Electronics Research institute
CrossMark
Journal of Electrical Systems and Information Technology 3 (2016) 320–332
www.elsevier.com/locate/jesit

# Adaptive protection coordination scheme for distribution network with distributed generation using ABC

A.M. Ibrahim [a,*], W. El-Khattam [a], M. ElMesallamy [b], H.A. Talaat [a]

[a] *Faculty of Engineering, Ain Shams University, Egypt*
[b] *ABB, Egypt*

Received 13 October 2015; accepted 5 November 2015
Available online 2 August 2016

**Abstract**

This paper presents an adaptive protection coordination scheme for optimal coordination of DOCRs in interconnected power networks with the impact of DG, the used coordination technique is the Artificial Bee Colony (ABC). The scheme adapts to system changes; new relays settings are obtained as generation-level or system-topology changes. The developed adaptive scheme is applied on the IEEE 30-bus test system for both single- and multi-DG existence where results are shown and discussed.


*Keywords:* Adaptive protection; Artificial Bee Colony; Directional over current relay; Distribution generation; Optimal coordination

## 1. Introduction

The electrical power system may be subjected to many types of faults during its operation that can damage the equipment connected to this system, so the importance of designing a reliable protective system arises, in order to achieve such reliability, a back-up protective scheme is provided in case of any failure in the primary protection. The back-up scheme should not operate unless the primary fails to take the appropriate action, which means it should operate after a certain time delay known as coordination time interval (CTI), giving the chance for the primary protection to operate first. The above mentioned scenario leads to the formulation of the protective relay coordination, which consists of selection of a suitable setting of each relay such that their fundamental protective function is met under the desirable qualities of protective relaying, namely sensitivity, selectivity, reliability, and speed (Anderson, 1999). However, introducing DG into the power system territories changes the existing protection scheme. Although DG has a lot of advantages on system design and operation (Griffin, 2000), also it has negative effects as well, one of these negative

* Corresponding author.
*E-mail addresses:* amrmohamedhassan@yahoo.com (A.M. Ibrahim), walid_el_khattam@hotmail.com (W. El-Khattam), mostafa_eg21@hotmail.com (M. ElMesallamy), hossam_talaat@eng.asu.edu.eg (H.A. Talaat).
Peer review under the responsibility of Electronics Research Institute (ERI).

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jesit.2015.11.012

effects is its effect on system protection, especially the disturbance caused to the existing relay coordination (Girgis and Brahma, 2001). This disturbance is caused by the change in value and direction of both the system's power flow (under normal operation) and short-circuits current (under fault conditions) (Barker and de Mello, 2000). The impact of DG depends on DGs: size, location, technology type, and method of interconnection with the power system (Brahma and Girgis, 2004). Due to of these impacts, the setting of all protection relays have to be checked to ensure that no mis-coordination happened in the system, and if there was, the optimal protective relays' settings have to be determined and set again, these leads to the introduction of adaptive protection scheme. One of the techniques that can be used to get the optimal settings is the ABC; which was introduced in Karaboga and Busturk (2007), that was motivated by the intelligent behavior of honey bees. ABC as an optimization tool provides a population-based search procedure in which individuals called foods positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar which is the optimal solution is selected.

## 2. Coordination problem formulation

DOCR coordination problem can be formulated as optimization problem, where the objective function to be minimized is the sum of the operating times of the relays connected to the system function in its Time Dial Setting TDS (Urdaneta et al., 1988). The above problem can be formulated mathematically as:

$$\min \sum_i \sum_j T_{ij_{\text{primary}}} \tag{1}$$

where $T_{ij}$ is the operating time of the primary relay $i$ for a fault $j$.

In this work, the following formula is used to approximately represent the OCR characteristics (IEC60255-3):

$$T = K_1 \frac{\text{TDS}}{M^{K_2} + K_3} \tag{2}$$

where

$$M = \frac{I}{I_{\text{P}}} \tag{3}$$

$I$ is relay current, $I_{\text{p}}$ is the relay's pickup current and $K_1$, $K_2$, $K_3$ are constants depending on the type of the relay simulated.

The coordination problem is subject to the following constraints (Urdaneta et al., 1988):

1) Coordination criteria: in order to achieve a reliable protection system, the primary protection has to be backed up by another protection scheme. The two protective schemes should be coordinated together, i.e., a predefined CTI collapses before the backup scheme comes into action. This CTI depends upon the type of the relays (electromechanical or microprocessor based), speed of the circuit breakers, and other system parameters.

$$T_{\text{backup}} - T_{\text{primary}} \geq \text{CTI} \tag{4}$$

2) Relay settings bounds: the main target of DOCR coordination study is the calculation of its TDS and $I_{\text{P}}$.

$$\text{TDS}_{i\min} \leq \text{TDS}_i \leq \text{TDS}_{i\max} \tag{5}$$

$$I_{\text{P}_{i\min}} \leq I_{\text{P}_i} \leq I_{\text{P}_{i\max}} \tag{6}$$

In this paper, the coordination problem is addressed as a linear optimization one, i.e., ABC is used to solve coordination problem of finding TDS of the relays for a given IP's. Also it should be clear that ABC is capable of addressing both linear and non-linear optimization problems.

