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# Optimal Protection Coordination for Microgrid with Grid Connected and Islanded Capabilities Using Dual Setting Directional Over Current Relays

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**Abstract**
Due to the increasing interest in distributed generation(DG) at various levels microgrid concepts have developed. A microgrid can operate either in islanded mode or in grid mode. In grid mode both connected grid and distributed generator contributed fault current but in islanded mode only DG contributed to fault current. Fault current level difference between different modes of microgrid operation is the main challenge in protection coordination. Directional overcurrent relays (DOCRs) are used as main protection equipment for the microgrid. DOCRs must detect and eliminate fault in both modes of operation, while coordination constraints between backup and primary relay are maintained. DGs in the distribution system cause bidirectional power flow. So it is better to have a relay that can respond differently for both directions. In this paper dual setting DOCRs are used which have two different settings for a different direction. A Genetic algorithm has been used as an optimization technique to determine optimal relay setting and coordination between relays in MATLAB. 9 bus Canadian distribution system is used as test system. In this research, it has been found that one optimal relay setting can be used for both grid mode and islanded modes of operation. In addition, the primary and backup relay can be coordinate effectively for the protection of microgrid without violating protection system constraints. The result shows that using dual setting DOCR total relay operation time in both primary and backup relay can be minimized compared to conventional DOCR.

**Keywords**
Microgrid, Genetic Algorithm (GA), Protection Coordination, DOCR,DG

## 1. Introduction

Microgrids is active distribution networks having different distributed generator, energy storage and loads [1]. Worldwide development of renewable energy resource has become an important due to climate change, air pollution and global warming caused by greenhouse effects.Renewable energy sources like wind, solar, hydro, etc are important sources of energy for the future which are commonly available in nature and can be connected directly at low voltage distribution levels. To transmit power from generating station to consumer level DG does not require high voltage transmission lines[2]. Distributed generation can be referred to any electricity-generating technology unit located in the effective point of the electrical distribution system near the load center to fulfill the demand of increasing load, cover future demand, decrease transmission loss, and better energy transfer. Due to the increasing interest of DGs in various level microgrid concepts have developed[3].

Protection scheme in power system network is used to clear the fault as quickly as possible to isolate little section as possible. The protection scheme must ensure that the relay can distinguish between normal and abnormal conditions[4]. For any fault occurring on a line, the first line of defense is primary protection, in case primary protection fail to operate, the second line of defense i.e. backup protection must operate after certain time delay.[5].Due to the integration of DG, the nature of the distribution system has changed. conventional distribution has a radial structure in which power flow in single direction but the connection of DG in the distribution system cause power flow bidirectional.

The Main challenge in microgrid protection is different SC levels between different modes of operation. During abnormal condition both connected DG and main grid supply fault current in grid mode whereas, in islanded mode only connected DG supply fault current[6]. Due to additional fault power supply from grid SC level in grid mode is higher than islanded mode[7]. The contribution of fault current in the system depends on the nature and type of the distribution network (radial or meshed) as well as the type of DG[8]. Inverter-based DGs inject low fault current because of controller limiter whereas synchronous generators have a significant effect on the short circuit level.

## 2. Single- Setting and Dual- Setting DOCR

The shape of relay characteristics is mainly defined by two settings, Pickup current setting(Ip) and Time Dial Setting(TDS). Figure 1 shows, three bus meshed network having three bus with six number of conventional type directional overcurrent relays. conventional type DOCR operates only in forward direction. if fault occur in forward direction relay near to fault acts as a primary relay and in case it fails to operate the relay in same direction acts as a backup relay. In single setting DOCR, if fault occurs at point A primary relay are R1 and R2 in case primary relay fail to operate R5 and R6 will act as backup relay respectively. This type of relay has only one setting for fault in a forward direction and it does not operate in a reverse direction.

