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Impact of Fault Current Limiters (FCL) on the Optimization of Overcurrent Relay Settings on a Radial Distribution Network with Distributed Generation

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Abstract. The goal of this paper is to analyze the impact caused by integrating Fault Current Limiters (FCLs) in the optimization of overcurrent relay settings. This is to extensively observe and examine the optimization functions or problems with regards to time discrimination between primary and backup relay pairs in a radial distribution system. These are with relevancy to the injection of distributed generation in a radial distribution network, which generates an increase in fault current level and miscoordination between the protection systems of the electrical power system involved. FCLs as known to be a great addition in limiting damaging currents were used and observed under different variables, particularly, the location and type. Genetic algorithm was implemented in MATLAB to optimize and solve the function problem on each test case the paper focused on. The improvement focused on determining which test case performed better and has values approaching to an electrical system without any uncertainties caused by distributed generation. The results showed that inductive FCLs when installed near the distributed generator location is more effective in fault current limitation and has values approaching to the values of the operation time of the base case. On the other hand, resistive FCLs is more effective in fault current limitation and coordinating the primary and backup relay when installed adjacent to the utility generator.

Keywords: fault current limiters, overcurrent relay settings, time discrimination, distributed generation, inductive FCLs, resistive FCLs

1. Introduction

Because of the increase in demands for electricity, generally due to the growing population, and the rise of the cost of installing new power plants and transmission lines, distributed generation are being utilized. [1] Distributed generation (DG) is installed in a distribution network to fulfil extra demand at peak hours. [2-3] However, these induce negative impacts on the electrical system when installed incorrectly, e.g., fault current [4-5] and miscoordination. [6]

Planning and overseeing future needs are vital in a power system. It is the protection engineers' job to accumulate data and update the existing protection settings on the primary and backup relay once a gradual change happened in the configuration [7], for instance, injection of distributed generation. Therefore, correct design and implementation of relay pairing are needed for a system to operate properly in limiting abnormality. [8] Much effort has been devoted to most of the papers in determining the optimal location and size of DGs, simultaneously. In [9], Monte Carlo Simulation method was used to determine the best placement and sizing of FCLs with uncertainties such as generation sources and stochastic loads. As an observation from the previous studies, authors mostly focused on the miscoordination instigated by installing DGs alone [4], [10]. Meanwhile, this paper centered on the uncertainties caused by DGs on radial distribution networks, and in effect, the researchers applied different scenarios, wherein the implementation of FCLs of two locations and two types are analyzed to resolve the main problem.

The principal objective of the study is to implement FCLs as an aid in determining the optimal overcurrent relay settings of radial distribution network composed of DGs. Specifically, (1) to model the 9-Bus Canadian System using ETAP simulator, (2) to develop test cases with the implementation of the FCLs

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and DGs with a degree of uncertainty, (3) to design a load flow algorithm, (4) to implement a symmetrical fault algorithm, (5) to optimize the overcurrent relay settings using Genetic algorithm, and (6) to analyze the impact of FCLs in solving the main problem of the study.

2. Methodology

2.1. System implementation

The process begins with modelling the 9-Bus Canadian System, as well as other test cases, using ETAP simulator. Load flow analyses and symmetrical fault analyses were administered for every test case, including the base case. These analyses are vital in developing relay coordination matrix which is the principal aspect in optimizing relay setting that will act as the chromosome in the improved genetic algorithm. Lastly, comparison of results was done to verify the treatment done.

