Electrical Power and Energy Systems 105 (2019) 454–469

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A pilot-based distance protection scheme for meshed distribution systems with distributed generation

Aristotelis M. Tsimtsios[a], George N. Korres[b], Vassilis C. Nikolaidis[a,*]

[a] Department of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi 67100, Greece
[b] School of Electrical and Computer Engineering, National Technical University of Athens, Iroon Polytechniou 9, 15780 Athens, Greece

ARTICLE INFO

Keywords:
Distance protection
Distributed generation
Meshed distribution system
Pilot protection

ABSTRACT

This paper proposes a pilot-based distance protection scheme for meshed distribution systems with a high penetration of distributed generation. The proposed scheme assumes distance relays installed at the opponent ends of each main line segment. A forward distance element is enabled in each relay to protect the main line segment, while, a reverse distance element is enabled in each relay for protecting adjacent buses and laterals. The relays protecting a main line segment or a bus/lateral communicate in a permissive logic, ensuring protection sensitivity and security at the same time. The scheme provides efficient primary and backup protection against faults of any type, even with a considerable fault resistance, and under weak-infeed conditions. It is also appropriate for both the grid-connected and the islanded mode of system operation. Coordination of the distance protection scheme with the lateral protection means is also addressed. Existing numerical distance relay technology is considered, to enhance the applicability of the proposed scheme. Offline setting of the distance relays is required, which has to be performed once. Only one setting group is ultimately extracted for each relay, suitable for different fault/system conditions, avoiding the need for adaptive protection techniques. The proposed scheme is applied to a test meshed distribution system and conclusions are drawn. Comparison with directional overcurrent and differential protection shows the advantages of the designed distance-based protection scheme.

1. Introduction

The integration of distributed generation (DG) into distribution systems imposes the reconsideration of conventional overcurrent protection techniques, due to several issues encountered under the presence of DG [1]. This is further necessitated by the prospect of operating distribution networks in a looped/meshed configuration, which aims to enhance their reliability, but also to improve their voltage profile, to reduce power losses, and to increase their DG hosting capacity [2].

In order to maximize the reliability of distribution networks, which is the main purpose of looped/meshed operation, this concept requires the installation of circuit breakers, operated by relays, at both ends of each line segment, and, usually, the use of communication means to ensure protection efficiency under various conditions concerning the mode of system operation (i.e. grid-connected vs. islanded), the DG contribution and the faults occurring (e.g. fault type/position, fault resistance etc.). Although this prospect requires a considerable investment, the latter can be considered justified, taking into account the operational/maintenance benefits gained by the distribution system operators (DSOs) and DG producers [3]. In fact, such multi-relay communication-assisted protection schemes have been considered for real-world applications, even for looped distribution systems without DG [4,5], to enhance their reliability.

So far, multi-relay schemes using directional overcurrent relays have been mainly considered in the literature as a solution for looped/meshed distribution systems. Within this context, optimization algorithms are a promising tool for setting directional overcurrent relays protecting such networks [6–9]. Communication-based adaptive directional overcurrent protection is applied to deal either with DG-connection and system-configuration changes [10,11], or with the transition from the grid-connected to the islanded mode of system operation [11]. Pilot-based directional overcurrent protection schemes could also be applicable to actual looped distribution systems without DG [4,5], or to looped microgrids [12].

Alternatively, advanced differential protection schemes have been considered for protecting each line segment in looped [13] or meshed [14,15] distribution systems, while, communication-assisted multi-relay schemes, applying alternative protection principles, are also proposed for such applications [16–18].

* Corresponding author.
E-mail address: vnikolai@ee.duth.gr (V.C. Nikolaidis).

https://doi.org/10.1016/j.ijepes.2018.08.022
Received 5 April 2018; Received in revised form 19 July 2018; Accepted 18 August 2018
0142-0615/ © 2018 Elsevier Ltd. All rights reserved.

The advantages of distance relays (e.g. inherent directionality and non-direct dependency on short-circuit currents [19]) render them a promising option for modern distribution systems, although their application is still challenging [20]. So far, distance protection schemes proposed for distribution systems mainly regard radial networks.

Distance protection is applied to grid-connected radial distribution systems without DG in [21,22]. The reach of the distance zones is empirically set in these applications, which, in general, might prove unreliable if DG and various fault/system conditions are also considered.

The presence of DG renders the application of distance protection more challenging. The authors of [23] consider a distance relay for protecting a grid-connected radial feeder with DG, which coordinates with other protection means. Moreover, the underreach effect of DG infeed is dealt with through an overreaching distance zone. However, the resistive reach of the distance zones is set based on a rule of thumb, so, the actual effect of fault resistance is not taken into account. Distance-relaying applications for grid-connected radial feeders with DG are also examined by the authors as part of [24,25]. Multiple distance zones are applied, which are suitably extended to address the DG infeed effect, while, coordination with lateral fuses is addressed. Nevertheless, similarly to the abovementioned paper, the effect of fault resistance is still empirically considered. In [26], distance relays are intended to replace the undervoltage relays of DG units and some of the feeder overcurrent relays, in a grid-connected radial feeder. The issue of distance relay coordination with lateral protection is also mentioned. However, the performance of the distance relays is adversely affected by infeed/outfeed currents and fault resistance. Distance protection is applied to radial feeders with DG, as part of [27,28]. Mho-based distance elements are used, which are empirically set, taking into account the infeed constants. Fault resistance effect is not actually dealt with, while, coordination with lateral protection is also not considered. In [29], an adaptive distance protection scheme is applied to a grid-connected radial feeder with DG. Only solid phase faults are considered, while, coordination with lateral protection is not addressed in this work either.

