Operation Schemes of Smart Distribution Networks With Distributed Energy Resources for Loss Reduction and Service Restoration

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***Abstract*—The integration of Distributed Energy Resources (DERs) into the future Smart Distribution Network (SDN) has challenging issues regarding the successful development of smart grids. The SDN offers new opportunities in the improvement of the efficiency of power distribution networks. The DERs will be distributed in the existing distribution networks, interconnected in customer areas and operated on its own schedule without communication to the control center of the existing distribution system. The DER units have both positive and negative effects regarding SDN operations. With the appropriate operation of the DER units in the SDN, losses can be reduced during normal operations and they can support local loads during abnormal conditions. Thus, the positive effects of the DER units need to be enabled in the SDN by adopting advanced operation schemes. In this paper, the smart control functions for the DER units in the SDN are defined and classified. In addition, the integration schemes for the SDN with DER units are introduced. The proposed operation strategies will be implemented into the Korean Smart Distribution Management System (KSDMS) as operation schemes used for loss reduction and service restoration. A sample case study shows the effectiveness of the proposed operation schemes to achieve smart operation functions for the SDN with DER units.**

***Index Terms*—Distributed energy resources, loss reduction, network reconfiguration, service restoration, smart distribution network.**

I. INTRODUCTION

THE development of the operation schemes for the future Smart Distribution Network (SDN), where the Distributed Energy Resources (DER) units will be interconnected, is a challenging issue in the future operation of smart grids. The existing distribution networks are primarily radial, built for centralized generation with few sensors, and so are dependent on manual restoration. In many utilities, the interconnection of the DER units into the distribution networks is regulated to within certain limits, due to their technical interconnection problems. Previous works [1]–[7] have discussed the negative effects of the DER units in conventional distribution networks.

The next generation smart grid will be required to accommodate increased customer demands and will require DER units to ensure a high power quality and energy efficiency. In recent years, many studies relating to the Smart Distribution Management System (SDMS) have been introduced [8]–[16]. The SDN needs to have a fast and accurate access to the network status. This requires periodic and fast estimations of network security, as well as collecting a variety of real-time information from the network components. The changes in the topology of the SDN and the role of the distribution control center must be considered. In the SDN, the grid topology is not only radial, but looped and meshed networks will also have to be considered under the normal operation conditions. Therefore, the role of the control center can no longer be merely the indication of faults in the distribution network. The control center concept must change into the Energy Management System (EMS).

The interconnection of the DER units increases the complexity of the automatic or smart control functions of the SDMS. Therefore, the DER must be seamlessly integrated into the SDMS in order to prevent operational problems and to supply high quality electricity. Currently, the "islanding" of DER units is not allowed in the conventional distribution networks of many utilities. However, one of the frequently quoted positive features of the SDMS is the ability of the DER units to continue to supply power to local loads and to assist in the network restoration process. In a normal operation state, the DER units would reduce the network losses. The DER units would have a cooperative function used to improve the reliability and quality of the supplied electric power.

It is necessary to enable a two-way exchange of real-time information between the SDMS and the DER units in order to enhance the power quality and to optimize the efficiency of the network performance. Taken from many studies, the positive roles of the DER units in the SDN are:

1) quality improvement: a dynamic voltage support, ensuring a voltage profile improvement over feeders, active filters, etc.;
2) reliability improvement: UPS functions, local service restoration (intentional islanding), etc.;
3) economic benefits: a relatively high energy efficiency, loss reduction, load leveling, etc.

However, a few integrated operation proposals have been presented that are able to cope with the above situations [17]–[20].

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In [19] and [20], operation strategies are presented which use a network reconfiguration of the automated distribution systems using DER units from the viewpoint of the operation state. Concerning the loss reduction issues using DER units, many research works are focused on the methods used for determining the optimal sites and capacities for HV and LV systems from the viewpoint of the planning state [21]–[28]. Therefore, new operation schemes for the SDMS need to be developed that enable the positive roles of the DER units in the SDN. This paper discusses the integration schemes for the DER units in the SDMS. In view of the operational aspects needed for integrating the DER units into the SDMS, the methodologies for the integration operation schemes are introduced.

II. The Operation Procedures of the Application Mode of the SDMS

The SDMS applications are composed of three parts: real-time mode application, study mode application, and event driven mode applications.

