Proceedings of IOE Graduate Conference, 2019-Winter
Peer Reviewed
Year: 2019 Month: December Volume: 7
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Coordination of Over-Current Relays in Power Distribution Networks with DG Considering Transient Stability Constraint

Shahabuddin Khan[a], Ananta Adhikari[b]

[a] *Department of Electrical Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, Nepal*
[b] *Department of Electrical and Electronics Engineering, School of Engineering, Pokhara University, Nepal*
Corresponding Email: [a] sk@wrc.edu.np , [b] anantaadhikari07@gmail.com

Abstract

Due to concern over environment and depletion of fossil fuel, there is increase in Distributed Generation integration to the system, which in turn increases problem caused by high DG penetration. At low penetration level, effect of DG on power system stability and protection are negligible, but when penetration level increases the effect of DG is no longer negligible. Both these problem can be removed by proper relay co-ordination considering transient stability of the system. In this paper, relay co-ordination of over current relay has been carried out considering transient stability as a constrained with varying nature of DG. Simplex optimization has been used to determine the relay co-ordination between relays in MATLAB. At first, relays were coordinated without considering transient stability for standard inverse relay type. Later stability of the system were checked and those relay which cause instability were changed to very inverse relay type and the system was re-coordinated to obtain optimal TDS setting for all relay's suitable for both protection as well as transient stability. The test system used was modified IEEE 14 Bus mesh system. In this paper, optimal relay co-coordination has been obtained assuring protection and stability of the system. In this research it has been found that fault current increase near the buses where DG is inter-connected and despite proper relay co-ordination the system may become unstable if Critical Clearing Time is not used as relay co-ordination constraint.

Keywords

Simplex, Distributed Generation, Transient Stability, Coordination, Relay

1. Introduction

Installing distributed generation (DG) in distribution systems has various advantages: for example, improving reliability, mitigating voltage sags, unloading sub-transmission and transmission system, and sometimes utilizing renewables. All of these factors have resulted in an increase in the use of DGs. DG penetration may adversely affect the network protection in terms of increasing fault current level which can lead to mis-coordination between Over-Current Relays(OCRs). There are mainly two types of DGs, which include synchronous and inverter-based. Synchronous based DGs inject high fault currents and result in significant changes in fault current levels [1]. M. Mansour et al [2] propose a technique for finding optimal coordination between OCRs using Modified Particle Swarm Optimizer. In this research the optimization is solved as linear programming problem considering constant DG supply. The research is carried on 3, 6 and 8 bus system and is found to be able to converge faster than other techniques. Tuning PSO has not been carried out in this work. Research can be carried out on the coordination problem of a mixed protective scheme along with DOCR. P. P. Bedekar et al [3] presents a hybrid GA-NLP method for the determination of TMS and PS of OCRs. In this research problem was formulated as non-linear objection function with an aim of reducing total time of operation of overcurrent relays and the result was compared with hybrid GA-LLP. The algorithm was tested for various system configurations, including multi loop systems, and was found to give satisfactory results and the proposed method can be easily applied to a system with combination of numerical and electromechanical relays and combination of OCRs with different characteristics. However the research doesn't consider the varying nature of DG and transient stability constraint. In previous research it has been assumed that DGs are stable during fault clearance time. However, DGs are classified as small power generation units which may lose their stability before fault clearance time. Transient stability of DG and the impact of transient stability on overcurrent protection has been discussed in [4].