## 3. Artificial Bee Colony ABC

Artificial Bees Colony algorithm (Karaboga and Busturk, 2007) was proposed for solving numerical optimization problems, it was used in relay coordination in Uthitsunthorn et al. (2012). ABC shows great results in DOCR coordination in ElMesallamy (2014). The colony of artificial bees contains three groups of bees: employed bees and unemployed bees: onlookers and scouts. First half of the colony consists of employed artificial bees and the second half constitutes the artificial onlookers. The employed bee whose food source has been exhausted becomes a scout bee. The position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality or fitness of the associated solution. The number of the employed bees is equal to the number of food sources, each of which also represents a site, being exploited at the moment or to the number of solutions in the population. In artificial bees' algorithm, the steps given below are repeated until a stopping criterion is satisfied.

### *3.1. Initial phase*

Swarms are created randomly by the following formula in the initial phase:

$$X_{ij} = X_{\min j} + rand\,(0, 1)\left(X_{\max j} - X_{\min j}\right) \tag{7}$$

### *3.2. Employed bees phase*

Each employed bee determines a food source representing a site. Each employed bee shares its food source information with onlookers waiting in the hive and then each onlooker selects a food source site depending on the information taken from employed bees. To simulate the information sharing by employed bees in the dance area, probability values are calculated for the solutions by means of their fitness values using the following equation. The fitness values might be calculated using the above definition as expressed in Eq. (8).

$$Pf_i = \frac{f_{iti}}{\sum_{j=1}^{n} f_{iti}} \tag{8}$$

$$f_{iti} = \begin{cases} \dfrac{1}{a + f_i} & fi \geq 0 \\ 1 + abs\,(f_i) & fi < 0 \end{cases} \tag{9}$$

### *3.3. Onlooker bees phase*

Onlookers are placed onto the food source sites by using a fitness based selection technique, for example roulette wheel selection method.

### *3.4. Scout bees phase*

Every bee swarm has scouts that are the swarm's explorers. The explorers do not have any guidance while looking for food. In case of artificial bees, the artificial scouts might have the fast discovery of the group of feasible solutions. In the searching algorithm, the artificial employed bee whose food source nectar has been exhausted or the profitability of the food source drops under a certain threshold level is selected and classified as the artificial scout. The classification is controlled by "abandonment criteria" or "limit". If a solution representing a food source position is not improved until a predetermined number of trials, then that solution is left by its eloyed bee and the employed bee becomes a scout.

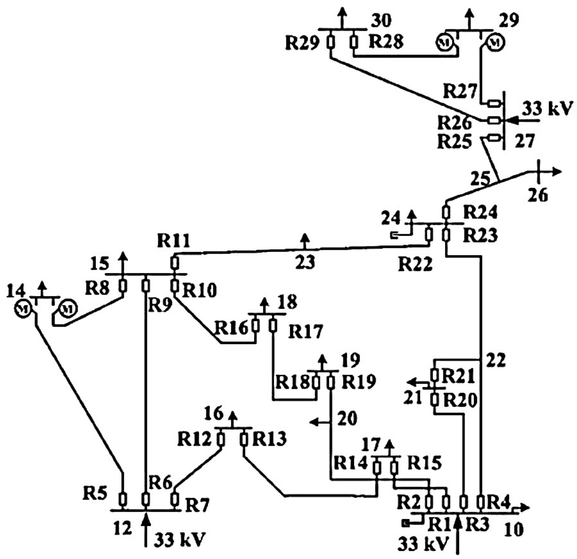


Fig. 1. IEEE 30 bus system.

## 4. Coordination with the impact of DG

The IEEE 30 bus test case represents a portion of the American electric power system (in the Midwestern US) as of December, 1961 (Univ. Washington Seattle, 2006). But as the main target of this paper is the distribution level to address the impact of DG, the distribution level (33 kV) portions are only considered. Modified network of the IEEE 30 Bus Test system is shown in Fig. 1; it has 22 distribution level buses and 29 relays (El-Khattam and Sidhu, 2008), where the system is modeled with all of its detailed parameters. The system is fed from three primary distribution substations (132/33 kV) at buses 10, 12, and 27. Each primary distribution feeder is protected by two directional overcurrent relays, one relay at each end. The system model is assumed to have 29 existing directional overcurrent relays. It is assumed that all relays are identical and have normal inverse relay curves which is represented by Eq. (2) with the following constants 0.14, −1, and 0.02 for $K_1$, $K_2$, and $K_3$, respectively (IEC 60255-3 type A). the $I_p$s are set to be 1.75 times the full load current, CTI is assumed to be 0.3 s for each backup-primary relay pair. Two candidate DG locations are assumed which are substation bus 12 and load bus 19. DG locations are chosen based on environmental and fuel availability restrictions (El-Khattam and Sidhu, 2008). The chosen DG technology is a synchronous type, 10 MVA capacity, operating nominally at 0.9 lagging power factor, and 0.15 p.u. transient reactance based on its capacity (El-Khattam and Sidhu, 2008). The DG is practically connected to the substation bus through a transformer which is assumed to have 10 MVA capacity and 0.05 p.u. reactance based on its capacity.