Firstly, the real-time mode applications aim to analyze the current network conditions and recommend better operation solutions. It is composed of the topology processor, state estimator, real-time power flow, and load management and forecasting. The Application Service Interface (ASI) is used for operation control of real-time mode applications.

Secondly, the study mode applications are used to examine various candidate solutions, including the reconfiguration of the network and switching on/off of the devices, for the future network conditions. It is composed of the dispatcher power flow, optimal network reconfiguration, and generation forecasting. The operation procedures of the study mode applications are shown in Fig. 1. The study ASI is used for operation control of study mode applications. As shown in Fig. 1, study mode applications are run by the operator. The operator creates the study circumstance by using ASI. The database of real-time mode is copied to the study mode memory. In a study circumstance, the operation of applications is controlled by study ASI and operator.

Finally, the event driven mode applications are for the fault clearing and restoration for current operations. It is composed of the network protection, protective coordination, and service restoration. The Smart Alarm Processor (SAP) is used for operation control of event driven mode applications. The operation procedures of service restoration are shown in Fig. 2. As shown in Fig. 2, the alarm and event data from real-time measurement and application results are gathered. The sub-functions of SAP filtered the numerous alarm and event data; fault section identification, system loss, and topology change. The result of these sub-functions is used for the input of SAP and the SAP control the operation of event driven mode applications, i.e., network reconfiguration, protective coordination, and service restoration.

III. The Classifications of the DER Units for Smart Control Functions

In the SDN, a two-way data exchange between the SDMS and the DER units are necessary. The SDMS collects the network status data and transfers the smart control information to the smart devices in the SDN, such as the time of use rates, the command and control signals, etc. In addition, the SDMS monitors the status of the DER units and commands the DER units in order to enhance the network performance and efficiency. All of the DER units need to be controlled by the SDMS. However, the two-way communication network and remote command functions are not available in small-scale DER units. Therefore, it is necessary to classify the DER units according to their ability of the smart control functions.

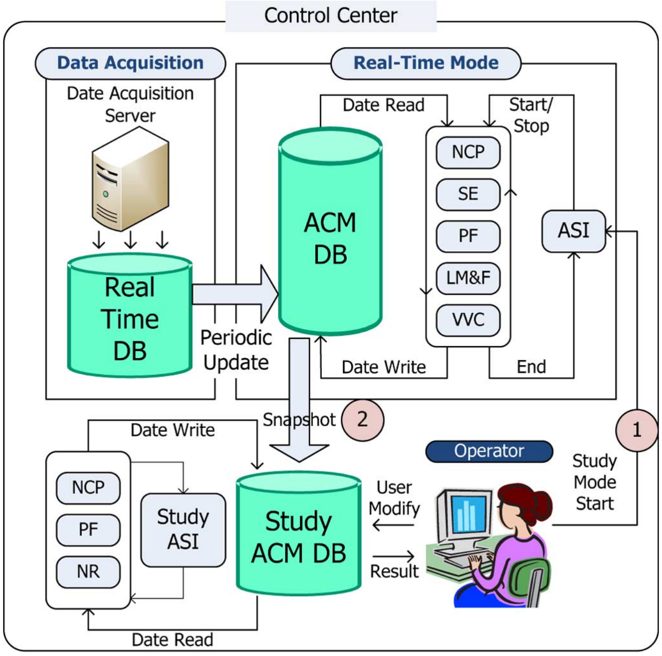


Fig. 1. The operation procedures of the study mode applications.

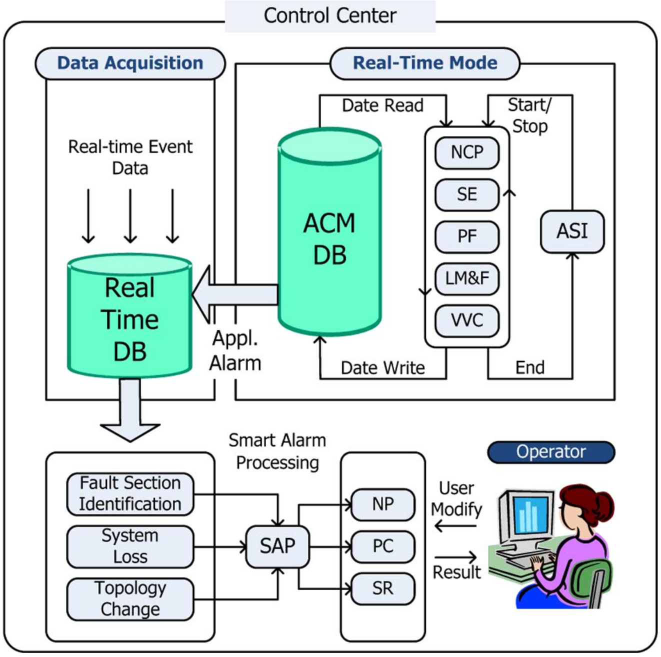


Fig. 2. The operation procedures of the event driven mode applications.

