Integrating Operation of Dispersed Generation to Automation Distribution Center for Distribution Network Reconfiguration

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

Abstract - *Due to the many attractive aspects of DG in the future power distribution system, distribution automation will be a center hub of integration of the distribution system and resources to satisfy the various needs of customers in a competitive and deregulated environment. In this paper, operation strategies are presented which use network reconfiguration of the automated distribution systems with DG as a real-time operation tool for loss reduction and service restoration from the view of distribution operation. The algorithms and operation strategies of an automated distribution system with DG are introduced to achieve the positive effects of DG in distribution systems. A simple case study shows the effectiveness of the proposed operation strategies.*

Keywords - operation strategies, dispersed generation, network reconfiguration, loss reduction, service restoration, distribution automation

1. Introduction

The operation of the distribution system is a challenging problem in the *next-generation distribution system* which has various customer owned generation units, i.e. *dispersed generations* (DG). The introduction of these devices increases the complexity of existing operation schemes of distribution automatic function. In accordance with the deregulation of the electric market and preference of green energy, DG supplying electricity to customers in a district area is very attractive to both utilities and customers. When regulations on the power supply are relaxed and a number of dispersed generations are introduced into the power system, unexpected problems may occur in power system operation and planning as discussed in previous research works [1-11].

DG increases the complexity of controlling, protecting, and maintaining distribution systems. Hence, DG must be integrated into the *Distribution Automation System* (DAS) to prevent operational problems and supply high quality electricity. DG units would have the cooperative function to improve the reliability and quality of the supplied electric power. The expected roles of DG in the next-generation distribution system are as follows:

1. Quality improvement: dynamic voltage compensation, voltage profile improvement over feeders, etc.
2. Reliability improvement: UPS function and local service restoration.
3. Economic benefits: relatively high-energy efficiency, loss reduction, and load leveling.

Unfortunately, few integration proposals to cope with the above situations have been presented [11-15]. In the areas of loss reduction with DG, determining methods of optimal sites and capacities of DG units in HV and LV systems are proposed from the viewpoint of the planning state [16-17]. Therefore, advanced operation and integration strategies should be developed to achieve the above-mentioned roles of DG in view of the operation state.

In this paper, operation strategies are presented which use network reconfiguration of the automated distribution systems with DG as a real-time operation tool for loss reduction and service restoration from the viewpoint of distribution operation.

To fully support implementation of proposed operation strategies, the following assumptions are required:

1. The distribution system is fully automated, i.e. remote controlled switch and fault detection and isolation.
2. The operation status of DG is monitored in a distribution management system

2. Operation Strategies of DG for Loss Reduction

2.1 Loss reduction problems with DG

There are several operational schemes in power distribution systems, one of which is network reconfiguration. Feeder reconfiguration for loss reduction is one of the most important functions of an automated distribution system to reduce distribution feeder losses and improve system security. This is one of the most important functions of the automated distribution system in a normal operation state. There are a number of closed and normally opened switches in a distribution system, and the number of possi-

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Joon-Ho Choi and Seung-Il Moon are with School of Electrical and Computer Engineering, Seoul National University, Seoul 151-742, Korea.

Jae-Chul Kim is with Department of Electrical Engineering, SoongSil Univeristy, Seoul 156-743, Korea.

ble switching operations is tremendous. Thus feeder reconfiguration becomes a complex decision-making and time-consuming process for system operators. To implement these processes efficiently, many algorithms are developed [18-22]. DG has loss reduction effects in the distribution network. But, with the advent of DG, network reconfiguration becomes more complicated since the distribution network changes from a single source to multiple sources increasing the complexity of existing distribution operation schemes

In general, network reconfiguration for loss minimization can be formulated as follows:

$$Minimize\ L = \sum_{i=1}^{n} loss_i \tag{1}$$

Where, n : number of branch and $loss_i$: loss at branch i .
Subject to.

1. Radial network constraint: distribution network should be composed of a radial structure considering the operational point of view.
2. Isolation constraint: all nodes are energized.
3. Voltage constraint: voltage magnitude at each node must lie within their permissible ranges to maintain power quality.
4. Current constraint: current magnitude of each branch (feeder, laterals, and switches) must lie within their permissible ranges.

2.2 Proposed schemes for loss reduction

In network reconfiguration problems with DG, if we know the installation node and capacity (output power) of DG, then network reconfiguration with DG for loss minimization could be solved by the existing loss reduction techniques. Under these assumptions, if we present DG as constant power sinks, then the DG could be represented by a negative load, i.e. current flowing reverse to load. Therefore, DG could be embedded into the interconnected node as a negative load. In addition, in automated distribution, if node voltages and current injections are known from the installed meter then the load states could be estimated by the existing state estimation techniques. Under this procedure, interconnected DG units are also embedded into the distribution network.

