FUZZY-LOGIC BASED AUTONOMOUS OPERATION OF SMALL-SCALE MICROGRID IN EMERGENCY

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ABSTRACT

In this paper, an autonomous operation algorithm of small-scale MG in emergency based on a fuzzy logic is proposed. The proposed algorithm is implemented as an application program named EMC (emergency controller) for MG EMS (energy management system) and it use an iterative judgment and control in a very short cycle using the alarm/event type data, unlike typical application programs that utilize snapshot type datasets. We propose a fuzzy-based decision logic to overcome the communication problems and bad data in the field which is difficult to apply autonomous operation. In order to distinguish between malfunction and internal/external faults of the MG, the membership function based on the overcurrent and the low alarm is presented and the fuzzy inference is performed using it. Also, the module configuration for EMC is presented, which consists of emergency classification module, fuzzy logic module, multiple emergency processing module and control processing module. The validity and applicability of the proposed algorithm was demonstrated using the 500 kW campus microgrid of the Chonnam National University constructed with KEPCO (Korean Electric Power Corporation). The reliability and economic efficiency of the system can be improved benefitting from the ability of autonomous handle of the emergency situation with proposed algorithm.

INTRODUCTION

In recent years, Development and dissemination of the grid-connected microgrid (MG) have been increasing, along with issues such as renewable energy dissemination policies, customer participation in the electricity market, and grid operation technology. In general, the grid-connected MG has two main purposes. The first is to obtain economic profits through the peak power reduction and market participation of MG. The second is to increase the reliability of the grid through islanding operation in case of a disturbance outside MG. For the small-scale MG, if the operator is on duty at all times, manpower and maintenance costs are incurred, significantly lowering economic efficiency. Therefore, it is necessary to develop and verify an algorithm capable of autonomous operation an emergency situation (ES) that may occur in MG without deploying operator. The related works on the ES of MG are as follows. Gu proposed method of detecting an internal fault if the measured value of the measurement point violates the setting value[1]. Brearley and Prabu described why it is difficult to apply the protection coordination algorithm of the existing distribution system to MG and proposed a solution [2]. The solution is hard to apply because it is necessary to change settings and install new facilities additionally. Lin et al. proposed a method for detecting a ES occurring outside MG [3]. Papadimitriou proposed a method of detecting an external fault according to the magnitude of current by inserting an impedance at the grid connection point[4]. Kato proposed an islanding operation strategy through load/power generation control in case of external ES [5]. The related works on the external ES have proposed fragmentary measures such as disturbance detection and an islanding operation strategy. As a consequence, there are two major problems in performing the integrated ES operation of the actual MG through the related works. First, integrated ES handling is difficult because each of the related work proposes fragmentary strategy for the specific ES. Second, in the case of the actual MG, error data occur depending on communication errors and malfunctions of devices. However, the related works did not consider error data. Therefore, autonomous operation of MG ES through related work is difficult.

In this study, the autonomous operation algorithm of MG for ES was proposed. The proposed algorithm used alarm data with non-periodicity. Also, it has a two major features. First, it can detects internal and external ES through the alarm data. An integrated ES operation algorithm that performs message output and device control was proposed. Second, we constructed a fuzzy model which can improve the handling of error data and ES detection. In addition, priorities are provided to each ES by applying a rule base focused on load recovery to cope with multiple ESs. To verify the generality and validity of the proposed algorithm, Functional testing was conducted on a test network. Furthermore, the applicability of the algorithm was verified by conducting a field test on an MG site constructed inside the Chonnam National University.

ALGORITHM OF EMC

Unlike the periodic application programs of the MG energy management system (EMS) used to increase economic efficiency, the purpose of the proposed algorithm is the autonomous processing of the non-periodic ES by MG. The proposed emergency controller (EMC) performs judgement and control using non-periodic alarm/event data, unlike the existing application programs that use snapshot data. Fig. 1 shows the overall flowchart of the EMC algorithm. As shown in Fig. 1, EMC consists of four major modules. The ES classification module (ESCM) performs preprocessing of alarm data through data clustering. After, The ESCM is temporarily determine the type and location of ES. The fuzzy module (FM) calculates certainty factor for the temporarily determined type and location of ES in ESCM. FM determines the re-execution of ESCM and processes error data through the calculated certainty factor. The multiple ES processing module (MESPM) provides priorities to each ES according to the rule base focused on load restoration when FM produces multiple results. The FM and MESPM perform intermediate processing to judge the results obtained from the previous modules while the algorithm is executed. Finally, the control processing module (CPM) performs post-processing processes such as maintenance operator message transmission and device control for each ES.