Two cases are examined to show the impact of adding DG on the setting of the protective relays and the mis-coordination that may be happen.

1) Case A: It is the base case with well-established relay coordination, where there is no DG presented in the system.
2) Case B: DG is added to the system, where relays mis-coordination happened.

**Case A.** Relay Coordination for the Original system. This case is considered as a base system case without DGs to evaluate the most optimal relay settings. ABC is used to find the optimal TDS of the system. A MatLab program is developed to calculate short circuit and load flow for this system, the 3-ϕ faults are applied at the near-end of each relay (close-in faults), also another MatLab program is used to simulate the ABC technique, the convergence of ABC to the optimum solution are shown in Fig. 2. A sample of the results are shown in Tables 1–3.

**Case B.** In this scenario, the system experiences DG operation in its territories. The presence of DG will change the normal power flow as well as the short-circuit current all over the system, which is not restricted to the DG connected bus. A DG of (10 MVA) will be added at bus 12 then at bus 19 and finally at both 12 and 19 simultaneously; due to

Table 1
Sample relay current, fault current and $I_P$ for Case A.

| | Relay | Short circuit (A) | Load current (A) | Pickup (A) |
|---|---|---|---|---|
| Primary | 1 | 6352 | 111.97 | 195 |
| Backup | 19 | 658 | 118.44 | 207 |
| | 23 | 363 | 109.7 | 191 |
| Primary | 5 | 7003 | 134.7 | 235 |
| Backup | 9 | 1065 | 312.46 | 546 |
| | 12 | 1164 | 150.11 | 262 |

Table 2
TDS values of modified 30 bus system without DG.

| Relay no. | TDS |
|---|---|
| 1 | 0.3991 |
| 2 | 0.2786 |
| 3 | 0.1909 |
| 4 | 0.347 |
| 5 | 0.1 |
| 6 | 0.241 |
| 7 | 0.3705 |
| 8 | 0.1 |
| 9 | 0.103 |
| 10 | 0.3117 |
| 11 | 0.2309 |
| 12 | 0.211 |
| 13 | 0.3296 |
| 14 | 0.2904 |
| 15 | 0.2394 |
| 16 | 0.1673 |
| 17 | 0.2528 |
| 18 | 0.265 |
| 19 | 0.1795 |
| 20 | 0.1 |
| 21 | 0.1 |
| 22 | 0.2788 |
| 23 | 0.1 |
| 24 | 0.2553 |
| 25 | 0.2635 |
| 26 | 0.149 |
| 27 | 0.1 |
| 28 | 0.1 |
| 29 | 0.1 |

Table 3
Sample of primary and backup relay operating time and their CTI got by ABC for Case A.

| Relay pairs | ABC | | |
|---|---|---|---|
| | $T_{primary}$ (s) | $T_{backup}$ (s) | CTI (s) |
| 1,19 | 0.78 | 1.08 | 0.30 |
| 1,23 | 0.78 | 1.09 | 0.32 |
| 9,16 | 0.42 | 0.75 | 0.32 |
| 9,22 | 0.42 | 0.95 | 0.52 |

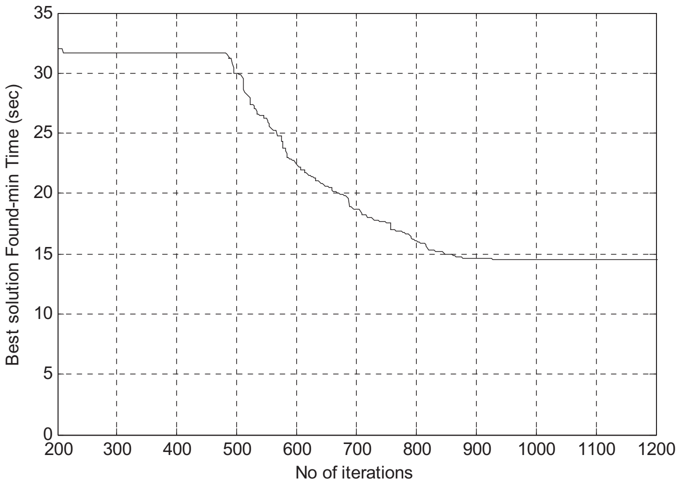


Fig. 2. Convergence of ABC to the optimal solution without DG.

the presence of DG a relay mis-coordination happened. Fig. 3 shows the CTI for a sample relay pairs before and after adding the DG at bus 12, it was found that 18 relay pairs are less than 0.3 s when DG is added at bus 12, 22 relay pairs when DG is added at bus 19 and 24 relay pairs when DGs are added at both bus 12 and 19.

