Impact of Distributed Generation on Protective Coordination of Electrical Distribution System: A Review

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Abstract

With growing global concerns about environmental impacts and the need to accommodate load growth, distribution power operators are increasingly focusing on integrating Distributed Generation (DG) into their systems. However, the integration of DG alters the power flow configuration from a unidirectional to a multidirectional system. As a result, it is crucial to assess the margin required to maintain proper protection coordination when incorporating DG into a power system. Achieving this requires careful placement of protection devices and effective coordination between relays. This study reviews existing research on the impact of DG integration on the coordination of protective devices in power system protection.

Keywords: *Distributed Generation, Protection Relay, Protection Coordination, Load Growth, Distribution System.*

1. INTRODUCTION

The protection system is a crucial component of any power network, designed to detect and isolate faults when they occur. Typically, distribution systems are configured in a radial design, where power flows from the source to the connected customers [1, 2].These systems include protection devices such as fuses, reclosers, relays, and circuit breakers, which are relatively simple in design. These devices are coordinated to interrupt the unidirectional flow of fault currents from the source toward the fault point [3. 4].

In response to the growing demand for electricity, distribution system operators are increasingly focusing on incorporating Distributed Generation (DG) into their networks to accommodate load growth from customers [3-9[. DG refers to electric generators located close to the point of use, capable of supplying power directly to local customers or being interconnected with utility grids. DG technologies are broadly categorized into two types: renewable technologies (such as photovoltaic and wind turbines) and non-renewable technologies (such as combustion turbines and fuel cells) [10]. Renewable DG technologies, in particular, offer significant environmental benefits compared to non-renewable alternatives. A selection of available renewable DG technologies is summarized in Table 1 [11-18].

The integration of DG into electrical power networks provides various economic, environmental, and technical advantages [12, 13, 17]. However, one critical aspect of this integration is ensuring that DG is properly connected to the utility grid system in a way that maintains protection. System protection becomes a major challenge when interconnecting DG, as improper coordination could pose significant risks to both personnel and equipment. Addressing these protection issues is vital for the safe and efficient use of DG within the power grid [19, 20].

Table 1: Options for Small Scale Distributed Generation

Type	Size Range (kW)	Electrical Efficiency (%)	Applications
Biomass energy	5-10000	40-50	Co-generation and grid Support
Fuel Cells	1-1000	41-66	Co-generation and grid support
Micro Turbines	30-5000	20-35	Stand-by power, reliability, power quality and cogeneration
Photovoltaic Arrays	1-100	5-15	Base load, peak shaving
Reciprocating Engines	5-7000	25-45	Backup power, base load, grid support and peak Shaving
Stirling Engines	1-25	12-20	Vehicles, Refrigeration Aircraft, Space
Wind systems	Several kW-5000	20-40	Remote power, grid Support

A. Effects of Distributed Generation on System Protection

Electrical power networks are susceptible to faults and power quality issues, which highlight the need for effective system protection [21, 22]. Power system protection involves detecting faults in power system components and isolating the affected areas. Its primary objectives are to safeguard the public, enhance system stability, minimize equipment damage, and protect the system from overloads. Protection is mainly achieved through overcurrent devices such as fuses, relays, and circuit breakers, which are installed in series to monitor current flow and interrupt or open the circuit to isolate faults [23-31.

However, integrating Distributed Generation (DG) into a distribution network can increase fault levels near the point of connection. This can push the network closer to its fault level limit, potentially leading to equipment damage, plant failures, and risks to personnel safety, as well as interruptions in supply. The presence of DG can also create coordination challenges, resulting in the unnecessary isolation of larger portions of the network [27, 33, 34].

B. *Distributed Generation Interconnection Protection*

For a Distributed Generation (DG) unit to be integrated into a distribution system, it must be connected to the network through an interconnection point known as the Point of Common Coupling (PCC), which can present several challenges. Therefore, it is essential to ensure proper protection to prevent damage to both the DG and utility equipment, enabling the DG to operate in parallel with the utility grid [23, 27, 32]. The utility typically establishes specific protection requirements for the interconnection of DGs, which depend on factors such as the size and type of the generator, the interconnection point, and the configuration of the interconnecting transformer [34-40].

The protection requirements for DG interconnection are based on the following considerations [41-45]:

i. Protection should address the failure of parallel operation between the DG and the utility.
ii. Protection against fault currents and transient overvoltages generated by the DG during fault conditions within the system.
iii. Safeguarding the DG from potential hazards during disturbances, such as automatic reclosing, which could cause serious issues depending on the type of generator used.
iv. The network characteristics at the point of DG interconnection.
v. The power transfer capacity at the interconnection point.

I. RELATED WORKS

Various methods have been used to analyze the impact of Distributed Generation (DG) on power system protection. This section reviews past studies and highlights their limitations.

Nimpitiwan and Heydt (2004) examines the consequences of integrating DG into electric power systems using impedance matrices. They discussed the increase in system fault currents due to DG installation and analyzed techniques for evaluating fault current changes. Their findings highlighted the need for adjustments in protective relays and circuit interruption settings, but they noted that their scheme was effective for isolating faulted sections but not guaranteed to provide an optimal protection solution [29].

Coster *et al.* (2007) studies the effects of small Combined Heat and Power (CHP) units on the protection of medium-voltage (MV) cable grids. Using DIgSILENT PowerFactory, they showed that the impact of DG on short-circuit currents varied with the location and size of the DG. They found that overhead line connections were limited due to protection blinding but focused only on three-phase faults, neglecting other fault types [7].