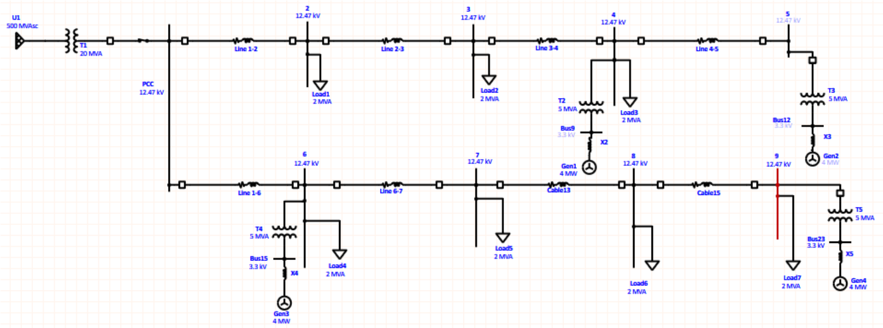

Fig. 1: 9-Bus Canadian system implemented in ETAP. [4]

The system is composed of four (4) distribution generation by which the location is predetermined. All the parameters in the system are predetermined. Test cases are determined through accumulation of data from previous studies. The base case constituted to the 9-bus Canadian system with no integration of DGs. Test case 2 highlighted the installation of four DGs as shown in Fig. 1. Meanwhile, Test cases 3 to 6 have the same parameters as the Test case 2. But as a treatment, Test case 3 and 4 have connection of FCLs adjacent to DGS with 6% and 21%, respectively. Test cases 5 and 6 have the same impedance but located adjacent to the utility generator.

Load flow analyses and symmetrical fault analyses are important conditions in planning. The researchers used the appropriate case embedded in MATLAB MATPOWER concerning the system for the current study to produce outputs such as branch data and power flows. Meanwhile, researchers generated admittance matrices in per unit values and inversing them provided fault current for respective buses – as an output for running a symmetrical fault algorithm. Lastly, Genetic algorithm was used in producing the chromosome with the fittest value with respect to the optimization function.

Relay coordination matrix is attained through employing the outputs from the two previously conducted algorithms. The A values and M values are computed from equation (1) and (2), respectively. Equation 1, as shown below, used the values of the symmetrical fault current and load flow current. OLF is the overload factor and for this paper, it was specifically appointed to be 1.5 since it is commonly used for lines, transformers, and generators. M is the plug setting multiplier and α describes the characteristics of the relay. In this paper, the values of the α, β, and L are 0.02, 0.14, and 0, respectively.

Afterwards, these values, are to be optimized using the objective function in the equation (3). Equation (4) shows the constraints applied. Optimized Time Dial Settings is the optimal solution that the improved genetic algorithm produced. Determining the optimal TDS values of each relay and consequently solving the minimum operating times can be calculated using Equation 3. These are subjected to the constraints as described in Equation 4 giving the bounds of the Time Dial Settings of each relay. It was taken as 0.025 and 1.2 seconds.

$$M=\frac{I_{fault}}{OLF*I_{pickup}} \quad (1)$$

$$A=\frac{\beta}{M^{\alpha}-1}+L \quad (2)$$

$$\min=T_1+\ldots+T_{21} \quad (3)$$

$$T_{backup}-T_{primary}\geq 0.4s \quad (4)$$

$$T_{opprimary}=A*TDS+L \quad (5)$$

$$T_{opbackup}=A*TDS+L+0.4 \quad (6)$$

The first step in the algorithm is to generate the first pool of parent chromosome which is done through setting several sets of relay settings that are randomly selected and are in relation to all the constraints introduced which contains the TDS values. In order to assess the objective function, evaluation of each chromosome must be done in order to select the only suitable chromosomes. After each iteration, a new set of TDS values belonging to the set of relays are fed to the algorithm, until a series of examinations and evaluation were done, and a new set of offspring were generated that is considered as the fittest. Having more iteration will give advantageous change to crossovers and mutations in improving the offspring.

To compare and analyze the impact of FCLs, specifically, inductive and resistive FCLs installed in a locale wherein DGs are injected and the utility grid, T-tests were utilized. This test identified if there are significant differences in the operation time of the primary and backup relays. The significance value of 0.05 was used to confirm any differences in the treatment.