In the SDMS, the study mode applications are now open for future development of the advanced operation schemes and solutions. Thus, the optimal operation schemes of the SDN with DER units could be integrated into the study/event driven mode applications. To integrate a DER unit into the SDMS, some preliminary work is required on its smart control functions. The DER smart control functions of the KSDMS are classified as follows:

A. The Communication/Control Function

The two-way communication network of the DER units is an essential function needed for its status monitoring and cooperative operation in the SDMS. The controllability of the DER is an important criterion for DER command and control in the SDMS. They can be classified by their communication capability and the command and control agreements between the utility and the owner of the DER units.

1) The CDER (Communication/Controllable DER): a DER using a two-way communication network with command and control agreements with the SDMS.
2) The NCDER (Non- Communication/Controllable DER): a DER that is not available for command and control agreements with the SDMS.

Obviously, a DER unit without a communication network is classified as a NCDER.

B. The Black Start-Up and Intentional Islanding Support Function

The start-up and intentional islanding capability of DER units is an important criterion in service restoration. It is classified into two categories, black start or non-black start, as follows:

1) The BDER (Black-start DER): the cogeneration, full-scale inverter, and separately-excited machine types, etc. These types of DERs have load-frequency control functions and support an intentional islanding operation. This function is classified by the energy source availability.
2) The NBDER (Non Black-start DER): The wind generation, photovoltaics (PV), self-excited machine types, etc. These types of machines cannot support an intentional islanding operation due to their source availability uncertainty of wind and solar insolation. However, wind farms, PVs, and other self-excited machine types with energy storage can be classified as BDER.

C. The Energy Storage Function

Some DER units have their own energy storage capability for economic reasons. This type of the DER unit can charge and discharge the energy for load leveling and balancing and also regulate the real power output. They can be classified as follows:

1) The DERES (DER with energy storage): a DER that is equipped with energy storage devices.
2) The NDERES (DER without energy storage): a DER that is not equipped with energy storage devices.

D. The Q Control Function

The modern inverter used for DER interconnection can control reactive power output without a loss of efficiency. These functions of the DER units reduce losses and improve the voltage profiles of the networks. They can be classified as follows:

1) The QDER (Q controllable DER): a DER that is able to control the reactive power output of the DER units.
2) The NQDER (Non-Q controllable DER): a DER that is not able to control the reactive power output of the DER units.

E. The Availability Function During an Emergency State and Operation Status Function After Fault Clearance

The operation status of DER units after the fault clearance is very valuable information for the service restoration process and it is classified as follows:

1) The SDER (Survived DER): DERs that successfully sustain their interconnection operation to the utility grid after a fault is cleared.
2) The NSDER (Non-Survived DER): DERs that are disconnected (lose an interconnection operation) from the utility grid during a fault and cannot recover when the fault is cleared.

IV. The Loss Minimization With DER Units in the SDN

A. The Loss Minimization in a Radial Network Topology

The feeder reconfiguration for loss reduction is one of the most important functions of a distribution system in order to reduce distribution feeder losses and improve system security. This is one of the most important functions of the distribution network in a normal operation state. Clearly, feeder reconfiguration with DER units will be a primary smart operation function in the normal operation state. There are a number of normally closed and normally open switches in a distribution network. Therefore, the number of possible switching combinations is tremendous, that makes the feeder reconfiguration a complex and time-consuming decision-making process. In order to implement these processes efficiently, many algorithms have been developed. However, network reconfiguration becomes more complicated with the advent of DER since the distribution network changes from a single source to multiple sources.

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

$$\underset{\{s\}}{\text{Minimize}}\ L = \sum_{i=1}^{n} L_i \tag{1}$$

where n is the number of branches, L_i is the loss at branch i, and $\{s\}$ is the open switch set.

