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Mini Review

Review on Coordination of Time Overcurrent Relays in Electrical Distribution Network

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Abstract: Integration of distributed generators in micro grid causes bidirectional current flow as a result of the need for readjustment of the setting of the overcurrent protective relays in the electrical network. Adaptive coordination is one of the solutions that adjust the setting of protective relays according to the dynamics of the distribution network. Various algorithms had been reported on the adaptive coordination of time overcurrent relays. This paper reports a survey about the coordination of time overcurrent relays in micro grid electrical distribution network. The review found that there is limited research on distributed control rules of the multi agent coordination of protection relays. Furthermore, it was found that the trend of coordination algorithms focused on the nature inspired algorithms.

Keywords: protection; relay; coordination; operating time; distribution network; algorithm

I. INTRODUCTION

The electrical distribution network encompasses the electrical conductors transporting electrical energy from sources to sinks. In this context the sources are represented by the electrical generators and substations, and the sinks are represented the electrical loads. The electrical distribution networks are geographically distributed in a non-uniform arrangement based on the settlements of the societies who are the users of the electrical energy. Load current in electrical distribution networks varies close to the setting of protective relays the condition that causes false tripping commands of relays. In the legacy electrical distribution network the source of power is the utility source, however the higher demand on power and reliability issues have brought the need for installation of distributed generators in the electrical distribution network near the load centres. The modern electrical distribution network has different sources of power including solar power, distributed generators, and energy storage systems; all these are integrated in the distribution networks to supply power required for the loads. Along the distribution networks, there are protection devices to control the electrical power. Relays are among the protection devices that sense and send tripping commands to the circuit breakers on the occurrence of a fault. As the network expands the number of relays increases and their accuracy of operation depends on coordination. Coordination of relays in the electrical distribution network is among the classical protection problems with the objective to set the operating time for the relays as accurately as possible to allow the proper operation of the protection system when a fault occurs. The coordination of relays in electrical distribution networks is affected by the operating level of the electrical network, dynamics of the electrical current in the system, characteristics of protection devices, the type of the protection scheme, and the type of technology used. The operation of the power system protection devices involves current, and time. This approach had been a normal practice in the power system protection industry and its implementation had been revealed in transmission lines and substations. The need for installation of protection devices in the distribution networks brings attention about the parameters of the agents for protection.

Introduction of the overcurrent relays in power systems dates back in 1905 according to ABB products [1]. The coordination of overcurrent relays involves optimizing the setting of individual relay and was first reported in 1988 [2]. The author in [2] used the minimax optimisation approach. Since the year 2012 various articles about coordination of the overcurrent relays had been published. In 2012 the author in[3] reported the use of Seeker Algorithm for coordination of overcurrent relays. One of the drawbacks of the Seeker Algorithm is the high computational time requirement. In 2014 the Table based Algorithm was reported for use in inverse time overcurrent relay [4]. The disadvantage of the Table based Algorithm is the requirement for high memory resource but its advantage is high speed of performance [4]. The use of hybrid particle swarm optimization-gravitational search algorithm for overcurrent relay coordination was reported in 2016[5]. The metaheuristic algorithm was reported in 2017 for coordination of overcurrent relays [6]. Advantages of metaheuristic algorithm is smaller processing time [6]. The use of metaheuristic algorithm was also reported in 2018 for coordination of overcurrent relays [7]. The hybrid Whale Optimisation algorithm and Grey Wolf optimizer algorithm was reported in 2019 for coordination of overcurrent relays [8]. The enhanced differential evolution multi-objective algorithm was reported in 2019 for coordination of overcurrent relays [9]. The Teaching Learning Based Optimisation algorithm was reported in 2021 for coordination of overcurrent relays [10]. Advantage of the Teaching Learning Based Optimisation algorithm includes less computational efforts for problems of high dimensionality. According to the trend of publication, the research on new algorithms comes into application from time to time but no superior algorithms for every type of the problem [11]. The direction of research for optimisation algorithms shows that the nature inspired algorithms are among the state of the art methods for optimization [12].

