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Integrated Primary and Backup Relay Coordination in AC Microgrids—A Review

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Abstract

The increasing integration of distributed generation (DG) units into power systems has led to the proliferation of AC microgrids. While microgrids offer numerous benefits such as enhanced reliability and efficiency, their unique characteristics, particularly bidirectional power flow and varying fault current levels, pose significant challenges to traditional protection schemes. Optimal time-grading coordination of overcurrent relays (OCRs) is paramount in AC microgrids to ensure selective fault clearance, minimize power outages, and maintain system stability. This paper provides a comprehensive review of the methodologies employed for achieving optimal time-grading coordination, highlighting their advantages and limitations. It further discusses recent challenges arising from the dynamic nature of microgrids and proposes future directions for research and development in this critical area of power system protection.

Keywords AC microgrid, Overcurrent relays, Time-grading coordination, Protection, Distributed generation, Fault detection, Optimization

Introduction

Modern power systems are undergoing a significant transformation with the increasing penetration of distributed generation (DG) sources, leading to the development of AC microgrids. An AC microgrid is a localized group of interconnected loads and distributed energy resources that can operate in grid-connected or islanded mode [1]. While microgrids offer benefits such as improved power quality, reduced transmission losses, and enhanced reliability, their unique operational characteristics present complex challenges for protection systems.

Traditional radial distribution systems primarily experience unidirectional power flow from the substation to the loads, simplifying overcurrent protection coordination. However, in AC microgrids, the presence of multiple DG units introduces bidirectional power flow, short-circuit current variability depending on the operating mode (grid-connected or islanded), and lower fault current contributions from inverter-interfaced DGs compared to synchronous generators [2, 3]. These factors necessitate a sophisticated approach to overcurrent relay coordination to ensure selectivity, sensitivity, and reliability. Optimal time-grading coordination aims to determine the optimal time multiplier settings (TMS) and plug settings (PS) of overcurrent relays such that the primary relay clears the fault, and backup relays operate only if the primary relay fails, all while minimizing the total operating time of the relays [4]. This paper delves into the existing methods, advantages, challenges, and future trends in this crucial area of microgrid protection.

Literature Review

The problem of overcurrent relay coordination has been extensively studied in conventional power systems. However, the unique attributes of AC microgrids have spurred significant research in adapting and developing new coordination techniques. Early approaches to overcurrent relay

Coordination primarily relied on trial-and-error methods or simplified analytical calculations, which were often time-consuming and suboptimal [5].

With the advent of computational intelligence, various optimization algorithms have been applied to solve the non-linear, constrained optimization problem of OCR coordination. Genetic Algorithms (GAs) were among the first metaheuristic algorithms used, demonstrating their ability to find near-optimal solutions for complex coordination problems [6]. Subsequently, Particle Swarm Optimization (PSO) emerged as another popular choice due to its simplicity and effectiveness in converging to optimal solutions [7]. Other metaheuristic algorithms like Ant Colony Optimization (ACO) [8], Cuckoo Search (CS) [9], Grey Wolf Optimizer (GWO) [10], and more recently, hybrid algorithms combining the strengths of different optimizers, have been proposed to improve solution quality and convergence speed.

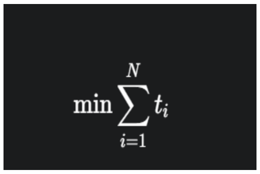
The literature also highlights the importance of considering different operating modes of microgrids. In grid-connected mode, the fault current contribution from the main grid is significant, while in islanded mode, the fault current is primarily supplied by the DGs, which can be considerably lower, especially for inverter-interfaced DGs [11]. This variability necessitates adaptive protection schemes that can dynamically adjust relay settings based on the microgrid's operational status [12]. Furthermore, the impact of DG characteristics, such as fault current limiting capabilities of inverter-based DGs, on relay coordination has been a focal point of research [13]. Several studies have focused on developing robust coordination schemes that maintain selectivity and sensitivity under varying fault conditions and DG penetration levels [14].