Subject to:

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

B. Representation of DER Units for Loss Reduction Problems

In the SDN, the SDMS monitors the status of the DER units, i.e., the voltage at the installation node and output powers of the

DER units need to be monitored periodically. For DER units that have communication and controllability function (CDER), when the SDMS notices the output power of the DER units, they can be represented as constant power sinks (P-Q node). For DER units that have CDER/QDER functions, they can also be represented by the P-Q node. Thus, DER units that have CDER and/or CDER/QDER functions are represented by a negative load, i.e., the current flowing in reverse to the load. For DER units that have CDER/DERES functions, they can be obviously represented by the P-Q node. However, they can be represented by both positive and negative loads (active load) according to their operation state, i.e., a charge or discharge operation.

C. The Loss Minimization in a Radial Network Topology With DER Units

Using two-way communication networks between the SDMS and the DER units, the network reconfiguration with DER units for loss minimization can be solved by using the existing loss reduction algorithms by representing the DER as a P-Q node. Therefore, these DER units need to be embedded into the interconnected node as a load. In the SDMS, the node voltages and current injections are monitored and estimated using a smart meter. Under this procedure, the DER units that have CDER and/or CDER/QDER functions are also embedded into the SDN. These procedures simplify the network reconfiguration in the SDN with DER units. These are very reasonable assumptions for the radial network topology.

For loss reduction problems with DER units that have CDER can be solved by using (1). However, for loss reduction problems with DER units that have CDER/DERES/QDER functions, an additional DER functions, i.e., remote command/control of DER output, are needed to be considered. These can be generally formulated as:

$$\underset{\{s\},P_{DER}^{j},Q_{DER}^{j}}{\text{Minimize}} \quad L=\sum_{i=1}^{n} L_i \tag{2}$$

where P_{DER}^{j} is the real power allocation of the j-th DER and Q_{DER}^{j} is the reactive power allocation of the j-th DER.

Subject to:

1) Radial topology constraint
2) Isolation constraint
3) Voltage constraint
4) Current constraint
5) Real and reactive power constraints—the real and reactive power of the DER units must lie within their permissible limits.

D. The Loss Minimization in a Looped/Meshed Network Topology With DER Units

In the looped/meshed network topology, a DER with CDER/QDER/DERES functions will support the loss reduction of the systems. The reactive power control of a DER with the QDER function can support voltage profiles and loss reduction. In addition, the real power control of a DER with the DERES function can also support voltage profiles and loss reduction. The SDN can be efficiently operated from the SDMS command and control for the reactive power output and charge/discharge operation of the DER units. This problem seems like the optimal power flows in the traditional power systems.

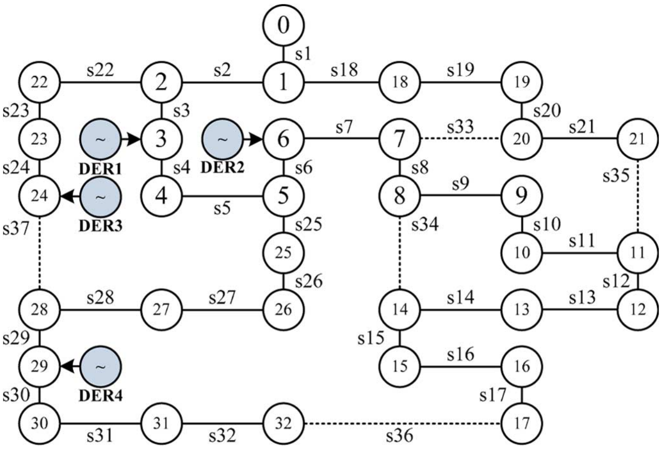


Fig. 3. The 32 bus test system with the DER units.

TABLE I
THE INSTALLATION NODES AND THE CAPACITIES OF THE DER UNITS

DER	Installation node	Rated Capacity/P.F (kW/p.f.)	Q control availability/ control limits
1	3	100/unity	NQDER
2	6	100/unity	NQDER
3	24	200/unity	QDER/0.9 lag. ~ 0.9 lead.
4	29	100/unity	NQDER

The optimal loss minimization of the looped/meshed network topology needs to be performed by the scheduling of the active/reactive power of the DER units that have CDER/QDER/DERES functions and the load estimation.