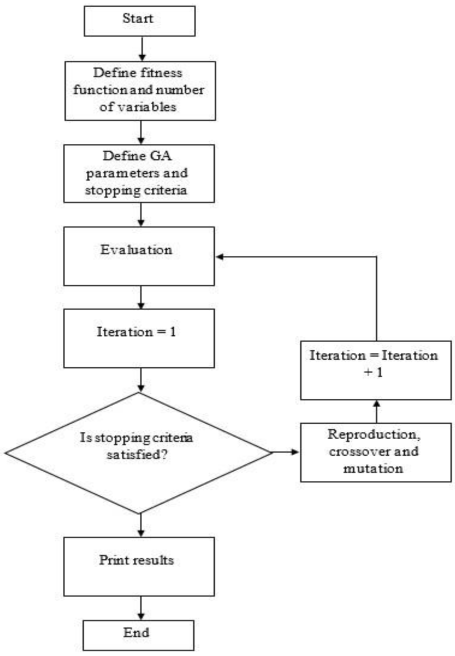

Fig. 2: Genetic algorithm flowchart. [5]

2.2. Results and discussion

Based on the composition of the A matrix, it was revealed that the injection of DGs caused an increased in fault current, especially on the buses where DGs are suddenly injected. When the values from the base case and Test case 2 were statistically compared, they have significant differences from each other. In this relation, A matrices are also in commitment to this trend since the M values are solved using these elements, which both values are used as a component in the minimization function given in Equation (3).

The program written in MATLAB produced 21 TDS values which were optimized in 10 runs. During the first run of the algorithm, the minimized objective function summed up to 119.2999438, and during the 10th run, the objective function summed up to 17.99766972.

The script written by the researchers also produced the time difference in time operation of the relay pairing. With the help of Equations 5 and 6, time operation for primary and backup relay was generated. In order to determine which performed better in fault current limitation and recovering miscoordination developed, the researchers compared the optimized time difference between the Test case 1 and other test cases. The lesser P value is considered more effective, in comparison to Test case 1, which is expected to perform without uncertainties from the DGs.

Table 1: Optimized TDS values

Relay	TDS	Relay	TDS
1	0.03680861761	12	0.07237931847
2	0.0541260202	13	0.04779414339
3	0.03314767587	14	0.1070864091
4	0.06490892402	15	0.0251675488
5	0.02802872055	16	0.1516773429
6	0.08098241542	17	0.08527851456
7	0.03208643045	18	0.08567222253
8	0.116364969	19	0.1583095227
9	0.05285954422	20	0.04662601365
10	0.04120738295	21	0.132757814
11	0.04846801166	-	-

It was revealed that the Test case 3 performed better since it has values approaching Test case 1. Test case 3, as defined in this paper is, 6% inductive FCL installed adjacent to DGs, performed better compared to Test case 4 – 21% resistive FCL installed at the same location. Although, it is expected that higher impedance would perform better, the local of the installation required lower inductive value.

On the other hand, Test case 6 has values approaching the values of Test case 1. In this paper, Test case 6 is defined as 21% resistive FCL installed at the utility generator, while Test case 5 is defined to be 6% inductive FCL installed at the same local.

Fig. 3: Comparison between test cases.

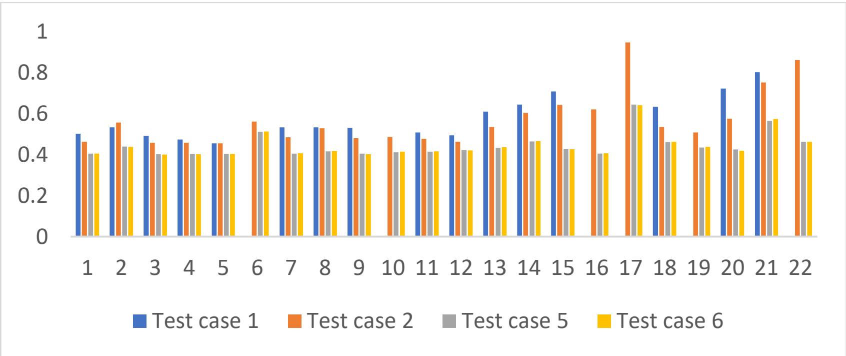

Fig. 4: Comparison between test cases.

