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# Investigate dynamic and transient characteristics of microgrid operation and develop a fast-scalable-adaptable algorithm for fault protection system

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ABSTRACT

A microgrid (MG) system mainly consists of renewable energy sources, distributed generators, loads and energy storage devices. Development of the microgrid brings some emerging challenges. One of them is a microgrid fault protection system. In order to develop an optimal fault protection algorithm, this paper surveys dynamic and transient behaviours with respect to two operation modes of a microgrid, namely, islanded and grid-connected modes. Modelling and simulation of the MG's operation are performed by PSCAD/EMTDC software. A surveyed typical MG structure includes one dispatchable power source of microturbine (μT) system, another non-dispatchable power source of photovoltaic (PV) generation system and one battery power conditioning system (PCS). Whereas dynamic characteristics of the MG are investigated in cases of power change of loads or sources and motor starting, transient properties are surveyed through staged fault tests (e.g. single-phase and three-phase to ground faults) and the MG's operation transition between grid-connected and islanded modes. Simulation results are compared to actual experiment results performed at a 380 V microgrid at Institute of Nuclear Energy Research (INER), Taiwan. From achieved dynamic and transient properties, this paper proposes a fast-scalable-adaptable (FSA) computing algorithm for a fault protection system to improve MG's reliability and adaptability operation. This new algorithm uses parameters of current, voltage and angle phase along with a communication network to protect online the microgrid. The proposed algorithm can solve challenging problems of high penetration of inverter-based distributed generators, reduced fault current values and non-directional power flow. Moreover, the algorithm can get a critical fault clearing time within one fault cycle, high accuracy and reliability for fault detection, identification of different types of faults and optimal isolation of faulted zones. Simulation and experiment results validate the proposed fast-scalable-adaptable fault protection algorithm.



## 1. Introduction

Development of an optimal fault protection strategy is essential for microgrid's operation against all various types of faults. At a grid-connected operation mode of microgrid, conventional overcurrent protection solutions can be applied [1]. High fault current values flowing from a grid power source can activate overcurrent relays to clear faulted sections inside a microgrid or isolate whole the microgrid system in case of faults occurred at the grid side. At an islanded operation mode, the conventional protection solutions are no longer to be used for the microgrid because of new challenges as follows:

- High penetration of distributed generators (DGs) causes non-directional power flows.
- Fault current values change significantly between grid-connected and islanded operation modes [1]. Reduced fault current level of inverter-based DGs causes a blind of protection during the faults because protection devices based on high short-circuit current cannot be activated by low fault currents at the islanded mode [2,3].

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- Nuisance tripping of protection due to the faults on adjacent feeders [4].

A developed MG fault protection strategy must solve the aforementioned challenges. Instead of only using one current parameter, other parameters can be additionally utilised to enhance accuracy and reliability of MG protection operation such as voltage, total harmonic distortion of current and voltage, phase displacement, frequency. There are two different protection philosophies of microgrid operation. One is that a MG protection system has the same operation principle for both islanded and grid-connected modes [5]. At that case, a static switch (SS) is designed to open first for all internal or external faults of the microgrid. When the SS opens, the faults inside a MG can be quickly cleared due to various techniques that do not rely on high fault current values. If the external faults are detected, the MG is isolated by the SS to assure its normal operation state. However, because of fault detection and microgrid isolation only first performed by the SS, if the SS has any false tripping, the MG's operation can be at a risk or isolated from the grid for a long-time period. Another one is that the MG system has two independent protection parts including: one protection part for the grid-connection mode and another part for the islanded operation mode. With the former, a standard overcurrent protection system can be used. With the latter, several protection methods are strongly developed in recent years such as adaptive protection solutions, voltage based methodologies, differential protection methods, overcurrent protection using additional fault current sources, and other less common methods [6]. In this paper, the author focuses on the second MG protection philosophy. To be precise, traditional overcurrent protection methods are utilised for the grid-connection operation case of the MG, whereas a novel fast-scalable-adaptable fault protection algorithm is proposed to protect the MG at the islanded operation case.