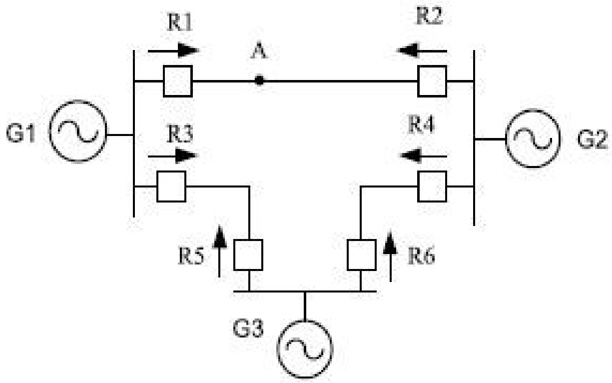


**Figure 1:** Conventional DOCR

New dual setting DOCRs have dual property which can operate in both forward and reverse direction. If fault current flows in forward direction relay act as a primary relay[9] and if fault current flows in opposite direction same relay acts as backup relay. These types of the relay have two different pair of setting in one relay.

Figure 2 shows an example of a distribution system having three bus and six dual setting DOCR[10]. Arrow denotes the relay operation directions. For the same fault in point A, primary relay are relay R1 and R2, and R3 and R4 act as their backup relay respectively. In this case relay R1 and R2 use forward setting (TDSfw1, Ipfw1) & (TDSfw2, Tpfw2) and acts as primary protection and relay R3 and R4 use reverse setting (TDSrv3, Iprv3) and (TDSrv4, Iprv4) respectively and acts as backup relays.

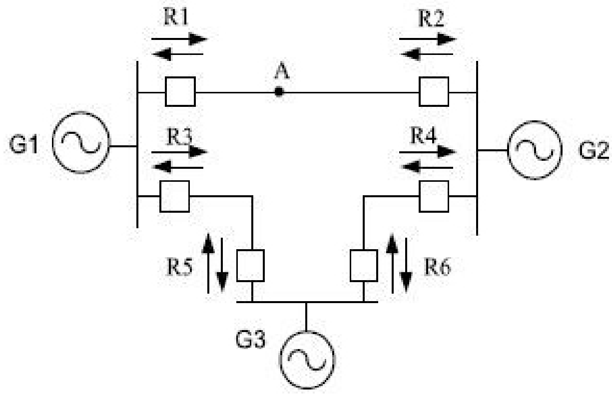


**Figure 2:** Dual-Setting DOCR

## 3. Methodology

### 3.1 Problem Formulation

In conventional DOCR operation time of relay is an inverse function of the SC current flowing through it. Two parameters used to define this function are TDS of the relay and Ip (minimum value above which relay starts to operate). The general representation of these characteristics is:

$$t_{ij} = TDS\frac{A}{(\frac{I_{sc}}{I_{pi}})^B - 1} \quad (1)$$

Where,$i$ and $j$ represent the relay identifier and the fault location identifier respectively. A and B are constants and vary according to the type of DOCR used. In this paper, DOCR having standard inverse characteristics are chosen where value of A and B is set to 0.14 and 0.02 respectively.

The dual setting DOCR operation time can be expressed as follows:

$$t_{ij}^{p} = TDS_{fwi}\frac{A}{(\frac{I_{scij}}{I_{pfwi}})^{B}-1} \quad (2)$$

$$t_{ij}^{b} = TDS_{rvi}\frac{A}{(\frac{I_{scij}}{I_{prvi}})^{B}-1} \quad (3)$$

where, $TDS_{f}wi$ is time dial setting in forward direction, $I_{pfwi}$ is pickup current setting in forward direction and $t_{fwij}^{p}$, is operation time of relay i when the relay acts as primary protection and $TDS_{rvi}$ is time dial setting in reverse direction, $I_{prvi}$ is pickup current setting in reverse direction and $t_{rvij}^{p}$ is operation time of relay i when it acts as a backup protection[11].

