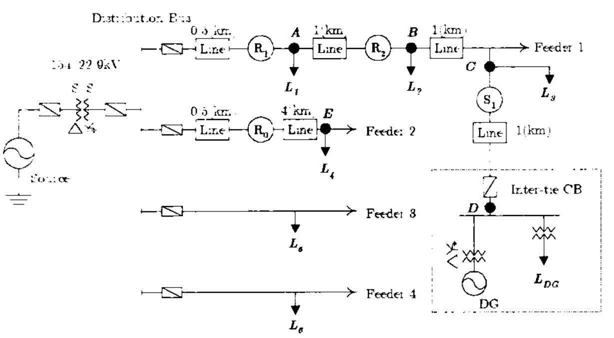

Fig. 3 A test system model

Table 1 Specifications of the sample system

Utility Source	Zero-sequence impedance	0.257 + j1.336 (%)
	Positive-sequence impedance	0.072 + j0.757 (%)
S/S Transformer	Rated Capacity	45/60 (MVA)
	Impedance	j11
Feeder ACSR 160mm^2	Zero-sequence impedance	11.99 + j29.26 (%/km)
	Positive-sequence impedance	3.47 + j7.46 (%/km)
	Number	4
DG system	Rated capacity	1 MW
	Rated voltage	480 (V)
	Step-up transformer	480/23000 (V)
		1.2 (MVA)
		j7
	Internal Load	L_{DG}: 0.9 (MVA) PF 0.9

Table 2 Specifications of recloser sequence

	Fast operation (Cycles)	Delay time operation (Cycles)	Operation sequence
Recloser 1 (R_1)	2.64 + (5)*	4.2 + (5)*	1F 1D
Recloser 2 (R_2)	3.64 + (5)*	3.9 + (5)*	1F 1D

*: Average breaker opening time

Since a fault contribution of DG units depends on the their excitation type, i.e. self or separately excited, generator types of DG units are considered as two types, synchronous and induction machine. The parameters of the DG unit are very important in the dynamic and isolation study. In this paper, the parameters of DG units are used which are taken from [5]. The detailed parameters of these generators are listed in the Appendix.

The distinction of a reclosing type, i.e. radial and passive reclosing, using a magnitude of the fault currents and the voltage dips are not proper because these are influenced by the impedance between the utility source and DG units. In addition, it is affected by fault location, type, and generator type of DG. Therefore, dynamic responses and their characteristics of DG units should be investigated and classified by a reclosing type.

3.2 Fault on interconnected feeder and nearby feeder

To investigate the dynamics of DG, the following assumptions are considered: (1) the operation of the inter-tie CB, sectionaliser and relay are locked to investigate the dynamics of the DG generator, (2) the recloser is operated by the operation sequence as shown in Table 2, and (3) the permanent fault occurred at 3 (sec).

The 3-phase to ground fault and 1-phase to ground fault are applied to the synchronous generator type DG and induction generator type DG, respectively. The above described simulation conditions are performed by using the PSCAD/EMTDC simulation tool.

The dynamic responses of DG with a synchronous generator during a 3-phase to ground fault for radial and passive reclosing are shown in Fig. 4 and 5, respectively. The dynamic responses of DG with an induction generator during a 1-phase to ground fault for radial and passive reclosing are shown in Fig. 6 and 7, respectively. The voltages, current, and electric torque response of DG are illustrated in these figures.

From the results, the characteristics of DG units with the reclosing type can be classified as follows:

3.2.1 Separately excited DG (synchronous generator):

In the case of passive reclosing, a fault current of the DG is increased by the fault inception. And it is decreased to the normal value by 1st breaker tripping within a few cycles. Similarly, the terminal voltage of DG is decreased by a fault inception and increased to the normal value by 1st breaker tripping. Hence, it can be seen that a fault contribution of DG is temporarily cleared by the breaker tripping. But it is repeated by the reclosing operation sequence.

In the case of radial reclosing, a fault current of the DG does not decrease to the normal value because a fault source is not interrupted and cleared by the reclosing operation. In addition, in view of the mechanical stress of the DG, the radial reclosing greatly impacts on mechanical stress since the maximum electrical torque reaches about 6 ($p.u.$). This depends on the impedance between the DG and fault location. Therefore, the electrical torque of radial reclosing is larger than that of passive reclosing in radial distribution systems in general.