With advancement of technology, the coordination of relays can be implemented either with communication or without communication. The coordination that is associated with communication builds up both the physical electrical connections and the communication between the relays. The combination of protection system and telecommunication results in teleprotection. Other literatures describe as the communication assisted adaptive protection. In teleprotection the relays are connected by the telecommunication network as shown in Fig.1.

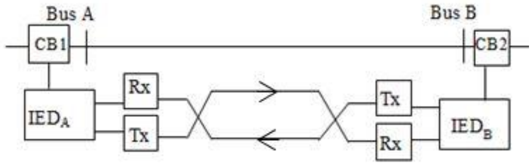

Figure 1. *Teleprotection Layout*

From **Fig.1**, the CB represents circuit breaker, IED represent the Intelligent Electronic Device, Tx represent transmitter, Rx represent the Receiver. The technology evolution of relays changed from static relays in 1974 to numerical relays in 1999 [1]. By the year 2000 the relays technology had advanced to digital relays and IEDs with high selectivity. Coordination of protective relays especially on overcurrent relays had been published by various researchers reporting different methods and techniques to improve the coordination of relays. There had been various review articles on the coordination of relays. A review of the protection challenges such as bidirectional fault current, and various levels of fault current under different operating conditions had been reported in [13]. The need for different settings for the protection devices placed along the network for micro grid had been addressed by the use of the logic selectivity method [14]. The Evolutionary Particle Swarm Optimisation algorithms based on Fuzzy systems had been used to address the challenges of designing robust and flexible power systems under a variety of operating conditions [15]. The method of Micro grid Central Controller reconfiguration algorithm based had been reported to address the change of topology of micro grids and dynamics in fault current magnitude [16]. Numerical optimisation-based solution to directional overcurrent relay coordination had been solved by Mixed Integer Linear Programming and Linearization of variables using disjunctive inequalities [17]. First Depth Search and Variable Neighborhood Search methods were applied to address the problem of difficulty in the determination of an optimal setting for relay coordination [18]. The need to have new protection schemes for modern power system had been addressed in [13]. Researches show that there are advantages of using teleprotection in coordination of relays [15-16, 19-20].

With the increasing complexity of modern distribution systems, the utilization of multi-agent coordination mechanisms has gained attention to enhance the performance and efficiency of teleprotection relays. Multi agent approach for coordination of relays had been reported in different articles [21-25]. Adaptive coordination has been reported in various articles about optimal coordination of overcurrent relays with the aim of overcurrent relays to self-adjust the setting of the protection when the operating limits change [24], [26-30]. In this paper there are four next sections. Section two contains the method that was used in the systematic review. Section three comprises of result. Section four is the section with the discussion. Section five provides conclusion from the review study.

II. METHODOLOGY

A systematic literature review was conducted to identify relevant research articles, conference papers, and technical reports. The selected research articles were those related to coordination of overcurrent relays and the use of multi-agent coordination in teleprotection relay systems. The selected studies were analyzed and synthesized to provide an overview of the current state of research in this area. The works of literature on the coordination of relays had been synthesized by a systematic review that employed the evidence-based practice methodology [31, 32], and used the results from various studies on the coordination of relays. Steps that were involved to carry out the systematic review included; identification, selection, assessment, extraction and synthesis. Selection involved screening the articles, extraction, and synthesis. The screening process was achieved by the use of the exclusion and inclusion criteria. To get an understanding of the research about coordination of relays the research questions were involved including; Where do the articles on coordination of relays in electrical networks are published? What types of articles had been published on the coordination of relays in electrical distribution networks? Which themes had been covered in the published literature on the coordination of relays? What method had been used in the published articles on the coordination of relays in electrical distribution networks?

Searching of articles on the topic of protection and coordination of relays specified the publication time from January 2013 to December 2022. The articles were accessed from various online resources. The online resources included but were not limited to; google scholar, IEEE, web of science, Researchgate, arXiv, vendors of equipment, conference proceedings, and published standards. The inclusion and exclusion criteria were applied to screen the articles for further detailed review. The search involved the search theme and the search strategy (**Table 1.**). Some of the search theme included; coordination, adaptive, overcurrent relay. Some of the search strategies included: ‘relay’ OR ‘IED’ AND ‘coordination’ AND ‘adaptive’ AND ‘protection’ AND ‘overcurrent’ AND ‘relay’ AND ‘coordination’ AND ‘AC’ AND ‘microgrid’. ‘relay’ AND ‘coordination’ OR ‘multiagent’ OR ‘multi-agent’.