Manjunatha and Vittal (2010) address the challenges in designing protection schemes for DG-connected distribution networks. They discussed solutions such as higher-rated inverters, communication links, energy storage devices, adaptive protection, and the use of artificial intelligence and centralized protection. Their study stressed the need for trade-offs to maximize benefits in terms of minimizing interruptions and disturbances [25].

Rahman and Das (2010) investigate the impact of DG on power system protection by simulating a radial feeder with existing protection and DG using PSCAD/EMTDC software. They identified issues like false tripping, unintentional islanding, and resonance, and analyzed relay coordination before and after DG integration. However, their study did not account for the reduction in power losses after DG installation [37].

Jiadong *et al.* (2012) focused on the impact of DG on the sensitivity and selectivity of distribution network protection. Their analysis, which used impedance current limiters, showed that DG could cause an increase in fault currents. While their proposed method ensured proper protection response, it was not guaranteed to offer an optimal solution [19].

George *et al.* (2014) studies the effects of increased DG penetration on power grid protection, particularly using adaptive relays. They found that DG caused protection relay malfunctions due to the intermittent nature of certain DG types and increased fault levels. They recommended adaptive relaying and multi-agent systems but noted that these approaches did not guarantee optimal protection [13].

Elhaffar *et al.* (2015) explored the use of communication infrastructure and Intelligent Electronic Devices (IEDs) to enhance protection schemes in distribution systems. Their study, based on ETAP software, highlighted the potential protection issues caused by DG and feeder relays, but it did not evaluate the reliability and time delay of communication media, which could affect system robustness [12[.

Monadi et al. (2015) provided a comprehensive review of protection methods for DG-integrated AC and DC distribution systems. They discussed the advantages and disadvantages of different methods but noted that conventional protection schemes needed to be adapted for DG integration. Further investigation was required for multi-terminal DC systems [28].

Ogden and Yang (2015) examined the effects of DG on low-voltage distribution network protection. They identified problems such as blinding, unintentional islanding, and incorrect feeder reclosing, and suggested considering grid topology and DG characteristics when setting protection relays. However, the study suggested further investigation was needed to test the proposed solutions [32].

Maor (2017) analyzed the effect of DG integration in distribution networks using advanced simulation techniques. Using the IEEE 13-bus system, their approach proved more effective than conventional fault current sensing but did not consider the reduction of power losses following DG integration [26].

Norshahrani *et al*. (2017) reviewed progress in protection strategies to mitigate the effects of DG in distribution networks. They divided strategies into maintaining conventional protection systems or modifying them and highlighted the benefits and costs of each. However, they noted that both approaches still require further research for effective implementation.

Yousaf and Mahmood (2017) proposed a strategy for mitigating coordination issues caused by DG integration, using recloser-fuse coordination on an 11-kV radial distribution feeder. Their simulations showed that fast recloser operation could restore coordination during temporary faults, but the method did not guarantee an optimal solution for overall system protection [45].

Idoniboyeobu and Udoha (2018) studied the benefits of DG from Solar Renewable Energy (SRE) in Nigeria, using the Newton-Raphson power flow algorithm in ETAP software. They found that DG reduced technical losses and improved the voltage profile and power quality but noted that the load flow model could not provide optimal solutions for DG integration in the distribution network [17].

Katyara *et al.* (2018) reviewed methods for optimal sizing and placement of DGs in distribution systems and the related protection coordination issues. Their study highlighted that the location and rating of DG units significantly affected protection coordination but lacked practical implementation [21].

Osabohien and Uhunmwangho (2018) investigated the effect of DG on Port Harcourt Electric Distribution Company's network, using fault current limiters and coordinated relay-operated reclosers. Their results showed improved coordination, but their proposed solution did not guarantee optimal protection [34].

Jhansi (2019) explored the impacts of DG penetration on distribution systems and reviewed traditional protection strategies. The study highlighted the effects of DG on energy loss, harmonics, short circuits, and islanding but did not involve practical work [11].

Shrivastava *et al.* (2019) analyzed fault current levels and relay coordination in a modified IEEE 4-bus system with integrated Solar Photovoltaic Plants (SPPs). Their results showed that DG increased fault currents and impacted relay coordination. They proposed using evolutionary optimization techniques for relay coordination, but their study focused on a small distribution network and could be expanded for larger areas [42].

The analysis of the impact of Distributed Generation (DG) on power system protection revealed that existing studies largely relied on theoretical assumptions, with limited focus on practical planning methods. Various coordination and optimization techniques, such as impedance matrices, impedance current limiters, adaptive relays, recloser-fuse coordination, bi-directional power flow, and algorithms like the Newton-Raphson power flow method, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Cuckoo Search Algorithm, were primarily implemented in MATLAB or similar computational environments. However, the transfer of these concepts into planning tools has been inefficient. Furthermore, the performance of many of these methods was highly case-specific, making it difficult to generalize their applicability. This highlights the need for a modern meta-heuristic approach capable of providing optimal solutions for power system protection with high accuracy.

II. CONCLUSION

This study provides a thorough review and analysis of previous research on various techniques addressing the impact of Distributed Generation (DG) on power system protection. The findings will contribute to resolving protection coordination issues in power systems with DG integration and improve the operation and planning of electrical power networks

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