3.2.2 Self excited DG (induction generator):

It can be seen that the induction generator does not completely lose an excitation by the 1-phase to ground fault. The excitation current sourced from the unfaulted phase. Similar to the synchronous machine, it is shown that a fault contribution of a DG is temporarily cleared by the breaker tripping. But it is repeated by the reclosing operation in the case of passive reclosing. In the case of radial reclosing, the induction generator completely loses an excitation within a few cycles during the 1st dead time. In addition, the electrical torque of radial reclosing is larger than that of passive reclosing. As a result, the radial reclosing greatly impacts on the mechanical stress of the DG.

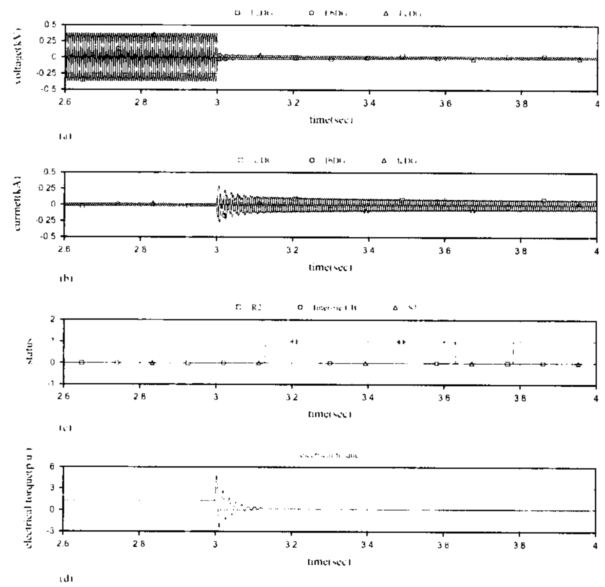

Fig. 4 Dynamic responses of Syn. Gen. (3-phase to ground fault on B): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser, (d) electrical torque

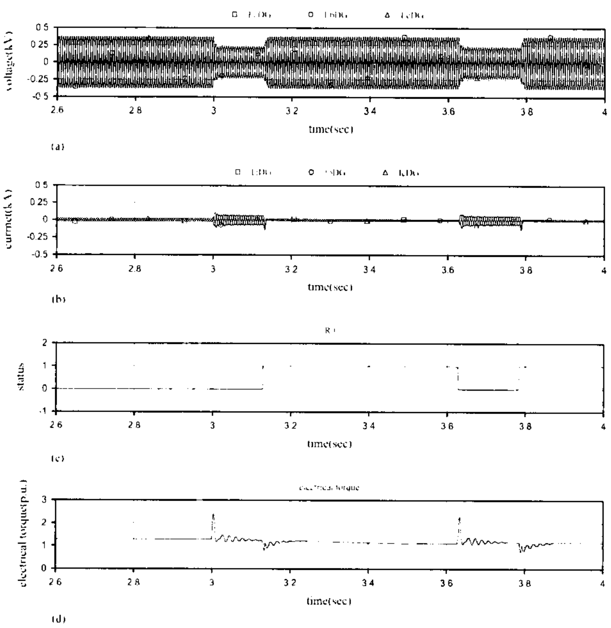

Fig. 5 Dynamic responses of Syn. Gen. (3-phase to ground fault on E): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser, (d) electrical torque

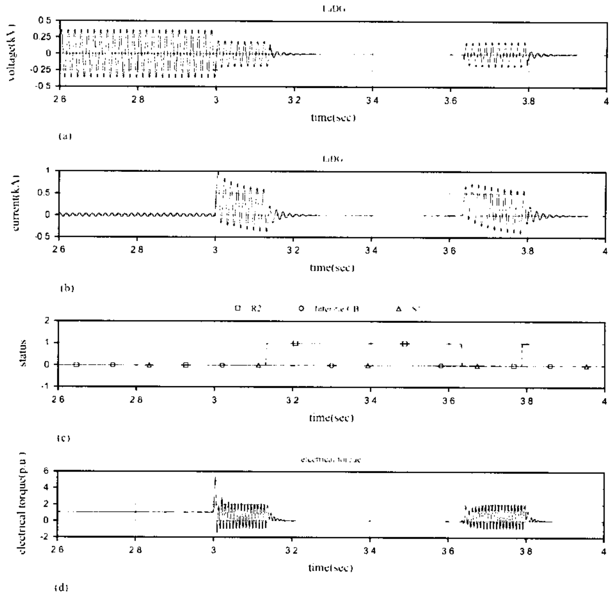

Fig. 6 Dynamic responses of Ind. Gen. (1-phase to ground fault on B): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser, (d) electrical torque

