Recloser-fuse settings in distribution systems with optimizing multiple distributed generation considering technical aspects

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Article Info	ABSTRACT
	With the widespread of using distributed generation, the connection of DGs in the distribution system causes miscoordination between protective devices. This paper introduces the problems associated with recloser fuse miscoordination (RFM) in the presence of single and multiple DG in a radial distribution system. Two Multi objective optimization problems are presented. The first is based on technical impacts to determine the optimal size and location of DG considering system power loss reduction and enhancement the voltage profile with a certain constraints and the second is used for minimizing the operating time of all fuses and recloser with obtaining the optimum settings of fuse recloser coordination characteristics. Whale Optimizer algorithm (WOA) emulated RFM as an optimization problem. The performance of the proposed methodology is applied to the standard IEEE 33 node test system. The results show the robustness of the proposed algorithm for solving the RFM problem with achieving system power loss reduction and voltage profile enhancement. **

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1. INTRODUCTION

The main Nowadays, distributed generations are a vital part of electrical distribution systems [1]. The connection of DGs affects the power flow, voltage condition and the feeder losses. Therefore, proper sizes and location of DGs in the distribution system can attain some economical, technical and environmental benefit. Optimizing DG was investigated to improve voltage profile and reduce system power loss in distribution system as technical aspects [2-5]. For achieving economical and environmental aspects, renewable energy sources (RES) based DG were integrated to reduce energy emission and cost [6]. But with high penetration of DGs in the systems has negative impacts on the existing protection devices causing false tripping and miscoordination problem [7, 8]. The typical electric networks are designed as a radial in nature. The main benefits of the radial systems are their lower cost and simplicity in protection system. These protection schemes comprise of main devices such as recloser and fuses. The coordination between Recloser and fuse are implemented based on the fuse-saving principles [9]. When the transient fault occurs in any branch of the network, fast operating mode of recloser permit the fault to self clear before melting the fuse. But when a permanent fault occurs, the fuse must operate before slow operating mode of recloser to avoid the interruption of loads between fuse and recloser. So, the protection coordination between all fuses and the recloser must be achieved to prevent the miscoordination between them. Thus, the Recloser in the radial system is imperative as 70 to 80 % of all faults occurs in distribution system are transient in nature [10]. The short circuit current due to contribution of DGs increase the current pass through the fuse and permit fuse to operate before and faster than the recloser which leads to undesirable miscoordination [11].

The fault current is increased with increasing the penetration of DGs and the flows of the current are changed. As a result, due to the insertion of DG sources, the distribution scheme becomes active. Therefore, the DG can cause opposing effects to the current protection system, resulting in coordination failure and consequently reducing system reliability [12]. Diverse studies have been devoted in literature to mitigate the adverse effect of the miscoordination between recloser and fuse in the presence of DGs. A new adaptive approach with high penetration level of DG based PV source to keep the coordination between fuse and recloser without any changes in conventional protection settings of PV under worst fault condition was introduces in [13]. In [14], multi objective optimization approach is used to determine the minimum size of fault current limiter, optimal setting of time multiplier and pickup current settings of the devices to restore coordination of protection network with high penetration of DGs based synchronous machine besides economical solution for protection coordination with high capacities of DGs. In [15], the proposed approach is based on the connection of DG in the feeder via four switches and divides the feeder in a few protected zones to avoid the false tripping and to improve system reliability. In [16], An optimum setting of the recloser and the fuses using interior point method (IPM) based algorithm was introduced to remain proper coordination for multiple network conditions systems in the presence of FCLs with single/multiple DGs. Integrating DG in radial system can mitigate, activate the recloser feature and feeder relay with change in recloser curve by modifying the time multiplier setting using minimum ratio of recloser current to fusing current to insure that the coordination is achieved as illustrated in [17]. In [18], an adaptive setting of recloser is performed by adjustment the instantaneous over current device with the presence of different sizes of DG. The proposed methods in [19], [20] consider the maximum permissible capacity of DG connected in distribution system to prevent any protection miscoordination between fuse and recloser. Multi objective function investigated in [21] with maximum threshold value for DG penetration level in distribution system considering various technical impacts using different optimization techniques to avoid recloser -fuse miscoordination problem.

This paper presents a general framework to maintain the coordination between fuse and recloser in the distribution system with optimizing single/multiple DGs over a certain constraint considering system power loss reduction and voltage profile enhancement. For this purpose, a multi objective function based on WOA has been applied to find the optimum sizes and locations of single/multiple DGs to obtain the optimum settings of fuses and recloser which can coordinate properly with different sizes and location of DGs in the system with suitable time coordination interval.

The salient points of this paper can be summarized as follow:-

a) Introduce optimum setting of time multiplier setting for recloser fast and slow mode considering the operating times of all fuses with keeping the coordination time interval between them.

b) Providing Multi objective function related with single and multiple DG to maintain recloser-fuse coordination considering power loss reduction and voltage profile enhancement.

c) The simulation results of the presented WOA are compared with those obtained from other optimization algorithm such as Genetic algorithm (GA), Particle Swarm Optimization (PSO) and interior point Method (IPM) algorithms

d) The effectiveness of the proposed methodology is applied to the standard IEEE 33 node test system.

The rest of the paper is organized as follow: Section 2 introduces the problem formulation related with the setting characteristics of fuse and recloser, while Section 3 clarifies the whale optimizer algorithm, furthermore, Section 4 display the application and the simulation results, and finally, Section 5 demonstrates the conclusions. At the end of the paper, an updated list of references is attained.

