

A Multi-agent Based Service Restoration in Distribution Network with Distributed Generations

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Abstract— The amount of distributed generation (DG) integrations in the distribution network is increasing. In order to enhance the service reliability, intentional islanding operation and coordinated operations of DG with supporting feeders can be considered to assist service restoration during fault. This paper presents a multi-agent based fault restoration system with and without DG assistance and compares its performance with centralized processing scheme. Network simulation results indicate that for fault detection, isolation and service restoration, a multi-agent system could outperform the centralized processing system. Equipped with adequate synchronizing equipment in the distribution system, coordinated operations of DG and supporting feeders could minimize the un-served load during fault.

Index Terms—Distributed generation, multi-agent system, service restoration, feeder reconfiguration.

I. INTRODUCTION

Incorporating technologies such as automated switches, remote terminal units (RTU), servers/workstations, SCADA software and network management tools, modern feeder dispatch control system (FDCS) can perform system monitoring, supervisory controls, and automated fault detection, isolation and service restoration (FDIR). Currently, FDCS adopts a centralized control and management model. Control center executes solicited or unsolicited data polling to all connected feeder terminal units (FTU) so as to collect information for application processing. There is a limitation to such a model in terms of speedy fault processing. During multiple faults scenario, data collection and processing done by the control center could require a considerable time to complete as data volume for transmission is usually high.

Previous study results have shown that FDIR could be effectively executed with the cooperation among FTU. In this scheme, local FTU exchange information with other FTU to handle network outage. In comparison to the centralized processing model, distributed processing could reduce fault processing time and increases system reliability.

Protection relay that works with feeder circuit breaker (FCB) would induce it to trip when there is a fault at its protection zone. For safety reason, DG in the affected area will also be tripped to prevent islanding operation. Following that,

FDIR function is triggered to automatically isolate terminal switches of the fault zone(s), and service restoration procedure is identified and executed. In this process, FCB would be reclosed in order to restore electricity to network upstream to the fault zone. Following that, downstream service restoration will also be executed so that de-energized zone could be minimized. Downstream recovery proposition depends on the allowable load that could be transferred to the neighboring feeders through tie switches. Partial or no downstream restoration solution could be proposed if neighboring feeders can not support the additional loads that are to be transferred.

As there is a rapid increase of quantity and capacity of DG integrations in the distribution network, if DG capacity could be exploited during FDIR downstream restoration, it would greatly enhance the system reliability and reduce unnecessary outage time suffered by affected healthy network. Using a distributed processing technique, i.e., the multi-agent technique, this paper explores the feasibility of using DG for supporting FDIR function in FDCS.

II. DG ASSISTED SERVICE RESTORATION

DG could be used for service restoration in two occasions [1]:

- 1). DG is within the downstream restoration zone: The downstream restoration zone refers to the area between downstream fault zones to the normal open tie switches that divide neighboring feeders. Activation of DG depends on the capability of neighboring feeders to absorb incoming loads at restoration zone. If supporting feeders could absorb all incoming loads, DG would not be activated. However, if only partial load transfer to the neighboring feeders is possible, DG could offer additional help. Prior to activate DG, the additional loads that can be restored by DG should be carefully calculated in order to avoid overloading the supporting feeders and maximize service recovery on affected healthy network.

Using Figure 1 as an example, if there is a permanent fault occurs between switches S1 and S2, the FCB of the affected feeder would be tripped. In addition, the DG within the network needs to be disconnected to prevent un-intended islanding operation. When the fault zone has been identified and isolated, FCB would be reclosed to restore electricity to the

upstream network. Downstream network would be re-energized via supporting feeders through tie switches as illustrated in Figure 1(b).