Inclusion criteria included analysis based on the theoretical papers, working paper, quantitative and qualitative empirical studies. There were many criteria for inclusion, to mention few criteria; the distribution network was also inclusion criteria, the microgrid was one of the inclusion criteria, and also the overcurrent protection was the inclusion criteria. Exclusion criteria included analysis based on the publication year beyond the specified, electrical transmission network, non-relevance of the contents of the article, and the article with language other than English. The searched articles were stored in the computer folder and the computer folder was added to the Mendeley Desktop [33]. The file name of the article had to have the author’s name, title of the article, journal name and year of publication.

Table 1. *Steps*

Step	***Output***
Searching	Total number of articles
Screening	Abstract and title
Eligibility	Full text review
Detailed analysis	Quantitative/Qualitative Synthesis

The published articles about coordination of relays that involved communication were further analysed in detail with the focus on the differential protection and overcurrent protection to obtain the extent of the application of the protection schemes. The methods for differential protection work on the principle of difference of the electrical current between two points. The sampled value packets loss was used for transformer differential protection, time-frequency transform-based differential protection had been reported for use in micro grid, also the Intelligent Differential Microgrid Protection Scheme had been reported. Other relevant published articles included the variable tripping time differential protection for micro grid, Feature Cosine and Differential Scheme for Micro grid, secure communication for line current differential protection systems over packet switched networks and Packet-Based Networks for Current Differential Protection Application. The overcurrent protection schemes work on the principle of pickup current setting of the protection device considering the constraint of the coordination time interval.

In order to illustrate the involvement of the algorithms, this study adopted the three bus electrical network shown in **Fig.2** [34, 35]. The set of data used in this study was as those in [35]. In this review the Genetic Algorithm (GA) was used to optimise the TMS of the backup relays and then the optimised TMS was used to compute the corresponding operating time. The results obtained by using GA were compared to the result from the literature [35].

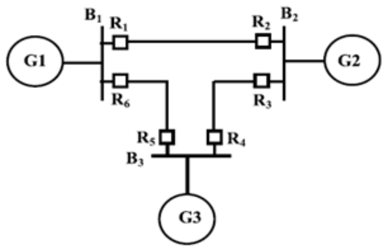

Figure 2. *Three bus network*

The fault currents for the three bus network were as shown in **Table 2** [35].

Table 2: *Fault currents*

	Primary Relay Fault current (A)		Backup Relay Fault current (A)
R1	2075.0	R5	400.7
R2	1621.7	R4	700.64
R3	1779.6	R1	760.17
R4	1911.5	R6	622.65
R5	1588.5	R3	558.13
R6	1855.4	R2	380.70

Equation (1) was the time current curve.

$$t=TMS\left(\frac{\beta}{PSM^{\alpha}-1}\right) \quad (1)$$

Equation (2) was the objective function.

$$F(t)=\sum_{i=1}^{N} t_i \quad (2)$$

Equation (3) was the constraint.

$$t_i^{backup} - t_i^{primary} \geq CTI \quad (3)$$

where:

t_i is the operating time of individual relay in seconds.

F(t) is the total operating time of all relays in the network.

$t_i^{primary}$ is the operating time of the primary relay

t_i^{backup} is the operating time of the backup relay

CTI is the coordination time interval.

N was the number of relays.

The values of α and β were 0.02 and 0.14 respectively.

Equation (4) was used to compute the Plug Setting Multiplier(PSM).

$$PSM=\frac{CTRxFault\ current}{Plug\ setting} \quad (4)$$

The CTR was the current transformer ratio. The GA was implemented by python and the steps were:

i. Start;

ii. Initialise the parameters;

iii. Initialise objective function;

iv. Extract one parent in each iteration;

v. Carry out crossover and mutation;

vi. Return best result.

The lower and upper limits of the TMS were 0.1000 and 0.3000 respectively.