A novel FSA fault protection algorithm uses a new designed digital relay type along with communication channels to protect trunk lines and directional overcurrent relays without any communication link among them to protect all branches only containing loads or DG sources in the microgrid. Aside from one current parameter, two other parameters consisting of voltage and phase angle are measured to supply for the novel fault protection strategy. A 95% confidence level of Chi-square distribution is utilised to select threshold values of sampled current and voltage signals and phase angles. The FSA fault protection scheme has three main functions as follows: fault detection and elimination at a critical time within one fault cycle (a fault clearing time is total of all algorithm's computing time and communication time among protective relays); identification of different types of faults occurred; and optimal isolation of faulted zones. More clearly, regarding fault prediction and detection, a three-point method is used. Determination of the faulted zones can be done through evaluation of phase angles and directional change of current. New designed digital relays can transmit and receive measurement signals from other upstream and downstream relays through a communication system at a very short latency [7].

On the other hand, in order to successfully develop a FSA fault protection scheme, it is essential to survey dynamic and transient characteristics of a typical microgrid. A surveyed typical microgrid is a real 380 V multi-grounded microgrid test bed at Institute of Nuclear Energy Research – Taiwan. The INER microgrid consists of a microturbine generation system, a photovoltaic generation system and a battery power conditioning system. Modelling and simulation on operation of the INER 380 V microgrid are done by PSCAD/EMTDC software. Besides that, actual experiments are also conducted at the INER microgrid. Performed tests to observe transient properties are: staged fault tests with grounding fault types and microgrid's operation transition between islanded and grid-connected modes. Additionally, other tests performed to survey dynamic properties are: motor starting and power change of loads. Simulation and experiment results from the above tests are used to validate the scalability and adaptability operation as well as a fast response of the proposed FSA fault protection scheme.

The rest of paper is organised as follows. Section 2 presents theoretical study on existing protection solutions of the microgrid and a surveyed typical microgrid configuration. Section 3 analyses simulation and experiment results to investigate dynamic and transient characteristics of the microgrid. Section 4 shows a detailed design of the FSA fault protection system. Section 5 presents analysis and discussion on operation of a designed MG fault protection algorithm. Finally, Section 6 gives some briefly conclusion on this new fault protection algorithm.

## 2. Theoretical study

### 2.1. Microgrid's existing protection solutions

#### 2.1.1. Adaptive protection systems

Adaptive protection solutions have the ability to online control protective relays to adapt with changes of microgrid's operation mode and structure. For example, an adaptive protection method is developed to compare the drop voltage magnitude between two cases of faults and overloads, then time-current characteristic of protective relays are adjusted [8]. Others are related to setting of adaptive relays updated due to operating current states along with a microgrid's central protection unit [9,10].

#### 2.1.2. Voltage based methodologies

Conventional protection solutions use protective relays operating based on high short-circuit levels, which are no longer to be used for microgrid's operation at the islanded mode [3]. Therefore, protection solutions using voltage measurements are developed. For instance, a protection method using the *abc*–*dq*0 voltage transformation is proposed. Measured voltage signals are converted from the *abc* operating frame into the *d*–*q* frame and compare to reference voltage values [11]. However, the *abc*–*dq*0 transformation method is affected by harmonics and reliability of sampled voltage values [12]. Another protection method works based on total harmonic distortion (THD). It is suitable for the grounding fault protection regarding microgrids having inverter-based DGs [13]. The voltage THD of various feeder relays is analysed to determine the faulted zones. However, the THD detection method is merely used as a backup protection type due to problems posed by dynamic loads connected and various fault locations. In order to improve the reliability and accuracy of the THD method, instead of detecting distortion of voltage magnitude, a positive sequence component of the voltage is used [14].

#### 2.1.3. Differential protection methods

Differential protection is the most common method used for the microgrid. Several various approaches are developed from a differential methodology. For example, a protection scheme considering both direction and amplitude of current signals is developed for a microgrid system dominated by inverter-interfaced DGs [15]. Another fault protection method works based on symmetrical and differential current components [16]. However, differential current detection is not effective for case of unbalanced loads. Therefore, instead of using the differential current, one MG protection approach can use differential energy [17]. It is less sensitive to synchronisation errors in comparison with differential currents in time-domain. In addition, a new protection scheme has been developed using digital differential relays assisted by communication networks [7].