Figure 1(b) assumes that the supporting feeder does not have enough capacity to support full load transfer from affected network. The left reserve of the feeder from Substation 2 could only support additional load between switches S4 and S6, and the feeder from Substation 3 could support load between switches S9 and S10. Since there is a DG inside the restoration zones supported by Substation 2, if the left margin of the supporting feeder and DG could support more load as depicted in Figure 1(c), DG would be integrated. Activating DG would essentially stretch the recovery zone from switches S4 and S6 to S3 and S6.

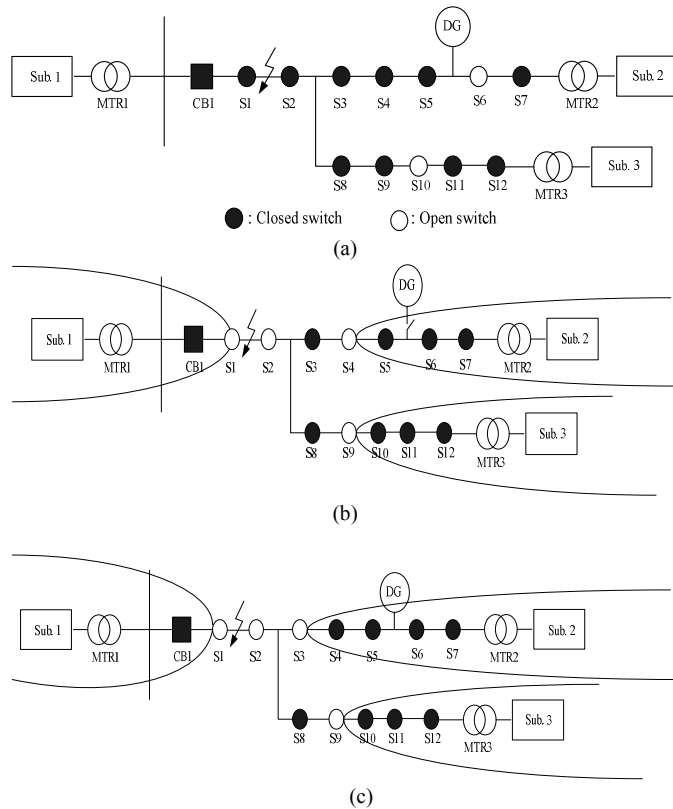


Figure 1. DG within downstream restoration zone.

2). DG is situated at non-restored zone: This area lies downstream of the fault zone and is unable to be restored by the supporting feeders due to reasons such as exceeding allowable loading limit of connecting feeders or there is no supporting feeder at all. In this case, to avoid long interruption, intentional islanding operation of the DG could be considered. However, prior to the activation of DG operation, the feeder section that could be supported by the DG has to be carefully calculated. If the total load exceeds the DG rating, then DG should be used to support load that is within its capability. In occasions where neighboring islands could be operationally synchronized, the switch between the neighboring islands would be closed to form a combined network and possibly increase the restored zone. If there is a switch between neighboring islands and feeders, coordinated synchronization could be performed in order to support additional load. Figure

2 shows the flow diagram of a DG augmented service restoration procedure.

