Multi-objective Approach for Optimal Protection of Micro-Grids with Grid Connected and Islanded Capabilty

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Abstract-Inspite of several formulations discussed for coordination issues of Directional Over Current Relays (DOCRs) in Micro grids,the coordination of DOCRs is yet a great task to be solved. A protection scheme is optimally designed taking both modes of microgrid operation, grid connected mode and autonomous mode simultaneously. A Multi objective approach yielding better coordination is discussed. There are two major objectives as follows; former is the synchronization period between primary and secondary relays, latter is the relay operation time. The problem is solved using Modified Firefly Algorithm (MFA)and the simulation results show that the DOCRs operates with better coordination both in autonomous and grid connected mode.

Keywords: Directional Over Current Relay (DCOR), Microgrid, Protection coordination**,** Modified Firefly Algorithm (MFA)

1. Introduction

The progressing demand for electricity and environment pollution concern emphasizes distributed generation (DG) as a new blooming technology for providing reliable and environmental friendly supply [1]. The introduction of multiple number of DG into distribution systems results in a microgrid. A microgrid is a group of generators preferably a renewableand loads interconnected, that can be operated in connection with the grid or operated autonomously ensuring reliable supply to the customer [2]. In recent years, the relay coordination problem with the inclusion of DG should be seriosly viewed due to different contingencies in power system.If a fault occurs in the system the primary relay should first operate to clear the fault.If the primary relay fails, thebackup relay should come into action after a time interval called Coordination Time interval(CTI) [3, 4]. Numerous literatures have been proposed for relay coordination problem. Over current protection issues in a microgrid have been presented in [5].The solutions include use of Fault Current Limiters (FCL), directional protection and designing the relays with two settings,one for grid operated mode and another for autonomous mode.In [6] a protection scheme for online rapid fault location using a artificial neural network (ANN) is presented for a wide range of system conditions. The relay co-ordination achieved by FCL to limit the DG fault current is analyzed in [7].

There are often changes in power system network structure due to sudden fault conditons, maintenance activities, and may be due to network expansion. As a result DOCRs fail to coordinate with their backup relays.Each primary and back up relay pair is assingned different coordination time inerval for each network structre [8,9].In [10]the operating time of all the relays for near-end faults is minimized considering changes in the network topology due to contingency.

The settings of FCL and DCOR optimally set for different network topology for both grid-connected and islanded operation of micro grids is presented in [11]. Communication technology is implemented for relay coordination in microgrids in [12,13]

Intensive researches have been carried out for relay coordination issues usng several evolutinary based optimization tools.Optimal coordination of DOCR in a distribution system by optimal setting of DCOR is presented in [14,15,16] implementing Particle Swarm Algorithm(PSO), in[17] using Genetic algorithm (GA),in[18] using harmony search algorithm (HSA) and Artificial Bee colony in[19].

In [20], Firefly Algorithm(FA) is applied to find the TMS and pick up current (I_p) so that the operation time of relay is reduced.Here the objective function is single. In [21]multi-objective approach is used to resolve the coordination of DOCRs using Modified Firefly Algorithm (MFA).A Fuzzy based multi objective optimization for solving protective relay setting and co-ordination is presented in [22]. The results were obtained for coordination problem using Modified Swarm Firefly Algorithm (MSFA) technique and Particle Swarm Optimization (PSO) in [23**].**Nelder-Mead (NM) simplex search method is presented for DOCRs coordination in [24].

But the multi objective approach for relay coordination problem considering both modes of micro grid operation is not dealt before in the past literatures. In the proposed work multi-objective optimization is taken to solve the relay co-ordination issues considering the both modes of operation of microgrid simultaneously.

2. Formulation of the protection coordination problem

The optimal values of TMS and $I_p$of each relay is computed to arrive at better protection coordination.

2.1. Relay Characteristic

The operating time for of an extremely inverse type relay is as follows [21]:

$$t_i = \left[\frac{K}{\left(\frac{I_{sci}}{I_{pi}}\right)^{\alpha} - 1} + L \right] TMS_i \quad (1)$$

in which, current of the short circuit is represented by Isc_i and i^{th} relay's current pickup setting is denoted by I_{pi}. The range of TMS values I_{pi} values and the constant factors K and α are assumed from [21].

