An Enhanced Load Transfer Scheme for Power Distribution Systems Connected with Distributed Generation Sources

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Abstract: - This paper presents an enhanced load transfer scheme for power distribution systems connected with distributed generation sources. Load transfer is an important approach to improve the reliability of power distribution systems. The proposed load transfer scheme takes into account the effects of distributed generation sources on power distribution systems. Hence, it is more useful than conventional load transfer scheme. In this paper, the procedures of conventional and proposed load transfer scheme are addressed in detail. Two example systems for computer simulation were constructed and several simulation scenarios were carried out by this work. Simulation results shown in this paper clearly indicate the troubles of conventional load transfer scheme and the practicability of the proposed load transfer scheme.

Key-Words: - Load transfer, Distribution system, Distribution feeder, Distributed generation source, Interconnection.

1 Introduction

Load transfer is an important approach to improve the reliability of power distribution systems [1-6]. For a power distribution system, equipment fault or maintenance will result in the interruption of electric service. Customers may suffer great losses of safety and/or money during interruption of electric service. In order to shorten the duration of interruption of electric service, transferring the loads of the faulted distribution feeder to health distribution feeders as soon as possible is an important task for utilities [7-9].

For a power distribution system without distributed generation sources (DGSs), the load transfer scheme is very simple. Once a fault happens to a distribution feeder, power engineers can transfer the loads of the faulted distribution feeder to supported distribution feeders via switchgears if the faulted area has been isolated. The major consideration of conventional load transfer is that the currents of supported distribution feeders must be lower than their thermal limits after load transfer.

Nowadays, more and more DGSs are operated with power distribution systems in parallel for reducing CO_2 emission and greenhouse effect [10-13]. DGSs, such as photovoltaic arrays, wind turbines, hydro generators and cogeneration systems are all generating facilities [14-19]. They can generate electric power into the distribution feeders connected and change their operating states [20-23]. When a fault happens to a distribution feeder which connects with DGSs, the DGSs together with the loads of the faulted distribution feeder will be transferred to supported distribution feeders. Under this circumstance, the operating states of supported feeders will be affected by the DGSs. If the effects are too large, security of the power distribution systems and customers are injured [5,6]. Because the conventional load transfer scheme does not consider the effects of DGSs, it is not suitable for power distribution systems with DGSs.

In this paper, the conventional load transfer scheme is introduced first and then an enhanced load transfer scheme is presented. The proposed load transfer scheme takes into account the effects of DGSs on the operating states of power distribution systems. Moreover, two example systems are constructed and several simulation scenarios are carried out by this work. Simulation results summarized in this paper not only indicate the troubles of conventional load transfer scheme, but also demonstrate the practicability of proposed load transfer scheme. The proposed load transfer scheme is useful for the operation of modern power distribution systems interconnected with DGSs.

2 Conventional Load Transfer Scheme

In order to heighten the reliability of a power distribution system, distribution feeders interconnect with each other for load transfer.

Fig. 1 shows a schematic configuration of a power distribution system. Each distribution feeder is equipped with several isolated switches [24,25]. Isolated switches can isolate the faulted segment of the faulted feeder while a fault happens. and the tie breakers are used to connect health segments of faulted feeder with other health distribution feeders when a fault happens. For a power distribution system without DGSs, the load transfer task is simple. The load transfer scheme can be carried out so long as the currents of supported distribution feeders are all lower than their thermal limits after load transfer.

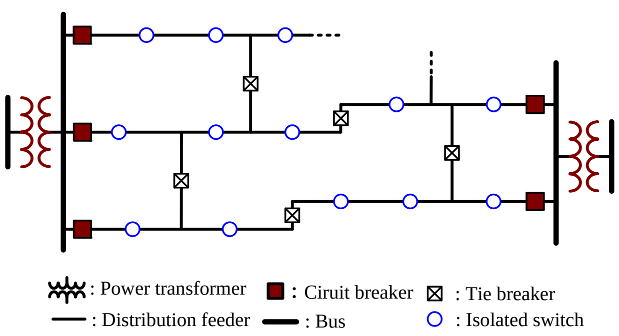

Fig. 1 A schematic configuration of a power distribution system

Fig. 2 shows the flowchart of conventional load transfer scheme. When a fault happens to a distribution feeder, the circuit breaker of the faulted feeder trips first. Then the following steps are executed to finish the load transfer task.

