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The Evolution of Power System Protection: From Conventional to Smart Grid Protection

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Abstract
Over time, there have been multiple changes to the power system that we currently use. These modifications result from either the development of science and technology or shifts in the needs of the clients. The "Smart Grid" is the name given to our current picture of the electrical power grid of the future. Numerous functional and operational features of this power system are intended to address the problems with cost, generation shortfall, and dependability in the power system. The majority of power systems worldwide continue to function as conventional power systems, with one-way power flow and one-way communication. The principles and protection plans of the electricity system are affected by the switch to a smart grid (SG), since the SG will include distributed generation (DG) units and other

Keywords- -power system; protection; smart grid; transitioning; schemes; distributed generation.

I. INTRODUCTION

The power system faces numerous obstacles as a result of consumer expectations for a highly reliable supply of electricity, laws governing the effects of electricity generation on the among many other things, the environment. To address these issues, a smart power system is envisaged, one that functions with intelligence, adaptability, and high dependability while having minimal environmental impact. In order to do these and make the protection system compatible with the future power grid, a significant overhaul is required. The smart grid, which combines communication and information technology advancements with the electricity system, has a number of functions. In order for these qualities to materialize and reach their maximum potential, the various elements of intelligent management, intelligent protection, and intelligent infrastructure systems. The conventional defense mechanism is predicated on high-level fault current of the system, however DG units and Micro-grids in the smart grid lower this high-level fault current [2], [3]. Furthermore, the bidirectional power flow in the Smart Grid (SG) system due to DG units and Micro-grids necessitates the development of new protection schemes and systems for the SG to operate effectively and dependably. The stability and dependability of the measurement system employed for the protection system determine how effective a protection strategy in an SG is.

A Wide Area Measurement System (WAMS) that uses Phase Measurement Units (PMUs) to provide time-synchronized phasor measurements for the Global Positioning System (GPS) Research has focused a lot of attention on measures for smart grid safety, control, and monitoring. Many academics have developed various strategies for leveraging WAMS to improve the smart grid's security framework. According to research, because of low-speed connection that cannot improve the quick protection required for primary protection, interregional protection based on WAMS can only be viable for backup protection [4]. The introduction of the fifth generation mobile network (5G) is a result of advancements in communication technology. It offers Ultra-High Reliable Low Latency Communication (URLLC). This technology of communication has the power to change This paper's primary contribution is knowledge on the creation of new protection plans to meet the gaps in protection at various phases of power system developments. An overview of pertinent works for each approach has been provided to aid the researcher in comprehending the ideas of protection. The study also outlines the security needs for a smart grid by referencing the various transitional phases of the security system. The paper is structured as follows: Section II compares and contrasts the traditional grid with the smart grid that is envisioned; Section III examines the evolution of traditional protection to the present day power system protection; Section IV outlines the requirements and state of the art for the smart grid protection; and Section V offers recommendations.

II. The Smart Grid vs. The Conventional

The power system, often known as the "conventional grid" or "traditional grid," is made up of the distribution, transmission, and generating systems. The location of the power producing facility, which is often a thermal or hydroelectric plant, is typically far from the customers. As a result, the primary substation transformers convert the generated power's voltage into a high voltage, which is then transferred over a considerable distance to secondary substations where it is stepped down and dispersed throughout the consumer region [1]. The overall cycle that occurs for power to go from the place of generation to the consumer is detailed in the narrative above. Information and electricity flow in a single direction. Customers are not involved in choosing when to make decisions. The smart grid, on the other hand, has been characterized in a variety of ways. It is also referred to as the 21st century power system or the future power grid. The terms are either stemmed or from the operation or capacity of the smart grid. The idea of the smart grid is summed up by the term "smart grid," which is described as the fusion of power system and information technologies to provide dependable, safe, secure, and reasonably priced electricity delivery [1], [7]. In other words, the smart grid is a power system that is intended to use and analyze a lot of data, and that data will be transferred between devices and control centers via various media. The ability for customers to install renewable energy sources means that power and information will travel both ways.

III. Systems of protection and their evaporations

Because of its complexity and vulnerability to a range of disruptions, including natural disasters and fluctuations in consumer demands, the electricity system is where Protection is used to identify any anomaly, react to it, and, in the event of a temporary problem, restore the power system to its operational state. In power system protection engineering, the relay—which uses relaying principles or schemes to identify anomalies—is a crucial component of the protection system. Electro-mechanical relays were the first type of protective relays to be created. These relays were converted from electro-mechanical to semi-conductor relays as science and technology developed [8]. Semiconductor relays were followed by integrated circuit relays and, currently in use, microprocessor-based relays. Relays' performance is only affected by technological advancements in terms of security, dependability, speed, selectivity, etc., but the underlying Even now, concepts that were created a century ago are still in use. These ideas encompass differential, directional, overcurrent, and distance relaying. On the basis of these ideas, various systems and algorithms have been devised.