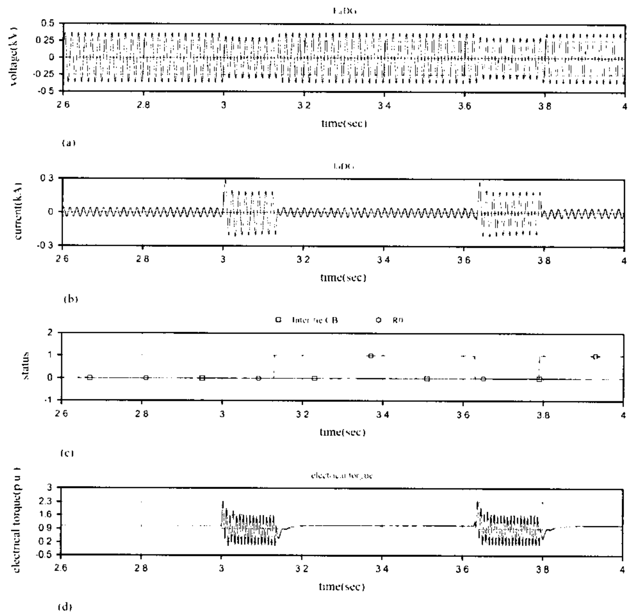

Fig. 7 Dynamic responses of Ind. Gen. (1-phase to ground fault on E): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser, (d) electrical torque

4. A new inter-tie protection schemes of DG

4.1 Distinction of reclosing type

From the above simulation study, the characteristics of DG dynamics with the reclosing type are classified. The important features are transition of the voltage and current of the DG unit from the fault inception to the few cycles after the 1st breaker opening as shown in Fig. 8. Generally, the transition dynamics of the current and the voltage are dominated by the governor type, inertia constant, and exciter controller. But it is shown that voltage and current reach the normal value within 2-3 cycles after breaker opening in the small-scale DG units. Therefore, an observation period at least 15 cycles of the voltage and current transition should be used for distinction of the reclosing type in a sample system. The observation period depends on the system characteristics such as the reclosing sequence setting time.

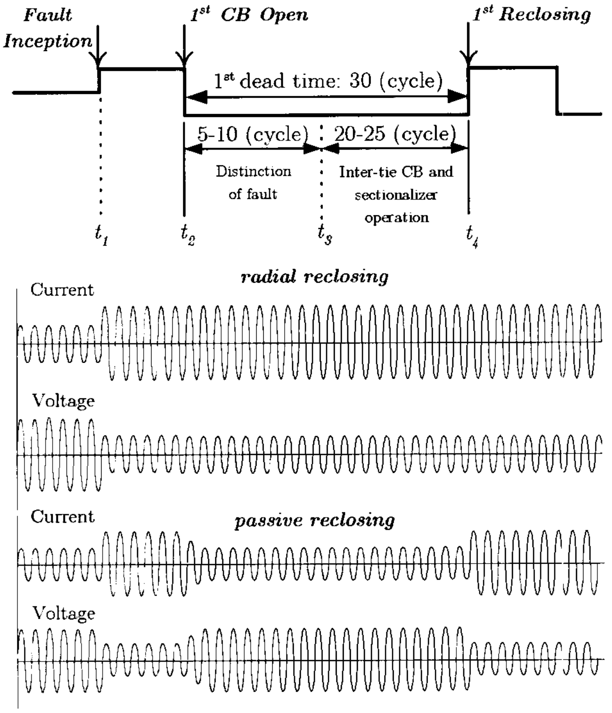

Fig. 8 Characteristic of voltage and current response of the DG by the reclosing type

4.2 Algorithms of the proposed schemes

From the characteristics of the DG with the reclosing type, the algorithms of inter-tie protection schemes are proposed as follows:

1. Initializing relay.
2. Measure voltage, current, and power flow of inter-tie point, i.e. node D of the sample system.
3. If a fault inception is detected, then $F=1$, otherwise $F=0$ and go to step 2. Fault inception can be determined by the reverse current of inter-tie point.
4. If generator cannot lose excitation (self excited generator type), then go to step 5.
5. If DG can sustain interconnection operation during a reclosing operation, then go to step 6, otherwise go to step 12. This is a predefined user function. It can be defined by the fault current, magnitude of voltage dips, and electrical torque of the DG to prevent a severe mechanical damage of the DG.
6. Store faulted-phase voltage and current during an observation period after a fault inception.
7. If $V^f_{t12} \cong V^f_{t23}$ and $I^f_{t12} \geq I^f_{t23} \leq I_n$, then $CE=0$, otherwise $CE=1$. Hence, if $CE=0$ then fault occurred in the nearby feeders (passive reclosing).
8. If $F=1$ and $CE=0$, then go to step 10.
9. If $F=1$ and $CE=1$, then go to step 11.
10. Sustain inter-tie operation until the reclosing sequence, and go to step 2.
11. Open inter-tie CB.
12. If necessary, load shedding mode with predefined user procedures.
13. After the reclosing sequence, watch the live condition of interconnected condition, i.e. voltage of interconnected line. If voltage of line is alive, then go to step 15. The line voltage should be live when a fault occurred in nearby feeders.
14. Go to step 13.
15. Synchronous operation of DG is performed to the utility gird after a reclosing sequence time, and go to step 2.

5. Case study

The aforementioned test system and reclosing sequence are used in the case study to verify the effectiveness of the proposed schemes. A fault is assumed to be a permanent fault. The proposed inter-tie protection schemes are applied to the DG protection system. Two cases are studied, i.e. a fault on interconnected feeder (radial reclosing) and a fault

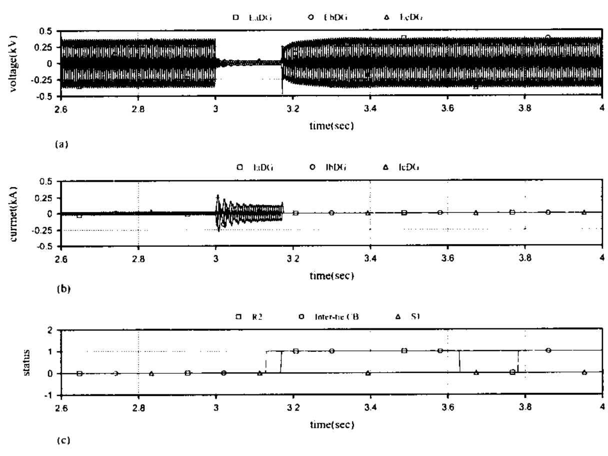

Fig. 9 Dynamic responses of Syn. Gen. under the proposed schemes (3-phase to ground fault on B): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser

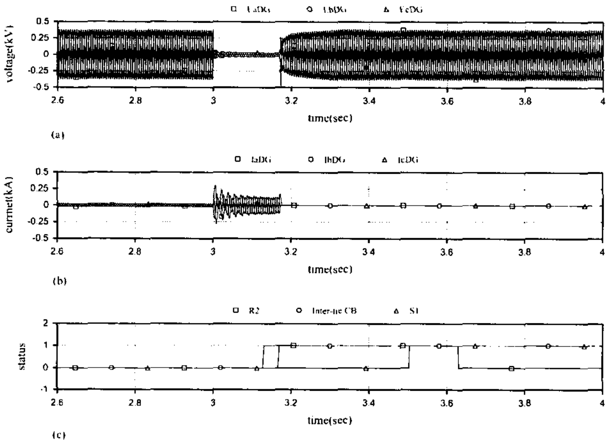

Fig. 10 Dynamic responses of Syn. Gen. under the proposed schemes (3-phase to ground fault on C): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser

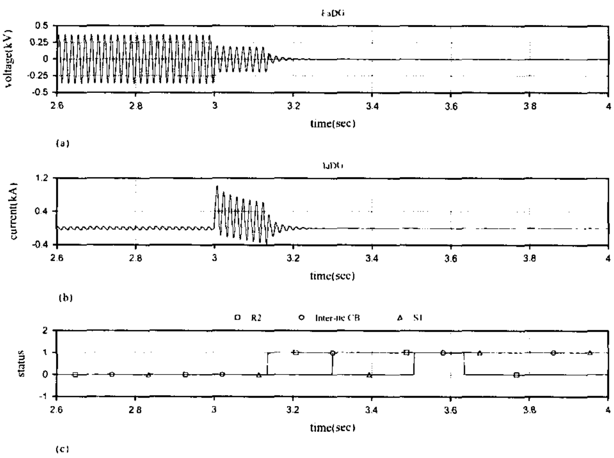

Fig. 11 Dynamic responses of Ind. Gen. under the proposed schemes (1-phase to ground fault on C): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser

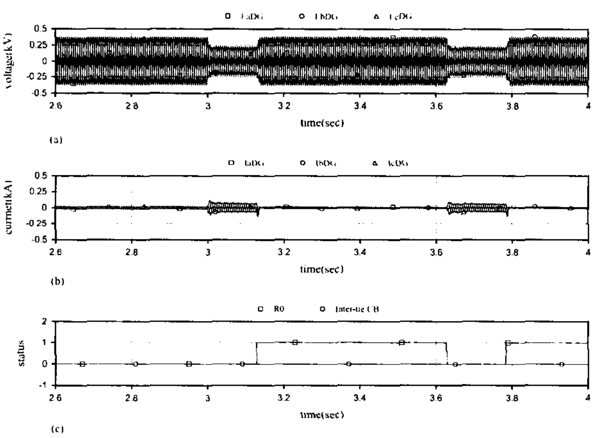

Fig. 12 Dynamic responses of Syn. Gen. under the proposed schemes (3-phase to ground fault on E): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser

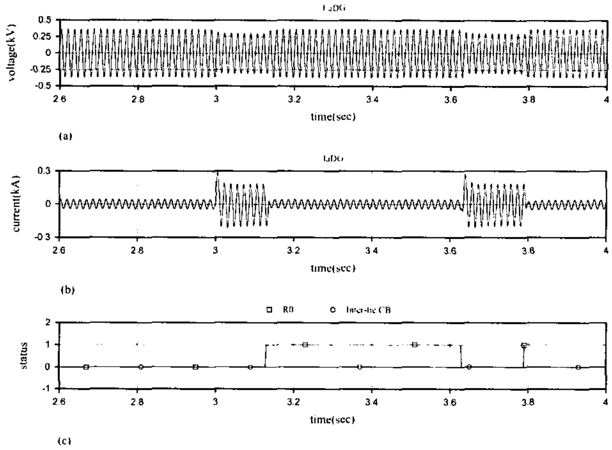

Fig. 13 Dynamic responses of Ind. Gen. under the proposed schemes (1-phase to ground fault on E): (a) voltage, (b) current, (c) operation status of recloser and sectionaliser

on nearby feeders (passive reclosing). The predefined voltage dips are set to 30 % in the case study. The results of radial reclosing are shown in Fig. 9, Fig. 10, and Fig. 11 for synchronous and induction generators, respectively. The results of passive reclosing are shown in Fig. 12 and Fig. 13 for synchronous and induction generator, respectively.

From the results, the effectiveness of the proposed inter-tie schemes is: (1) the proposed schemes could be successfully applied to the utility interactive DG, (2) the proposed schemes increase the reliability, availability, and security of the DG units, and (3) the application of the proposed schemes coordinate well with the existing recloser sectionaliser-coordination.

6. Conclusion

In this paper, the impacts of the DG on recloser-sectionaliser coordination that is widely used in the protection practices of the MGN distribution system are discussed. From the analysis, it can be seen that the DG should be disconnected from the utility grid as soon as possible (within about 10 cycles) to ensure coordination of the recloser-sectionaliser in view of existing protection practices. Through the analysis of the dynamic characteristics of the DG, the inter-tie protection schemes of the DG for the reclosing type (passive and radial reclosing) are proposed. The effectiveness of the proposed inter-tie schemes is verified by a case study from the PSCAD/EMTDC simulation. The proposed inter-tie protection schemes could be implemented in the multi-function type of digital relay of the DG.

In the case of a temporary fault, isolation operation of the DG could occur in the downward part of the upline recloser in some rare cases. Therefore, it is recommended that an anti-islanding algorithm be integrated into the proposed inter-tie protection schemes. In addition, it can be seen that the DG units could be mechanically damaged by the successive passive reclosing when predefined voltage dips are set to a larger value.

Utility should reevaluate their reclosing practices, i.e. dead time interval and reclosing sequence. A longer 1st dead time and shorter reclosing sequence could be an alternative solution to solve this problem. However, determination of the first dead time interval is very difficult and their evaluation depends on the system characteristics. Utilities would have to provide and set up common interfaces and standards.

7. Appendix

In the dynamic study of small-scale DG units, the exact parameters of DG units are very important since it differs from a large generation machine. The verified and approved parameters of DG units are used in this paper which are taken from [5].