III. RESULT

Various articles used different types of networks for testing the proposed methods and algorithms. The operating time of the relay is the dependent variable that depends on the value of the load current and pick up current. The value of fault current was less than 12 kA and the range of pickup current was between 0.5 A to 1.15 A [36, 37]. Based on the time current curve characteristics, the published articles that mentioned the type of curve either used the IEC 60255-3 or IEEE C37.112. However, some articles did not specify the reference type of the time current curve. There was high number of articles related with optimisation algorithms. The review identified several studies that explored the integration of multi-agent coordination to enhance teleprotection relay systems. These studies reported that the use of agents and communication-based protection demonstrated improvements in fault detection accuracy, reduction in communication delays, and increased reliability through collaborative decision-making among teleprotection relays.

The articles focused on the areas such as coordination, algorithm, teleprotection, agent, and communication as shown in **Fig. 3. Table 3.** shows some of the algorithms that were used in the recent articles concerning the coordination of relays. **Fig. 4.** was the result for the extent of the use of the differential protection and overcurrent protection.

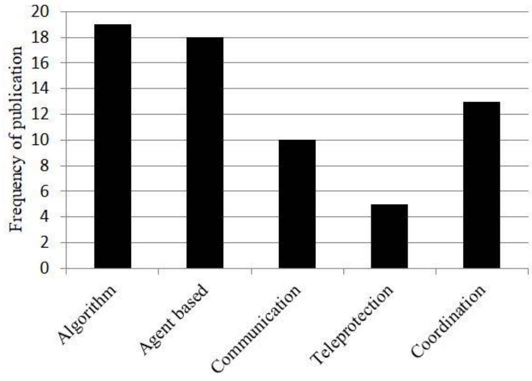

Figure 3. *Focus area of the published articles*

Table 3*: Result for backup relays*

	Literature	This Review
Relay	Time[s]	Time[s]
R1	0.5482	0.5066
R2	0.6840	0.6163
R3	0.6686	0.4942
R4	0.5826	0.6056
R5	0.4973	0.4750
R6	0.7541	1.1102

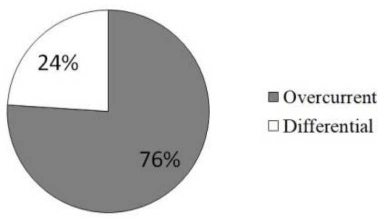

Figure 4. *Differential and Overcurrent protection*

IV. DISCUSSION AND CONCLUSION

1. Discussion

Although this article carried out the systematic review on coordination of relays in electrical distribution networks it does not lack limitation of the findings. Among the limitation that might have excluded the essential information for coordination of relays could be caused by specifying the year of publication because the year of publication was among the inclusion criteria, there could be best article in the topic under context that could have been excluded due to being out of the specified year of publication.

With reference to the reviewed literatures, for teleprotection based coordination of relays, it had been reported that the Open Network Operating System controller based on the Software Defined Network had minimum failure occurrence compared to other controllers, which were tested for use in teleprotection. The optimisation of protection relays for the network with 14 protection relays 78.6 % of them were coordinated by an extremely inverse curve [15]. For two different methods; one used the potential energy boundary and another used the bisection, there was a difference of 2.028 cycles [15]. From the reviewed articles the percentage of studies based on differential protection method was 24%, while the percentage studies based on overcurrent relays was 76% as shown in **Fig. 3.** Most of the differential protection systems were implemented in power transmission lines in which the differential relays installed in transmission substations use the difference in currents to detect the faults while communicating with the remote relays through telecommunication channel. Further the analysis also was carried out moving from the power transmission line to the lower level of the power distribution line, the lower was the percentage of the application of the teleprotection with overcurrent relays. The implication was that there were few studies carried out using teleprotection with overcurrent relays in the power distribution networks.