A new relay coordination has to be done again, to evaluate the new optimal relay settings, ABC technique is used to find the optimal TDS of the system. A sample for the new TDS settings and a sample of three phase fault current for all scenarios are shown in Tables 4 and 5 respectively.

Fig. 4 shows the CTI for a sample relay pairs with/without the DG at bus 12 and after doing the coordination again.

## 5. Adaptive coordination scheme

From the previous section the importance of adaptive protection arises as the coordination study has to be done every time a DG installed in the network as proposed in Chandran et al. (2014).

The used adaptive scheme in this paper is similar to that in ABB microgrids (2012), but it is valid up to two DGs placed on buses 12 and 19 of IEEE 30 bus system. The steps of normal coordination are simply carried out as described in previous section, only four modes of operations are considered:

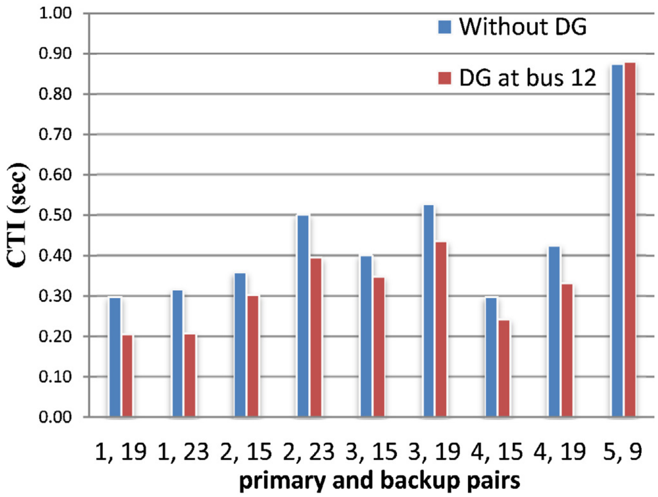


Fig. 3. CTI for a sample relay pairs without/with adding the DG at bus 12.

Table 4
Sample TDS setting values after adding DGs obtained by ABC.

| | Relay | TDS (DG at bus 12) | TDS (DG at bus 19) | TDS (DG at bus 12 & 19) |
|---|---|---|---|---|
| Primary | 1 | 0.43 | 0.48 | 0.45 |
| Backup | 19 | 0.20 | 0.26 | 0.24 |
| | 23 | 0.11 | 0.12 | 0.19 |
| Primary | 5 | 0.1 | 0.1 | 0.1 |
| Backup | 9 | 0.1 | 0.15 | 0.14 |
| | 12 | 0.22 | 0.29 | 0.25 |

Table 5
Three phase near end fault current seen by primary relays in all scenarios in amperes.

| Relay no. | Fault current (No DG) | Fault current (DG at bus 12) | Fault current (DG at bus 19) | Fault current (DG at bus 12 and 19) |
|---|---|---|---|---|
| 1 | 6352 | 6584 | 6921 | 7138 |
| 2 | 6804 | 7099 | 6967 | 7252 |
| 3 | 6906 | 7241 | 7502 | 7818 |
| 4 | 7099 | 7449 | 7707 | 8038 |
| 5 | 7003 | 7876 | 7360 | 8282 |

Mode I: No DG
Mode II: DG at bus 12
Mode III: DG at bus 19
Mode IV: DGs at buses 12 and 19

### 5.1. Requirements of adaptive protection scheme

#### 5.1.1. Substation master computer

The master computer is the main component of this scheme, it communicates with all the relays in the system choosing the correct settings for each relay using communication module, also the master computer monitors the system for any topological changes.

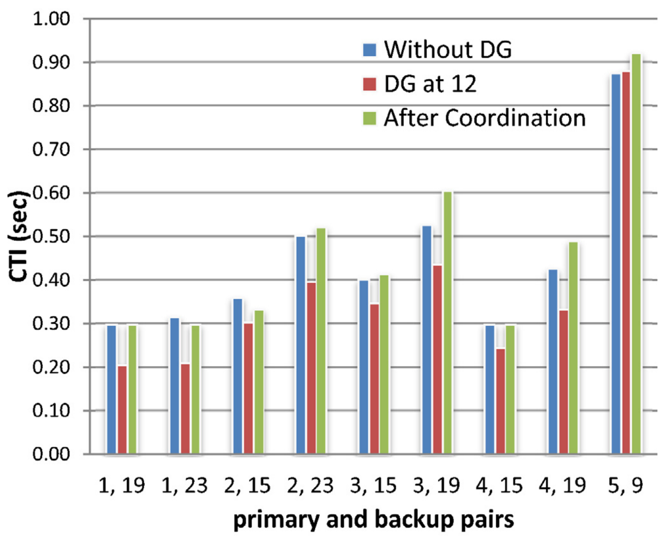


Fig. 4. CTI for a sample relay pairs without/with adding the DG at bus 12 and after coordination.