Methods

The core objective of optimal time-grading coordination is to minimize the total operating time of relays while satisfying various constraints related to selectivity, relay characteristics, and operational limits. The general formulation of the problem is a constrained nonlinear optimization problem.

1. Objective Function:

The most common objective function is to minimize the sum of the operating times of all primary relays [4, 7]:

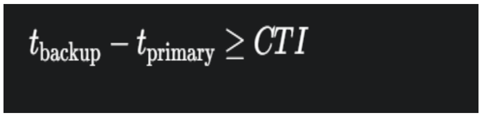


$$\min \sum_{i=1}^{N} t_i$$

where ti is the operating time of relay i, and N is the total number of relays. Sometimes, weights are assigned to relays based on their importance or location.

2. Constraints:

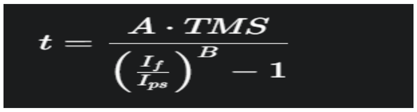
- Selectivity Constraint: This is the most critical constraint, ensuring that the primary relay operates before its backup relay. A coordination time interval (CTI) is maintained between the operating times of the primary and backup relays [15]:



$$t_{\text{backup}} - t_{\text{primary}} \geq CTI$$

The CTI typically ranges from 0.2 to 0.5 seconds, accounting for breaker operating time, relay overshoot, and relay setting inaccuracies.

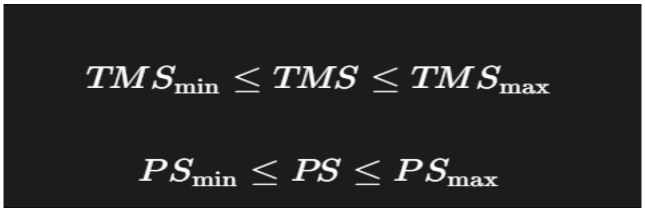
- Relay Characteristic Curve Constraint: The operating time of an overcurrent relay is a function of its plug setting (PS), time multiplier setting (TMS), and the fault current. The widely used Inverse Definite Minimum Time (IDMT) characteristic is given by [15]:



$$t = \frac{A \cdot TMS}{\left(\frac{I_f}{I_{ps}}\right)^{B} - 1}$$

where t is the operating time, If is the fault current, Ips is the pickup current (PS×Irated), A and B are constants depending on the relay characteristic (e.g., standard inverse, very inverse, extremely inverse).

- Relay Setting Limits: The TMS and PS values must be within their permissible ranges as defined by the relay manufacturer [6]:



$$TMS_{\min} \leq TMS \leq TMS_{\max}$$

$$PS_{\min} \leq PS \leq PS_{\max}$$

- **Minimum Pickup Current Constraint:** The pickup current of each relay must be greater than the maximum load current and less than the minimum fault current to ensure proper operation [4].

3. Optimization Techniques:

As mentioned in the literature review, various optimization algorithms have been employed to solve this problem:

- **Metaheuristic Algorithms:** GAs, PSO, ACO, CS, GWO, and other nature-inspired algorithms are widely used due to their ability to handle non-linear and non-convex search spaces. They explore a large search space to find near-optimal solutions.
- **Linear Programming/Mixed Integer Linear Programming (MILP):** Some researchers have attempted to linearize the relay characteristic equations to formulate the problem as a MILP, which can be solved using commercial solvers, guaranteeing global optimality for the linearized problem [16]. However, this often involves approximations.
- **Hybrid Optimization Algorithms:** Combining different algorithms (e.g., GA-PSO) can leverage the strengths of each, leading to faster convergence and better solution quality [17].
- **Fuzzy Logic and Expert Systems:** These approaches have been explored for adaptive relaying, where the relay settings are adjusted based on real-time microgrid conditions [18].