2.2. Coordination Constraints

Protection coordination is that design of relays such that the primary relay operates first and in case of its failure the back relay comes into action. The time interval between the primary and backup relay is termed as coordination time interval (CTI). This CTI depends on type of relay, Circuit Breaker (CB) speed, microprocessor or electromechanical parts of relay, overshoot interval of the relay and the additional parameters of the system. The CTI is given by [11]:

$$\Delta t_{pb} = t_b - t_p - CTI \quad (2)$$

Where, the secondary relay's operation interval is denoted by t_b, the key relay's operation interval is specified as t_p and the value of *CTI* lies between 0.1s and 0.5s.

2.3. Objective Function

A objective function is formulated using the overall key relay's operation interval and the overall coordination intervals of the relay to find the best values of TMS's and I_p's. Two mode of operation of the microgrid will be considered in the problem. The objective function is as follows:.

$$T = \min \sum_{c=1}^{C} (\alpha_1 \sum_{i=1}^{N} t_{ci}^{q} + \alpha_2 \sum_{j=1}^{P} (\Delta t_{cpb} - \beta_2 (\Delta t_{cpb} - |\Delta t_{cpb}|))^r) \quad (3)$$

where, *c* is the identifier of mode of operation of micro grid with *C* =2 representing the two modes of operation of micro grid .

where, the i^{th} relay's nearby fault operation interval is denoted as t_{ci}, the synchronization interval between two adjacent relays is represented as Δt_{cpb}, the total count of the available relays is denoted by *N*, the count of available key and secondary pair of relays are represented as *P*, the value of *i* lies between 1 to N, in which *i* is the relay, α_1 and α_2 are the control weights and non-synchronization parameter is represented as β_2. The powers raised in the equation are denoted using parameters such as *q* and *r*. In order to attain maximum relay operation interval during both the operation modes of microgrid, it is necessary to optimize the power values and coefficients of the equation including *α1, α2, β2, q* and *r*.

3. Modified Firefly Algorithm

Firefly Algorithm (FA) is a meta heuristic Algorithm whis is based on the characteristics of fire flies in the darkness[20].One of the character of fire fly is that all the fire flies belong to one sex.They flash light in darkness and are attraced towards each other.The intensity of flashing is determined from the objective function.The attraction of fire flies is proportinal to their flashing property but decreases with distance between the two fire flies.The firefly with less flashing property is attracted towards greater flashing.If there is no difference in flashing property the fire fly will move randomly.

I*(r)* is the function that specifies attractiveness of a firefly and the equation is represented as follows:

$$I(r) = I_0 \, e^{-\gamma r^2} \quad (4)$$

The attractiveness is denoted by I_0 when the value of r =0, in which the distance that ranges between on firefly and the other firefly is *r*and the coefficient oflight absorption is *γ*.

The i^{th} firefly gets attracted to another firefly, namely, *j* which has high flashing light and its location is given by the following equation:

$$x_i' = x_i + I(r)(x_i - x_j) + \alpha(rand - 0.5) \quad (5)$$

in which x_i' is the forthcoming location where the firefly tends to move. x_i is the present location of the i^{th} firefly and $x_j$is the location of the j^{th} firefly, the parameter used for randomization is denoted by *α*and the value of 'rand' ranges from 0 to1 [26].

But the results obtained with the FA algorithm may be local optimum but not global solution. The fire fly with greater flashing property is the global solution for theobjective function and it should be attracted towards a fire fly with much greater flashing property to improve performance of the algorithm to arrive at global optima.A parameter to make the brightest fire fly to move in the direction such that the brightness of the fire fly increases is introduced to accelerate the convergence is [21].

$$del = 1 - \left(\frac{10^{(-4)}}{9}\right)^{\left(\frac{1}{maxgen}\right)} \quad (6)$$

$$\alpha = (1 - del) * \alpha \quad (7)$$

Where, the parameters used for accelerating convergence is given by *α*and *del*. The range in which the fireflies can move are ensured by specifying the boundary limits [21].The flowchart for the execution of MFA and the coordination among DOCRs is formulated in Fig. 2.

4. System details

4.1. Test Systems under Study

The test system is presented in Figure.1 [11].The simulation is performed by inducing fault in the middle of the lines.The fault current magnitudes and fault MVAare computed for the induced fault. For each of the considered fault two primary and two back up relays are associated.