2.3. Conclusions

Uncertainties from the injection of distributed generation require planning due to the increase in fault current level and consequently caused miscoordination between the operating time of the primary and backup relay. After the design and development of algorithm, it was heightened how important pre-fault condition, during the fault condition, and post-fault conditions are in planning a protection setting. These conditions were used to analyze the impact of FCLs on the optimization problem and constraints, especially highlighting the type and local of installation. In conclusion, it was revealed that 6% inductive FCL is more effective when installed adjacent to the distributed generations. And 21% resistive FCL is more effective at the utility generator.

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4. References

[1] S. Patil and A. Thorat, "Development of Fault Current Limiters: A Review," in *2017 International Conference on Data Management, Analytics and Innovation (ICDMAI)*, Feb. 2017, pp. 122–126.

[2] V. Singh Bhadoria, N. Singh Pal, and V. Shrivastava, "A Review on Distributed Generation Definitions and DG Impacts on Distribution System," in *International Conference on Advanced Computing and Communication Technologies (ICACCT^{TM}-2013)*, Nov. 2013. doi: 10.13140/RG.2.1.4439.4328.

[3] P. Kapoor, M. K. Singh, and Shashikant, "A Review on Distributed Generation Definitions and DG Impacts on Distribution System," in *International Journal of Innovative Science and Modern Engineering (IJISME)*, Apr. 2017, pp. 1–6.

[4] M. Abdel-Salam, M. El-Mohandes, and A. Osman, "PSO-based Protection Coordination and Power-loss Minimization in Distribution Systems with DG Sources using Optimal Fault Current Limiters," in *2019 21st International Middle East Power Systems Conference (MEPCON)*, IEEE, 2019, pp. 1119–1126. doi: 10.1109/MEPCON47431.2019.9008038.

[5] A. Alipour and M. Pacis, "Optimal Coordination of Directional Overcurrent Relays (DOCR) in a Ring Distribution Network with Distributed Generation (DG) using Genetic Algorithm," in *IEEE Region 10 Annual International Conference, Proceedings/TENCON*, Institute of Electrical and Electronics Engineers Inc., Feb. 2017, pp. 3109–3112. doi: 10.1109/TENCON.2016.7848621.

[6] A. Agheli, H. A. Abyaneh, R. M. Chabanloo, and H. H. Dezaki, "Reducing the Impact of DG in Distribution Networks Protection Using Fault Current Limiters," in *The 4th International Power Engineering and Optimization Conf. (PEOCO2010)*, 2010, pp. 298–303. doi: 10.1109/PEOCO.2010.5559205.

[7] M. A. G. Teodoro and M. C. Pacis, "System development of identifying the primary and backup pairs for directional overcurrent relays using expert theory system," in *2020 4th International Conference on Electrical, Telecommunication and Computer Engineering, ELTICOM 2020 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Sep. 2020, pp. 17–22. doi: 10.1109/ELTICOM50775.2020.9230520.

[8] J. P. Felix, K. G. Gonong, E. J. Macadaeg, M. Pacis, G. Magwili, and K. K. Quiao, "Optimal Directional Overcurrent Relay Settings Using Automated Interval Coordination Matrix Algorithm," in *2021 IEEE International Conference on Automatic Control and Intelligent Systems, I2CACIS 2021 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021, pp. 87–92. doi: 10.1109/I2CACIS52118.2021.9495904.

[9] Mohammad Amin Jarrahi, Mohammad Mohammadi, and Haidar Samet, "Optimal Placement and Sizing of Fault Current Limiters in Power Systems with Uncertainties," in *2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2019, pp. 1–6. doi: 10.1109/EEEIC.2019.8783947.

[10] M. E. Hamidi and R. M. Chabanloo, "Optimal Allocation of Distributed Generation with Optimal Sizing of Fault Current Limiter to Reduce the Impact on Distribution Networks Using NSGA-II," in *IEEE Systems Journal*, Institute of Electrical and Electronics Engineers Inc., Jun. 2019, pp. 1714–1724. doi: 10.1109/JSYST.2018.2867910.