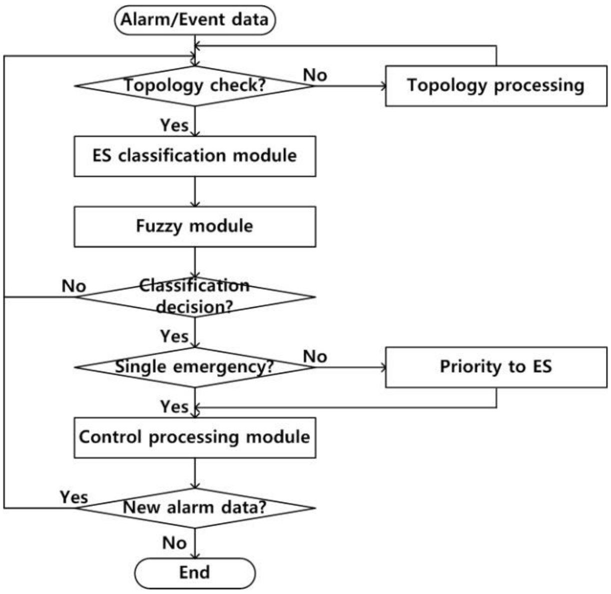


Fig. 1. Overall flowchart of EMC

Fuzzy Module

In the proposed algorithm, a fuzzy model was built to determine the re-execution of ESCM and process of error data through the number of low-voltage and overcurrent alarms in MG. Fig. 2 shows the proposed FM algorithm. The algorithm calculates certainty factor for all the paths in MG. For paths with low certainty factor, alarm data are recollected and the corresponding process is repeated. The accelerated certainty factor (ACF) of the fuzzy model operation was set to address the problem that the certainty factors of the paths are fixed when the additional alarm data of MG do not occur. When FM was executed initially, ACF was not applied to the certainty factor calculation. For a path with low certainty factor after initial execution, the certainty factor of the path was set to converge to the range between the maximum and minimum values by adjusting ACF according to the temporary classification results of ESCM. The certainty factor of a path can be calculated as follows[6].

$$\mathrm{CF_{path}} = \frac{\sum_{i=1}^{n} f(CF_i) * CF_i}{\sum_{i=1}^{n} f(CF_i)} * \mathrm{ACF_{path}} \quad (1)$$

where, $\mathrm{CF_{path}}$ is the certainty factor of the path, $\mathrm{ACF_{path}}$ indicates the ACF of the path, CF_i is the i-th value of certainty factor, $f(CF_i)$ is the membership of the CF_i. ACF can be determined as follows.

$$\mathrm{ACF_{path}} = \begin{cases} ACF_{path} + 20\% & ESCM\_flag_{path} = 1 \\ ACF_{path} - 20\% & ESCM\_flag_{path} = 0 \end{cases} \quad (2)$$

where, the initial value of $\mathrm{ACF_{path}}$ is 100% and $ESCM\_flag_{path}$ represents the temporary classification results of ESCM for the path. 1 or 0 denote a status in which the type and position of the ES are determined and a state in which the ES is not determined, respectively.