3.1 Finding, Identifying, Categorizing, and Positioning Faults

Over time, protection system research has changed in an effort to keep up with the demands of the complicated power system, which is always expanding and changing. Previous efforts on the Protection schemes employed the ideas of relaying with other scientific techniques like fuzzy logic, wavelets, etc. to achieve their goals. These schemes were designed to identify, locate, categorize, and discriminate defects when they occurred. A defect on line AB needs to be identified from a problem on CD, as Fig. 1 illustrates. Three line-current measurements are used in Das et al.'s [9] proposed fuzzy logic-based fault classification system to complete the classification in less than half a cycle. The similar fuzzy logic method was used in earlier studies by [10], [11] for fault categorization and identification. The creations of Using wavelets in conjunction with a fuzzy logic system, [12]'s work detected and recognized defects on transmission lines with series capacitor compensation. Understanding the kinds of fault is crucial to relay setting and, consequently, to the protection system operating more effectively. A series compensated transmission line fault location algorithm using PMUs was proposed in [13]. After testing, this algorithm produced results with 99.95% accuracy. To estimate the location of faults along a transmission line, reference [14] provided three distinct algorithms: travelling wave, impedance based, and a wavelet and artificial intelligence combination. Systems for identifying single-line failures in a delta-delta connected distribution system were presented in the publications [15] and [16]. High impedance faults and delta-delta coupled distribution systems are known to occur.

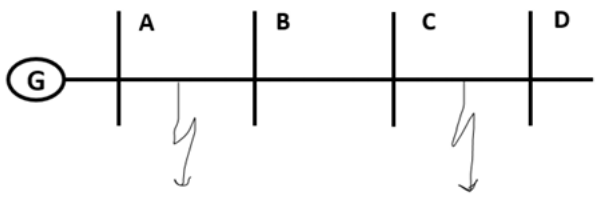

Figure 1. Fault on different points of the power system.

A system for defect detection in an urban, networked distribution system was proposed by Teo [17]. The purpose of this study was to address the issue of failure detection in a ring or networked distribution system under the given circumstance where the overcurrent backup protection kicks in and causes a widespread blackout when the primary protection fails. Additionally, [18] created a system with support vector machine (SVM) in conjunction with a fuzzy classifier to locate and categorize faults. This approach is based on the notion that real and reactive (PQ) power changes in both magnitude and direction when a power system malfunction occurs. A wavelet multi-resolution method was used in [19] to locate and identify faults in radial distribution systems. The method is implemented by the system using the current measurement that is available at the substation.

3.2 Power System Protection Integrated

Numerous methods for fault detection, location, and identification were developed concurrently with the development of the power system. Power engineers identified two key protection system malfunctions, specifically "unwanted tripping" and "failure to operate." Large-scale blackouts are caused by cascade tripping, which is the result of these two protection flaws. In order to address this issue, researchers developed integrated protection, which means that intersubstation or regional area settings are taken into account by the protection system or algorithm instead of just a local area setting. The authors of [20] created an integrated defense system using fuzzy inference principles. Three expert systems make up the system: the expert system for hybrid diagnostics, Expert systems for transmission network diagnosis and substation diagnosis are available. When there is a substation defect and a blackout that affects more than one substation, the hybrid diagnosis expert system is utilized for diagnosis. For the purpose of diagnosing faults in the transmission network and the substation, respectively, expert systems are employed. An integrated protection system for the shipboard power transmission network based on current differential fault detection and quick reconfigurations was presented by Yafeng et al. in their study [21]. Their system is capable of handling the reconfiguration of the shipboard power system and offers fast fault detection.

3.3 Adaptive Power System Protection

The constant alteration of the network topology in the power system made adaptive protection imperative. Because of the power's unpredictable nature various renewable energy generation Since the majority of them are weather-dependent, adding them to the power system grid as DG units necessitates that the protection system not be predicated on certain parameters. Therefore, accurate protection from a protection system that can adjust to the power system's present state is needed. An adaptive multiagent protection relay coordination method was presented by Hui et al. [22]. In order to achieve adaptive coordination, this strategy makes use of agent communication. An agent is made up of relays, DG units, and equipment agents. This agent-based relay coordination offers a self-correcting and self-checking feature. enhance its performance and increase its suitability for a complicated system. An adaptive voltage protection technique based on wide area information was proposed by Wang et al. in [23]. This It includes backup protection that relies on wide area information and primary protection that solely depends on local information with no communication lag. For a power system with distributed generation, the authors of [24] proposed an adaptive protection for backup and main protection. A transmission line adaptive current differential protection plan was introduced in [25]. Using the extended equal area criterion, Ariff et al. [26] suggested an adaptive out-of-step protection for generators.