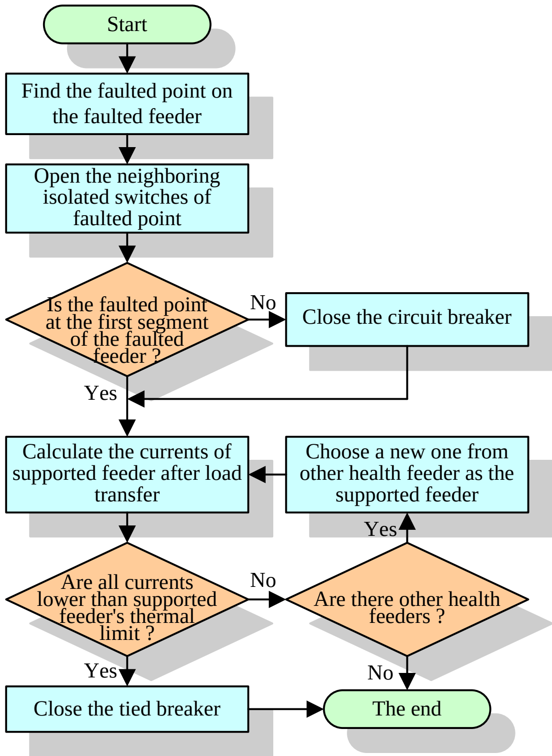

Fig. 2 Flowchart of conventional load transfer scheme

1. Find the faulted point of the faulted feeder.
2. Open the neighboring isolated switches of faulted point to isolate the faulted segment of the faulted feeder.
3. Identify the location of the fault point. Close the circuit breaker if the fault happens at the first segment of the faulted feeder. Otherwise, execute the next step.
4. Choose one health feeder as the supported feeder according to the rules of utilities.
5. Calculate the currents of supported feeder after load transfer.
6. Examine whether the current in each segment of the supported feeder is greater than its thermal limit.
7. If the answer is 'yes', the load transfer scheme chosen presently is unavailable. Choose a new one from other health feeders and repeat the step 5.
8. If no other health feeders can be chosen, the load transfer task stops.
9. If the answer of step 6 is 'no', it means that the currents of supported feeder are all not greater than their thermal limits, the load transfer scheme chosen at present is available.
10. Close the tie breaker between the faulted feeder and supported feeder.
11. The load transfer task is finished.

3 Proposed Load Transfer Scheme

DGSs are generating facilities. They generate active and reactive electric power into the power distribution systems interconnected with them and change the profiles of feeders' voltages and currents and increase the level of short-circuit current [26]. Moreover, the connection of DGSs may cause the problem of reverse power if the electric power generated by DGSs is larger than the demand of loads of distribution feeders connected. The reverse power may interfere with the protective mechanism of power distribution systems.

Because DGSs may cause some adverse effects on the supported distribution feeders, an enhanced load transfer scheme considering the effects of DGSs has been developed by this work. Fig. 3 shows the procedure of proposed load transfer scheme. The proposed scheme includes four restrictions, i.e. the limits of feeder voltages, feeder currents, short-circuit currents and reverse power. If a fault happens to a distribution feeder with DGSs, utilities' power engineers will execute following steps to finish the load transfer task.

1. Find the faulted point on the faulted feeder.
2. Open the neighboring isolated switches of faulted point to isolate the faulted segment of the faulted feeder.
3. Close the circuit breaker if the location of the fault isn't at the first segment of the faulted feeder.
4. Examine whether DGSs connect to the health segments of the faulted feeder.
5. If no, carry out the conventional load transfer steps described in section 2.
6. If yes, evaluate the effects of DGSs on the voltages, currents, short-circuit currents and reverse power of the supported feeder after load transfer.
7. Examine whether the voltages, currents, short-circuit currents and reverse power of the supported feeder exceed their limits.
8. If yes, i.e. one or more restrictions are violated, the load transfer scheme chosen presently is unavailable. Then chooses a new one from other health feeders and repeat the step 6.
9. If no other health feeders can be chosen, the load transfer task stops.
10. If the answer of step 7 is no, it means that all restrictions don't be violated. The load transfer scheme chosen at present is available.
11. Close the tie breaker between the faulted feeder and supported feeder chosen to transfer the health segments of the faulted feeder behind the faulted point to the supported feeder.
12. Finish the load transfer task.