Mosavi1 et al [5] have considered transient stability constraint as one of the most important factors in the optimization problem of optimal relay setting. Optimal values of TDS has been obtained for OCRs but the research doesn't consider active distribution network. T. Soleymani Aghdam et al [6] propose a novel stability constrained protection coordination problem formulation that incorporates transient stability constraints for determining the optimal relay settings. The proposed approach was tested on the IEEE-33 bus distribution system equipped with synchronous based DG and the proposed approach was compared against conventional protection coordination. The proposed scheme was capable of providing protection coordination while maintaining DG stability. However the paper doesn't consider the varying nature of DG output power. Huchel et al [7] have studied the impact of varying nature of DG power to protection system. With the increment of DG power there will be violation in protection coordination and will require frequent changes in relay settings. Research suggested a technique that can determine the optimal relay setting for OCRs considering future increase or decrease of DG power to the distribution grid. However this technique doesn't consider stability criteria for optimal OCRs co-ordination. In this paper, relay coordination has been carried out for distribution network with DG considering transient stability as a constraint.

2. Constraints of over-current relay coordination problem

In active distribution networks, usually the directional over-current relays are used as the main protection system. Directional Overcurrent protection is very common and inexpensive.

2.1 Relay's setting restriction

Each relay's picked up current has a minimum and a maximum value that is shown in Equation ((1)). These values are determined according to maximum allowable current and available settings on the relays [8]. These minimum and maximum values are considered to be 1.2 to 2 times of rated current that passed through the relays.

$$I_{Pimin} \leq I_{Pi} \leq I_{pimax} \tag{1}$$

For simplicity,

$$I_p = 1.5 \times I_{rated} \tag{2}$$

Similarly, the time delay of relays has a minimum and maximum value that is defined with current–time characteristic of relays in Equation (2). Both of the above limits are considered for all phases of optimization problem.

$$TDS_{imin} \leq TDS_i \leq TDS_{imax} \tag{3}$$

here,$TDS_{min} = 0.05 and TDS_{max} = 1$ The operation time of backup relays should be greater than that of primary relay for the same fault location. Coordination time interval (CTI) is used for this purpose. The value of CTI is chosen based on the Local Distributed Company (LDC) practice which consists of over travel time, the breaker operating time and safety margin for relay error [8]. This value for electromechanical relays is chosen to be 0.2. [6].

$$t_{j,i} – t_i \geq CTI_{j,i} \quad \forall i, j \in N \tag{4}$$

In the above equation ti is operating time of ith primary relay for near end fault at i. tj,i is operating time of the backup jth relay for a near end fault at the ith relay that is obtained by Equation (4).

$$t_{j,i} = TDS\left\{\frac{A}{M_{j,i}^{C} - 1} + B\right\} \tag{5}$$

where

$$M_{j,i} = \frac{I_{f_{j,i}}}{I_{p_j}}$$

In Equation(4), $I_{fj,i}$ is j^{th} relay's fault current for near-end fault at thei^{th} relay (in Amp). TDS is time delay setting, IP is relay's pickup current and A, B, C are constants whose values depend on the type of relays.

Table 1: ANSI/IEEE and IEC standard for overcurrent Relay

Curve Description	Standard	A	B	C
Moderately Inverse	IEEE	0.02	0.0515	0.114
Very Inverse	IEEE	2.0	19.61	0.491
Standard Inverse	IEC	0.02	0.14	0

2.2 Constraints of transient stability

If a fault remains in the network for a certain time, the network may become unstable. The maximum time in which the network transient stability is ensured during the fault is called Critical Clearing Time (CCT). This time must be considered in relays coordination, and the operation time of each relays should be lesser than its corresponding CCT. Therefore, an additional constraint that ensures the transient stability of the network will be added to the optimization problem as follows:

$$t_{Fi}^{pr} \leq CCT_{Fi} \forall i \in N \tag{6}$$

In this equation, t_{Fi}^{pr} is the operation time of i^{th} relay for fault at the beginning of its zone protection and CCT_{Fi} is critical clearing time ofi^{th} relay for the same earlier fault (Fi). The swing equation with damping neglected, for machine i is

$$\frac{h_i}{\pi_{fo}}\frac{d^2\delta\delta}{dt^2} = P_{mi} - \Sigma_{j=1}^{n}|E_i^r||E_j^r||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{7}$$

Where Y_{ij} are the elements of the faulted reduced bus admittance matrix and h_i is the inertia constant of machine i expressed on the common MVA base S_B.