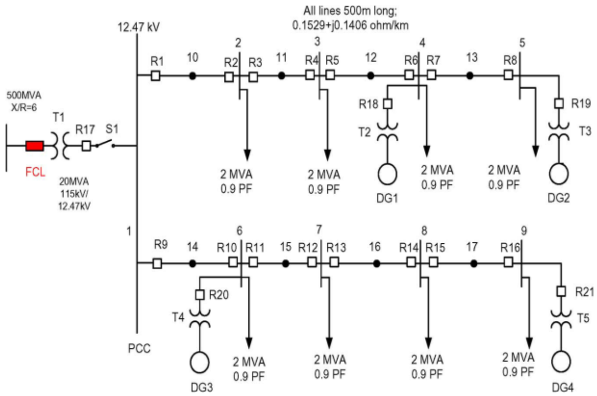

Figure 1. Test system

The work is simulated using 9 bus test system using Matrix Laboratory (MATLAB). The optimization is done for the parameters including *α1*, *α2, β2, q* and *r*. The suggested work shows the feasible nature of MFA in both operational modes of micro grid configuration. The flow chart for proposed system is shown in Figure 2.

The test system is analyzed taking two configurations

i. *Grid connected microgrid configuration:* The system is connected to grid and the analysis is performed. The system is supplied from the grid and also from all the DG. The MFA is run to find the values of α1, α2, β2, q and r, hence TMS and I_p of each of the relays are computed through optimization process to satisfy a grid connected constraints.

ii. *Double Configuration:* Here the optimization is carried out to consider two sets of constraints simultaneously. The first set is that involving the grid connected microgrid configuration constraints, while the second represents constraints under islanded operation. The system is said to be islanded when there is no supply from the grid and is powered only by DGs.

5. Results and Discussion

5.1. Grid connected microgrid configuration

The values of TMS and $I_p$are optimized considering the grid connected constraints and is shown in the table II. Short circuit analysis is performed for the test system and the fault current is calculated to obtain the pickup current. The relay operating times were obtained with best values of *TMS*, *Ip*using MFA algorithm. For optimizing the values of TDS and $I_p$the parameters α_1=2, α_2=1 and β=170 and optimized power number q=2, r=2 gives the best value of total TMS as 2680 milli seconds and pickup current as 3500 milli amperes

The total operating time of all primary relays is calculated as 14023.2 milli seconds in Table IV. It is observed for single configuration the coordination time interval between primary and back up relays are within the 200ms and is presented in Table V. So with the obtained settings of TMS and pick up current, the relays in the 9 bus system operate with proper coordination satisfying CTI, thereby increasing the effectiveness of the protection system.