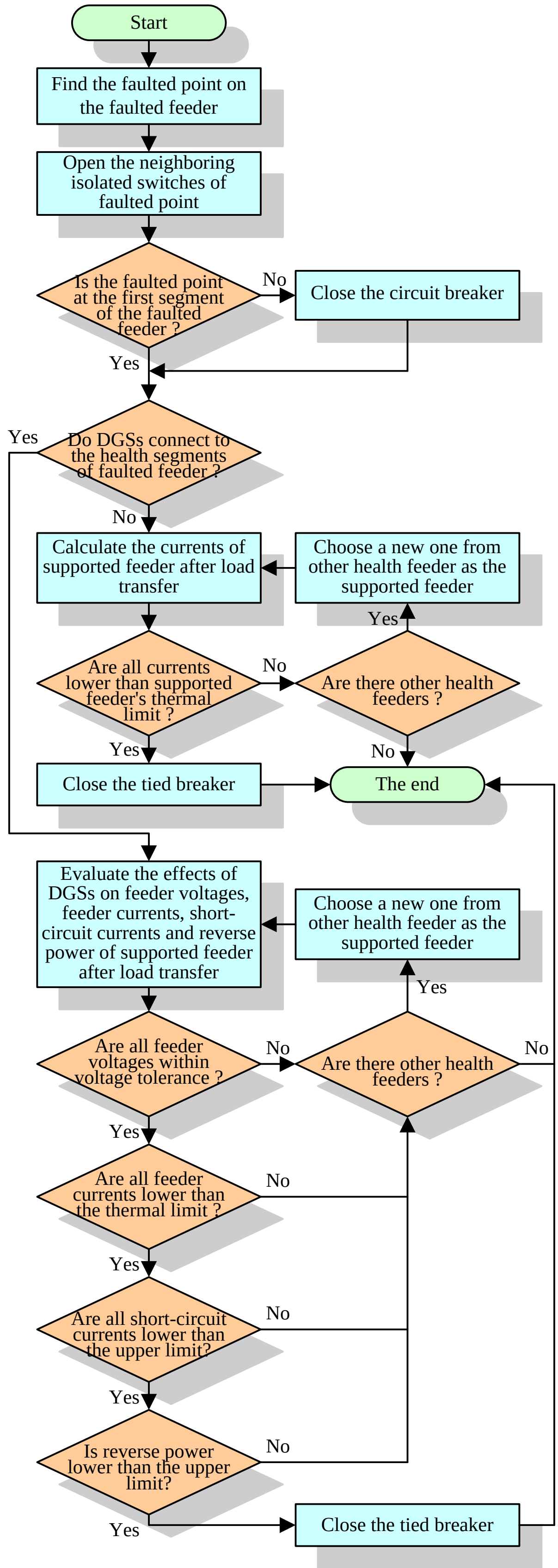

Fig. 3 Flowchart of proposed load transfer scheme

4 Effects of DGSs after Load Transfer

DGSs are generating facilities. They can generate electric power into the power distribution systems which interconnects with them and affect their operating states. In order to understand the effects of DGSs on power distribution systems while using conventional load transfer scheme, a case study was carried out by this work. Simulation results have been obtained and organized. The effects of DGSs on the feeder voltages, feeder currents, short-circuit currents and reverse power of power distribution systems after load transfer are presented and discussed in this section.

4.1 The Example System I

Fig. 4 shows the configuration of the example system I. It was employed to implement the case study. The parameters of power transformers and distribution feeders in the example system are shown in Table 1 and 2, respectively. The distribution feeders, YM-15 and ZH-21, were all named example feeders in this paper. But the example feeder YM-15 was set as the supported distribution feeder and the example feeder ZH-21 was set as the faulted distribution feeder. The dots on both example feeders represent the isolated switches, buses and their lumped load. All dots are at intervals of 1km. A tie breaker is installed at each end of both example feeders for load transfer if required.

In addition, there are DGSs in the example system. The number and capacity of DGSs in each simulation scenario adopted of this case study are different. They will be described in the related sections. The operating limits for the connection of DGS with a power distribution system are also described in the related sections.

Table 1 The parameters of power transformers in the example system

Rated capacity (MVA)	Nominal voltages		Winding impedance (%)
	Primary (kV)	Secondary (kV)	
25	69	11.4	j9.1

Table 2 The parameters of distribution feeder YM-15 in the example system

Feeder name	Total load (MVA)	Power factor (lagging)	Length (km)	Impedance (Ω/km)
YM-15	6	0.85	6	0.131+j0.371
ZH-21	10	0.85	10	0.131+j0.371

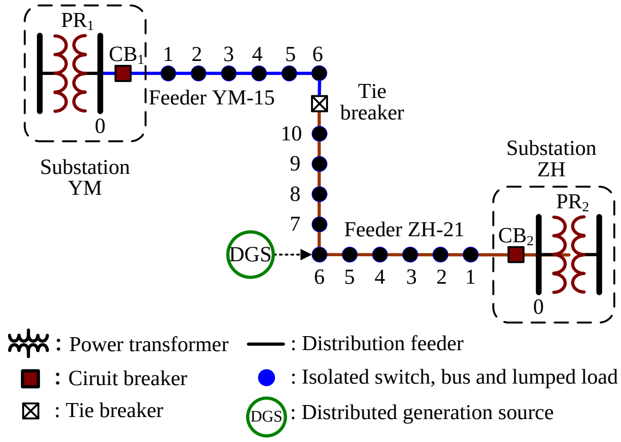

Fig. 4 The configuration of example system I

4.2 Effects on Feeder Voltages

4.2.1 Scenario definitions

Assuming that a short-circuit fault happens at the segment between bus 1 and circuit breaker of the example feeder ZH-21, the circuit breaker CB_2 and isolated switch in bus 1 open to isolate the faulted segment and then the residual segments of the example feeder ZH-21 from bus 1 to bus 10 are transferred to example feeder YM-15 via the tie breaker in the example system I. In this sub-section, three simulation scenarios were carried out to present the effects of DGSs on distribution feeder voltages after load transfer. In the three simulation scenarios, a DGS was operated with a power factor of 0.85 lagging, 1.0 and 0.95 leading, respectively. Moreover, each scenario included four sub-scenarios. The first sub-scenario represented that no DGS was connected to either feeder in the example system. The three other sub-scenarios represented that a DGS was connected to bus 1, 6 and 10 of the example feeder ZH-21, respectively. The capacity of the DGS in the simulation scenarios is 6, 3.9 and 2.3MW when it connects to bus 1, 6 and 10 of the example feeder ZH-21, respectively. Fig.5 shows the three connecting locations of the DGS for these simulation scenarios.

