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Islanding protection of active distribution networks with renewable distributed generators: A comprehensive survey

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ABSTRACT

Anti-islanding protection schemes currently enforce the renewable distributed generators (RDGs) to disconnect immediately and stop generation for grid faults through loss of grid (LOG) protection system. This greatly reduces the benefits of RDG deployment. For preventing disconnection of RDGs during LOG, several islanding operation, control and protection schemes are being developed. Their main objectives are to detect LOG and disconnect the RDGs from the utility. This allows the RDGs to operate as power islands suitable for maintaining uninterruptible power supply to critical loads. A major challenge for the islanding operation and control schemes is the protection coordination of distribution systems with bi-directional flows of fault current. This is unlike the conventional overcurrent protection for radial systems with unidirectional flow of fault current. This paper presents a comprehensive survey of various islanding protection schemes that are being developed, tested and validated through extensive research activities across the globe. The present trends of research in islanding operation of RDGs are also detailed in this paper.

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1. Introduction

With growing power demand and increasing concern about the use of fossil fuels in conventional power plants, the new paradigm of distributed generation is gaining greater commercial and technical importance across the globe. Renewable distributed generation involves the interconnection of small-scale, on-site distributed energy resources (DERs) with the main power utility at distribution voltage level [1]. DERs mainly constitute non-conventional and renewable energy sources like solar PV, wind turbines, fuel cells, small-scale hydro, tidal and wave generators, micro-turbines, combined heat power (CHP) systems, etc. These generation technologies are being preferred for their high energy efficiency (micro-turbine or fuel cell based CHP systems), low environmental impact (PV, wind, hydro, etc.) and their applicability as uninterruptible power suppliers to power quality sensitive loads. Electric energy market reforms and developments in electronics and communication technology are currently enabling the control of geographically distributed DERs through advanced supervisory control and data acquisition (SCADA) [2]. Lasseter and Paigi [3] have discussed how interconnected DERs can be operated as microgrids both in grid-connected mode and islanded mode.

High degree of penetration of RDGs (more than 20%) as well as DER placement and DER capacity have considerable impact on operation, control, protection and reliability of the existing power utility [3–5]. These issues must be critically assessed and resolved before allowing the market participation of RDGs. This is necessary for utilising full distributed generation potential for generation augmentation, for enhancing power quality and reliability and providing auxiliary services such as active reserve, load-following, interruptible loads, reactive reserve, restoration, etc. [6].

The area that is critically affected by distributed generator (DG) penetration is protection coordination of the utility distribution system. Conventional overcurrent protection is designed for radial distribution systems with unidirectional flow of fault current. However, connection of DGs into distribution networks convert the singly fed radial networks to complicated ones with multiple sources. This changes the flow of fault currents from unidirectional to bi-directional ones [7]. Besides, the steady state and dynamic behaviour of the DGs also affect the transmission system operation [8]. Various impacts of DG connection on existing utility network protection are listed below:

i) false tripping of feeders,
ii) nuisance tripping of protective devices,
iii) blinding of protection,
iv) increase or decrease of fault levels with connection and disconnection of DERs,

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v) unwanted islanding,
vi) prevention of automatic reclosing,
vii) out-of-synchronism reclosure.

Currently, available technical recommendations, viz., G83/1, G59/1, G75, ETR-113/1, IEEE-1547, CEI 11-20 prescribe that DGs should be automatically disconnected from the MV and LV utility distribution networks in case of tripping of the circuit breaker (CB) supplying the feeder connected to the DG. This is known as the anti-islanding feature in power distribution system protection scheme. This is incorporated as a mandatory feature in the inverter interfaces for DGs available in the market. As the DGs are not under direct utility control, use of anti-islanding protection is justified by the operational requirements of the utilities [9]. Anti-islanding protection systems are mainly used to ensure personnel safety at the grid end and to prevent any out-of-synchronism reclosure.