Based on the type of electrical network; when the benchmark IEC microgrid was used the result of the operating time for the relays had a minimum value of 0.0118s and a maximum value of 1.59s for individual relays [37]. The operating time for individual relays of the network with distributed generators had a minimum of 0.01s and a maximum of 1.3s [15]. The result of operating time for the backup relays in this review had greater spread in values as compared to the result from the literature. The average operating time for backup relays for three bus network was 0.63 seconds with the standard deviation of 0.24 in this review. The literature for comparison had average operating time of 0.62 seconds with the standard deviation of 0.1. The trend of publication on the coordination of relays in electrical distribution networks has been growing and is expected to grow as technology changes and new computational methods keep on evolving. The decentralised adaptive fuzzy based system had good performance compared to enhanced particle swam optimisation when used in the network with distributed generators [15]. The analysis was also carried out to find the extent of the use of the distributed multi agent coordination for relays as compared to other areas of control different from the coordination of relays. Distributed multi agent coordination had been mostly conducted in areas of unmanned aerial vehicles, unmanned ground vehicles, autonomous underwater vehicles, robotics, satellites, and game theory [38-45]. There are limited articles about the use of distributed leaderless multi agent coordination for coordination of protection relays.

The findings suggest that multi-agent coordination holds significant potential for enhancing the performance and reliability of teleprotection relays in electrical distribution networks. The collaborative nature of multi-agent systems enables efficient fault detection and isolation, leading to improved network resilience and reliability.

2. Conclusion

Most of the publications about the coordination of relays focus on adaptive protection through the use of information and communication technologies to design the coordination techniques capable to make relays adjust automatically their operational parameter settings according to the changes in the behavior of the electrical network. On the perspective of the use of communication in the protection relays most of the articles published about the coordination of relays mainly focus on the communication technologies that reduce communication delay. Although most of the articles didn't specify communication technologies required for teleprotection; it falls in the category of operational technology and not information technology. In other words, the communication required for protection relays is the operational technology. The operational technology can't tolerate the drop of the message communicated between the devices. In operational technology the dropped message when it was sent becomes useless and no need to push the message in time other than when it was sent. Based on the review it is undoubtedly that protection relays are geographically distributed on the land and they carry out computation of variables, there is a lack of control laws for the multi agent coordination of protection relays in electrical distribution networks. The relays and IEDs in the electrical distribution networks are geographically distributed according to the network of the streets and settlement of the society that uses electrical energy. Modeling the relays and IEDs using multiagent approach is essential to obtain the modern way to control these distributed protection components in the electrical network.

This systematic review provides a comprehensive overview of the current state of research on the application of multi-agent coordination for teleprotection relays in electrical distribution networks. The findings highlight the potential benefits of utilizing multi-agent coordination in enhancing fault detection accuracy, reducing communication delays, and improving the overall reliability of teleprotection relay systems. In this paper, a systematic review was carried out and obtained the findings from various studies, on the coordination of relays in terms of operating time of protection relays in electrical distribution networks. Findings used the available data to build on the evidence about various techniques in coordination of relays. The findings incorporated the requirements for innovation in the coordination of relays in the protection of the electrical network. It was evident from the review that most of the studies concerning multi agent coordination had been carried out in other areas different from protection relays. Also, the review found that the studies that reported about the coordination of protection relays had limited coverage of the distributed control rules. Therefore, there is limited research on distributed control rules of the multi agent coordination of protection relays.

V. Author Contributions

Godfrey Mhagama: Conceptualization, Literature review, Theoretical analysis, Writing.

Ndyetabura Y. Hamisi: Supervision, Review and editing.

Shililiandumi Naiman: Supervision, Review and editing.

VI. Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] B. Lundqvist, "100 years of relay protection, the Swedish ABB relay history," Västerås, 2001. [Cited 10/12/2023]. http://library.abb.com/global/scot/scot296.nsf/veritydisplay/c1256d32004634bac1256e19006fd705/$File/PAPER_2001_08_en_100_Years_of_Relay_Protection__the_Swedish_ABB_Relay_History.pdf.

[2] A. J. Urdaneta, R. Nadira, and L. G. Pérez Jiménez, "Optimal Coordination of Directional Overcurrent Relays in Interconnected Power Systems," *IEEE Trans. Power Deliv.* 3 (3) (1988) pp. 903–911. https://doi.org/10.1109/61.193867

[3] T. Amraee, "Coordination of directional overcurrent relays using seeker algorithm,"

IEEE Trans. Power Deliv. 27 (3) (2012) pp. 1415–1422. https://doi.org/10.1109/TPWRD.2012.2190107