*5.1.2. Microprocessor relays*

To follow instruction, read information, communicate with the outside world, store settings and switch between them. Microprocessor-based relay firmware should evaluate the need to apply updated firmware. While many firmware updates may not be critical to the relay protection functions, updated firmware that corrects critical protection functions should be given priority (North American Electric Reliability Corporation NERC, 2013).

*5.1.3. Communication facility*

An important part of wide-scale Adaptive Protection is the communication system required to transmit data and commands between substation's computer and relays. IEC and IEEE have standard communication protocols for digital relays that should be adopted by all of the relays' manufacturers, promoting the use and security of the more advanced features of digital relays, the communication could be through the internet (Zachary Zaremski, 2012).

*5.2. Proposed adaptive protection scheme*

1. The master substation computer periodically checks the status of DGs connected to bus 12 and 19 to detect the current mode, and selects the correct settings saved on digital relays that could have up to six groups of settings.
2. The communications with the microprocessor relays and DGs could be through GSM using communication module that are connected to the main substation computer.
3. In case of communication failure due to any unexpected circumstances a default group of settings have to be set in order to maintain minimum reliability of protection scheme. The group settings number (5) is assigned to communication failure mode.
4. Only 5 settings are stored in the relays while the rest group is spare.

Setting 1: mode I no DG
Setting 2: mode II DG at bus 12
Setting 3: mode III DG at bus 19
Setting 4: mode IV DGs at buses 12 and 19
Setting 5: communication failure
Setting 6: spare
Fig. 5 shows the proposed adaptive protection scheme

## 6. DG loading effects

Different DG loadings will affect the relay current which will require new settings for the relay pickup current $I_p$.

In this section the DG loadings is taken into consideration, a complete load flow studies have been carried out for loading the DG by (40, 60, 80 and 100%) of its capacity. It has to be mentioned that from practical point of view (Cummins Power Generation white paper, 2007); loading up to 30% of DG capacity were neglected to protect the Synchronous DG engine from damage. Four modes of operation are shown in Table 6.

Mode I: loading condition 1 with no DG.

Mode II: loading conditions from 2 to 5 with DG at bus 12.

Mode III: loading conditions from 6 to 9 with DG at bus 19.

Mode IV: loading conditions from 10 to 25 with DGs at both buses 12 and 19.

It was found that some of relay currents of different loading conditions at 40, 60 and 80% of DG capacity exceed the $I_p$ based on the 100% DG loading which may lead to false trip if settings of 100% DG loading are adopted. Thus the system security will be violated. Table 7 shows a sample of these conditions as the encircled relays current at 40, 60 and 80% of DG loading exceeds the $I_p$ current based on 100% of DG loading. Fig. 6 shows the number of possible relays false trip.

*Proposed optimum settings for adaptive protection scheme to be stored in the relays*

- To solve the described issue for all loading conditions the pickup currents are set based on maximum relay current that may pass at different loading of DG for each mode multiplied by 1.5.

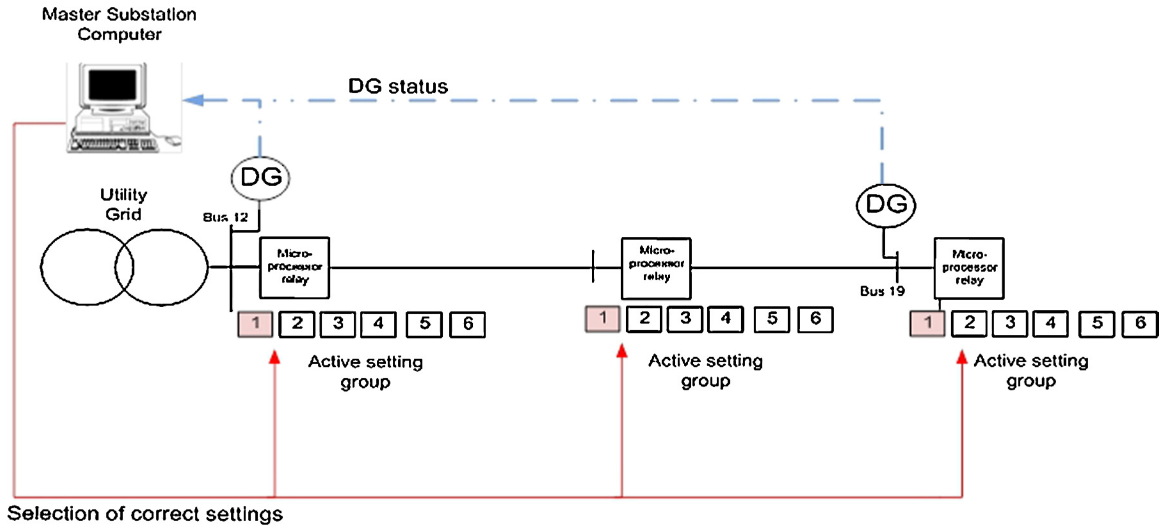


Fig. 5. Proposed adaptive protection scheme.