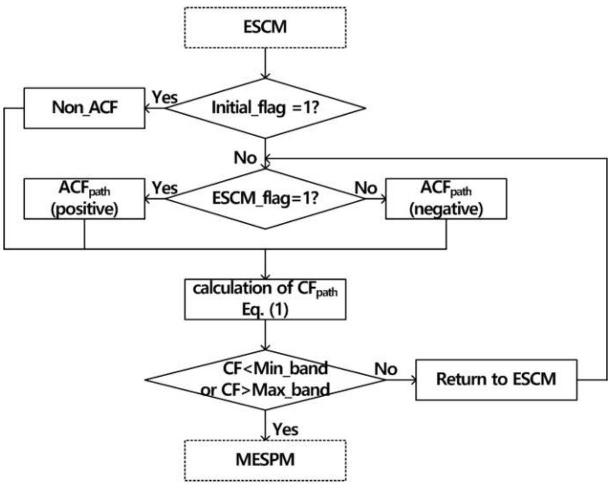


Fig. 2. Algorithm flowchart of FM

Multi Emergency Processing Module

MESPM provides priorities to each ES based on a rule when multiple ESs occur. The priority of the proposed MESPM is based on the load restoration. Table 1 shows the priorities of ESs when multiple ESs occur. In the table, ⓐ→ⓑ represents that ⓐ has a higher priority than ⓑ. When multiple ESs occur in MG (①, internal fault and ②, device malfunction), priorities are provided according to the importance of load. When ES in MG and external ES (③, external fault) occur simultaneously, external ES is handled preferentially because all loads in MG are off. When an internal communication error (④, internal communication error) and ES in MG occur, the load is restored by giving a priority to ES in MG. when an internal communication error and external ES occur simultaneously, it cannot perform the autonomous control such as the ESS and the remote control of the protection device due to the occurrence of the internal communication error. Therefore, priority is given to internal communication error. In the case of an external communication error (⑤, external communication error), the lowest priority was given because it is far from load restoration.

Table 1. Rules for multiple emergency processing

ES Type	①	②	③	④	⑤
①	Load priority	Load priority	③→①	①→④	①→⑤
②	Load priority	Load priority	③→②	②→④	②→⑤
③	③→①	③→②	③	④→③	③→⑤
④	①→④	②→④	④→③	④	④→⑤
⑤	①→⑤	②→⑤	③→⑤	④→⑤	⑤

CASE STUDY

To demonstrate power trading between multi MGs and autonomous operation, the joint project by the Korea Electric Power Corporation (KEPCO) and the Chonnam National University is underway. The field test was conducted in one of the campus MGs constructed by the said project to verify the applicability of the proposed EMC. In the MG, facilities capable of performing ESS, PV, and load control were constructed. In addition, RTU was installed at the protective device position inside MG to acquire alarm data such as the contact state, low voltage, and over current of the protective device. Fig. 3 shows the network diagram of MG for which the field test was conducted. Fig. 4 represents the constructed ESS and artificial load.

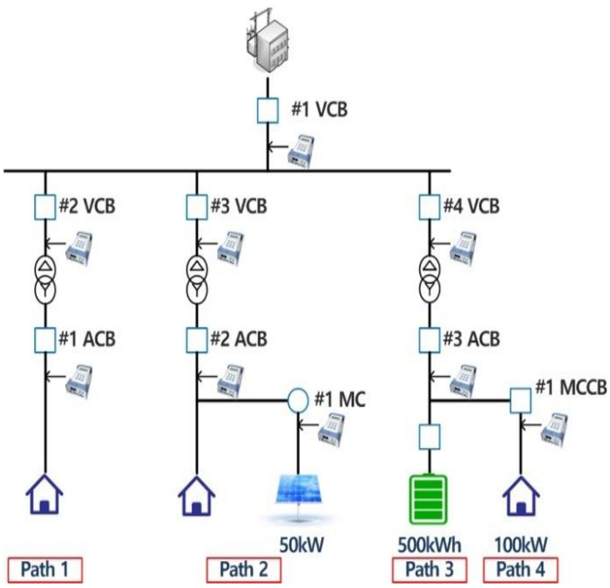


Fig. 3. Network diagram for case study


(a) 500kWh PCS and battery


(b) 100kW load bank
Fig. 4. Picture of the demonstration MG site

1) Case Study 1

Case Study 1 represents the EMC results when multiple ESs occur in MG. Table 2 shows the alarm data generated in Case Study 1. Fig. 5. shows the overall result for Case Study 2. Fig. 5(a) shows the detected ES type and device by EMC. Fig. 5(b) shows the message sent to the maintenance operator. In case of case study 2, The FM calculation resulted in the certainty factor values of 0.803 for path 1, path 2 and 0.19 for path 3, 4. As a result, Path 1 has detected the # 1 ACB as an internal fault because the certainty factor is higher than the max band. also, path 2 has detected the #3 VCB as a device malfunction. but, path 3, 4 handled of error data because the certainty factor is lower than the min band.