[4] Z. N. Stojanovic and M. B. Djuric, "Table Based Algorithm for Inverse-Time Overcurrent Relay," *J. Electr. Eng.* 65 (4) (2014) pp. 213–220. https://doi.org/10.2478/jee-2014-0033

[5] A. Srivastava, J. M. Tripathi, S. R. Mohanty, and B. Panda, "Optimal over-current relay coordination with distributed generation using hybrid particle swarm optimization-gravitational search algorithm," *Electr. Power Components Syst.* 44 (5) (2016) pp. 506–517. https://doi.org/10.1080/15325008.2015.1117539

[6] M. H. Costa, R. R. Saldanha, M. G. Ravetti, and E. G. Carrano, "Robust coordination of directional overcurrent relays using a matheuristic algorithm," *IET Gener. Transm. Distrib.* 11 (2) (2017) pp. 464–474. https://doi.org/10.1049/iet-gtd.2016.1010

[7] S. Roy, S. B. Perli, and N. V. P. Babu, "Intelligent coordination of overcurrent and distance relays using meta heuristic algorithms," *Int. J. Electr. Eng. Informatics* 10 (4) (2018) pp. 675–703. https://doi.org/10.15676/ijeei.2018.10.4.5

[8] A. Korashy, S. Kamel, F. Jurado, and A. R. Youssef, "Hybrid Whale Optimization Algorithm and Grey Wolf Optimizer Algorithm for Optimal Coordination of Direction Overcurrent Relays," *Electr. Power Components Syst.* 47 (6–7) (2019) pp. 644–658. https://doi.org/10.1080/15325008.2019.1602687

[9] M. Y. Shih, A. Conde, and C. Ángeles-Camacho, "Enhanced self-adaptive differential evolution multi-Objective algorithm for coordination of directional overcurrent relays contemplating maximum and minimum fault points," *IET Gener. Transm. Distrib.*, 13 (21) (2019) pp. 4842–4852. https://doi.org/10.1049/iet-gtd.2018.6995

[10] B. Dumala, "Optimal Coordination of Over Current Relays Using Teaching Learning Based Optimization Algorithm" 4 (3) (2020) pp. 10–20.

[11] T. A. W. Mykel J.Kochenderfer, *Algorithms for Optimization*, Cambridge: MIT Press, 2019.

[12] R. V Rao, V. J. Savsani, and D. P. Vakharia, "Computer-Aided Design Teaching – learning-based optimization : A novel method for constrained mechanical design optimization problems," *Comput. Des.* 43 (3) (2011) pp. 303–315. https://doi.org/10.1016/j.cad.2010.12.015

[13] S. Beheshtaein, R. Cuzner, M. Savaghebi, and J. M. Guerrero, "Review on microgrids protection," *IET Gener. Transm. Distrib.* 13 (6) (2019) pp. 743–759. https://doi.org/10.1049/iet-gtd.2018.5212

[14] A. Alvarez de Sotomayor, D. Della Giustina, G. Massa, A. Dedè, F. Ramos, and A. Barbato, "IEC 61850-based adaptive protection system for the MV distribution smart grid," *Sustain. Energy, Grids Networks* 15 (October) (2018) pp. 26–33. https://doi.org/10.1016/j.segan.2017.09.003

[15] A. E. C. Momesso, W. M. Wellington, and E. N. Asada, "Adaptive directional overcurrent protection considering stability constraint," *Electr. Power Syst. Res.* 181 (December) (2019) p. 106190. https://doi.org/10.1016/j.epsr.2019.106190

[16] B. J. Brearley, R. Raja Prabu, K. Regin Bose, and V. Sankaranarayanan, "Adaptive relay co-ordination scheme for radial microgrid," *Int. J. Ambient Energy* 43 (1) (2020) pp. 2180-2193. https://doi.org/10.1080/01430750.2020.1722226

[17] S. T. P. Srinivas and K. Shanti Swarup, "A New Mixed Integer Linear Programming Formulation for Protection Relay Coordination Using Disjunctive Inequalities," *IEEE Power Energy Technol. Syst. J.* 6 (2) (2019) pp. 104–112. https://doi.org/10.1109/jpets.2019.2907320

[18] M. Dolatabadi and Y. Damchi, "Graph Theory Based Heuristic Approach for Minimum Break Point Set Determination in Large Scale Power Systems," *IEEE Trans. Power Deliv.* 34 (3) (2019) pp. 963–970. https://doi.org/10.1109/TPWRD.2019.2901028

[19] B. M. Buchholz and Z. Styczynski, *Smart grids - Fundamentals and technologies in electricity networks*, vol. 9783642451. Springer Berlin Heidelberg, 2014.

