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Transient stability of a distribution subsystem during fault-initiated switching to islanded operation

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ABSTRACT

This paper investigates the transient stability of a load-rich distribution subsystem during the switching process to islanded mode instigated by a permanent fault. When operating in islanded mode, the subsystem must maintain a generation-load power balance and use at least one distributed generator (DG) to regulate the system frequency and voltage. Therefore, switching control must be executed after the disconnection of the main grid and a strategy which includes a DG coordination method and a single-step load shedding scheme is proposed. Other factors also have a substantial impact on the system transient performance, including the type of subsystem load, the DG penetration level, the fault clearance time and the switching control delay. To perform the study, a distribution subsystem was simulated using PSCAD/EMTDC software, consisting of a mix of synchronous and inverter-based DGs and a combination of static loads and dynamic motor loads. Simulation results show the proposed switching control strategy can effectively ensure successful switching from grid-connected to islanded mode under different fault conditions and DG penetration levels.

1. Introduction

Increasing use of distributed generation in utility distribution networks has encouraged researchers to consider intentional islanding. Intentional islanding normally happens as a consequence of routine switching or pre-designed protective actions against grid faults [1,2]. Current utility practices, such as IEEE Std. 1547-2003 [3], do not normally permit islanding operation and require all downstream DG units to be disconnected after the grid supply fails due to a fault. The exception is during routine maintenance or when a pre-designed microgrid is deliberately operated in islanded mode. This requirement is imposed to address safety concerns and to comply with the existing control and protection constraints of distribution networks [4]. However, to fully utilise the benefits of DG technology, such as maintaining uninterrupted service and offering high quality and reliable power to customers, autonomous islanded operation needs to be considered. As a result, the IEEE Std. 1547-2003 and IEEE Std. 1547.4-2011 [5] suggest intentional islanding is an important task for future consideration.

An islanding-possible system should contain a cluster of DGs which are capable of operating in either grid-connected or islanded mode and switching between these modes when required [6]. Immediately after the disconnection of the main grid, the islanded subsystem will experience rapid and severe frequency and voltage deviations. The intensity of these deviations depends on various factors, including the type of DGs and their control approaches, the type of load, the DG penetration level, the severity of the fault that triggers islanding, the fault clearance time and the switching control delay.

Fault-initiated switching from grid-connected to islanded mode was investigated previously in [6–8]. However, all these studies were conducted on pre-designed generation-sufficient microgrids, i.e. the installed generation capacity exceeds the local load demand. Paper [2] studied a load-rich microgrid, but only considered inverter-based DG and constant impedance loads. In this study, the amount of load shedding was analytically computed based on the voltage change rate and proved effective in ensuring a successful transition. Islanding events triggered by various types of fault were studied in [7], and in this scenario, the microgrid included a mix of synchronous and inverter-based DGs. Paper [8] investigated the transient behaviour of induction motor (IM) loads during an islanding event triggered by a three-phase fault, and used the critical clearing time to evaluate the transient stability of the microgrid. In the aforementioned papers, inverter-based DGs were assumed to be fully dispatchable and can participate in the system frequency regulation using their rapid response to smooth the transients during the transition process.

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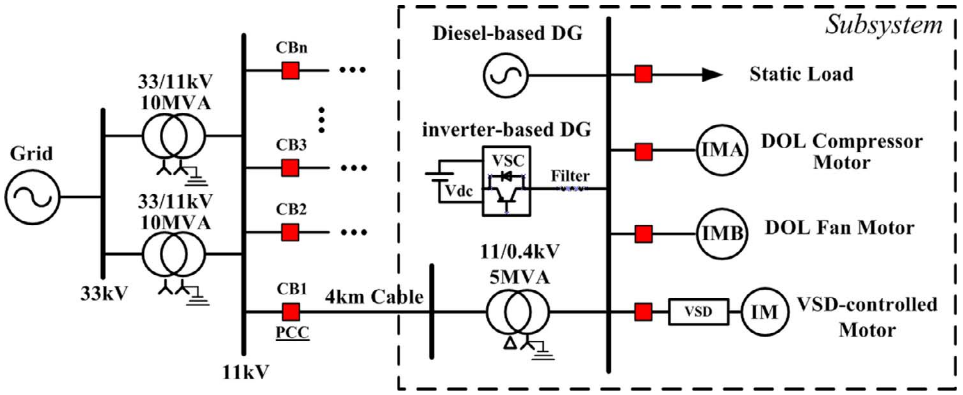

Fig. 1. Single line layout of the distribution system under study.