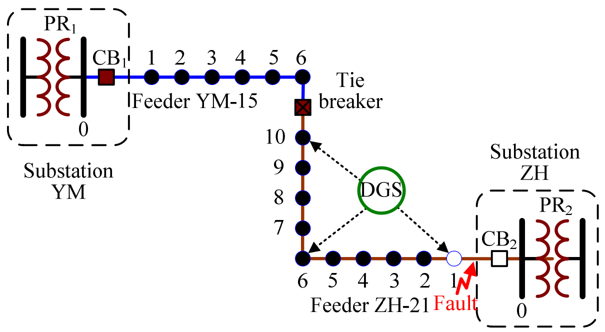

Fig.5 The three connecting conditions of the DGS for the simulation scenarios in subsection 4.2

4.2.2 Simulation results

The voltage profiles of example feeder YM-15 and ZH-21 after load transfer are shown in Fig. 6 to 8. This figure indicates the voltages along the example feeder vary largely. The voltages along example feeder ZH-21 all exceed the voltage limitation of 5% of normal voltage when the example DGS's power factor is 0.85 lagging or 0.95 leading. Under this circumstance the feeder voltage control is more difficult than ever. Oppositely, the voltage profiles of both example feeders are within upper and lower voltage limitations when the example DGS's power factor is 1.0. For this reason, to keep a DGS's power factor at 1.0 to reduce the effect on feeder voltages after load transfer is an important task for DG owners.

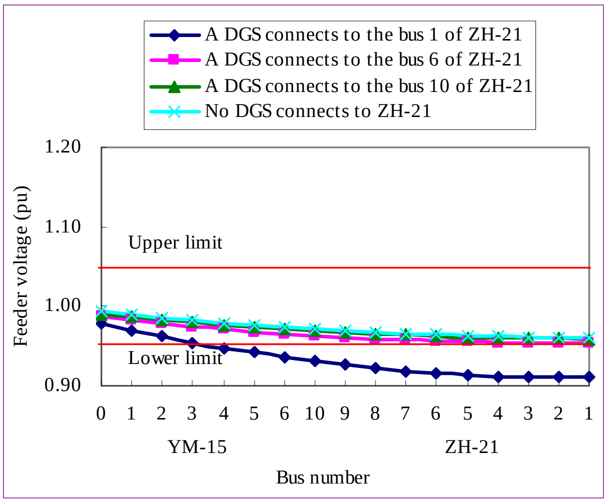

Fig.6 Voltage profiles of example feeders YM-15 and ZH-21 (DGS's power factor is 0.95 leading)

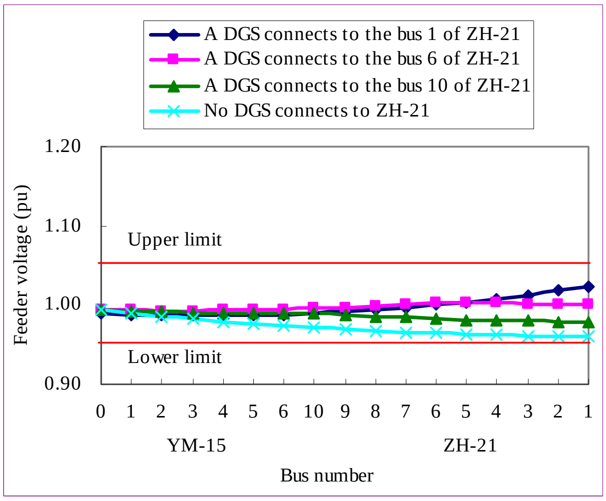

Fig.7 Voltage profiles of example feeders YM-15 and ZH-21 (DGS's power factor is 1.0)