[20] M. G. Maleki, H. Javadi, M. Khederzadeh, and S. Farajzadeh, "An Adaptive and Decentralized Protection Scheme for Microgrid Protection," *Power Syst. Prot. Control Conf. (PSPC), Tehran, Iran*, no. July, 2016. https://doi.org/10.20944/preprints201907.0251.v1

[21] M. J. Daryani, A. E. Karkevandi, and O. Usta, "Multi-Agent Approach to Wide-Area Integrated Adaptive Protection System of Microgrid for Pre-and Post-Contingency Conditions," *Proc. - 2018 IEEE PES Innov. Smart Grid Technol. Conf. Eur. ISGT-Europe 2018*, pp. 1–6.

https://doi.org/10.1109/ISGTEurope.2018.8571785

[22] M. S. Rahman, T. F. Orchi, S. Saha, and M. E. Haque, "Multi-Agent Approach for Overcurrent Protection Coordination in Low Voltage Microgrids," *IEEE Power Energy Soc. Gen. Meet.*, vol. 2019-Augus, 2019. https://doi.org/10.1109/PESGM40551.2019.8974053

[23] X. Tong *et al.*, "The study of a regional decentralized peer-to-peer negotiation-based wide-area backup protection multi-agent system," *IEEE Trans. Smart Grid* 4 (2) (2013) pp. 1197–1206. https://doi.org/10.1109/TSG.2012.2223723

[24] Z. Liu, C. Su, H. K. Hoidalen, and Z. Chen, "A Multiagent System-Based Protection and Control Scheme for Distribution System with Distributed-Generation Integration," *IEEE Trans. Power Deliv.* 32 (1) (2017) pp. 536–545. https://doi.org/10.1109/TPWRD.2016.2585579

[25] Z. Liu, Z. Chen, H. Sun, and Y. Hu, "Multi agent system based process control in wide area protection against cascading events," *2013 IEEE Grenoble Conf. PowerTech, POWERTECH 2013*, pp. 445–450. https://doi.org/10.1109/PTC.2013.6652293

[26] M. Singh, B. K. Panigrahi, and A. R. Abhyankar, "A hybrid protection scheme to mitigate the effect of distributed generation on relay coordination in distribution system," *IEEE Power Energy Soc. Gen. Meet.*, pp. 13–17, 2013. https://doi.org/10.1109/PESMG.2013.6672159

[27] K. I. Tharakan, P. Sasikumar, and C. Vaithilingam, "Wireless protective relaying for smart grid," *ARPN J. Eng. Appl. Sci.* 11 (21) (2016) pp. 12756–12759.

[28] A. Yadav and A. Swetapadma, "Improved first zone reach setting of artificial neural network-based directional relay for protection of double circuit transmission lines," *IET Gener. Transm. Distrib.* 8 (3) (2014) pp. 373–388. https://doi.org/10.1049/iet-gtd.2013.0239

[29] O. Nunez, F. Valencia, P. Mendoza-Araya, R. Palma-Behnke, G. Jimenez, and J. Cotos, "Microgrids protection schemes," *CHILECON 2015 - 2015 IEEE Chil. Conf. Electr. Electron. Eng. Inf. Commun. Technol. Proc. IEEE Chilecon 2015*, no. November, pp. 597–602, 2016. https://doi.org/10.1109/Chilecon.2015.7400439

[30] H. Karimi, G. Shahgholian, B. Fani, I. Sadeghkhani, and M. Moazzami, "A protection strategy for inverter-interfaced islanded microgrids with looped configuration," *Electr. Eng.* 101 (3) (2019) pp. 1059–1073. https://doi.org/10.1007/s00202-019-00841-6

[31] P. R. Zuzelo, "Evidence-based practice methodology: Use the correct approach," *Holist. Nurs. Pract.* 32 (6) (2018) pp. 340–342. https://doi.org/10.1097/HNP.0000000000000297