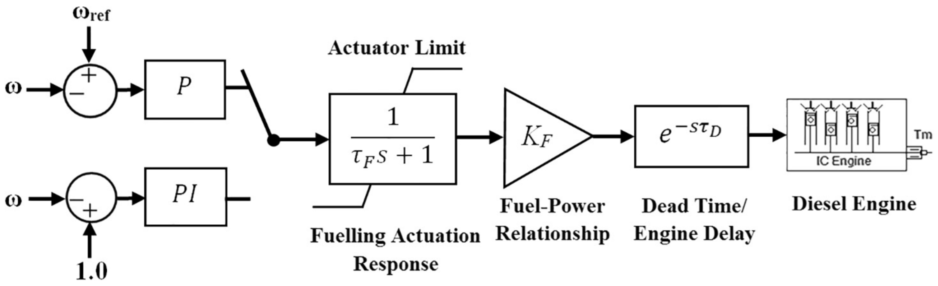

Fig. 2. Diesel engine governor model.

Load shedding priority is another critical factor affecting the transient performance of a load-rich subsystem during the islanding switching process. Load shedding priority has been extensively investigated, which can be determined by either technical or social reasons, such as voltage stability indicators [9], customers' willingness to pay [10] and the dynamically computed critical nature of the load [11]. In this paper, load shedding priority is designed based on the transient stability of different types of load during the fault-initiated islanding. IM's dynamics when experiencing a fault induced voltage dip was studied in [8,12,13]. The main emphasis of [8] was the stability of microgrids with or without IM loads. Three- and single-phase IMs were analytically evaluated in [12,13] respectively. Motor stalling phenomenon can be seen in both types of motor, which may result in delayed voltage recovery and other stability issues.

When the switching control strategy proposed in this paper is applied, real time simulations were conducted on various scenarios to validate the reliability of the strategy. The major contributions of this paper include: (1) comprehensive research into the electromagnetic transients during the islanding switching initiated by various types of fault, (2) assessment of a single-step load shedding scheme designed to ensure successful islanding switching of a load-rich subsystem containing motor loads, and (3) analysis of the other factors that might affect the system transient stability during the switching process, including the DG penetration level, the fault clearance time and the switching control delay.

Clarification of the scope of this paper is important for future researches. First, the results are specific to a subsystem consisting of a mix of synchronous and inverter-based DG. Second, the subsystem is load-rich and the maximum active power generation available from the DG units is 40–80% of the total subsystem load delivered in grid-connected mode. Third, real-time system information must be available and this requires monitoring and communication infrastructures, such as the GOOSE based system applied in a real industrial project [14]. Lastly, generator protections designed to detect the over/under frequency and voltage conditions are not considered in this paper, i.e. the DG units are assumed to be capable of riding through the abnormal conditions resulting from the fault and the subsequent islanding.

Analytical methods for power system transient assessment are highly complicated, especially for a low-inertia islanded subsystem which is vulnerable to disturbances. Therefore, in this paper, analysis and validations are achieved by repetitive time-domain simulations conducted in PSCAD/EMTDC.

2. System under study

Without considering the energy storage system, at least one conventional synchronous-machine-based DG is essential for an islanded subsystem because it is dispatchable and provides the essential inertia. Consequently, this generator can maintain the stability of the island after losing the main grid. In comparison, an inverter-based DG provides a higher degree of controllability on its output frequency, voltage and power [7], but it is normally intermittent and controlled as a current source.

Fig. 1 shows the layout of an islanding-possible distribution subsystem based on a typical British distribution network consisting of radial feeders [15], the parameters of the system are specified in Appendix A. Formation of the island is initiated by the protective tripping of circuit breaker CB1 (the point of common coupling, PCC), this isolates the subsystem from the upstream fault. The behaviour of automatic reclosers is not considered in this study.

Generation in the subsystem includes a 2 MW diesel-based synchronous DG (DSG) and a 1.5 MVA inverter-based DG (IBG). Subsystem loads consist of static loads and IM loads. A composite 1MVA drive-controlled IM and two composite 1MVA direct-online (DOL) IMs with constant torque and quadratic torque loading respectively are simulated. This paper focuses on load-rich islands, where the island generation capacity is less than the local load demand.

2.1. Diesel-based synchronous DG

The 2 MW DSG was simulated using the standard 5th order synchronous machine model available in the library of PSCAD/EMTDC.