3.4 Protecting the Power System Widely

The power system grid is meeting our needs as we integrate new technologies and methods of power generation into it, but it's also growing increasingly complicated and challenging to manage with protection and control systems. The current complexity of the electricity system presents a problem for the utility business in the form of a rapidly developing system-wide disruption. Since the 2003 Northeast American blackout, researchers have focused on ways to reduce cascading failure in the electrical system, which might cause a wide-spread blackout. The primary source of wide area data is synchronized phasor measurements from PMUs positioned at different buses across the power system [27]. When we look into the origins and characteristics of power outages, backup protection in power systems is a critical component that can be evaluated. significant disruptions to the system. Traditional backup protection systems are self-contained and reliant on local data, which makes it challenging for the protection system to discern between excessive loads and internal faults. As a result, under extreme stress, the system may malfunction [28]. It was suggested in [29] to use fault steady state components for a wide area backup protection and to construct a fault detection algorithm. The algorithm functions by creating a region of protection correlation (PCR) If a fault arises while the power system is operating normally, the algorithm finds the PCR where the fault happened, and then it calculates the fault correlation factor to find the branch that is malfunctioning. A wide area backup protection plan for transmission grids was presented by Eissa et al. [30]. The plan obtains positive sequence voltages and currents at the buses using phasor measurement units, compares these values to identify the bus closest to the fault, and then computes the absolute difference of the positive sequence current angles for all connected lines. A wide area backup protection strategy based on fault component voltage distribution was proposed by Zhiqin et al. in their article [31]. There are two components to the scheme: Fault the identification of fault elements (FEI) and area detection (FAD). Only the substation with the FAD transmits data to the regional wide area backup protection system once the faulty area has been identified.

Table.1 DEVELOPMENT OF RESEARCH IN POWER SYSTEM PROTECTION

Protection system research stage	Power development system	Identified protection inadequacies
Fault detection, location, identification and classification	Addition power of technologies new system and increased complexity in the power system	Failure of protection methods in individual protection equipment
Integrated Protection	Addition of DG units to the power system	Failure to protect in all conditions due to varying N/W topology
Adaptive Protection	Smart grid development	Cascading failure
Wide protection area	Under research	Under research

Using phasor data, Neyestanaki et al. [32] suggested an adaptive wide area backup protection system for transmission lines. The plan separates the electricity grid into backup protection zones (BPZs) that may adjust to the conditions of the power system depending on the positioning of the phasor measurement units and the network topology. Zare et al. made an effort to address the communication latency limitation related to broad area backup protection in article [33]. The plan put a lot of effort into regionalizing the power system so that each region could use the created algorithm to lower the computing load. Protection control center locations, the quantity and arrangement of protective zones, the number of measuring devices (MDs), and the communication channels connecting the MDs of were subjected to integer linear programming (ILG) optimization. A large area backup protection plan for series compensated transmission lines was presented by Jena et al. [34] utilizing units of phasor measurement. The plan makes use of the phase angle of the positive-sequence integrated angle (PAPSII), which is tracked constantly at the Phasor Data Concentrator (PDC) for every line.

IV.DUTIES FOR SMART GRID PROTECTION

Given that electricity generation will fluctuate constantly, the protection system requirements for the future smart grid will be difficult. the network topology as a result of DG units being integrated into the power grid. DG units are supposed to boost power supply efficiency and dependability as a component of the smart grid. However, because of their capacity to dynamically alter the fault current level, their existence presents a threat to the power system protection system. This necessitates the need for a protection system with self-healing capabilities that can adjust to the constantly changing network and is resilient to both system disruptions and natural disasters. The authors of [35] introduced a novel approach to distance protection that addresses In their work on smart grid protection, Chandrarante et al. [37] also examined self-healing capability by taking into account three distinct protection scheme types: overcurrent protection, protection against directional overcurrent and transformer damage. In order to accomplish the goal of adaptability and self-healing capabilities, the smart power system needs to be outfitted with advanced sensors, measuring tools, and quick communication technologies to gather system data and facilitate communication between control centers and protective devices. A smart protection system uses a variety of measuring equipment, including PMUs and Intelligent Electronic equipment (IEDs).

Conclusion

Power system protection evolved together with the power system over time to keep up with the advancements in the power system. These the protection methods utilized for the power system relaying underwent the most alterations. The different stages of power system protection that fall between fault finding, identification, and classification and integrated, adaptive, and wide area protection have all been covered in this work. It was shown what kind of protection a smart grid needed. It will be very advantageous to use 5G technology to create a wide area protection plan for the power system's primary protection in order to address communication delays and reliability problems in protection systems.

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