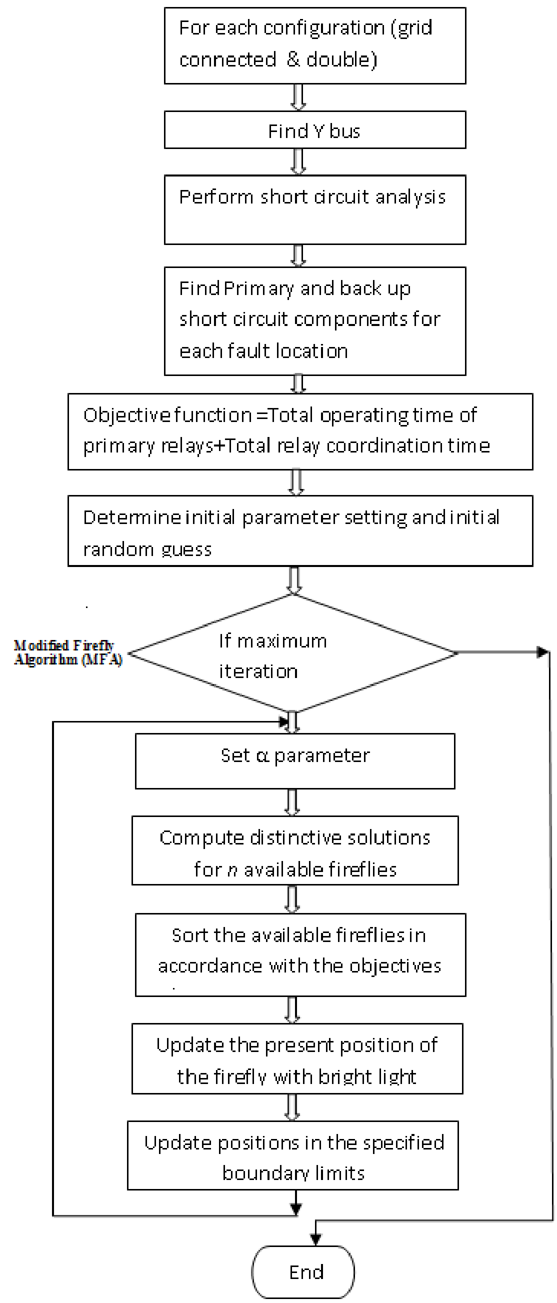

Figure 2. Flow chart for proposed system

Table 1. control parameters of MFA

Parameters	value
Available fireflies, *n*	100
Randomness, α,	0.1
Attractiveness at r = 0,I_0	0.1
Coefficient for absorption, γ	1.0

Table 2. Time Multiplier Setting & Pick Up Current For single Configuration With DG Capacity = 5 MVA

Parameters	**α_1 =2, α_2 =1,β=170**		
TMS No	TMS (ms)	$I_{P\ No}$	I_P (mA)
TMS_1	90	I_{P1}	140
TMS_2	80	I_{P2}	170
TMS_3	80	I_{P3}	210
TMS_4	70	I_{P4}	240
TMS_5	50	I_{P5}	220
TMS_6	110	I_{P6}	220
TMS_7	50	I_{P7}	80
TMS_8	100	I_{P8}	60
TMS_9	200	I_{P9}	160
TMS_{10}	150	I_{P10}	260
TMS_{11}	160	I_{P11}	280
TMS_{12}	90	I_{P12}	180
TMS_{13}	200	I_{P13}	120
TMS_{14}	100	I_{P14}	140
TMS_{15}	140	I_{P15}	80
TMS_{16}	180	I_{P16}	70
TMS_{17}	180	I_{P17}	320
TMS_{18}	220	I_{P18}	110
TMS_{19}	110	I_{P19}	150
TMS_{20}	160	I_{P20}	150
TMS_{21}	160	I_{P21}	140
Total TMS (ms)	2680	**Total I_P**(mA)	3500

5.2. Double-Configuration

Table 3 illustrates the values of TMS, I_p considering grid connected mode and autonomous mode simultaneously. The optimal operating time for all primary relays in double configuration is presented in Table IV

Table 3. Time Multiplier Setting & Pick Up Current For grid connected portion of dual Confiquaration With DG Capacity = 5 MVA

Parameters	**α_1 =2, α_2 =1, β=170**		
TMS No	TMS (ms)	$I_{P\ No}$	I_P (mA)
TMS_1	90	I_{P1}	150
TMS_2	80	I_{P2}	180
TMS_3	90	I_{P3}	170
TMS_4	80	I_{P4}	140
TMS_5	40	I_{P5}	320
TMS_6	200	I_{P6}	120
TMS_7	60	I_{P7}	180
TMS_8	80	I_{P8}	20
TMS_9	120	I_{P9}	140
TMS_{10}	200	I_{P10}	160
TMS_{11}	120	I_{P11}	140
TMS_{12}	130	I_{P12}	100
TMS_{13}	190	I_{P13}	40
TMS_{14}	120	I_{P14}	180
TMS_{15}	130	I_{P15}	80
TMS_{16}	120	I_{P16}	160
TMS_{17}	120	I_{P17}	200
TMS_{18}	200	I_{P18}	210
TMS_{19}	170	I_{P19}	160
TMS_{20}	200	I_{P20}	140
TMS_{21}	120	I_{P21}	210
Total TMS (ms)	**2660**	**Total I_P** (mA)	3200

Table 5 show the relay coordination time for relay pairs for the 9-bus system. This table was obtained for grid connected configuration and from the grid-connected portion of the double configuration problem. The micro grid portion of the double -configuration problem can be simulated in the same way.

It is proved from the results that each primary relays in the system have a backup relays for efficient protection. All primary-backup relays are correctly coordinated within The CTI is within the 200 milliseconds and this reveals the optimal coordination between the primary and back up relays In the case of grid connected mode of double configuration the MFA algorithm gives minimum co-ordination time 2152.1 milli seconds and is similar to that obtained in case of single configuration 2045.69 milli seconds. By analyzing the two modes of operation of microgrid simultaneously we are able to find a feasible solution for settings of relay, whether the micro grid is grid connected or is in islanded mode.