These procedures simplify the network reconfiguration with DG and are very reasonable.

In loss reduction with DG, some additional constraints are added

1. Line capacity constraints: the reverse power of DG cannot exceed the corresponding line capacity limits. This is also included and considered in the above-mentioned constraints.

3. Operation Strategies of DG for Service Restoration

3.1 Service restoration problems with DG

In service restoration, the load transfer is power supplement operation, which is to supply from a normal area to outage area. This is one of the most important functions of the automated distribution system in an emergency operation state. To implement these processes efficiently, many algorithms are developed [22-27].

In the distribution network with DG, the implementation of DG could increase the reliability of electric service if DG support and provide "a backup island" during upstream utility source outages. To be effective, this requires reliable DG units and careful coordination of utility sectionalizing and protection equipment. Any time such a scheme is implemented, it needs to be well planned to avoid causing problems, i.e. unnecessary isolation and energizing.

The DG unit must able to load follow during an islanded operation and the switch will need to sense if a fault current has occurred downstream of the switch location and send a signal to block islanding if a fault has occurred within the island zone. When utility power is restored on the utility side, the switch must not close unless the utility and "island" are tightly in synchronism. This requires measuring the voltage on both sides of the switch and transmitting that information to the DG units supporting the island so that it can "synchronize" with the utility and allow re-interconnection.

In implementing intentional islanding and supporting service restoration of DG in the automated distribution system, it greatly improves the reliability of distribution. However, this is complicated but new automated switch technologies and communications approaches make these schemes much more practical than in the past years. A new service restoration strategy should be developed in the automated distribution network with DG units.

3.2 Proposed schemes for service restoration

To integrate DG in service restoration, some preliminary work should be required on its integrating factor. The integrating factors of DG are classified in three categories

1. Start-up and intentional isolation capability of DG
2. Controllability of DG in distribution automation, i.e. DG command and control
3. Operation status of DG after being fault isolated, i.e. interconnection status of DG.

The start-up and intentional isolation capability of DG could be an important criterion in service restoration. It is classified into two categories, i.e. black or non-black start, as follows:

1. **BDG** (Black-start DG): Cogeneration, separated excited power converter, and separately-excited ma-

chine type, etc.: This type of machine can support an intentional isolation operation. This function could be classified by the energy source availability.

2. **NBDG** (Non Black-start DG): Wind generation, photovoltaics, self-excited machine type, etc.: This type of machine cannot support an intentional isolation operation and has an uncertainty of source availability, i.e. wind and solar insolation.

The controllability of DG could be an important criterion for DG command and control in a distribution automation center. It could be classified by the communication capability of DG and an agreement between the utility and the owner of DG:

1. **CDG** (Controllable DG): DG with communication capability and a command and control agreement with the distribution automation center.
2. **NCDG** (Non-controllable DG): DG without communication capability and a command and control agreement with the distribution automation center.

The operation status of DG after being fault cleared could be classified as follows:

1. **SDG** (Survived DG): Those that are successfully sustain interconnection operation to the utility grid after a fault is cleared.
2. **NSDG** (Non-Survived DG): Those that are disconnected (lose an interconnection operation) from the utility grid during a fault.

From the above classification of DG, the proposed integrating strategies for service restoration are:

I. Find a fault location.
II. Isolate a fault section.
III. Identify the DG interconnection status: SDG or NSDG:
IV. Find the optimal route that minimizes an isolation area with SDG units. This process called ***option I***.
Minimizing isolation areas & switch operation.
Subject to.
   1. Voltage constraints and line thermal capability constraints.
   2. The NSDG units are excluded from the network restoration process.
   3. SDG units are assumed to be a negative load. SDG units must be interconnected with a utility grid (isolation operation of SDG units is not allowed).
V. If there are un-restored (isolation) areas, then go to step VI and otherwise go to step VII.
VI. Identify DG capability (BDG or NBDG and NCDG or CDG): This process is called ***option II***.
Intentional isolation operation mode:
   1. Search a new route by considering all DG units with BG and CDG as a power source: In this step, the restoration problems are changed from the single source searching to the multiple source searching. Hence, DG could support and follow isolated loads.
VII. The NSDG units are interconnected to the networks by the synchronous operation if their interconnected nodes are sound grid.
VIII. All NSDG units in the network are re-interconnected to the networks.
   1. If there is no better solution, then maintain current status. Otherwise go to step VI.
   2. If faults are completely recovered, then turn to the *normal operation mode*.