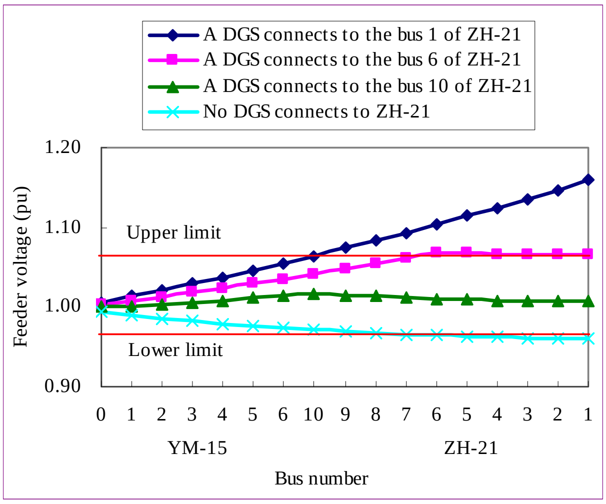

Fig.8 Voltage profiles of example feeders YM-15 and ZH-21 (DGS's power factor is 0.85 lagging)

4.3 Effects on Feeder Currents

4.3.1 Scenario definitions

In practice, the currents flowing in a distribution feeder in normal operating conditions can't exceed the feeder's thermal limit. This regulation is for guaranteeing the supported distribution feeder has enough capacity to serve the load of faulted distribution feeder. However, the interconnection of DGSs changes this situation. When a faulted distribution feeder with DGSs is transferred to a supported distribution feeder which also has connected DGSs, the currents flowing in the supported distribution feeder may exceed the feeder current limits. To figure out this effect, a scenario was employed and carried out. In this scenario, two DGSs were connected to bus 3 of example feeder YM-15 and bus 1 of example feeder ZH-21 separately. The generation capacity of each DGS is 6MW. Fig.9 shows the connecting locations of the two DGS for this simulation scenario. Assuming that a fault happens at the same place as described in the above scenarios, the example feeder ZH-21 and the DGS connected it are transferred to example feeder YM-15 together.

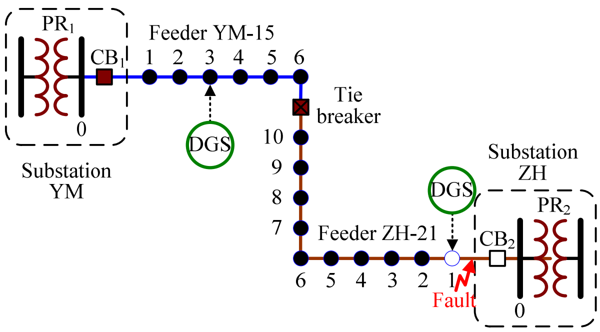

Fig.9 The connecting locations of the two DGS for the simulation scenario in subsection 4.3

4.3.2 Simulation results

The magnitudes of example feeder currents after load transfer are shown in Fig. 10. This figure shows that the some currents in the example feeder YM-15 exceed the feeder current limit of 450A. The reason is that both DGSs are connected to the example feeder YM-15 after load transfer. The generation capacity of a DGS is larger, the situation of supported distribution feeder currents exceeding limits become more severe. It is harmful to system security.

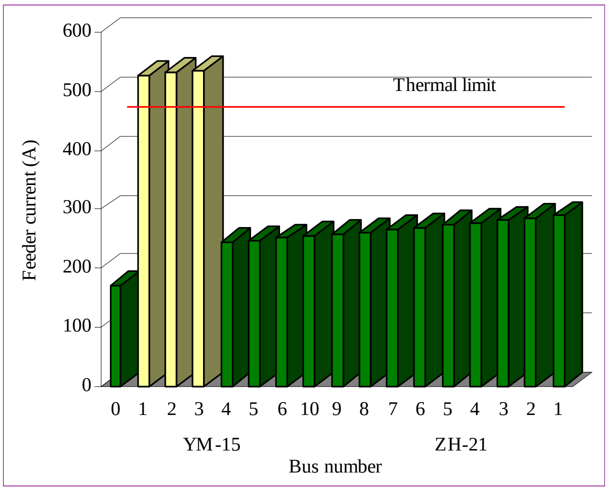

Fig.10 Current profiles of example feeder YM-15 and ZH-21 after load transfer

4.4 Effects on feeder currents

4.4.1 Scenario definition

When a DGS joints a distribution system, the level of short-circuit current of this system increases and may exceed the short-circuit current limits of the distribution feeders. The capacity of a DGS is larger, the effect on the short-circuit current level of the connected distribution feeder is larger, too. In order to reveal this problem, three scenarios were carried out by this work. The first scenario represented the original short-circuit current level of the example feeder YM-15 without connecting DGSs. The two other scenarios represented the contribution of short-circuit current level of DGSs to example feeder YM-15 after load transfer. In the second scenario a DGS was connected to bus 5 of the example feeder ZH-21. In the third scenario two DGSs were connected to bus 5 and 10 of the example feeder ZH-21, respectively. Both DGSs have the same capacity of 4.6MW. Fig.11 shows the connecting locations of the two DGS for third simulation scenario.