3. Proposed objective function

Minimize

$$T_{OPR} = \Sigma_{I=1}^{N}\Sigma_{J=1}^{M}\Sigma_{S=1}^{L}\left\{t_{ij,s}^{p} + t_{ij,s}^{b}\right\} \tag{8}$$

where N is the set of all fault locations, M is the set of all system relays, and L is the set of all examined combinations. $t_{ij,s}^{p}$ and$t_{ij,s}^{b}$ are respectively the operating times of primary and back-up relay for the fault at location i and for combination s of DG capacities. L is determined considering DG variation at 10% resolution

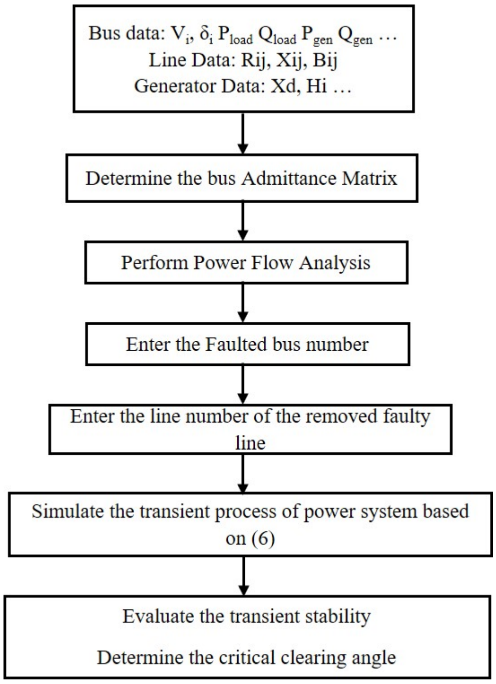

Figure 1: Flowchart for Transient stability Analysis

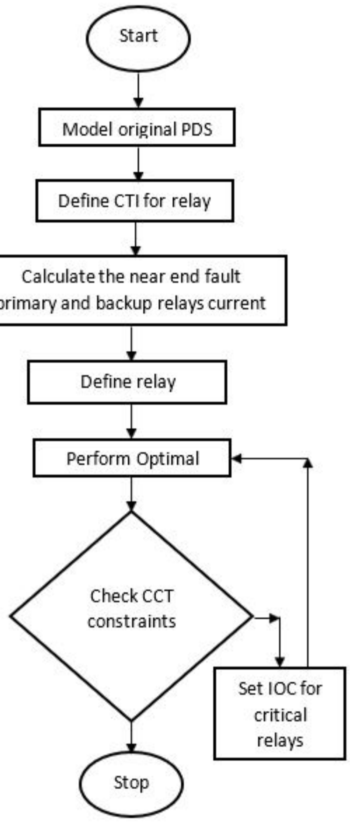

Figure 2: Flowchart for Optimal Relay Setting

4. Effect of DG on Fault Current

The objective function with constrained is tested on Modified IEEE 33 Bus System and as shown in figure 4, the fault current has been increased when DG is considered in the system.

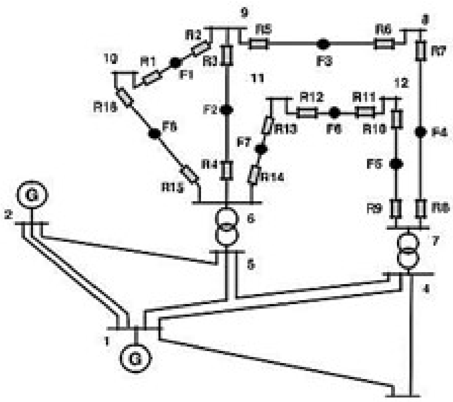

Figure 3: Modified IEEE 14 Bus

It is seen that fault current has increased in large amount to those buses which are nearer to bus where DG is integrated. It is due to the fact that DG act as supply and its impedance is being connected in parallel with the network which reduces overall impedance and hence fault current increases.