7.1 DG with synchronous generator

The parameters of the synchronous generator are as follows:

X_d : 2.38 $X_d^{'}$: 0.264

$X_d^{''}$: 0.201 X_q : 1.10

$X_q^{''}$: 0.376 $T_{d0}^{'}$: 2.47 (sec)

$T_{d0}^{''}$: 0.0018 (sec) $T_{q0}^{''}$: 0.01 (sec)

The model of exciter is IEEE AC Type1 and its parameters are as follows:

T_E : 0.2 K_E : 1.0

K_A : 500 T_F (Sec): 0.49

EFD_{max} (p.u.): 5.4 EFD_{min} (p.u.): 0

S_E (max): 0.66 S_E (0.75max): 0.25

$V_{R max}$ (p.u.): 9.0 $V_{R min}$ (p.u.): 0

K_F (sec): 0.1 T_A (sec): 0.02

T_B (sec): 0 T_C (sec): 0.02

The parameters of the hydro-governor are as follows:

T_P (sec): 0.05 T_G (sec): 4.3

σ : 0.05 T_r (sec): 0.75

δ : 0.24 T_W (sec): 0.15

7.2 DG with induction generator

The induction generator parameters are as follows:

X_S : 0.098 r_S : 0.010

X_r : 0.120 r_r : 0.012

r_m : 35 X_m : 2.48

Acknowledgement

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References

[1] R. C. Dugan and D. T. Rizy, "Electrical Distribution Protection Problems Associated with the Interconnection of Small Dispersed Generation Devices", *IEEE Trans. On PAS*, Vol. PAS-103, No. 6, pp. 1121-1127, June 1984.

[2] Hebert B-L Lee, Sherret E. Chase, and Roger C. Dugan, "Over Voltage Considerations for Interconnecting Dispersed Generators with Wye-Grounded Distribution Feeders", *IEEE Trans. On PAS*, Vol. PAS-103, No. 12, pp. 3587-3594, Dec. 1984.

[3] D. T. Rizy, W. T. Jewell, and J. P. Stovall, "Operational and Design Considerations for Electric Systems with Dispersed Storage and Generation", *IEEE Trans. On PAS*, Vol. PAS-104, No. 10, pp. 2864-2871, October 1985.

[4] Frank A. Woodbury, "Grounding Considerations in Cogeneration", *IEEE Trans. On IA*, Vol. IA-21, No. 6, pp. 1523-1532, Nov/Dec. 1985.

[5] W. B. Gish, "Small Induction Generator and Synchronous Generator for DSG Isolation Studies", *IEEE Trans. On PWRD*, Vol. 1, pp. 231-239, April 1986.

[6] Daniel J. Love, "Considerations for Ground Fault Protection in Medium-Voltage Industrial and Cogeneration Systems", *IEEE Trans. On IA*, Vol. IA-24, No. 4, pp. 548-553, July/Aug. 1988.

[7] Louie J. Powell, "An Industrial View of Utility Cogeneration Protection Requirement", *IEEE Trans. On IA*, Vol. IA-24, No. 1, pp. 75-81, Jan./Feb. 1988.

[8] C. L. Wagner, W. E. Ferro, W. B. Gish, and R. H. Jones, "Relay Performance in DSG islands", *IEEE Trans. On PWRD*, Vol. 4, No. 1, pp. 122-131, Jan. 1989.

[9] Harrison K. Clark, "Industrial and Cogeneration Protection Problems Requiring Simulation", *IEEE Trans. On IA*, Vol. IA-25, No. 4, pp. 766-775, July/Aug. 1989.

[10] R. M. Rifaat, "Critical Considerations for Utility/Cogeneration Inter-tie Protection Schemes Configuration", *IEEE Trans. On IA*, Vol. IA-31, No. 5, pp. 973-977, Sep/Oct. 1995.

973-977, Sep/Oct. 1995.
[11] IEEE Std. 929-2000, Recommended Practices for Utility Interface of Photovoltaic (PV) Systems, IEEE 2002.
[12] Joon-Ho Choi, "Operation and Integration Strategies of Dispersed Generations in Power Distribution System", Ph. D. Dissertation, Dept. Elec. Eng., SoongSil University, Seoul, Korea, 2002.

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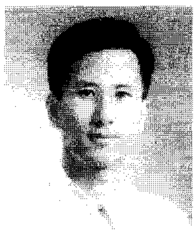

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