## 3.2 Constraints

Equation 4 shows the maximum and minimum value of pickup current.

$$\&I_{pimin} \leq I_{pfwi}, I_{prvi} \leq I_{pimax} \quad (4)$$

Where, $I_{pimax}$ and $I_{pimin}$are the maximum and minimum values in forward and reverse direction of relay i.

$$\&TDS_{imin} \leq TDS_{fwi}, TDS_{rvi} \leq TDS_{imax} \quad (5)$$

where,$TDS_{imax}$ and $TDS_{imin}$ are the maximum and minimum value of Time dial setting in forward and reverse direction of relay i.

Coordination time interval (CTI) represent the time interval between backup relay and primary relay.[12]. In protection system, relay operation time of primary must be faster than backup relay. It is set to be 0.2, in this paper.

$$t_{rvij}^{b} - t_{fwij}^{p} \geq CTI \quad (6)$$

## 3.3 Objective Function

The objective function is to minimize the relay operation time for both primary and backup relays, while maintaining the condition of protection coordination using dual setting relays for microgrid considering both mode grid-connected and islanded mode.

$$MinimizeT = \sum_{c=1}^{c}\sum_{i=1}^{N}\sum_{j=1}^{M}(t_{fwcij}^{p} + \sum_{k=1}^{k} t_{rvcij}^{b}) \quad (7)$$

Where c is the microgrid operation mode identifier. M and N is the total number of fault location and the total number of relays. $t_{fwcij}^{p}$ is operation time of primary relay i in the forward direction during fault at j. $t_{rvcij}^{b}$ is operation time of backup relay i in the reverse direction for fault at j. k represents the total number of backup relay for a fault at j.

The methodology followed in this study is summarized in flowchart depicted in Figure 3.

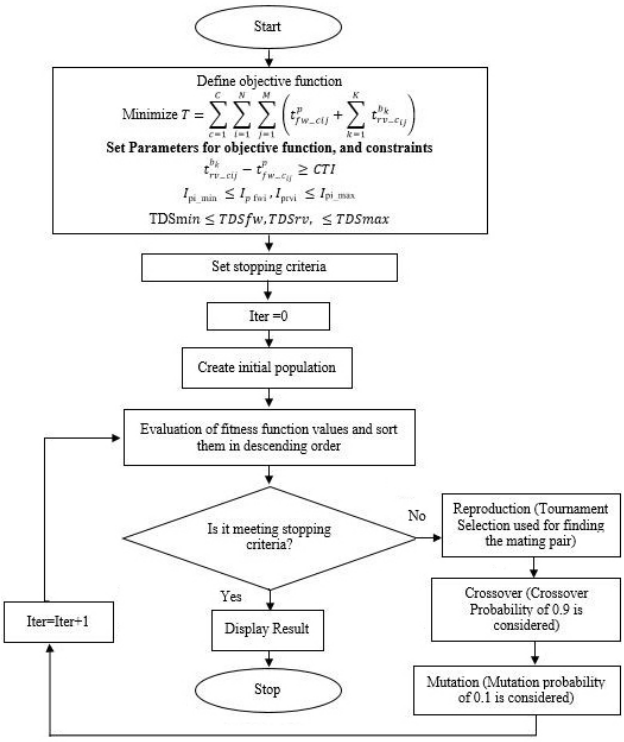


**Figure 3:** Flowchart of the optimization algorithm

General Step to find optimal relay setting and operation time of relays.

1. Read the microgrid network bus data and line data (i.e. real power, reactive powerand branch impedance of each load node).
2. Run load flow and short circuit analysis, and save all branch current magnitude, short circuit level and fault current level of all fault location.
3. Define objective function and all constraints of protection coordination scheme.
4. Set stopping criteria.
5. Set Iter=0.
6. Create initial population (define number length of chromosomes and number of population).