4. Case Study

4.1 Loss reduction

The 32bus test system is chosen for analyzing the network reconfiguration with DG units because it is widely used as a benchmark model. The data of the 32bus test system is taken from [18]. The initial configuration of the 32bus test system is shown in Fig. 1. In Fig. 1, the number in circle and the number with "s" indicate the node and the line switch, respectively. In the case study, DG units are installed in a selected heavy loaded node. Four cases are considered: the initial network without DG units/with DG units and the optimum network without DG units/with DG units.

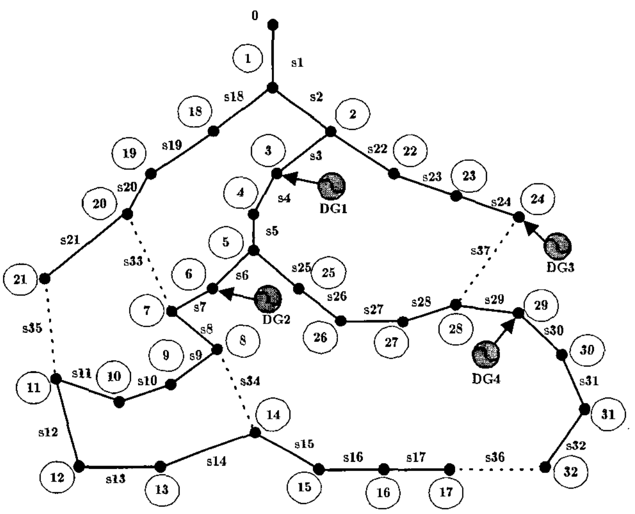


Fig. 1 Initial network configuration for loss reduction

Table 1 Installation Nodes and Capacities of the DG Units

DG	Installation node	Capacity (kW/p.f.)
1	3	50/0.8 lagging
2	6	100/0.9 lagging
3	24	200/0.9 lagging
4	29	100/unity

Table 2 Open Switches of Test System for Case Study

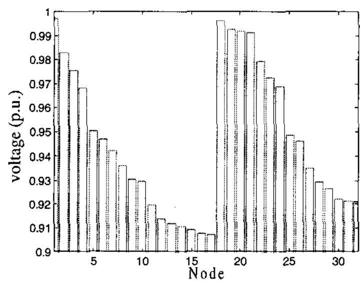
Case	Open switch
Initial network without DG	s33, s34, s35, s36, s37
Optimum network without DG	s7, s9, s14, s32, s37
Initial network with DG	s33, s34, s35, s36, s37
Optimum network with DG	s7, s9, s14, s28, s32

Table 3 Loss of Case Study

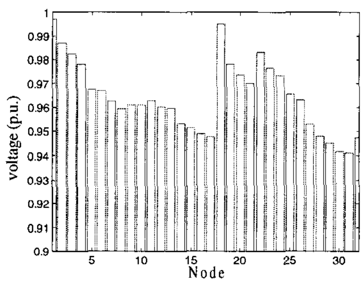
Case	Loss (kW)
Initial network without DG	188
Optimum network without DG	125
Initial network with DG	156
Optimum network with DG	102

Table 4 Loss Reduction of Case Study

Case	Loss reduction (%)
Initial network without DG	-
Optimum network without DG	33.5
Initial network with DG	17
Optimum network with DG	45.7



(a)



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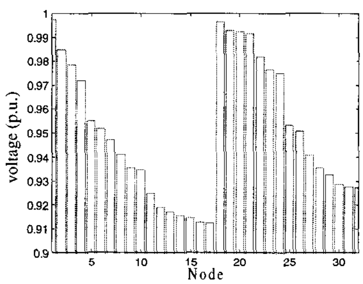

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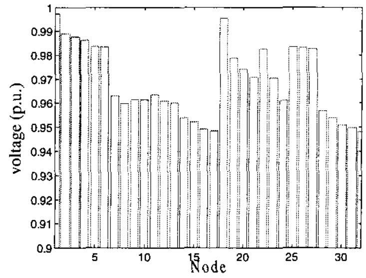

(d)

Fig. 2 Voltages at nodes for case study: (a) initial network without DG, (b) optimum network without DG, (c) initial network with DG, (d) optimum network with DG.

The open switches, loss, and loss reduction of the case study are shown in Table 2, 3 and 4, respectively. The voltage at each node for the case study is shown in Fig. 2.