Alternative techniques have also been proposed, intending to deal with the effect of DG infeed and/or fault resistance. In [30], a distance protection scheme, applied to a grid-connected/islanded radial feeder, is proposed, where the DG infeed effect is compensated by calculating the infeed error term through current measurements. However, this compensation would not be directly applicable under the effect of fault resistance, which is not taken into account in this work. In addition, coordination of the distance relays with lateral protection means is not addressed. A measurement-based infeed-current compensation methodology is also used in [31]; however, fault resistance is not dealt with in this case as well. Coordination of backup main line distance protection with primary main line overcurrent protection is also addressed, although the latter does not hold for coordination with lateral protection. In [32], the distance relays protecting a grid-connected radial feeder against single-line-ground faults are set through an optimization algorithm, considering a specific range of fault resistance values. Nevertheless, the efficiency of this algorithm can be limited due to system changes and/or under the presence of DG, while, coordination with common lateral protection means is not taken into account. A promising distance-based approach for a grid-connected radial distribution network with DG is presented in [33]. This approach is fault-location-oriented, aiming to compensate for impedance calculation errors due to DG infeed and fault resistance. Communication means and multi-point measurements are required for this purpose. However, the accuracy of this methodology can be limited when load and fault resistance are high, while, the methodology is not applicable against single-line-ground faults (i.e. the most frequent faults).

Despite the fact that pilot-based distance protection has been traditionally applied to transmission systems [34], its proper application/adaptation to modern distribution systems could be considered for addressing several of the aforementioned issues. A pilot-based distance protection scheme for a grid-connected/islanded microgrid is proposed in [35,36], which is, however, applicable only to a radial configuration. Moreover, specific guidelines for setting the impedance characteristics used against various fault/system conditions are not given. Faults with a considerable resistance are not simulated, thus, the effect of fault resistance is not actually dealt with. Coordination of the distance relays with other protection means encountered in distribution systems (e.g. fuses) is also not addressed. A permissive underreaching transfer trip (PUTT) logic is applied as part of [37], but only for the sake of accelerating the operation of one of the two distance relays protecting a line segment in a radial microgrid, on condition that this relay has already detected the fault inside its second distance zone. Multiple setting groups are stored for protection against various system conditions (adaptive logic), while, Mho-based distance zones are used, whose settings are extracted based on a rule of thumb. The latter might prove unreliable for various resistive faults. Moreover, the scheme is tested only for low-resistance three-phase faults, while, coordination with lateral protection means is not addressed.

Another concept considering a distance relay as a protection element in a grid-connected, radial distribution network has been recently proposed in [38]. However, in this work, the distance relay is only examined as the interconnection relay of a wind farm, while, the authors investigate the effect of wind power intermittency on the relay's performance, solely in terms of polarization using the pre-fault voltage. Other impedance-based protection schemes for radial distribution feeders with DG have also been proposed, as part of a differential [39,40] and an inverse-time-impedance [39] protection principle though; hence, actual/common distance protection is not examined in these papers.

The advantages of distance protection could become more prominent in looped/meshed distribution networks with DG, although their consideration for actual applications might still prove problematic [41]. Despite the significant issues to be addressed in this direction, relevant research efforts are limited. In [35], a central distance-based protection scheme is considered for an islanded, ring-type microgrid; however, the issues mentioned previously for the radial application of the same work hold in this case as well. Distance protection is considered for a grid-connected ring-type network in [42], although intermediate DG infeed is not taken into account. Coordination with lateral protection means is also not addressed. In [43] and [44], distance protection is, respectively, applied to a meshed and a looped distribution system with DG, using multiple setting groups (adaptive logic) against different system conditions. Fault resistance effect and coordination with lateral protection means are not addressed in these papers. A preliminary attempt by the authors to apply distance protection to a looped distribution network with DG is also included in [25].

As part of [45,46], the authors also analyze the considerable effect of zero-sequence compensation, DG infeed and fault resistance specifically on distance relays protecting distribution systems. These factors might lead to severe impedance calculation errors, compromising protection dependability and security if their concurrent effect is not properly considered during relay setting. However, the latter has not been sufficiently addressed in the literature so far. Note that, although [45,46] refer to radial feeders, the aforementioned influencing factors must be considered for setting distance relays in looped/meshed distribution networks as well.

In this work, a distance-based protection scheme for meshed distribution systems with DG is developed, intending to address all the aforementioned issues encountered in the literature, concerning the application of distance protection to distribution systems. For the sake of enhancing the applicability of the proposed solution, existing distance relay technology (i.e. tested by vendors in real-world applications) is exploited, which is, however, properly adapted to the needs of the present application. The designed distance scheme is suitably set to provide efficient protection against solid and non-solid (with a

Download English Version:

https://daneshyari.com/en/article/9952127

Download Persian Version:

https://daneshyari.com/article/9952127

Daneshyari.com