7. Evaluate fitness function and sort them in descending order

8. Perform Reproduction to find best solution for mating using tournament selection procedure.

9. Increase number of iteration by 1 until stopping criteria is not met.

10. Display result if stopping criteria met.

## 4. Result and Discussion

The Main objective of this works is to find an optimal relay setting that work for both modes of microgrid operation.Figure 4 shows 9 bus Canadian distribution system . The objective function with constraints is tested on 9 bus system.

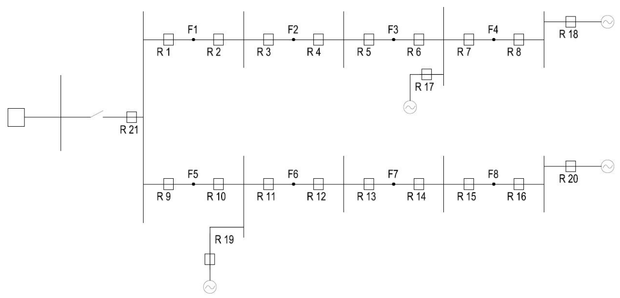


**Figure 4:** 9 bus test system

The system has one 20 MVA, 115/12.47 kV substation transformer connected at bus 1. Four DG units each rated 5MVA are connected at a different bus. Line impedance is 0.1529+j0.1406 ohm/km having 500m length. System uses 21 dual setting DOCR as protection device. The current transformer ratio of each dual setting DOCR in this system is 500:1A. Due to short electrical distribution lines in the microgrid system three-phase midpoint fault along the line are considered. Eight additional nodes are considered at a midpoint in the system to analyze the short circuit. Due to the existence of DG the microgrid system. Each fault is deals with at least two main relays, one from each side, and every main relay has a backup relay for protection[13].

In a grid mode, both utility grid and DGs contribute SC current during an abnormal condition, whereas in islanded mode only connected DGs contribute fault current in the system. Figure 5 shows that the SC current level difference in grid mode and in islanded mode.