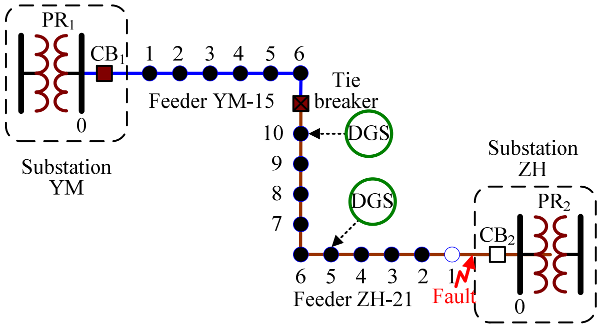

Fig.11 The connecting locations of the two DGS for the third simulation scenario in subsection 4.4

4.4.2 Simulation results

Fig. 12 shows the levels of short-circuit currents at each bus along the example feeder YM-15 before and after load transfer. This figure indicates that the short-circuit currents of example feeder YM-15 don't exceed the limit of 10kA before load transfer. However, the short-circuit current on the secondary bus of power transformer T_1 exceeds the short-circuit current limit of 10kA after load transfer if a short-circuit fault occurs in the bus. Of course, this situation is caused by the DGS connected to example feeder ZH-21 and by the load transfer.

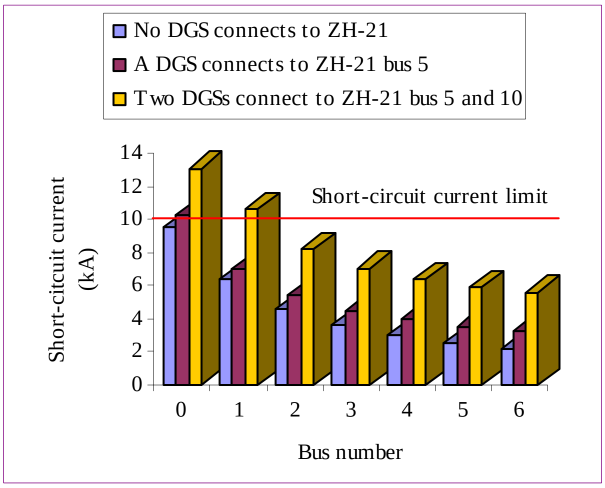

Fig.12 The the levels of short-circuit currents at each bus along the example feeder YM-15 before and after load transfer

4.5 Effects on Reserve Power

4.5.1 Scenario definition

The total electric power generated by all DGSs may be larger than the total loads in the same distribution system. The surplus electric power will flow through the power transformer and then enter the transmission system or flow into other power transformers. The surplus power is called the reverse power. Reverse power do interfere with voltage control systems and the coordination of protective facilities. Hence, it must be limited.

A simulation scenario was carried out here. Assuming two DGSs are connected to bus 3 of example feeder YM-15 and bus 9 of example feeder ZH-21, separately. Both DGSs have the same generating capacity of 4MW and both are operated with a unit power factor. The total active loads of the example Feeder YM-15 and Y are 5.2 and 8 MW, respectively. Fig.13 shows the connecting locations of the two DGS for this simulation scenario. Assuming that a fault happens at the segment between bus 7 and 8 of the example feeder ZH-21, the isolated switches in bus 7 and 8 open to isolate the faulted segment and then the residual segments of the example feeder ZH-21 from bus 9 to 10 are transferred to example feeder YM-15 via the tie breaker in the example system I. Of cause, the DGS connected with bus 9 of the example feeder ZH-21 was transferred to feeder YM-15 as well.

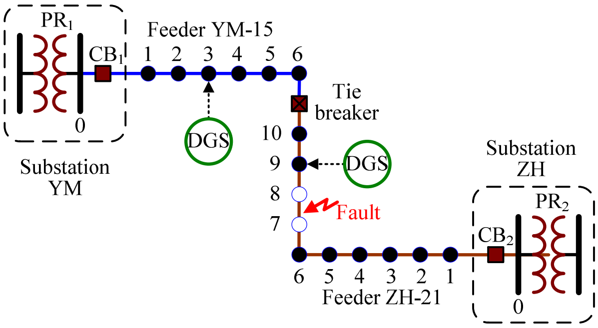

Fig.13 The connecting locations of the two DGS for the simulation scenario in subsection 4.5

4.2.4 Simulation results

Fig. 14 shows the active power supplied by the power transformer PR_1 and the total generating capacity of DGSs before and after load transfer. The total active power demand of example feeder YM-15 is 5.2MW before load transfer. The capacity of the DGS connected to bus 3 of example feeder YM-15 was only 4MW. Hence, the reverse power problem didn't happen. However, the reverse power problem happened after load transfer. The active power demand of example feeder YM-15 increased to 6.8MW because the loads in the bus 9 and 10 of example feeder ZH-21 were transferred to it. Moreover, the DGS connected to the example feeder ZH-21 was transferred to it as well. The total generation capacity of both DGSs was 8MW and larger than the total active demand of example feeder YM-15. Hence, the surplus power feed back to power transformer PR1, and then the reverse power problem happened.