Table 6
Different loading conditions of DGs at bus 12 and 19.

| Mode | Loading condition | DG at bus 12 loading as % of its capacity | DG at bus 19 loading as % of its capacity |
|---|---|---|---|
| Mode I | 1 | 0 | 0 |
| Mode II | 2 | 40 | 0 |
| | 3 | 60 | 0 |
| | 4 | 80 | 0 |
| | 5 | 100 | 0 |
| Mode III | 6 | 0 | 40 |
| | 7 | 0 | 60 |
| | 8 | 0 | 80 |
| | 9 | 0 | 100 |
| Mode IV | 10 | 40 | 40 |
| | 11 | 40 | 60 |
| | 12 | 40 | 80 |
| | 13 | 40 | 100 |
| | 14 | 60 | 40 |
| | 15 | 60 | 60 |
| | 16 | 60 | 80 |
| | 17 | 60 | 100 |
| | 18 | 80 | 40 |
| | 19 | 80 | 60 |
| | 20 | 80 | 80 |
| | 21 | 80 | 100 |
| | 22 | 100 | 40 |
| | 23 | 100 | 60 |
| | 24 | 100 | 80 |
| | 25 | 100 | 100 |

Table 7
Security check: Mode III DG at bus 19 with loading conditions 6, 7, 8 and 9 and the $I_p$ current based on the 100% loading.

| DG at bus 19 | | | | | |
|---|---|---|---|---|---|
| Relay | Cond.6 | Cond.7 | Cond.8 | Cond.9 | Ip based on 100 % |
| 1 | 118.9 | 120.4 | 121.9 | 123.4 | 215.9 |
| 2 | 121.5 | 101.6 | 81.8 | 62.4 | 109.3 |
| 3 | 311.3 | 311.6 | 311.8 | 312.1 | 546.2 |
| 4 | 148.0 | 148.2 | 148.5 | 148.7 | 260.2 |
| 5 | 130.9 | 128.3 | 125.6 | 123.0 | 215.2 |
| 6 | 297.4 | 287.4 | 277.4 | 267.4 | 468.0 |
| 7 | 129.1 | 127.4 | 125.8 | 124.2 | 217.3 |
| 8 | 23.9 | 21.3 | 18.8 | 16.2 | 28.4 |
| 9 | 297.4 | 287.4 | 277.4 | 267.4 | 468.0 |
| 10 | 77.9 | 64.1 | 50.7 | 37.9 | 66.3 |
| 11 | 101.7 | 103.3 | 104.9 | 106.5 | 186.4 |
| 12 | 129.1 | 127.4 | 125.8 | 124.2 | 217.3 |
| 13 | 63.6 | 62.0 | 60.4 | 58.8 | 103.0 |
| 14 | 63.6 | 62.0 | 60.4 | 58.8 | 103.0 |
| 15 | 118.9 | 120.4 | 121.9 | 123.4 | 215.9 |
| 16 | 77.9 | 64.1 | 50.7 | 37.9 | 66.3 |
| 17 | 22.1 | 10.8 | 14.9 | 23.5 | 41.1 |
| 18 | 22.1 | 10.8 | 14.9 | 23.5 | 41.1 |
| 19 | 82.5 | 62.7 | 43.1 | 24.3 | 42.5 |
| 20 | 311.3 | 311.6 | 311.8 | 312.1 | 546.2 |
| 21 | 40.8 | 40.3 | 39.8 | 39.3 | 68.7 |
| 22 | 41.0 | 42.7 | 44.4 | 46.0 | 80.5 |
| 23 | 108.4 | 109.3 | 110.2 | 111.1 | 194.4 |
| 24 | 32.1 | 30.9 | 30.0 | 29.3 | 51.2 |
| 25 | 78.4 | 75.4 | 72.4 | 69.4 | 121.5 |
| 26 | 124.1 | 124.1 | 124.0 | 124.0 | 217.0 |
| 27 | 109.2 | 109.2 | 109.2 | 109.1 | 191.0 |
| 28 | 65.2 | 65.2 | 65.2 | 65.1 | 114.0 |
| 29 | 124.1 | 124.1 | 124.0 | 124.0 | 217.0 |

- For communication failure mode; the setting is based on $I_p$ equals 1.5 times the maximum relays load current that may pass in all conditions for all modes.
- The primary and backup relays short circuit currents used in TDS optimization are taken as the maximum short circuit of the four modes to ensure selectivity of the protection scheme.
- The DOCR's $I_p$ and TDS settings for the five groups are shown in Tables 8 and 9 respectively.

