Electric Power Systems Research 151 (2017) 273–282

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Comparison of Programmable Logic and Setting Group Methods for adaptive overcurrent protection in microgrids

Emilio C. Piesciorovsky*,[1], Noel N. Schulz[2]

Department of Electrical and Computer Engineering, College of Engineering, Kansas State University, Manhattan, KS, USA

ARTICLE INFO

Article history:
Received 6 March 2017
Received in revised form 1 May 2017
Accepted 27 May 2017

Keywords:
Relays
Real time systems
Adaptive systems
Overcurrent protection
Power distribution protection
Laboratories

ABSTRACT

Adaptive overcurrent protection systems for microgrids with distributed generators require that overcurrent relays need to be adjusted to different circuit paths and feeder fuses. Adaptive overcurrent protection systems in recent publications were based on the Setting Group method, using the functions resident in the relay. In this paper, the Programmable Logic method was developed for an adaptive overcurrent protection system, using the programmable logic and math operators instead of the functions resident in the relay. The Programmable Logic and Setting Group methods were validated using a real-time simulator with two relays in-the-loop. The selectivity, reliability and speed of the adaptive protection system based on the Programmable Logic and Setting Group (previous work) methods were compared for a microgrid with distributed generators (diesel generators). Similar results were obtained with both methods. However, the Setting Group method limited the number of overcurrent settings by the available setting groups of relays, and disabled the relays for a fixed amount of time, reducing the relay's availability. On the other side, the Programmable Logic method is recommended because it improves the capacity of relays by using one setting group, and avoids relays to be disabled because switching setting groups is not being necessary. In microgrids that require an adaptive overcurrent protection system for different circuit paths and seasonal (winter and summer) settings, adaptive overcurrent protections based on programming alternative is a better solution. This requires relay engineers to be trained in relays' programming techniques.

1. Introduction

The installation of distributed generators (DGs) to improve the reliability of power systems has changed drastically how power protection distribution systems are designed [1,2]. In microgrids with DGs, power line currents can flow in different directions depending on the selected circuit path in the microgrid, and protective relays need to be coordinated with different fuses depending on the selected circuit path. Most publications have explored adaptive overcurrent protection systems that coordinate protective relays with each other [3–11]. However, few publications reported the coordination of protective relays and fuses in adaptive protection schemes [12–14]. Protection relay systems must achieve the highest levels of speed, reliability, selectivity, simplicity and cost-efficiency [15]. Adaptive protections based on the relay's setting groups and their resident functions were used in recent publications [16–19]. These adaptive protection systems were based on the flexibility of relay setting group adjustment and the determination of optimal relay setting values [16], the on-line analysis of the actual microgrid configuration to adjust the active setting groups of the relays [17], the application of multiple allowed setting groups [18], and the selection of the optimal minimum number of relays and their settings for the relay's setting groups [19]. These reports used the Setting Group Method (SGM) which is restricted by the number of available relay setting groups [19]. The SGM limits the number of inverse time overcurrent settings for circuit paths by the available resident setting groups of relays, reduces the capacity of relays for using seasonal (winter and summer) overcurrent settings, and disables the relays during the time when setting groups are switched [14].

On the other side, the programmable scheme logic in modern multifunctional protective relays is an extremely powerful tool that allows the user to adapt the relay logic to very different applications or to change system conditions [20]. Advanced programmability allows relay engineers to implement the required characteristic

* Corresponding author.
E-mail address: emiliopiesciorovsky@hotmail.com (E.C. Piesciorovsky).
[1] Current address: Center for Energy Systems Research, Tennessee Technological University, Cookeville, TN, USA.
[2] Current address: College of Engineering, Washington State University, Pullman, WA, USA.