Table 2. Input alarm data of case study 1

Alarm type	Device
Low voltage	#1 ACB, #3VCB, #2ACB, #1 MC
Over current	#1 ACB, #4VCB

(a) Detection and location of ES

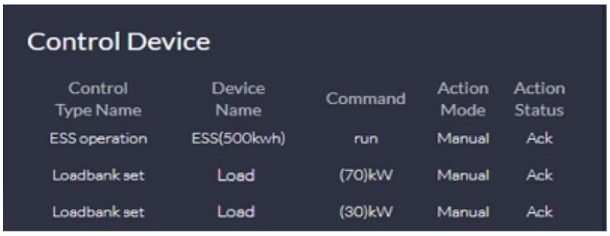
(b) Information of message on case study 1
Fig. 5. Result of case study 1

2) CASE STUDY 2

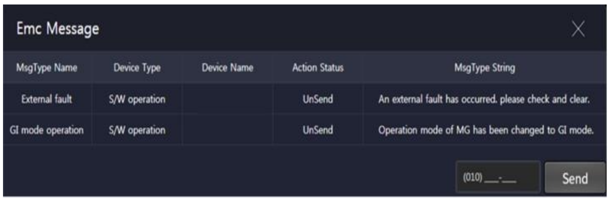
Case Study 2 represents the EMC results when a ES occurs outside MG. The islanding operating point of the microgrid was set to # 3 ACB. An external ES was simulated by forcibly opening #4 VCB. Table 3 shows the alarm data generated in Case Study 2. Fig. 6 shows the overall result for Case Study 2. Fig. 6(a) shows the output of the sequence commands for MG mode change and load shedding by external ES. Figure 6 (b) shows the output of message about operation mode change and external ES detection. Fig. 6(c) shows that #3ACB sub-section was operated separately from the main network. In case of case study 2, The FM calculation resulted that the certainty factor value of 0.803 was calculated for both Path 3 and 4. As a result, the external fault of #3 ACB section was detected. In case of external ES, EMC performs autonomous operation mode change and islanding operation through device control.

Table 3. Input alarm data of case study 2

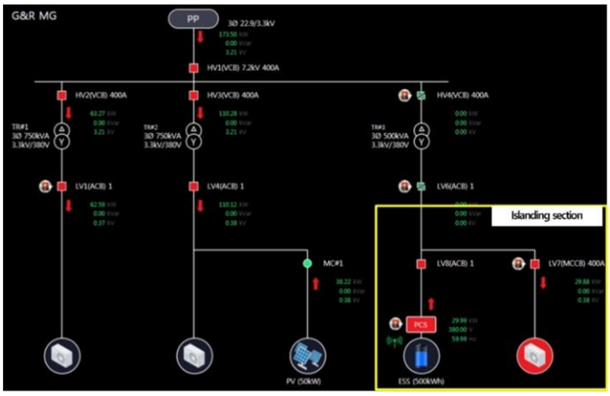
Alarm type	Device
Low voltage	#3 ACB, #1 MCCB



(a) Sequence of control commands



(b) Information of message on case study 2



(c) Actual operation screen

Fig. 6. Result of case study 2

CONCLUSION

In this study, an integrated Autonomous algorithm for an emergency situation (ES) in a microgrid (MG) was proposed. Case studies confirmed that the integrated management of ES is possible, including detection, judgement, and control. In addition, it was confirmed that error data can be handled by the constructed fuzzy model. Therefore, when the proposed emergency controller (EMC) is applied to the small-scale grid-connected MG, the reliability of the grid is expected to be improved due to the integrated autonomous management of ES. Furthermore, autonomous operation through EMC will reduce manpower and maintenance costs.

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