In general, the loss minimization in a looped/meshed network with DER units can be formulated as:

$$\underset{P_{DER}^{j},Q_{DER}^{j}}{\text{Minimize}} \quad L=\sum_{i=1}^{n} L_i \tag{3}$$

Subject to:

1) Real and Reactive power constraints—the real and reactive power of the DER units must lie within their limitation.
2) Isolation constraint—all of the nodes are energized.
3) Voltage and current constraints

E. Case Studies and Discussions

1) Case I: A widely used 32 bus benchmark test system was chosen for analyzing the network reconfiguration with DER units [29]. Fig. 3 shows the 32 bus test system with the DER units. The specifications of the DER units are listed in Table I. It is noted that the lagging power factor of the DER units means injecting reactive power flow to the grid.

In the Case I, it is assumed that all DER units operate with unity power factor. Thus, the available message received from the DER units is their real and reactive output power. There is no command and control from the SDMS. The results of the Case I are listed in Table II and Table III. From the results of the sample case study, the loss reduction effects of DER units are summarized as follow: It can be seen that the DER units

TABLE II
THE OPEN SWITCHES OF THE TEST SYSTEM FOR THE CASE I

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

TABLE III
THE LOSS AND % REDUCTION OF THE CASE I

Case	Loss reduction (kW/%)
Initial network without DER	173.53kW/-
Optimum network without DER	124.02kW/28.5%
Initial network with DER	149.86kW/13.6%
Optimum network with DER	105.76kW/39.1%

TABLE IV
THE OPTIMIZATION RESULTS OF THE CASE II

Optimum network with QDER	
Open switch	s7, s9, s14, s28, s32
P.F. of DER 3	0.9 lagging
Loss and % reduction	102.01kW/41.2%

have the effects of loss reduction and voltage profile improvement over the feeders. The additional loss reduction is about 10.6% through the network reconfiguration with the DER units. This result verifies the loss reduction effects of DER units in the SDN.

2) Case II: In Case II, it is assumed that the DER 3 is a QDER so that it can control its reactive power output. Thus, optimization problems should be solved by using (2) excluding real power allocations of the DER units. The open switch set and reactive power allocation of the DER 3 are determined and summarized in Table IV. It can be seen that the optimum network topology with a QDER is different from that of all-NQDER case (Case I). Moreover, additional 2.1% loss reduction can be achieved through the appropriate reactive power allocation of a QDER.

3) Discussions: Normally, in an actual system, the location and capacity of the DER units are not optimally selected since most of small-scale DER units are not utility-owned. If the owner of the DER units is a utility, the choice of locations is important because the additional DER units may reduce network losses. This optimization method permits the best location of DER units to be found so that the power losses and switching operations of the SDN are minimized. The determination method for finding the best locations can be solved and has been widely discussed in previous studies [21]–[28]. However, the optimum locations change with the load variations and the operation of the customer owned DERs. Therefore, integrating the DERs to the SDMS in an on-line manner is very important to the improvement of operational efficiency of the SDN.

V. THE SERVICE RESTORATION WITH THE DER UNITS IN THE SDN

For service restoration, the load transfer is a power supplement operation, which supplies power from a normal area to an outage area. This is one of the most important functions of the automated distribution network in an emergency operation state. Many algorithms have been developed in order to implement these processes efficiently.

For the intentional islanding issues of the DER in an existing distribution network, the IEEE 1547-2003 standard specifies that for an unintentional island in which the DER energizes a portion of the Area Electric Power System (EPS) through the point of common coupling (PCC), the DER interconnection system shall detect the island and cease to energize the Area EPS within 2 (sec) of the formation of an island [30]. Since IEEE Std. 1547-2003 states that intentional islanding is a topic under consideration for future revisions of the standard, many utilities state that intentional islanding is not allowed at this time. In the future, intentional islanding using DER units will be allowed in order to enhance the reliability of the SDN.

For the SDN using DER units, the DER units could increase the reliability of the electric service if the DER units support and provide a “backup island” during upstream utility source outages. In order to be effective, reliable DER units are required and a careful coordination of the utility sectionalizing and the protection equipment. Any time such a scheme is implemented, it needs to be well planned in order to avoid unwanted situations like unnecessary islanding and energizing.

