Renewable and Sustainable Energy Reviews 16 (2012) 4385–4395

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

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

State-of-the-art in the industrial implementation of protective relay functions, communication mechanism and synchronized phasor capabilities for electric power systems protection

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ARTICLE INFO

Article history:
Received 30 August 2011
Received in revised form
23 April 2012
Accepted 28 April 2012
Available online 20 June 2012

Keywords:
Protective relaying
Communication mediums
Communication protocols
Synchrophasor
Communication delays

ABSTRACT

Protective systems in electricity delivery networks have a major role to play in the increasing of renewable energy systems, and a broad understanding of their current a future application can aid into better taking them into account for achieving future energy networks that adapt for the incorporation of renewable energy generation sources. This paper provides a survey in the state of the art of protective relaying technology and its associated communications technology used in today's power transmission systems. The paper also provides the fundamental knowledge concerned with power system relaying communications. The unifying theme of this paper is to highlight that the future potential of these devices lies in realizing the possibility of going beyond their traditional application as stand-alone equipments with the single role of acting "the last line of defense" so that they can be handled with the increment of renewable energy power delivery systems in near future.

Contents

1. Introduction

Protective relays are usually expected not to operate during normal operating conditions, but must immediately respond to handle intolerable disturbances in power networks. This immediate availability criterion is necessary to avoid serious outages and damages to parts of or the entire power network, and more importantly, to ensure the safety of personnel. Ideally, a protective relay system should be capable of responding to an infinite number of abnormalities that may occur in the power grid. However, in practice, some compromises must be made by comparing risks. It is quite difficult to ensure stability and security of the entire power system if only local measurements are employed in monitoring, protection and control schemes. In this context, the operation of protective relays is of importance to the avoidance of blackouts. Most blackouts are triggered by random events ranging from single to multiple equipment failures. More importantly, cascading phenomena are one of the principal contributors to the blackouts. In most cases of cascading phenomena, the protection systems, specifically relays, contribute to a substantial proportion of blackouts [1,2] since they are capable of inducing domino-effect component disconnecting.

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http://dx.doi.org/10.1016/j.rser.2012.04.043

One promising way is to develop system wide protection and control mechanisms, complementary to the conventional local and zonal protection strategies, using synchronized phasor measurements (PMUs) and wide-area monitoring, protection and control systems (WAMPAC). In order to implement such mechanisms, synchronized phasor measurement may serve as an effective data source from which critical information about the system's condition can be extracted. Synchronized phasor measurement capabilities are now one of the features available in the most advanced protective relays commercially available, and the use of this feature is proliferating. Indeed, early applications of this technology for the synchronization of distributed generation to large power grids [3] and for islanding management [4] show a promising opportunity for the use of this technology in the combination of traditional protective devices for the integration of distributed renewable sources of energy [5,6].

Protective systems in electricity delivery networks have a major role to play in the development of renewable and sustainable energy systems, and a broad understanding of their current a future application can aid into better taking them into account to corporate with increasing of renewable energy generation sources. To this aim, this paper provides a survey in the state of the art of protective relaying technology and its associated communications technology used in today's power transmission systems. The paper summarizes the operating principles of relay applications, the available measurements used by relays and the protection schemes for various faults that occur frequently in power system. This aids readers to become familiar with the principles used by most common protective relays. Moreover, a review and comparison between different relay manufacturers is also provided to highlight the industrial state-of-the art in this field. The paper also provides the fundamental knowledge concerned with power system relaying communications. The various protocols and network topologies used for protective relaying purposes are explained. Associated communication standards are outlined in order to create a background on the communication technologies used by protection systems. The aims of this paper are the following:

- To briefly describe the impact of renewable energy sources on protection systems, and new required functions in protective relays needed to cope with these energy sources.
- To give readers a comprehensive overview of the state-of-the-art in the implementation of protective functions available in today's relays.
- To provide a general summary of fundamental concepts used for traditional power system protection.
- To give a comprehensive and detailed overview of the communication mechanisms used for power system relaying.

The unifying theme of this paper tries to highlight that the future potential of these devices lies in the possibility of going beyond the common view which catalogs them as stand-alone equipments with the single role of protection which should act as "the last line of defense". Instead, it should be realized that they play in a vital role in improving the system awareness, improving system stability and security as shown in [7,8]. For example, the combination of protective functions and synchronized phasors in protective relays could aid in coordinating better with power system controllers to mitigate outages [9], and to enable the smooth integration of distributed renewable sources of energy [5]. To this end the authors have chosen to emphasize the aspects of the communication mechanisms used for protective relaying, and the requirements that they should meet.

The remainder of this paper is organized as follows. Section 2 describes the impact of renewable energy sources affecting protection systems. Section 3 provides the comparison of relay characteristics between different vendors are surveyed. Section 4 summarizes common communication mediums and network topologies. In Section 5, different communication protocols are summarized and communication delays are also discussed in this section. In Section 6 conclusions are drawn.

2. Impact of renewable energy on protection systems

The growth of renewable energy integration has increased gradually in the last decade seeking to replace conventional generation methods. We can categorize the connection between renewable energy sources and main power systems into two types; which are remote and local connections. Renewable energy sources are located far away from the load-centers require an investment in new overhead lines and significant extension of the existing main grid. A good example of required transmission lines installation is the "Three Gorges dam" hydro power plant in China which transmit power across the country. There are many research works that have been carried on for improving grid integration for this type of connection such as for wind turbines [10,11] or photovoltic [12,13] connection. Meanwhile, the second type of connection is where renewable energy plants are installed locally, allowing local consumers to generate electricity for their own. This connection type grows rapidly, especially in distribution networks due to no long-distance transmission lines requirements. In other words, having renewable sources close to the load location reduce transmission losses and preventing network congestions.

In spite of many economic and technical advantages, high penetration of them would cause some negative impacts on distribution network operation. That is because the distribution system are usually designed and operated assuming one direction along feeders. Once a set of protective devices has been coordinated under this paradigm, reversing or allowing multi-directional power flow in some particular operations according to the infeed from renewable energy resources can cause a serious protective device maloperations. This problem has occurred in many countries, for example in Germany [14], UK [15], and South Korea [16]. This implies that and increasing amount of renewable energy resources (with intermitted energy productions) requires a larger focus on the operational planning and the actual on-line operation of power networks due to: increased need for balancing of production and demand, more adequate monitoring, more need for reserves, storage capability, etc. In addition, more challenges brought by the impact of distributed resources on distribution relay protection are summarized by IEEE-Power System Relay Committee, which can be found in [17].

In order to solve undesirable consequences (regarding integration of renewable sources) on protection systems, new functions are required in protective relays when compared to traditional devices. These functions would allow relays to change predefined-settings to ensure that the entire power system is protected at all times. Technical requirements for new protection system paradigms consist of [18]:

- Relays that satisfy the selectivity requirement. This is because the current time-graded protection schemes used at MV and LV networks are inapplicable to handle bidirectional flows.
- Relays which allow using programmable/or different tripping characteristics that can be parameterized remotely or locally, either automatically or manually.
- Using new/existing communication infrastructures and/or standard communication protocols (for example, IEC 61850 or ModBus) that allows individual relays to exchange information