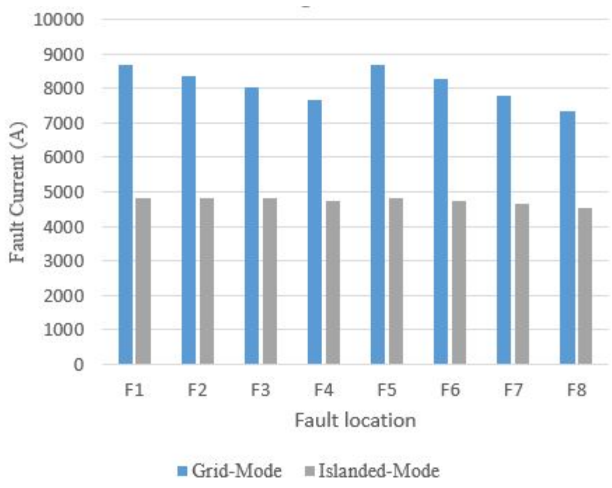


**Figure 5:** Different fault level in grid mode and in islanded mode

**Table 1:** Optimal Relay Settings for Dual Mode of Microgrid

| S.No | $TDS_{fw}$ | $TDS_{rv}$ | $Ip_{fw}$ | $Ip_{rv}$ |
|---|---|---|---|---|
| R1 | 0.1000 | 0.1506 | 0.2710 | 0.2710 |
| R2 | 0.1000 | 0.2172 | 0.2711 | 0.2711 |
| R3 | 0.1000 | 0.1725 | 0.3243 | 0.3243 |
| R4 | 0.1000 | 0.2181 | 0.3244 | 0.3243 |
| R5 | 0.1000 | 0.1522 | 0.4865 | 0.4865 |
| R6 | 0.1000 | 0.1746 | 0.4864 | 0.4865 |
| R7 | 0.1000 | 0.1419 | 0.3461 | 0.3465 |
| R8 | 0.1000 | 0.5279 | 0.3460 | 0.3900 |
| R9 | 0.1000 | 0.1750 | 0.2009 | 0.2009 |
| R10 | 0.1000 | 0.2171 | 0.2009 | 0.2020 |
| R11 | 0.1000 | 0.1467 | 0.2130 | 0.2130 |
| R12 | 0.1000 | 0.1904 | 0.2131 | 0.2130 |
| R13 | 0.1000 | 0.2296 | 0.0339 | 0.0658 |
| R14 | 0.1000 | 0.3301 | 0.0338 | 0.0345 |
| R15 | 0.1000 | 0.1222 | 0.2396 | 0.2396 |
| R16 | 0.1000 | 0.9872 | 0.2398 | 0.2398 |
| R17 | 0.1000 | 0.1171 | 0.24913 | 0.4915 |
| R18 | 0.1000 | 0.1310 | 0.4840 | 0.4840 |
| R19 | 0.1000 | 0.100 | 0.5735 | 0.5735 |
| R20 | 0.1000 | 0.1211 | 0.4622 | 0.4626 |
| R21 | 0.1000 | 0.2371 | 0.1137 | 0.1139 |

Table 1 shows the value of optimal relay settings obtained form optimization algorithm for forward and reverse direction.

**Table 2:** Relay Operation Times for midway Faults in a Grid-Connected Mode

| Fault Location | Operation time of relays in sec. | | |
|---|---|---|---|
| | Primary Relay | Backups relay | |
| F1 | R1fw | R9rv | R21rv |
| | 0.175 | 0.375 | 0.517 |
| | R2fw | R3rv | |
| | 0.238 | 0.468 | |
| F2 | R3fw | R2rv | |
| | 0.187 | 0.477 | |
| | R4fw | R5rv | |
| | 0.253 | 0.468 | |
| F3 | R5fw | R4rv | |
| | 0.217 | 0.478 | |
| | R6fw | R7rv | R17rv |
| | 0.294 | 0.551 | 0.544 |
| F4 | R7fw | R6rv | R17rv |
| | 0.186 | 0.478 | 0.552 |
| | R8fw | R18rv | |
| | 0.367 | 0.577 | |
| F5 | R9fw | R1rv | R21rv |
| | 0.201 | 0.463 | 0.475 |
| | R10fw | R11rv | R19rv |
| | 0.211 | 0.458 | 0.504 |
| F6 | R11fw | R10rv | R19rv |
| | 0.160 | 0.478 | 0.512 |
| | R12fw | R13rv | |
| | 0.277 | 0.497 | |
| F7 | R13fw | R12rv | |
| | 0.201 | 0.418 | |
| | R14fw | R15rv | |
| | 0.203 | 0.490 | |
| F8 | R15fw | R14rv | |
| | 0.171 | 0.472 | |
| | R16fw | R20rv | |
| | 0.290 | 0.524 | |

Table 2 present the relay operation times in grid mode for different fault locations. Obtained results shows that the coordination between backup and main relay is achieved in all fault locations. In case of fault at point 6, R10 and R19 are the backup relays for R11 and R13 is the backup relay for R12.In this case, the forward setting of relay R11fw and R12fw operate in 0.160s and 0.277s respectively. while the reverse setting of backup relay R10rv, R19rv, and R13rv operate in 0.478s, 0.512s, and 0.497s respectively. The total relay operation time is 14.208sec for grid-connected mode.