http://dx.doi.org/10.1016/j.epsr.2017.05.035

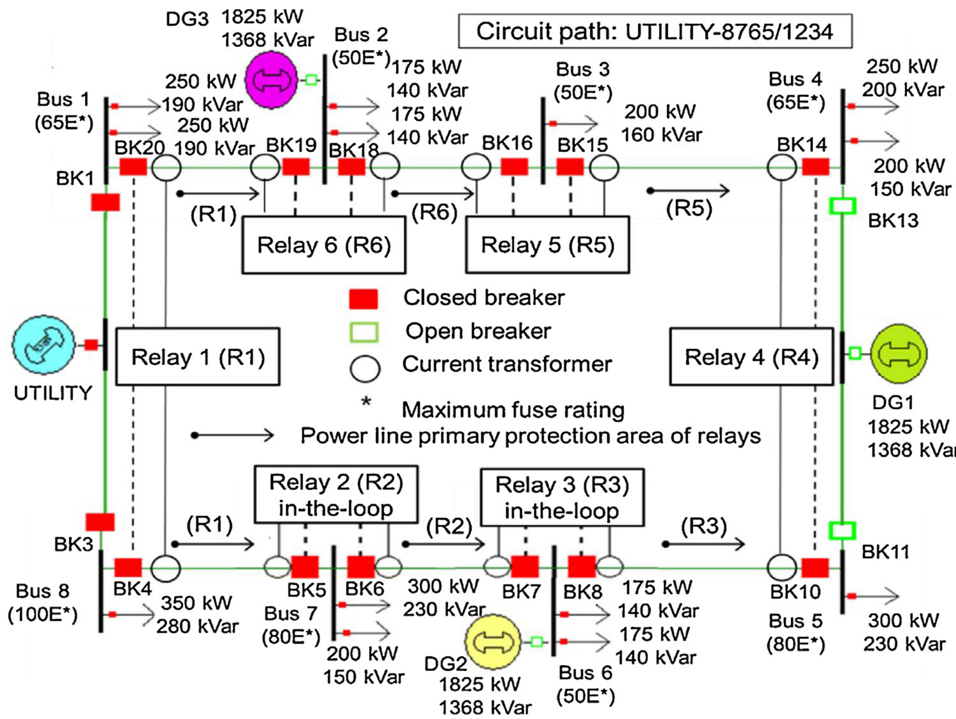

Fig. 1. Microgrid with DGs [22].

for special protection applications without using the relay's resident functions [21]. Adaptive protections could be created with the Programmable Logic Method (PLM), using the programmable logic and math operators instead of the functions resident in the relays. Then, relays would need one setting group, and would not be disabled because switching setting groups would not be necessary. Also, relays would have more available setting groups for seasonal (winter and summer) overcurrent settings, maximizing their capacity for other applications. In addition, relay settings for different circuit paths would allow more setting scenarios than the available settings groups of relays to perform adaptive overcurrent protections. In this paper, a fuse relay adaptive overcurrent protection (FRAOP) was used for a microgrid with DGs. The FRAOP achieved speed, reliability and selectivity. The FRAOP was created using the SGM and PLM, and both methods were compared, testing the adaptive overcurrent protection with a real-time simulator (RTS) and two relays in-the-loop. The application of PLM is encouraged in adaptive overcurrent protection systems to maximize the capacity of relays.

2. Microgrid and adaptive overcurrent protection

In the microgrid (Fig. 1), the line-to-line voltages of the areas were limited by the utility (115 kV), distributed transformers (7.2 kV), and generators (0.48 kV). The microgrid with distributed generators consisted of one utility source and three diesel generator units. Depending on the UTILITY source or DGs (DG1-3) that were connected to the microgrid (Fig. 1), the currents along the power lines for Relays 2 and 3 could flow in both directions, while the currents for the load branches could flow in one direction. For the circuit paths in the microgrid (Fig. 1), the circuit paths, protection areas, operational breakers, feeder fuses, and primary and backup relays could change for Relays 2 and 3, depending on the current directions along the power lines. Then, relays needed to be coordinated with different feeder fuses, depending on the circuit paths of the microgrid.

The constraints for development of the adaptive overcurrent protection are crucial to solve control problems [11]. As part of the constraints, the utility source and DGs were not allowed to be connected in parallel to avoid increasing the installation cost and complexity of the control system. In the microgrid, DGs and buses were limited by the prime power (1825 kW/1368 kVar), and voltage service (0.95–1.05 per-unit), respectively.

In Table 1, the test modes were defined as the circuit path configurations that allowed to feed the maximum load of buses with the prime power of DGs, and had bus voltages between the voltage service limits. These allowed circuit paths to be grouped into test modes that were segregated into islanding and grid connected operation configurations. In grid connected operation, the UTILITY source was connected to the microgrid. In islanding operation, the DG1, DG2, and DG3 were connected to the microgrid in case of equipment (source, power lines, and/or breakers) failure and/or maintenance operation.

Table 1 shows the allowed circuit paths (22 test modes) in the microgrid based on the prime power and bus voltage service limits of DGs. Based on adaptive overcurrent protection scenarios performed with Relays 2 and 3, the circuit paths for Relays 2 and/or 3 in bold were selected from Fig. 1 to calculate the inverse time overcurrent settings of relays.

3. Inverse-time current curves

In this adaptive overcurrent protection system, the fuse-relay and relay-relay were coordinated as backup-primary protective devices. In this study, relay curves needed to be represented into current-time plots to calculate the relay operating times, and to coordinate relays with fuses for the circuit paths in the microgrid. Therefore, the relay curves were given by Eq. (1) [22].

$$T_R = TDS \times \left(0.0963 + \frac{3.88}{(I/CTR/I_P)^2 - 1} \right) \quad (1)$$