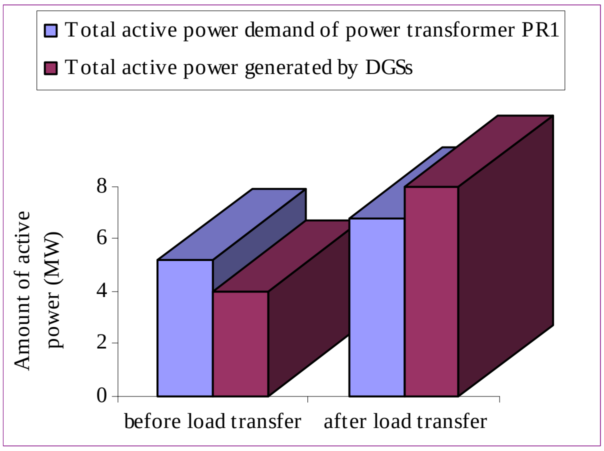

Fig. 14 The active power demand of power transformer PR_1 and generated by DGSs before and after load transfer

5 Examination of Proposed Load Transfer Scheme

5.1 The Example System II

In order to protect the security of the power distribution systems while performing a load transfer task, the conventional load transfer scheme should be modified to meet the new operating conditions that power distribution systems interconnect with DGSs. In this section another example system is employed to examine the ability of the proposed load transfer scheme. The configuration of the example system II is shown in Fig. 15.

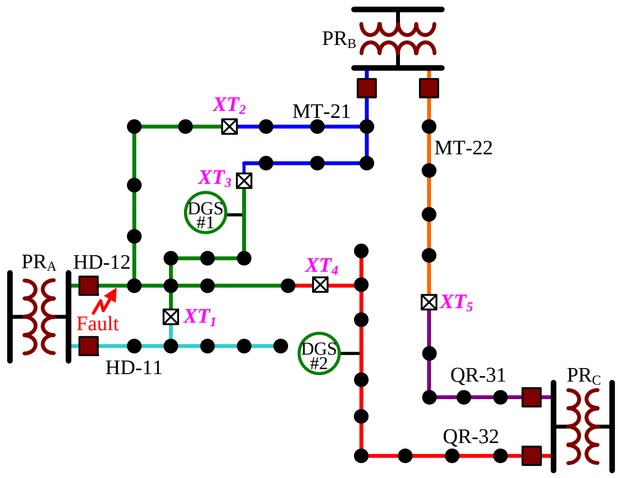

Fig.15 The configuration of example system II

In the example system, the power transformers PR_A, PR_B and PR_C supply two distribution feeders, respectively. The six feeders interconnect with each other by means of five normally open tie breakers XT_1 to XT_5 under the consideration of load transfer.

The black dots on all example feeders represent the buses and their lumped load. Each bus has a lumped load of 100kVA with a 0.85 lagging power factor. Each total load of the power transformers PR_A, PR_B and PR_C is 11, 7 and 4MW, respectively. Two DGSs connects with the example system. The DGS#1 connects to the example feeder HD-12 and The DGS#1 connects to the example feeder QR-32. The capacities of DGS#1 and #2 are 4.6 and 3MW, respectively. Their power factors are all 1.0.

5.2 Examination Results

Assume a short-circuit fault occurs in the feeder HD-12 between the bus 1 and 2. After isolating the fault segment, the load transfer procedure proposed by this work starts. However, the residual segments of the example feeder HD-12 can be transferred to feeder HD-11, MT-21 or QR-32 via tie breaker XT_1, XT_2, XT_3 and XT_4, respectively. Hence, there are four load transfer candidates for selection. The conventional load transfer scheme doesn't consider the effects of DGSs on the connected distribution feeders after load transfer. Hence, it isn't suitable for this selection task.

The four load transfer candidates are numbered candidate I to IV by this work. In order to obtain the best choice from the four load transfer candidates, the proposed load transfer scheme shown in section 3 was performed. The effects of DGSs on each example feeder to be transferred have been analyzed via computer simulation. Simulation results of the four load transfer candidates are shown in Fig. 16 to 19. The four figures indicate that only the candidate III is feasible because the voltages, currents, short-circuit currents and reverse power of the supported feeder MT-21 are all within the related limits. Hence, the tie breaker XT_3 should be closed and the others kept opened. The new configuration of the example system II after load transfer is shown in Fig.20.