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

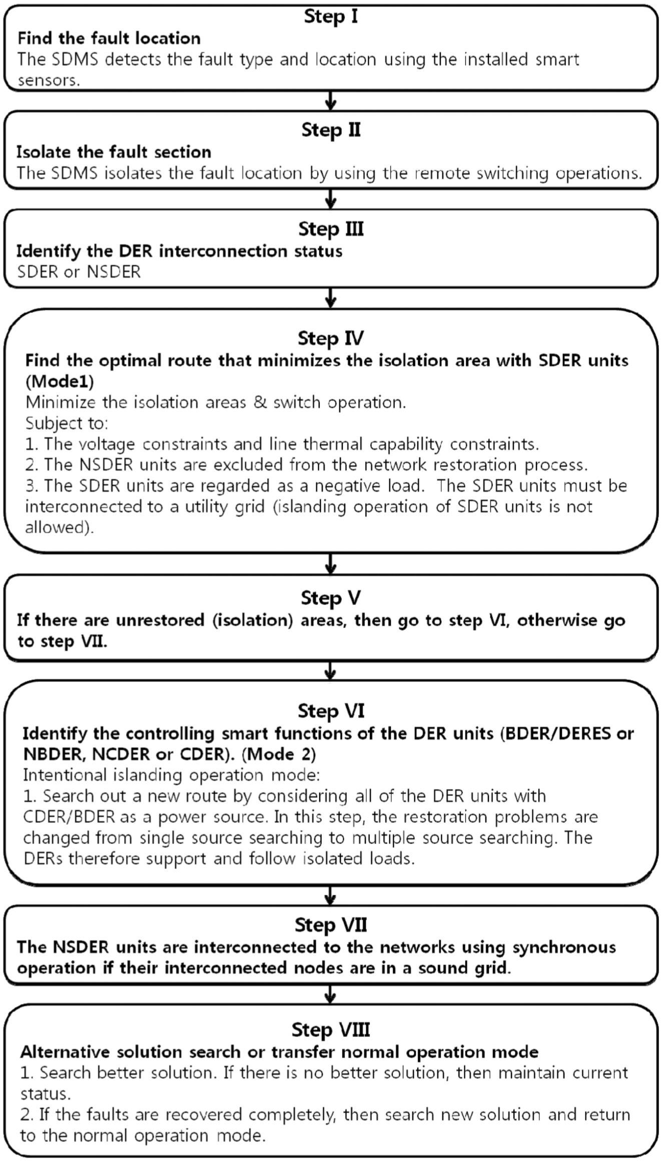
By implementing intentional islanding and supporting the service restoration of the DER units in the SDN, it greatly improves the reliability of systems. This is complicated, but the new automated switch technologies and communications approaches of the smart grid technologies make these schemes much more practical than in the past. Thus, a new service restoration strategy needs to be developed for the SDN with DER units.

A. Radial Network Topology With DER Units

To integrate DERs in service restoration process for a radial network topology, specified smart control functions of the DER units are required. The required smart control functions for the service restoration process are the communication and controllability function (CDER), the black start-up and intentional islanding supporting function (BDER/DERES), and the availability functions (SDER). Using the smart control functions of the DER units, the proposed operation scheme for service restoration in the SDMS are shown in Fig. 4.

B. In a Looped/Meshed Network Topology

In the looped/meshed network topology, the faulted section needs to be isolated from the network automatically. There is no load transfer switching operations in the looped/meshed network. In the SDN, the isolation of the faulted section can be done by the smart protection devices and the switchgear. During



Step I
Find the fault location
The SDMS detects the fault type and location using the installed smart sensors.

Step II
Isolate the fault section
The SDMS isolates the fault location by using the remote switching operations.

Step III
Identify the DER interconnection status
SDER or NSDER

Step IV
Find the optimal route that minimizes the isolation area with SDER units (Mode1)
Minimize the isolation areas & switch operation.
Subject to:
1. The voltage constraints and line thermal capability constraints.
2. The NSDER units are excluded from the network restoration process.
3. The SDER units are regarded as a negative load. The SDER units must be interconnected to a utility grid (islanding operation of SDER units is not allowed).

Step V
If there are unrestored (isolation) areas, then go to step VI, otherwise go to step VII.

Step VI
Identify the controlling smart functions of the DER units (BDER/DERES or NBDER, NCDER or CDER). (Mode 2)
Intentional islanding operation mode:
1. Search out a new route by considering all of the DER units with CDER/BDER as a power source. In this step, the restoration problems are changed from single source searching to multiple source searching. The DERs therefore support and follow isolated loads.