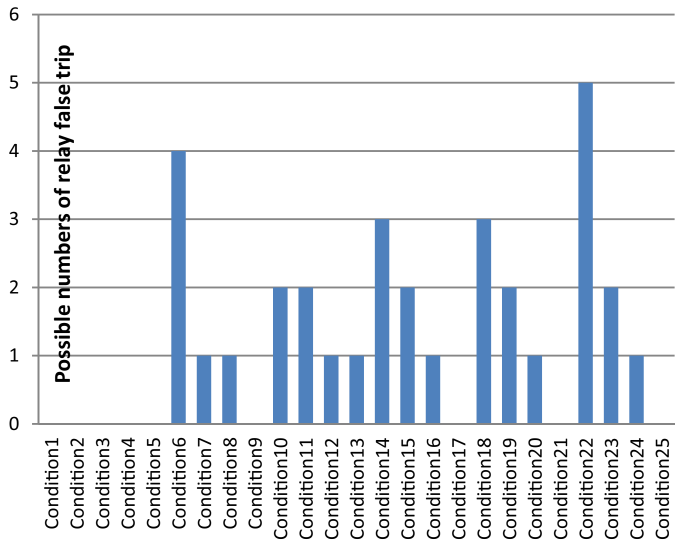


Fig. 6. Security check.

Table 8
DOCR's $I_p$ modes settings.

| Relay no. | $I_p$ (A) | | | | |
|---|---|---|---|---|---|
| | Mode setting 1 | Mode setting 2 | Mode setting 3 | Mode setting 4 | Mode setting 5 |
| 1 | 5.1 | 4.0 | 4.6 | 4.3 | 4.6 |
| 2 | 4.7 | 3.9 | 3.0 | 3.0 | 4.1 |
| 3 | 4.5 | 3.9 | 3.9 | 3.9 | 3.9 |
| 4 | 4.3 | 3.7 | 3.7 | 3.7 | 3.7 |
| 5 | 4.0 | 3.5 | 3.3 | 3.4 | 3.5 |
| 6 | 4.6 | 4.3 | 3.7 | 4.0 | 4.3 |
| 7 | 3.9 | 3.9 | 3.2 | 3.9 | 3.9 |
| 8 | 5.1 | 5.2 | 3.6 | 4.4 | 5.2 |
| 9 | 4.6 | 4.3 | 3.7 | 4.0 | 4.3 |
| 10 | 4.6 | 4.5 | 2.9 | 3.5 | 4.5 |
| 11 | 4.3 | 4.2 | 4.0 | 4.5 | 4.5 |
| 12 | 3.9 | 3.9 | 3.2 | 3.9 | 3.9 |
| 13 | 5.8 | 7.0 | 4.8 | 6.7 | 7.0 |
| 14 | 5.8 | 7.0 | 4.8 | 6.7 | 7.0 |
| 15 | 5.1 | 4.0 | 4.6 | 4.3 | 4.6 |
| 16 | 4.6 | 4.5 | 2.9 | 3.5 | 4.5 |
| 17 | 4.3 | 4.8 | 1.8 | 2.8 | 4.8 |
| 18 | 4.3 | 4.8 | 1.8 | 2.8 | 4.8 |
| 19 | 5.4 | 4.4 | 3.1 | 3.0 | 4.6 |
| 20 | 4.5 | 3.9 | 3.9 | 3.9 | 3.9 |
| 21 | 3.7 | 3.4 | 3.1 | 3.3 | 3.4 |
| 22 | 3.3 | 3.9 | 3.5 | 4.5 | 4.5 |
| 23 | 4.7 | 3.9 | 4.2 | 4.1 | 4.2 |
| 24 | 3.1 | 2.4 | 2.4 | 2.3 | 2.6 |
| 25 | 3.7 | 3.0 | 2.9 | 2.8 | 3.2 |
| 26 | 5.4 | 4.7 | 4.7 | 4.7 | 4.7 |
| 27 | 4.8 | 4.1 | 4.1 | 4.1 | 4.1 |
| 28 | 5.7 | 4.9 | 4.9 | 4.9 | 4.9 |
| 29 | 3.6 | 3.1 | 3.1 | 3.1 | 3.1 |

Table 9
DOCR's optimal TDS modes settings.

| Relay no. | TDS (s) | | | | |
|---|---|---|---|---|---|
| | Mode setting 1 | Mode setting 2 | Mode setting 3 | Mode setting 4 | Mode setting 5 |
| 1 | 0.40 | 0.41 | 0.44 | 0.44 | 0.47 |
| 2 | 0.28 | 0.26 | 0.37 | 0.31 | 0.40 |
| 3 | 0.19 | 0.12 | 0.14 | 0.15 | 0.14 |
| 4 | 0.35 | 0.30 | 0.26 | 0.39 | 0.38 |
| 5 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 6 | 0.24 | 0.26 | 0.33 | 0.31 | 0.33 |
| 7 | 0.37 | 0.32 | 0.39 | 0.38 | 0.46 |
| 8 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 9 | 0.10 | 0.10 | 0.16 | 0.14 | 0.16 |
| 10 | 0.31 | 0.34 | 0.44 | 0.40 | 0.44 |
| 11 | 0.23 | 0.20 | 0.29 | 0.26 | 0.27 |
| 12 | 0.21 | 0.21 | 0.31 | 0.27 | 0.27 |
| 13 | 0.33 | 0.26 | 0.33 | 0.32 | 0.39 |
| 14 | 0.29 | 0.30 | 0.37 | 0.32 | 0.36 |
| 15 | 0.24 | 0.21 | 0.27 | 0.29 | 0.31 |
| 16 | 0.17 | 0.17 | 0.31 | 0.19 | 0.32 |
| 17 | 0.25 | 0.30 | 0.43 | 0.35 | 0.37 |
| 18 | 0.27 | 0.25 | 0.38 | 0.26 | 0.38 |
| 19 | 0.18 | 0.22 | 0.36 | 0.30 | 0.32 |
| 20 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 21 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 22 | 0.28 | 0.27 | 0.24 | 0.41 | 0.41 |
| 23 | 0.10 | 0.10 | 0.23 | 0.21 | 0.23 |
| 24 | 0.26 | 0.21 | 0.23 | 0.17 | 0.17 |
| 25 | 0.26 | 0.21 | 0.29 | 0.32 | 0.33 |
| 26 | 0.15 | 0.10 | 0.10 | 0.10 | 0.10 |
| 27 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 28 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 29 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |

## 7. Conclusion

ABC is simply implemented using very few lines of computer code, and it is a general-purpose algorithm that can be used for both linear and nonlinear optimization problems. It shows a great capability of solving highly constrained coordination problem. Simulation results show that ABC succeeds to converge to feasible optimal setting.

The results show that as the DG's size and number changes, the chance of relays miscoordination increases which requires a new settings for DOCR, one of the possible solution to solve this issue is to use adaptive coordination. The proposed adaptive scheme is applicable and works effectively for existing power distribution systems, which lately install DG to get their benefits, protection system follow the network topological changes and connectivity of DG to the system and switches between the pre-calculated setting groups based on the actual operating state of the DG using standard communication and programmable logic, this adaptive protection may increase availability of local generation and reduce outage time for the customers without a need to change existing hardware, which leads to the increase of selectivity and security of the system.

## References

ABB microgrids: building blocks of the smart grid adaptive protection schemes for microgrids In: Presented at 3rd IEEE PES ISGT Europe, Berlin, Germany, October 14–17.

Anderson, P.M., 1999. Power System Protection. IEEE press, McGraw-Hill, Piscataway, NJ.

Barker, P.P., de Mello, R.W., 2000. Determining the impact of distributed generation on power systems: part1—radial distribution systems. IEEE Trans. Power Deliv. 15 (April), 486–493.

Brahma, S.M., Girgis, A.A., 2004. Development of adaptive protection scheme for distribution systems with high penetration of distributed generation. IEEE Trans. Power Deliv. 19 (January (1)), 56–63.

Chandran, M., Ravindra kumar, S., Somasundaram, P., 2014. Smart and adaptive over current protection for distribution system with distributed generation. Int. J. Adv. Res. Electr. Electron. Instrum. Eng. 3 (April (2)).

Cummins Power Generation white paper, 2007. How to Size a Genset: Proper Generator Set Sizing Requires Analysis of Parameters and Loads. Power Topic #7007.

El-Khattam, Walid, Sidhu, Tarlochan S., 2008. Restoration of directional overcurrent relay coordination in distributed generation systems utilizing fault current limiter. IEEE Trans. Power Deliv. 23 (April (2)).

ElMesallamy, Mostafa, 2014. Adaptive Protection Scheme for Distribution Network with Distributed Generation (M.Sc. thesis). Dept. Elect. Power and Machines, Univ. Ain Shams.

Girgis, A., Brahma, S.M., 2001. Effect of distributed generation on protective device coordination in distribution system. Proceedings of Large Engineering Systems Conference on Power Engineering (LESCOPE'01), July, pp. 115–119.

Griffin, T., 2000. Placement of dispersed generations' systems for reduced losses. Presented at the 33rd Hawaii Int. Conf. System Sciences.

Karaboga, D., Busturk, B., 2007. A powerful and efficient algorithm for numerical function optimization: artificial bee colony optimization. J. Glob. Optim. 39, 459–471.

North American Electric Reliability Corporation NERC, State of Reliability, May 2013.

Univ. Washington Seattle, Mar. 2006. IEEE 30 Bus system. Available: http://www.ee.washington.edu/research/pstca/pf30/pg_tca30bus.htm.

Urdaneta, A.J., Nadira, R., Perez, L.G., 1988. Optimal coordination of directional overcurrent relays in interconnected power systems. IEEE Trans. Power Deliv. 3 (July (3)), 903–911.

Uthitsunthorn, D., Pao-la-or, P., Chpong, T.K., 2012. Application of artificial bees colony algorithm for optimal overcurrent relay coordination problems. ECTI Trans. Electr. Eng. Electron. Commun. 10 (February (1)).

Zachary Zaremski, Brian, 2012. The Advancement of Adaptive Relaying in Power Systems Protection, MSC Thesis. Faculty of the Virginia Polytechnic Institute and State University, April 15th.