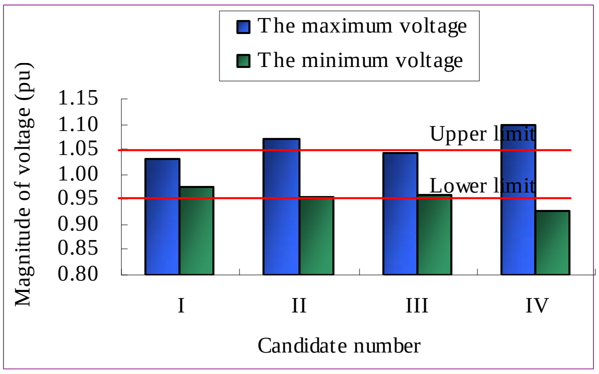

Fig.16 The maximum and minimum feeder voltages of each load transfer candidate

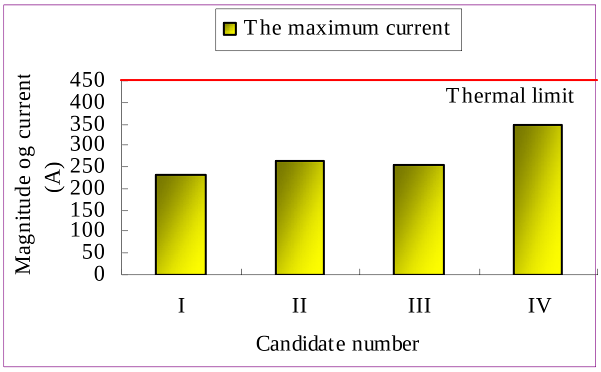

Fig.17 The maximum feeder currents of each load transfer candidate

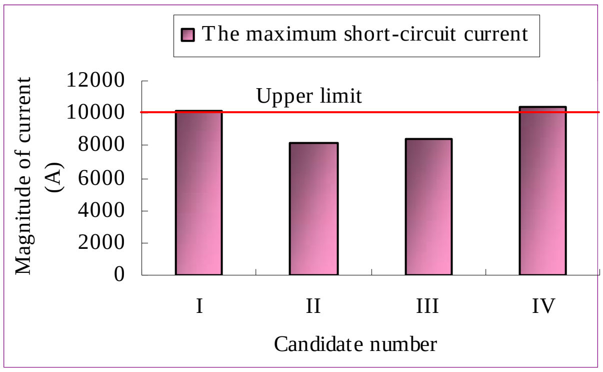

Fig.18 The maximum short-circuit currents of each load transfer candidate

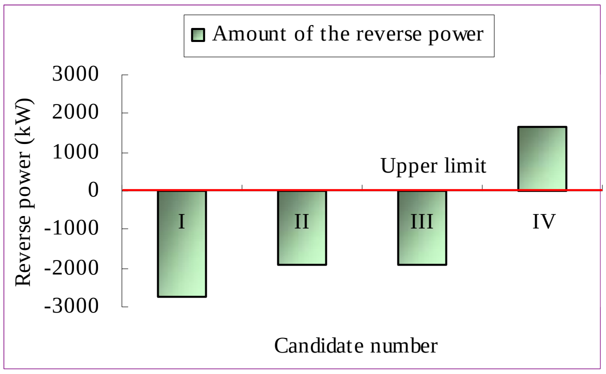

Fig.19 Reverse power of each load transfer candidate

6 Conclusion

This work has presented an enhanced load transfer scheme for load transfer safety of power distribution systems connected with DGSs. The effects of DGSs on the operating states of supported distribution feeders after load transfer also have been analyzed and presented in this paper. Moreover, the examination for the ability of the proposed load transfer scheme has been carried out. Important simulation results are also presented in this paper.

The simulation results presented in this paper indicated that the interconnection of DGSs do affect the results of load transfer tasks largely. When a distribution feeder with DGSs is transferred to another distribution feeder, the operating states of the later feeder may vary largely. Once the operating states of the later feeder exceed their limits, the load transfer task fails.

More and more medium and small-scale DGSs will operate with power distribution systems in parallel in the future. Conventional load transfer schemes of power distribution systems do not consider the situation of connecting DGSs. Hence, power engineers should put the effects of DGSs into their load transfer schemes, otherwise load transfer problems will appear gradually. When that occurs, the reliability of distribution systems will become worse.

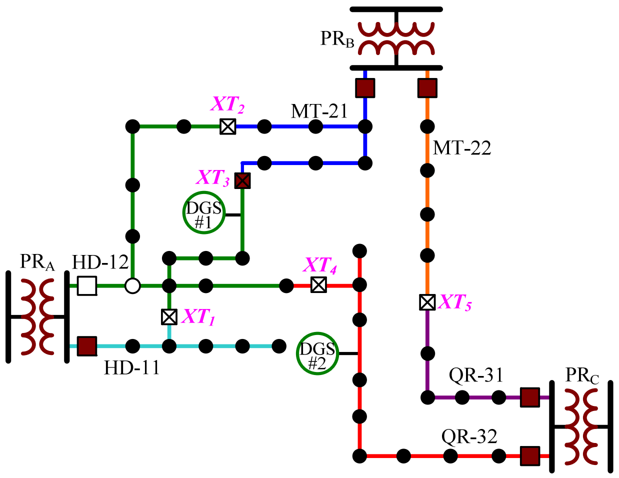

Fig.20 The new configuration of the example system II after load transfer

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