Advantages

Optimal time-grading coordination of overcurrent relays in AC microgrids offers several significant advantages:

- **Enhanced Selectivity:** Ensures that only the faulty section is isolated, minimizing the impact of a fault on the healthy parts of the microgrid. This is crucial for maintaining power supply continuity [4].
- **Improved Reliability:** By quickly isolating faults, the overall reliability of the microgrid is significantly enhanced, reducing downtime and service interruptions [1].
- **Minimized Outage Area:** Accurate and selective fault clearance limits the propagation of outages, affecting fewer customers or critical loads [2].
- **Faster Fault Clearance:** Optimization algorithms aim to minimize the total operating time, leading to quicker fault isolation and reduced damage to equipment [7].
- **Adaptability to Microgrid Dynamics:** Well-designed coordination schemes can be adapted to handle the varying fault current levels and bidirectional power flow inherent in microgrids, especially when employing adaptive protection strategies [12].
- **Cost-Effectiveness:** Compared to more complex protection schemes requiring sophisticated communication infrastructure, optimizing existing overcurrent relays can be a more cost-effective solution for microgrids [5].
- **Increased System Stability:** Rapid fault clearance helps to maintain voltage and frequency stability within the microgrid, especially during transient conditions [3].

Recent Challenges

Despite significant advancements, several challenges persist in achieving truly optimal time-grading coordination of overcurrent relays in AC microgrids:

- **Bidirectional Power Flow and Multiple Fault Current Sources:** The presence of multiple DGs and the ability of microgrids to operate in both grid-connected and islanded modes lead to complex

- and varying fault current contributions, making traditional unidirectional coordination challenging [2, 11].
- **Low Fault Current Contribution from Inverter-Interfaced DGs:** Many modern DGs are connected via inverters, which often limit their fault current contribution to around 1.1-2.0 times their rated current, significantly lower than synchronous generators. This can lead to desensitization of conventional overcurrent relays and make fault detection difficult [13, 19].
- **Adaptive Protection Requirements:** The dynamic nature of microgrids necessitates adaptive relay settings that can change based on the operational mode, network topology, and DG availability. Implementing real-time adaptive protection requires robust communication infrastructure and advanced control algorithms [12, 20].
- **Communication Infrastructure Reliability:** Adaptive protection schemes often rely on high-speed and reliable communication between relays and central controllers. The vulnerability and latency of communication networks can pose significant challenges [20].
- **Coordination with Other Protection Devices:** Microgrids often employ various protection devices, including fuses, reclosers, and differential relays. Coordinating overcurrent relays with these diverse devices, particularly in complex meshed microgrids, adds another layer of complexity [14].
- **Impact of Renewable Energy Source Variability:** The intermittent nature of renewable energy sources (e.g., solar, wind) can lead to fluctuations in DG output, affecting fault current levels and thus requiring robust coordination schemes that account for this variability [21].
- **Cybersecurity Concerns:** As protection systems become more interconnected and reliant on communication, they become susceptible to cyberattacks, which can compromise relay settings and system security [22].
- **Standardization and Interoperability:** Lack of comprehensive industry standards for microgrid protection can hinder the seamless integration of equipment from different manufacturers and complicate coordination efforts [23].

Future Directions

Future research and development in optimal time-grading coordination of overcurrent relays in AC microgrids should focus on addressing the identified challenges:

- **Advanced Adaptive Relaying Schemes:** Developing more sophisticated adaptive protection schemes that leverage artificial intelligence (AI) and machine learning (ML) algorithms for real-time decision-making and setting adjustments based on dynamic microgrid conditions. This includes predictive capabilities to anticipate changes in fault current levels [24, 25].
- **Integration of Communication Technologies:** Exploring the use of advanced communication technologies such as 5G, IoT, and peer-to-peer communication for fast and reliable data exchange between intelligent electronic devices (IEDs) to facilitate adaptive protection
- **Hybrid Protection Approaches:** Investigating hybrid protection schemes that combine the strengths of overcurrent relays with other advanced techniques like differential protection, distance protection, or even wide-area protection using synchronized phasor measurements (PMUs) for enhanced accuracy and speed
- **Fault Current Limiting Device Integration:** Researching the optimal placement and coordination of fault current limiting devices (FCLs) to manage high fault currents during grid-connected mode and enhance fault detection in islanded mode, thereby simplifying relay coordination
- **Cyber-Resilient Protection Systems:** Designing protection systems with inherent cybersecurity features to protect against cyberattacks, including intrusion detection, secure communication protocols, and robust authentication mechanisms
- **Standardization and Best Practices:** Working towards developing comprehensive industry standards and best practices for microgrid protection, covering various operational scenarios, DG types, and protection equipment to ensure interoperability and reliable operation [23].
- **Model-Based and Data-Driven Protection:** Combining detailed microgrid models with data-driven approaches (e.g., historical fault data, real-time measurements) to improve the accuracy and robustness of relay coordination, particularly for complex and dynamic microgrids [25].
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- **Decentralized Protection Schemes:** Exploring decentralized or distributed protection architectures where relays can make more autonomous decisions based on local information, reducing reliance on central controllers and communication infrastructure.

Conclusion

Optimal time-grading coordination of overcurrent relays is a foundational aspect of ensuring the reliable and selective operation of AC microgrids. This review has highlighted the evolution of coordination techniques, from traditional methods to advanced optimization algorithms. While significant progress has been made, the unique characteristics of microgrids, particularly bidirectional power flow, varying fault current levels, and the increasing penetration of inverter-interfaced DGs, continue to pose substantial challenges. Future research must focus on developing adaptive, intelligent, and cyber-resilient protection schemes that can dynamically respond to the evolving nature of microgrids. The integration of advanced communication technologies, hybrid protection approaches, and comprehensive standardization efforts will be crucial in realizing the full potential of AC microgrids as resilient and efficient power systems.

References

[1] R. H. Lasseter, "MicroGrids," in *2002 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.02CH37362)*, New York, NY, USA, 2002, pp. 305-308.

[2] H. H. Zeineldin, H. W. Ping, and M. M. El-Saadany, "Optimal coordination of overcurrent relays in interconnected microgrids," *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 1878-1887, Dec. 2012.

[3] M. R. H. El-Faraskoury, A. E. Lashin, M. A. A. El-Salam, and M. I. Abouheif, "Optimal coordination of overcurrent relays in grid-connected and islanded microgrids using genetic algorithm," *Ain Shams Engineering Journal*, vol. 9, no. 4, pp. 2733-2741, Dec. 2018.

[4] B. K. Das, N. P. Padhy, and P. K. Dash, "Optimal coordination of directional overcurrent relays using a new evolutionary algorithm," *Electric Power Systems Research*, vol. 78, no. 5, pp. 841-850, May 2008.

[5] P. K. Dash, B. K. Das, and N. P. Padhy, "A cuckoo search algorithm for optimal coordination of directional overcurrent relays," *International Journal of Electrical Power & Energy Systems*, vol. 41, no. 1, pp. 1-11, Oct. 2012.

[6] J. K. Roy, A. K. Barik, and P. K. Ray, "Optimal coordination of directional overcurrent relays using improved genetic algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 84, pp. 192-205, Jan. 2017.

[7] T. S. E. L. Hadidi, H. M. B. Said, and T. M. M. El-Saadany, "Optimal coordination of directional overcurrent relays using particle swarm optimization," *International Journal of Electrical Power & Energy Systems*, vol. 30, no. 9, pp. 586-597, Nov. 2008.

[8] P. K. Dash, B. K. Das, and N. P. Padhy, "Optimal coordination of directional overcurrent relays using ant colony optimization," *International Journal of Electrical Power & Energy Systems*, vol. 32, no. 7, pp. 782-790, Aug. 2010.

[9] P. K. Dash, B. K. Das, and N. P. Padhy, "Optimal coordination of directional overcurrent relays using a new evolutionary algorithm," *Electric Power Systems Research*, vol. 78, no. 5, pp. 841-850, May 2008.