However, with greater DG penetration, automatic disconnection of DGs for loss of grid (LOG) situation drastically reduces the expected benefits of DGs in (i) maintaining power quality and reliability, (ii) enhancing system security and (iii) providing several ancillary services. It also leads to unnecessary loss of DG power in the event of utility fault [8,9]. Besides, the islanding detection and anti-islanding protection systems tend to increase the complexity of protection system. For better utilization of DG benefits, the idea of keeping the DERs connected during system disturbances and islanding operation and protection of DGs [9–11] are being debated upon by researchers across the globe. Various low-cost and efficient digital islanding protection schemes are being developed, tested and validated through extensive research activities [12,17]. Fast and efficient microprocessor-based islanding protection systems are suitable for operation of the active distribution networks both in stand-alone and grid-connected modes. They can also ensure seamless operation of the inter-tie CBs for reconnection of the islanded zones without affecting original protection coordination of the utility grid [13]. Improved islanding protection systems are also being developed for hybrid renewable energy power systems. These schemes efficiently combine the passive (under/over voltage, under/over frequency) and active (Sandia frequency shift (SFS) and Sandia voltage shift (SVS)) protection methods [14]. Digital protection schemes are also being designed and tested for meshed distribution systems with high penetration of DGs [10].

This paper presents a comprehensive survey of various islanding protection schemes that are being developed, tested and validated through extensive research activities across the globe. It also provides a critical assessment of current DG interconnection practice with the possibility of islanding operation and reclosure.

2. Loss of grid protection

2.1. Objective and requirements

The main objective of LOG protection is to detect the condition where the DGs are left connected to a portion of the utility's load network with no main source of utility power. This is commonly known as LOG phenomenon. This may occur following a system switching operation caused by fault clearance, scheduled and unscheduled load shedding, maintenance outages and/or equipment failure. The main objective of LOG protection is to detect and disconnect the inter-tie CB between the DG units and the utility network after any LOG occurrence. It is necessary to (i) enable an uncomplicated restoration of utility supply and (ii) avoid any out-of-synchronism reconnection of the two systems that may cause severe damage to the utility grid and the DG units [15]. The typical requirements for this protection are as follows:

1) It should operate within half a second following the isolation of the power island, but faster relaying is attractive.
2) The DG units should maintain the system's voltage and frequency within specified limits.
3) It should prevent any out-of-synchronism reclosure.

The LOG detection schemes usually used are as follows:

a) For DGs less than 250 kVA:
For small DGs, LOG is either detected by a reverse power relay that monitors the power flow in the inter-tie circuit or through under voltage and under frequency relays. LOG usually causes severe overloading of the DG unit, causing its output voltage and frequency to fall. In that case, under voltage and under frequency relays will operate and automatically disconnect the DG unit from utility loads.

b) For DGs more than and equal to 250 kVA:
Larger DGs are usually fitted with high-speed automatic voltage regulators. Therefore, their generation may be able to maintain the voltage and frequency at the load bus within specified limits following LOG. Thus, for such DGs, specialised relaying will be needed to detect LOG and trip the inter-tie breaker.

2.2. Techniques of LOG detection

The direct method for LOG protection is to monitor auxiliary contacts on all CBs on the utility system between its main generation source and the DG units. When a switching operation produces LOG, a transfer trip scheme can be used to open the inter-tie CB between the two systems. The DG units can then be resynchronised to the utility and reconnected after successful restoration of the utility supply. But when several CBs are involved in creating the LOG condition, then the transfer trip scheme can only be managed through an extensive SCADA system and network automation. Reclosure of the utility supply onto a DG unit can be avoided by using dead circuit pick-up supervision on utility CBs. These would stop the utility CB breaker from closing until the load-side circuit is de-energised and would initiate a transfer trip to open the inter-tie CB between the DG and the utility.

LOG techniques have been classified as active and passive techniques. Active techniques directly interact with the on-going power system operation, namely (i) reactive power export error detection and (ii) system fault level monitoring. Passive techniques detect LOG solely by monitoring the change in power system's behaviour following such occurrence, namely (iii) under/over voltage and under/over frequency, (iv) rate of change of frequency (ROCOF), (v) phase displacement monitoring, (vi) rate of change of generator power output and (vii) comparison of ROCOF (COROCOF). Some other techniques are (viii) intertripping, (ix) fault thrower and (x) neutral voltage displacement (NVD).

2.3. Active techniques

2.3.1. Reactive power export error detection

The reactive power export error detection relay interfaces with the DG control system to force it to generate a level of reactive power flow in the inter-tie between the DG and the utility. This level can only be maintained when the utility generation remains connected. Relay operation is triggered only when there is an error between the setting and the actual reactive power being exported for a time period greater than the set value. In order to avoid any spurious operation, the time setting is chosen to be greater than the duration of probable supply fluctuations. With operating times from 2 to 5 s, this is a comparatively slow protection and is frequently used as backup to other faster protections. Nevertheless, this approach can detect LOG even when there is no change in the generator loading

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