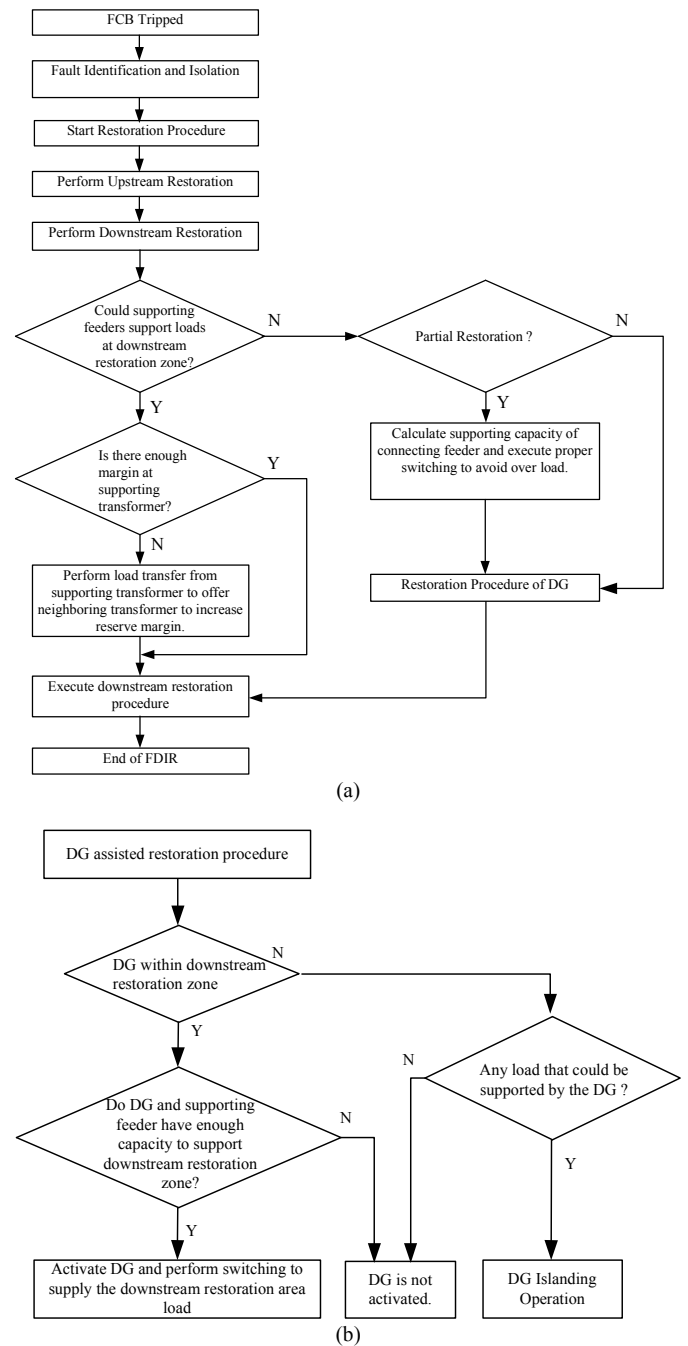


Figure 2. DG supported restoration procedure.

III. MULTI-AGENT BASED SERVICE RESTORATION

Intelligent Agent (IA) system can be considered as an automation software system that upon receiving command or certain operation condition tallies, pre-defined procedures could be executed individually by different players (agents) in the network. Coordinated operations and interaction will be performed without human intervention. Such a system has local

Figure 4 depicts the multi-agent structure for system monitoring and service restoration. Fig. 5 shows the execution procedure of multi-agent system and Table II shows the processing times. As shown in Table II, some of the tasks could be performed independently resulting in parallel processing and reduction in overall processing time.

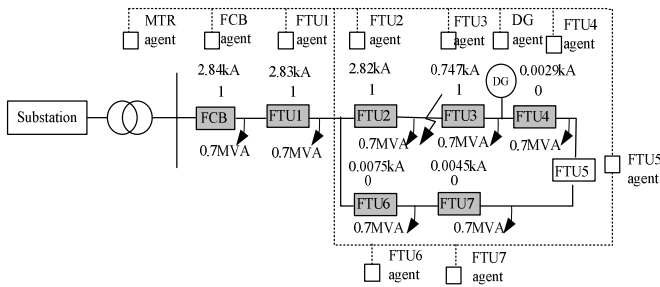


Figure 4. Multi-agent structure for processing scenario one.