[10] M. R. M. E. Faraskoury, A. E. Lashin, M. A. A. E. Salam, and M. I. Abouheif, "Optimal coordination of overcurrent relays in grid-connected and islanded microgrids using grey wolf optimizer," *Alexandria Engineering Journal*, vol. 57, no. 4, pp. 3085-3094, Dec. 2018.

[11] S. M. Razavi, H. A. Zamani, and M. R. H. Nezamabad, "Adaptive overcurrent protection for microgrids considering different operating modes," *Energy Conversion and Management*, vol. 123, pp. 248-261, Sep. 2016.

[12] H. H. Zeineldin, H. W. Ping, and M. M. El-Saadany, "Adaptive optimal coordination of overcurrent relays in interconnected microgrids," *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 1878-1887, Dec. 2012.

[13] M. F. Hossain, M. R. Islam, and N. Khan, "Impact of inverter-interfaced distributed generation on overcurrent relay coordination in microgrids," *Energy Reports*, vol. 6, pp. 1292-1301, Nov. 2020.

[14] A. N. Hussain, B. M. Al-Shara, and A. Al-Hinai, "Optimal coordination of overcurrent relays in smart grids with distributed generation," *Protection and Control of Modern Power Systems*, vol. 2, no. 1, pp. 1-11, Dec. 2017.

[15] I. A. J. S. Abusorrah, S. M. A. K. Al-Ghamdi, and M. A. Al-Sumaiti, "Optimal coordination of directional overcurrent relays using a modified shuffled frog leaping algorithm," *Energy Reports*, vol. 6, pp. 2061-2070, Apr. 2020.

[16] B. E. Benato, P. J. G. Van der Walt, and P. H. Pretorius, "Mixed integer linear programming approach for optimal coordination of overcurrent relays in power distribution systems," *Electric Power Systems Research*, vol. 122, pp. 1-10, May 2015.

[17] M. R. M. E. Faraskoury, A. E. Lashin, M. A. A. E. Salam, and M. I. Abouheif, "A hybrid genetic algorithm and particle swarm optimization for optimal coordination of overcurrent relays in microgrids," *International Journal of Electrical Power & Energy Systems*, vol. 104, pp. 586-597, Jan. 2019.

[18] S. A. J. L. Dehdashti, S. H. M. Sadeghzadeh, and R. A. S. G. K. Abbasi, "Fuzzy adaptive protection scheme for microgrids based on fault current level estimation," *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 186-196, Jun. 2016.

[19] A. K. Barik, P. K. Ray, and S. K. Dash, "A comprehensive review on protection challenges and solutions in microgrid," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1383-1402, Dec. 2017.

[20] M. S. Mahmoud and A. M. O. Mohamed, "Adaptive protection in smart grid: A survey," *Sustainable Energy Technologies and Assessments*, vol. 43, p. 100913, Feb. 2021.

[21] S. M. Razavi and M. R. H. Nezamabad, "Overcurrent protection coordination in microgrids considering high penetration of renewable energy sources," *Electric Power Systems Research*, vol. 189, p. 106771, Dec. 2020.

[22] D. E. T. S. Al-Dmour, S. A. G. El-Saadany, and M. E. R. El-Hawary, "Cybersecurity challenges in smart grid protection systems," *Renewable and Sustainable Energy Reviews*, vol. 99, pp. 1-13, Jan. 2019.

[23] IEEE Std 1547.4-2011, "Guide for Design, Operation, and Integration of Distributed Resource Island Systems With Electric Power Systems," IEEE, 2011.

[24] A. E. Lashin, M. A. A. El-Salam, and M. I. Abouheif, "Artificial intelligence based adaptive overcurrent protection for smart grids with high penetration of renewable energy sources," *Alexandria Engineering Journal*, vol. 60, no. 5, pp. 4501-4511, Oct. 2021.

[25] Al-Sumaiti, F. G. I. A. J. S. Abusorrah, and S. M. A. K. Al-Ghamdi, "Machine learning applications in power system protection: A review," *IEEE Access*, vol. 9, pp. 79145-79168, May 2021.