From the results of the case study, the loss reduction effects of DG units are summarized as follows:

1. It can be seen that DG units have the effects of loss reduction and voltage profile improvement over feeders. The additional loss reduction is about 12.2% through the network reconfiguration with DG units. This result verifies the loss reduction support of DG in the distribution networks.
2. The topological structures of the optimum network without DG units are different from those with DG units. The optimization is required to maximize the loss reduction effects of DG units. Therefore, DG should be integrated into the distribution automation center.

Normally in an actual system, the installation node and capacity of DG units may not be optimally selected. The reason is that owners of DG units determine the installation location and their capacity to improve their economic benefits. Generally, the owners of DG units are individuals and non-utilities, i.e. industrial, commercial and residential customers in case of small-scale DG units. Therefore, these are not controllable, especially their operation schedule and power factor.

If the owner of DG units is a utility, then the choice of locations is important because the additional DG units may cause an increase of power losses. This optimization permits the best location of generators to be found so that the power losses and switching operation in the distribution systems are minimized. The determination method for finding the best location can be solved. This issue is similar to capacitor placement problems. However, optimum locations are changed with the load variations and operation of the customer owned DG. Therefore, integrating DG to the distribution automation center in an on-line manner is very important to the improving of the operation quality of the distribution automation.

4.2 Service restoration.

The above mentioned test system is used for the case study and DG classified by their capability as shown in Table 5. The initial network with DG is the optimum network with DG that is the results of the above section. Two fault conditions are considered as shown in Table 6.

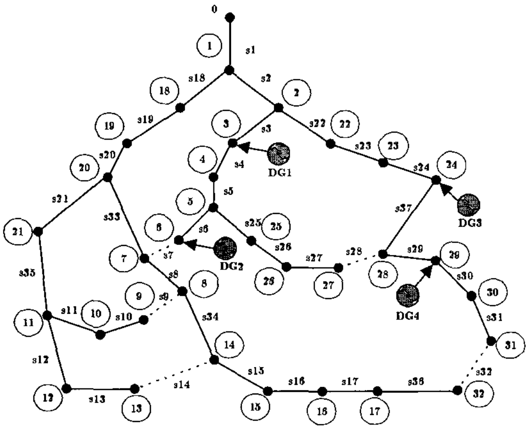

Fig. 3 Initial network configuration for service restoration

Table 5 Classification of DG Units

DG	Installation node	Controllability	Start-up capability
1	3	CDG	BDG
2	6	CDG	BDG
3	24	CDG	BDG
4	29	NCDG	NBDG

Table 6 DG Survival Status of Case Study

	Case I	Case II
Line open by fault	35	24
<u>DG status</u>		
DG 1	SDG	SDG
DG 2	SDG	SDG
DG 3	SDG	NSDG
DG 4	SDG	NDSG

Result: Case I

From Table 6, all of the DG units are assumed to be SDG during a fault. Hence, the network restoration problems could be solved by *option I* with SDG units.

Table 7 Results of Case I

	Open switch	Un-restored area	NSDG
Prefault network	s7, s9, s14, s28, s32	none	none
Reconfigured network after fault is cleared	s7, s35, s13, s28, s36	none	none