Step VII
The NSDER units are interconnected to the networks using synchronous operation if their interconnected nodes are in a sound grid.

Step VIII
Alternative solution search or transfer normal operation mode
1. Search better solution. If there is no better solution, then maintain current status.
2. If the faults are recovered completely, then search new solution and return to the normal operation mode.

Fig. 4. The proposed operation schemes of the service restoration in the radial network topology.

a fault, the DER units detect over-current and low-voltage conditions and disconnect from the network. After a fault is cleared, the DER units interconnect to the sound grid. The SDMS monitors the network status and transfers the interconnection signal to the NSDER.

The Low-Voltage Ride-Through (LVRT) function of the DER is necessary to enhance the reliability and stability of the SDN. This is also included in the contractual agreements and grid code of the DER units with the proper protection coordination schemes.

C. Case Studies and Discussions

The 32 bus test system is also used for the restoration case study. The smart control functions of the DER units are classified by their capabilities, as shown in Table V [19], [20]. It is noted that all DER units operate with unity power factor as shown in Table I. Two fault conditions are considered, as shown in Table VI.

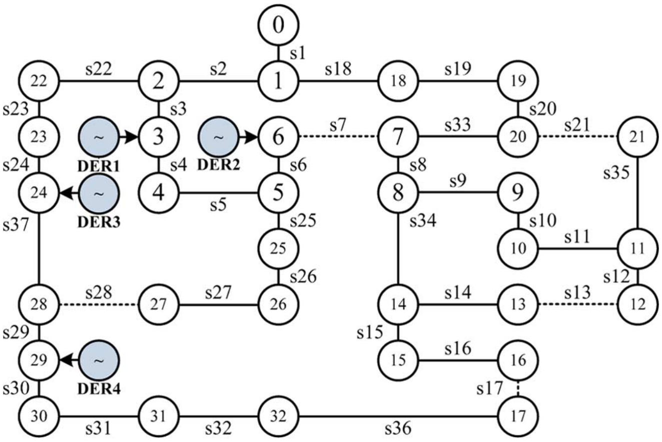


Fig. 5. The reconfigured network for Case I.

TABLE V
THE CLASSIFICATIONS OF THE DER UNITS

DER	Installation node	Controllability	Start-up capability
1	3	CDER	BDER
2	6	CDER	BDER
3	24	CDER	BDER
4	29	CDER	NBDER

TABLE VI
THE DER SURVIVAL STATUS OF THE CASE STUDY

	Case I	Case II
Line open by fault	21	30
DER status		
DER 1	SDER	SDER
DER 2	SDER	SDER
DER 3	SDER	NSDER
DER 4	SDER	NSDER

TABLE VII
THE RESULTS OF CASE I

	Open switch	Isolation area	NSDER
Prefault network	s7, s9, s14, s32, s37	none	none
Reconfigured network after fault is isolated	s7, s13, s17, s21, s28	none	none

1) Case I: Fig. 5 shows the reconfigured network for Case I. The solution processes of *Case I* are listed in Table VII and summarized as follows:

1) Identifying the DER status: all of the DER units are assumed to be SDER during the fault.
2) The network restoration problem can be solved by Mode I. The switch s9 is closed to energize the isolated network, i.e., node 9, 10, 11, 12, 13, and 21.
3) In order to maintain the network more efficiently, the network restoration problem is solved again. The switch s14 is closed and then switch s13 is opened. And then the switch s37 is closed and then switch s28 is opened, finally the switch s32 is closed and then switch s17 is opened.

2) Case II: Fig. 6 shows the reconfigured network for Case II. The solution processes of *Case II* are listed in Table VIII and summarized as follows:

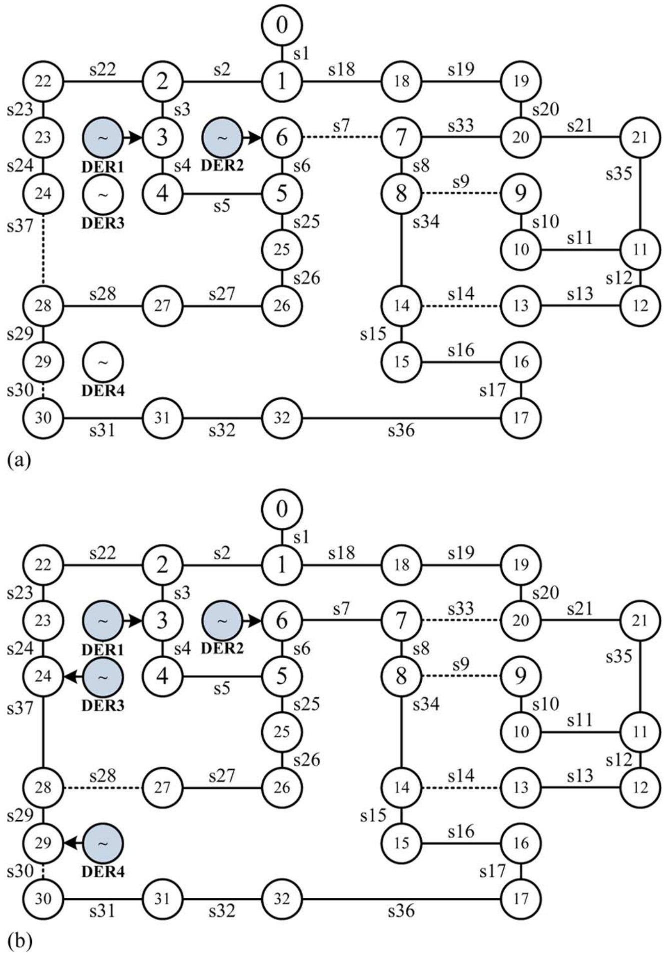


Fig. 6. The reconfigured network for Case II: (a) the reconfigured network after the fault is isolated, (b) the reconfigured network after all of the NSDER units are interconnected.

TABLE VIII
THE RESULTS OF CASE II

	Open switch	Isolation area	NSDER
Prefault network	s7, s9, s14, s32, s37	none	none
Reconfigured network after fault is isolated	s7, s9, s14, s30, s37	none	DER 3 DER 4
Reconfigured network after all NSDER units are interconnected	s9, s14, s28, s30, s33	none	none

1) Identifying the DER status: The DER 1 and DER 2 survived after clearing a fault, i.e., SDER.
2) The network restoration problem is solved by Mode I by excluding the NSDERs (DER 3 and DER 4). The switch s32 is closed to energize the isolated network.
3) The NSDERs (DER 3 and DER 4) are re-interconnected to the sound grid.
4) The network restoration problem is solved again after all of the NSDERs are successfully interconnected to the network. The switch s7 is closed and then switch s33 is opened. And then the switch s37 is closed and then switch s28 is opened in order to maintain the network more efficiently.

3) Discussions: In a SDN, the automatic detection and isolation of the faults are very important functions to improve the reliability of SDN. In view of the service restoration, it can be seen that one of the most essential function of the DER smart functions is the communication/control function in order to successful implementation of the proposed restoration schemes.

VI. DISCUSSIONS AND FUTURE WORK

Since it is well known that DER units play a positive, beneficial role in distribution systems, they are integrated into the operation and planning schemes for the SDMS. In this paper, the operation and integration schemes of the DERs in the network reconfiguration for loss reduction and service restoration are introduced. The proposed algorithm will be implemented as a study/event driven mode applications of the KSDMS. An important factor for a SDMS is the transfer/scheduling schemes between real-time operation mode and study/event driven mode. It is the key feature to determine the operation performance of the SDMS. In the near future, the detailed mode transfer/scheduling schemes will be developed to improve the operational performance of the SDMS.

In order to successfully implement the proposed DER operation strategies, the essential requirement of the DERs is the communication and control capability with the SDMS. Regarding the communication requirements, two-way communication networks are essential for the SDN. The data acquired is used to estimate the status of the network and the DER units. The required data sets and communication rates need to be carefully defined for the applications of the SDMS.

In the SDN, the issue of the availability and controllability can be settled by contractual agreements for large DER units. However, it is not mandatory for the customer owned DERs to be equipped with these monitoring and control ability. Therefore, the SDN operator must develop and provide incentives for owners of the DER units, such as incentives for emergency calls, DER command and control, and a special rate for electricity. In addition, the SDMS developer has to define the specifications of the smart control functions of the DER units and provide them to the DER manufactures.

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