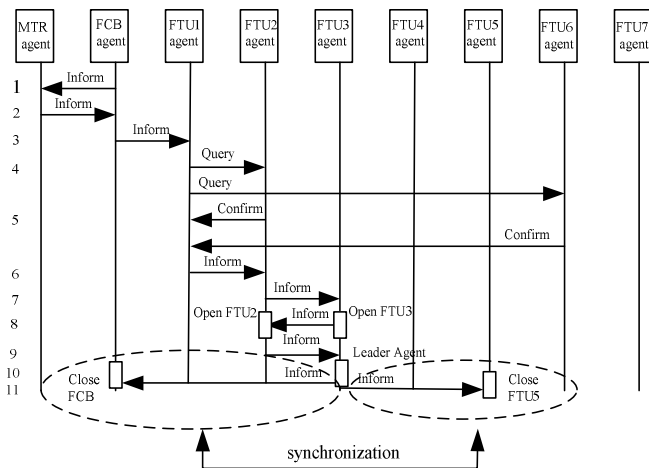


Figure 5. Execution procedure of multi-agent system in scenario one.

B. Scenario two

Fig. 6 depicts scenario two. A 3MVA DG is situated between FTU12 and FTU13. A permanent three phase fault occurs between FTU11 and FTU12. During service restoration, due to insufficient reserve of the neighboring feeder for load transfer, DG islanding operation for supporting service restoration is considered and results in a decrement of unserved load from 1.4MVA to 0.7MVA.

Fig. 7 depicts the multi-agent structure for this scenario. Fig. 8 shows the FDIR procedure performed. As shown in Fig. 8, it allows simultaneous fault processing at upstream and downstream. In addition, the search for supporting feeder limits of supply and actual section loads to be transferred over could also be executed concurrently by local agents.

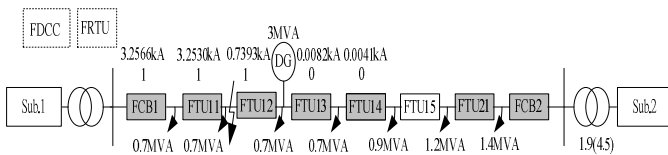


Figure 6. Scenario two.

TABLE II.

PROCESSING TIME OF MULTI-AGENT SYSTEM FOR SCENARIO ONE

| Scenario One – Multi-agents distributed processing | | |
|---|-----------------------------------|---------------------|
| Segment | Items of Processing | Processing time (s) |
| 1 | FCB→MTR | 0.533473 |
| | Detect fault feeder | 0.2667 |
| 2 | MTR→FCB | 0.533473 |
| | Detect downstream branch | 0.2667 |
| 3 | FCB→FTU1 | 0.533473 |
| | Detect fault area (1) | 0.2667 |
| | Detect fault area (2) | 0.2667 |
| | Detect fault area (3) | 0.2667 |
| 4 | FTU1→FTU2 | 0.533473 |
| | FTU1→FTU6 | 0.2667 |
| 5 | FTU2→FTU1 | 0.533473 |
| | FTU6→FTU1 | 0.2667 |
| 6 | IF status of branch flag set to 1 | 0.2667 |
| | IF fault occurred at branch | 0.2667 |
| | FTU1→FTU2 | 0.533473 |
| | Detect downstream branch | 0.2667 |
| 7 | FTU2→FTU3 | 0.533473 |
| | Detect fault area (1) | 0.2667 |
| | Detect fault area (2) | 0.2667 |
| | Detect fault area (3) | 0.2667 |
| | SW3 open | 3.533473 |
| Return message of SW3 open | | |
| 8 | FTU3→FTU2→Open | 0.533473 |
| | SW2 open | |
| 9 | Return message of SW2 open | 0.533473 |
| 10 | Find leader agent | 0.2667 |
| | FTU3→FCB→Close | 0.533553 |
| | FCB close | 3 |
| 11 | Return message of FCB close | 0.533553 |
| | Detect connecting feeder | 0.2667 |
| | Detect normal open switch | 0.2667 |
| | FTU3→FTU5→Close | 0.533513 |
| | SW5 close | 3 |
| | Return message of SW5 close | 0.533513 |
| Detect non-recovery zone | 0.2667 | |
| Total processing time | | 16.135483 |

Sync.