Table 4.Total operating time of primary relay

Primary Relay	Operation Time single configuration (ms)	Operation Time Double Configuration (ms)
t_1	596	600
t_2	997	1000
t_3	600.2	620
t_4	885	1000
t_5	365.4	380
t_6	1267	1460
t_7	113	120
t_8	2185	2200
t_9	685	760
t_{10}	1127.5	1140
t_{11}	589.6	570
t_{12}	1368	1480
t_{13}	367.5	380
t_{14}	1245	1300
t_{15}	165	140
t_{16}	1467	1560
Total time(ms)	**14023.2**	**14710**

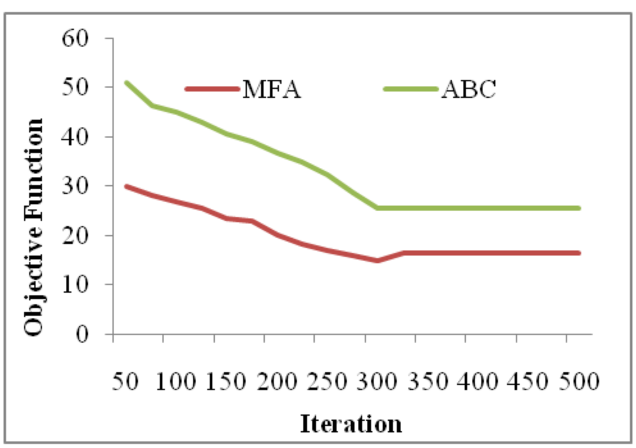

Figure 3. Comparison of Convergence characteristics of MFA and ABC

Table 5. Coordination Time for Primary And Back Up Relay Pairs

Δt_{pb}	Coordination Time For Primary and Back upRelay Pairs(ms)	
	Single Configuration	Grid Connected Mode Of Dual Configuration
$\Delta t_{1,10}$	185.4	195.5
$\Delta t_{1,17}$	198	200
$\Delta t_{2,4}$	181.6	191.6
$\Delta t_{3,1}$	285	300
$\Delta t_{4,6}$	29	0.3
$\Delta t_{5,3}$	113.4	121.4
$\Delta t_{6,8}$	2.9	0.3
$\Delta t_{6,18}$	152.3	169.4
$\Delta t_{7,5}$	1.2	0
$\Delta t_{7,18}$	178.6	198.4
$\Delta t_{8,19}$	12.3	0
$\Delta t_{9,2}$	234	250
$\Delta t_{9,17}$	186.5	198.5
$\Delta t_{10,12}$	19	2
$\Delta t_{10,20}$	0.2	0
$\Delta t_{11,9}$	0.3	0.4
$\Delta t_{11,20}$	287.6	300.7
$\Delta t_{12,14}$	0.23	0.2
$\Delta t_{13,11}$	1.96	0.2
$\Delta t_{14,16}$	1.8	2.2
$\Delta t_{15,13}$	1.4	1.2
$\Delta t_{16,21}$	2	0.3

The work was also analyzed and compared with Artificial Bee colony (ABC) algorithm. The convergence characteristics of MFA and ABC are depicted in figure 3. It takes about 350 iteration s to reach the global optima. With the optimized value of $\alpha 1$, $\alpha 2$, $\beta 2$, q and r, it is proved that MFA algorithm performs out ABC algorithm by offering better fitness function value of 16020 milli seconds.

6. Conclusion

In today's power system network the concept of microgrid plays a vital role in meeting the energy demand.

The protection being the major issue in integration of microgrids, the proposed work depicts the coordination of DCORs well both in grid connected mode and in autonomous mode. Co-ordination problem is solved using multiobjective approach. The co- ordination time interval was taken as one of the objective along the operating time of all primary relay and is analyzed considering grid and autonomous mode constraints simultaneously. The work was optimized using Modified fire fly Algorithm and is compared with ABC Algorithm. The optimal settings of TMS and I_p is computed so that the relay employed operates satisfactorily, when micro grid is in grid connection mode or it has to perform in islanded mode.

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