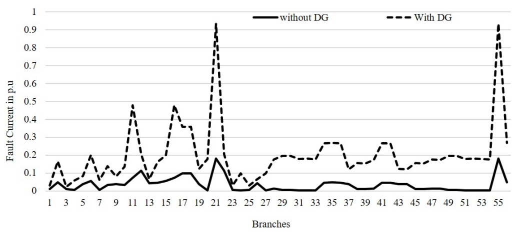

Figure 4: Fault Current in Relay Pair with and Without DG

5. Stability and Relays Operating Time

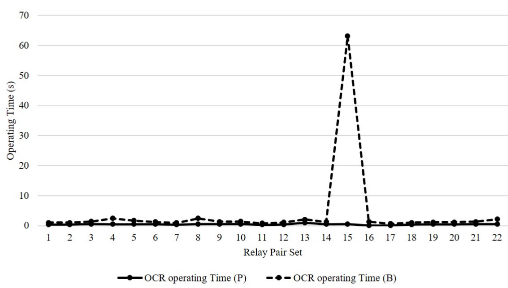

Figure 5: OCR operating time without DG

Relay Co-ordination between OCR's has been obtained for three cases: without DG as shown in figure 5, with varying DG power as shown in figure 6 and with varying DG considering transient stability as shown in figure 7.

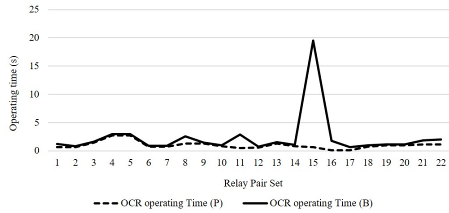

Figure 6: OCR time between Primary and Back-up relay with varying DG power

Table 2: CCTS AND OCRS OPERATING TIMES without CCT consideration

Relay Number	Critical Clearing Time(s)	OCR operating Time(s)
4	0.098	0.8528
8	0.125	0.5217
9	0.124	0.5604
10	0.3	1.3326
11	0.33	0.8275
14	0.11	0.7573
15	0.099	0.9549

Table 3: CCTS AND OCRS OPERATING TIMES with CCT consideration

Relay Number	Critical Clearing Time(s)	OCR operating Time(s)
4	0.098	0.0958
8	0.125	0.0841
9	0.124	0.059
10	0.3	0.1061
11	0.33	0.0718
14	0.11	0.0731
15	0.099	0.0741

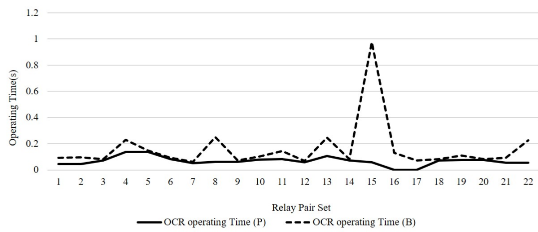

Figure 7: OCR time between Primary and Back-up relay with varying DG power and transient stability in consideration

Despite proper optimal OCR coordination for overall DG as shown in figure 6, the operation of relay nearer to the DG connected buses cause instability to the DG system. It is because the system CCT are less than OCR operating time to clear a fault as verified from table 2. This problem can be removed by changing the type of OCR from standard inverse to very inverse and the system will remain stable as shown in table 3.