**Table 3:** Relay Operation Times for midway Faults in Islanded Mode

| Fault Location | Operation time of relays in sec. | | |
|---|---|---|---|
| | Primary Relay | Backups relay | |
| F1 | R1fw | R9rv | |
| | 0.236 | 0.444 | |
| | R2fw | R3rv | |
| | 0.238 | 0.468 | |
| F2 | R3fw | R2rv | |
| | 0.235 | 0.563 | |
| | R4fw | R5rv | |
| | 0.253 | 0.468 | |
| F3 | R5fw | R4rv | |
| | 0.305 | 0.602 | |
| | R6fw | R7rv | R17rv |
| | 0.294 | 0.551 | 0.544 |
| F4 | R7fw | R6rv | R17rv |
| | 0.318 | 0.566 | 0.546 |
| | R8fw | R18rv | |
| | 0.367 | 0.577 | |
| F5 | R9fw | R1rv | |
| | 0.215 | 0.498 | |
| | R10fw | R11rv | R19rv |
| | 0.211 | 0.458 | 0.504 |
| F6 | R11fw | R10rv | R19rv |
| | 0.199 | 0.518 | 0.506 |
| | R12fw | R13rv | |
| | 0.277 | 0.497 | |
| F7 | R13fw | R12rv | |
| | 0.204 | 0.418 | |
| | R14fw | R15rv | |
| | 0.203 | 0.490 | |
| F8 | R15fw | R14rv | |
| | 0.205 | 0.696 | |
| | R16fw | R20rv | |
| | 0.290 | 0.524 | |

Table 3 present the relay operation times in the islanded mode for different fault locations . Obtained results shows that the coordination between backup and primary relay is achieved in all fault locations. In case of fault at point 6, R10 and R19 are the backup relays for R11 and R13 is the backup relay for R12. In this case, the forward setting of relay R11fw and R12fw operate in 0.199s and 0.277s respectively. while the reverse setting of backup relay R10rv, R19rv, and R13rv operate in 0.518s, 0.506s, and 0.497s respectively. The total relay operation time is 14.506 sec for islanded mode.

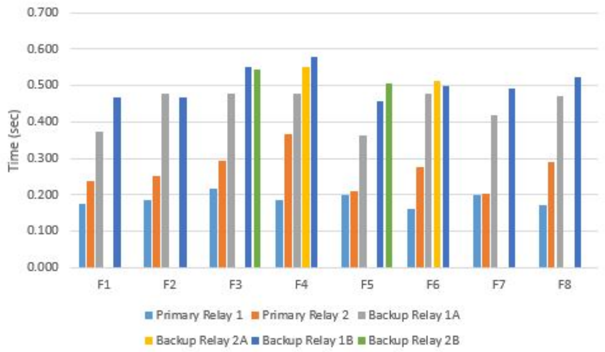


**Figure 6:** CTI between Backup and Main Relay operation time in grid mode

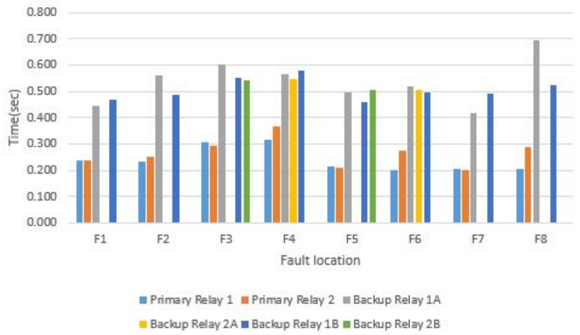


**Figure 7:** CTI between Backup and Main Relay operation time in islanded mode

Figure 6 and Figure 7 show the CTI between backup and main relay operation time in grid mode and in islanded mode respectively. it shows that the CTI between primary and backup relay is achieved which is more than 0.2 sec.

## 5. Conclusions

Microgrid have different levels of fault current in different operation mode. The fault current level in islanded mode is lower compared to grid mode. In this paper, to find one optimal relay setting that work for both operation mode a new dual setting directional overcurrent relay has been used. In this thesis, 9 bus Canadian distribution system has been analyzed with DG. Load flow and short circuit analysis have been done using DIgSILENT software and from the obtained data using optimization algorithm (GA) optimal relay setting has been found. The obtained result shows that one optimal setting can be used for both operation mode of microgrid. In addition, without violating protection system constraints of microgrid, the main and backup relay can be coordinate effectively. Comparative to conventional single setting DOCR, the overall relay operation time can be minimized using Dual setting DOCR.

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