[32] S. Panneer, J. R. Meenakshi, and S. Bharti, "Practice — A Methodology for Sustainable Models in the Helping Professions," *Soc. Work Educ. Res. Pract. Univ. Tamil Nadu*, pp. 161–172, 2020. https://doi.org/10.1007/978-981-15-9797-8_12

[33] D. Kusumaningsih, "Mendeley As A Reference Management and Citation Generator for Academic Articles," *Adv. Eng. Res.* 175 (ICASE-18) (2018) pp. 81–83. https://doi.org/10.2991/icase-18.2018.22

[34] T. Khurshaid, A. Wadood, S. Gholami Farkoush, J. Yu, C. H. Kim, and S. B. Rhee, "An Improved Optimal Solution for the Directional Overcurrent Relays Coordination Using Hybridized Whale Optimization Algorithm in Complex Power Systems," *IEEE Access* 7 (2019) pp. 90418–90435. https://doi.org/10.1109/ACCESS.2019.2925822

[35] K. Sarwagya, P. K. Nayak, and S. Ranjan, "Optimal coordination of directional overcurrent relays in complex distribution networks using sine cosine algorithm," *Electr. Power Syst. Res.* 187 (2020) p. 106435. https://doi.org/10.1016/j.epsr.2020.106435

[36] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, "Optimal coordination of over-current relays in microgrids considering multiple characteristic curves," *Alexandria Eng. J.* 60 (2) (2021) pp. 2093–2113. https://doi.org/10.1016/j.aej.2020.12.012

[37] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, "An Approach for Optimal Coordination of Over-Current Relays in Microgrids with Distributed Generation," *Electronics* 9 (10) (2020) p. 1740. https://doi.org/10.3390/electronics9101740

[38] G. Wang, C. Wang, X. Cai, and Y. Ji, "Distributed Leaderless and Leader-Following Consensus Control of Multiple Euler-Lagrange Systems with Unknown Control Directions," *J. Intell. Robot. Syst.*

Theory Appl. 89 (3–4) (2018) pp. 439–463. https://doi.org/10.1007/s10846-017-0554-1

[39] M. Rehan, M. Tufail, and S. Ahmed, "Leaderless consensus control of nonlinear multi-agent systems under directed topologies subject to input saturation using adaptive event-triggered mechanism," *J. Franklin Inst.* 358 (12) (2021) pp. 6217–6239. https://doi.org/10.1016/j.jfranklin.2021.06.014

[40] M. M. Eissa, "New protection philosophy for protecting complex smart grid with renewable resources penetration," *2012 IEEE Int. Conf. Smart Grid Eng. SGE 2012*, 2012. https://doi.org/10.1109/SGE.2012.6463966

[41] Z. Lin, L. Wang, Z. Han, and M. Fu, "Distributed formation control of multi-agent systems using complex laplacian," *IEEE Trans. Automat. Contr.*, 59 (7) (2014) pp. 1765–1777. https://doi.org/10.1109/TAC.2014.2309031

[42] Z. Yang, X. Pan, Q. Zhang, and Z. Chen, "Formation control of first-order multi-agents with region constraint," *Automatika* 61 (4) (2020) pp. 651–656. https://doi.org/10.1080/00051144.2020.1814979

[43] Q. Wang, Y. Wang, and H. Zhang, "The formation control of multi-agent systems on a circle," *IEEE/CAA J. Autom. Sin.* 5 (1) (2018) pp. 148–154. https://doi.org/10.1109/JAS.2016.7510022

[44] S. L. Bowman, C. Nowzari, and G. J. Pappas, "Coordination of multi-agent systems via asynchronous cloud communication," *2016 IEEE 55th Conf. Decis. Control. CDC 2016*, pp. 2215–2220. https://doi.org/10.1109/CDC.2016.7798592

[45] Q. Wang, H. Gao, F. Alsaadi, and T. Hayat, "An overview of consensus problems in constrained multi-agent coordination," *Syst. Sci. Control Eng.* 2 (1) (2014) pp. 275–284. https://doi.org/10.1080/21642583.2014.897658