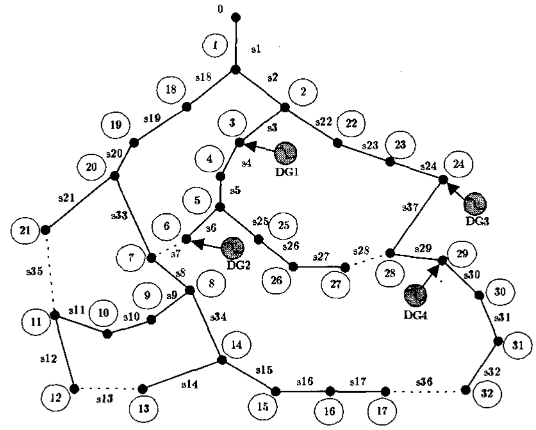

Fig. 4 Reconfigured network for case I

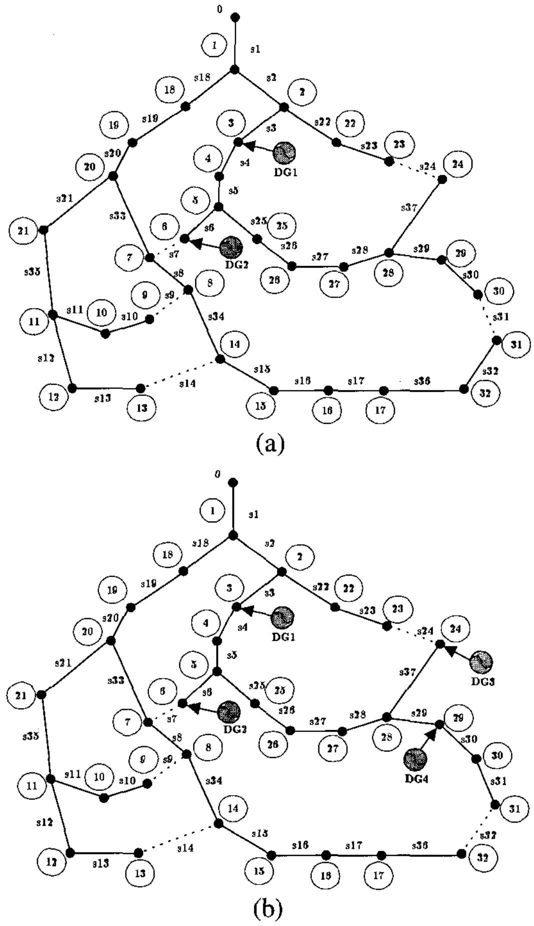

Fig. 5 Reconfigured network for case II: (a) reconfigured network after fault is isolated, (b) reconfigured network after all NSDG units are interconnected

Result: Case II

From Table 6, DG1 and DG2 survived during a fault, i.e. SDG. Therefore, first the network restoration problems could be solved by *option I* by excluding NSDG. And then it could be solved again after all NDSG are interconnected to the network unless there is an un-restored area. If there is an un-restored area, it should be solved again by *option II.*

Table 8 Results of Case II

	Open switch	Un-restored area	NSDG
Prefault network	s7, s9, s14, s37, s36	none	none
Reconfigured network after fault is isolated	s7, s9, s14, s24, s31	none	DG3 DG4
Reconfigured network after all NSDG units are interconnected	s7, s9, s14, s24, s32	none	none

5. Conclusion

Since it is well known that DG units play a positive, beneficial role in power systems, they are integrated into the existing or future power system operation and planning schemes. In this paper, the integration strategies of DG in network reconfiguration for loss reduction and service restoration are presented. To cope with these strategies successfully, it can be seen that the most important function of DG is the communication capability for DG command and control in the *Distribution Automation Center* (DCC). However, unfortunately this function cannot be obligatory in the case of a customer owned DG. Therefore, utilities must provide incentives for owners of DG units, such as incentives for the emergency call, DG command and control, and special electricity rate, to provide better electricity to the customers on an economic basis with intelligent and rational integrating strategies.

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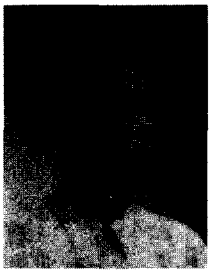
Joon-Ho Choi was born in Sampo, Kangwon-Do, Korea, on July 30, 1970. He received his B.S., M.S., and Ph. D. degrees in electrical engineering from Soongsil University, Korea, in 1996, 1998, and 2002, respectively. Currently, he is a Post-Doctoral Fellow of School of Electrical and Computer Engineering at Seoul National University, Korea. Dr. Joon-Ho Choi is a student member of IEEE and member of KIEE and KIIEE. From 2001, he has been the reviewer of IEEE PES Transactions Paper. His areas of interest are operation and integration strategies of dispersed generation, distribution automation system, and intelligent application of power system control.

E-mail: joono@korea.com

Jae-Chul Kim was born in Okku, Chollabuk-Do, Korea, on July 12, 1955. He received his B.S. degree from Soongsil University, Korea, in 1979, and M.S. and Ph.D. degrees from Seoul National University, Korea, in 1983 and 1987, respectively. Since 1988, he has been a professor of Electrical Engineering at Soongsil University. Dr. Jae-Chul Kim is a member of IEEE and KIEE. His areas of interest are distribution automation system and diagnosis of power system equipment.

E-mail: jckim@ee.ssu.ac.kr



Seung-Il Moon received his B.S. degree in electrical engineering from Seoul National University, Korea in 1985, and M.S. and Ph. D. degrees from Ohio State University in 1989 and 1993, respectively. Currently he is an associate professor of School of Electrical and Computer Engineering at Seoul National University, Korea. Dr. Seung-Il Moon is a member of IEEE and KIEE. His research interests include analysis, control, and modeling of the power system, and FACTS.

E-mail: moonsi@plaza.snu.ac.kr