Table 4: Relay Co-ordination Considering CCT

Fault Location	Primary Relay	Backup Relay	Primary Relay operating Time(s)	Backup Relay operating Time(s)
15	1	15	0.0442	0.0928
15	1	4	0.0442	0.0958
15	2	6	0.0719	0.0819
16	3	15	0.1382	0.2302
16	3	2	0.1382	0.1482
16	3	7	0.0819	0.0919
17	5	1	0.0512	0.0621
17	6	14	0.063	0.2498
17	6	16	0.063	0.073
18	7	9	0.0786	0.10470
18	8	3	0.0841	0.1436
19	9	12	0.059	0.069
19	10	8	0.1061	0.2469
20	11	10	0.0718	0.0818
20	12	3	0.0587	0.9755
21	13	5	0.0011	0.1301
21	13	9	0.0011	0.0718
21	14	11	0.0731	0.0831
22	15	14	0.0741	0.1115
22	15	5	0.0741	0.0841
22	16	2	0.0558	0.0935

Table 4 represents the operating time of the relay pair when DG is interconnected to the system and stability constraint is also considered.

6. Conclusions

With the increasing amount of DG in the system, the system becomes active and there arise a concern over protection system and stability of such system.

In this paper, first an IEEE 14 bus mesh system has been analyzed without integration of DG and the fault current and relay co-ordination has been found using simplex method. In next stage, two DG has been interconnected at Bus 6 and 9 with inertia and fault current analysis and relay co-ordination considering DG to be fixed output source has been performed. It was found that the fault current near DG integration has been increased. It is due to connection of DG's impedance in parallel with the impedances near the DG so overall impedance reduces. Hence fault current increases.

Later the same system has been analyzed considering DG's output power vary by a resolution of 0.1 and proper relay co-ordination has been found. It is seen that when some of the relay were operated, the DG system becomes unstable. This is because the DG's Critical clearing time is less than relay's fault clearing time. Despite proper co-ordination of relays considering DG, the operation of relay may cause instability to the DG's with inertia. So, the relay must be coordinated considering both effect of DG and stability for inertial DG. Considering both criteria, relay's operating time has been found which are best suited for DG connected system along with maintain stability.

References

[1] Natthaphob Nimpitiwan, Gerald Thomas Heydt, Raja Ayyanar, and Siddharth Suryanarayanan. Fault current contribution from synchronous machine and inverter based distributed generators. *IEEE Transactions on power delivery*, 22(1):634–641, 2006.

[2] Mohamed M Mansour, Said F Mekhamer, and Nehad El-Kharbawe. A modified particle swarm optimizer for the coordination of directional overcurrent relays. *IEEE transactions on power delivery*, 22(3):1400–1410, 2007.

[3] Prashant Prabhakar Bedekar and Sudhir Ramkrishna Bhide. Optimum coordination of directional overcurrent relays using the hybrid ga-nlp approach. *IEEE Transactions on Power Delivery*, 26(1):109–119, 2010.

[4] Amir Alipour and Michael Pacis. Optimal coordination of directional overcurrent relays (docr) in a ring distribution network with distributed generation (dg) using genetic algorithm. In *2016 IEEE Region 10 Conference (TENCON)*, pages 3109–3112. IEEE, 2016.

[5] Mazheruddin Hussain Syed, Hatem Hussein Zeineldin, and Mohamed Shawky El Moursi. Hybrid micro-grid operation characterisation based on stability and adherence to grid codes. *IET Generation, Transmission & Distribution*, 8(3):563–572, 2013.

[6] S Mohammad Ali Mosavi, Tohid Akbari Kejani, and Hamid Javadi. Optimal setting of directional over-current relays in distribution networks considering transient stability. *International Transactions on Electrical Energy Systems*, 26(1):122–133, 2016.

[7] Tohid Soleymani Aghdam, Hossein Kazemi Karegar, and Hatem H Zeineldin. Transient stability constrained protection coordination for distribution systems with dg. *IEEE Transactions on Smart Grid*, 9(6):5733–5741, 2017.

[8] Łukasz Huchel and Hatem H Zeineldin. Planning the coordination of directional overcurrent relays for distribution systems considering dg. *IEEE Transactions on Smart Grid*, 7(3):1642–1649, 2015.