2. PROBLEM FORMULATION
2.1. Settings of Recloser and Fuse Characteristics

To coordinate the recloser and fuse in distribution system, the fuse saving principle is established. The recloser close to the substation to protect feeder from any persistent fault and fuse are protect lateral feeder as illustrated in Figure 1. In case of temporary fault, fast mode of recloser is operate while fuse saving is adopted to prevent supply disconnect from consumers. During permanent fault, before the slow mode of recloser operate, the fuse must blow to avoid unnecessary operation of recloser as these disconnect great set of consumers. This operation is suitable for fuse recloser coordination to prevent unnecessary outages in the network [22]. The sequence of operation for fuse recloser coordination is depicted in Figure 2.
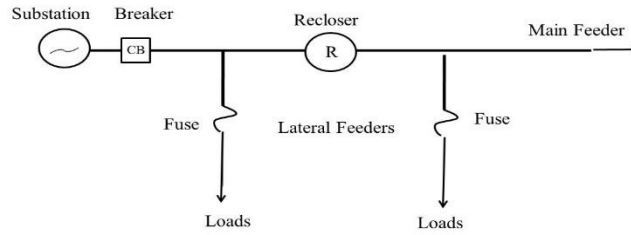
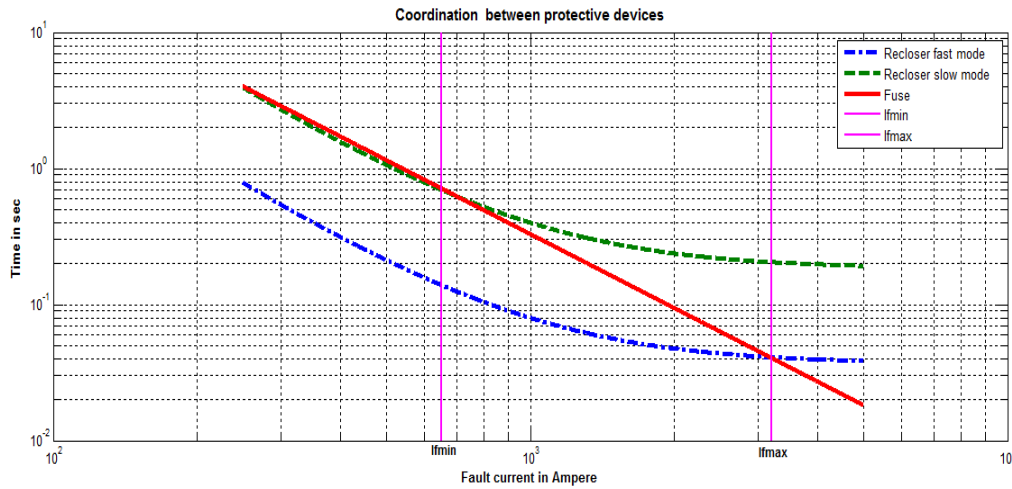Figure 1. Location of recloser and fuse in distribution network

Figure 2. Coordination scheme between recloser and fuse

The recloser usually used as total backup protection for any permanent fault and primary for any momentary fault. The operating time for fast and slow mode of recloser is presented as the following equation [23].

$$t(I_f) = TMS[\frac{A}{M^P - 1} + B] \tag{1}$$

$$I_{pickup} = OLF * I_{max} \tag{2}$$

where

TMS	Time multiplier setting
T(I_f)	Operating time of inverse-time overcurrent device
M	Ratio of I/Ipickup, (Ipickup is relay current set point)
A,B,P	Constants for particular curve characteristics
OLF	Over load factor
I_{max}	Max current through recloser
I_{pickup}	Pickup current setting of recloser

While fuses used as primary protection for any permanent fault. The common characteristic of fuse curve is illustrated as in [24].

$$Log\ (tf) = a log(I_{ff}) + b \tag{3}$$

where

t_f	operating time of fuse
I_{ff}	fault current passing through fuse
a, b	Fuse constant

From (3), when the value of constant b is high, the operating time of fuse is high.

2.2. Coordination as an Optimization Problem

The presence of DG in distribution network leads to difficulties in protection coordination and in technical impacts such as voltage profile and power loss. Thus the aim of this paper is to optimize the best size and location of DG to enhancing the voltage profile and reducing system power loss with the optimum settings of the fuses and recloser curve.

In this paper the DGs based on synchronous machine (DGSM) is considered as they can cause higher contribution for fault current and cause miscoordination between fuse and recloser [25]. The RFM emulated as an optimization problem. Thus, the multi objective function is developed to solve it and obtain optimum recloser-fuse coordination considering system power loss reduction and voltage profile enhancement.

2.3. Objective Function Formulation And Constraints

The objective function are classified in three parts such as optimal size of DG (F_{PDG}), voltage profile index (F_v), system power loss index (F_{loss}) [26].

a) Optimal sizes of DGs

The main objective is to find optimal sizes, number and location of DGs

$$\text{Max FPDG}, F_{PDG} = \sum_{i=1}^{nDG} P_{DGi} \tag{4}$$

where P_{DGi} power injected from DGs at node i and nDG is number of DG connected.

b) Voltage profile index (F_v)

The value of voltage profile index F_v depending on site and sizes of DGs and is used to reduce it from the reference voltage (V_{ref}) which is performed as

$$\text{Min Fv}, F_v = \frac{\sum_{i=1}^{n}|V_{ref} - V_i|}{V_{ref}}) \tag{5}$$

where V_i is the Voltage magnitude at bus i and n is the number of buses.

c) Total system power loss index (F_{loss})

For radial distribution network, the real and reactive power loss indices F_{loss} are factors used to determine the impact of DG in active and reactive power loss and depending on the location and size of DG and are expressed as

$$\text{Min Floss}, F_{loss} = \frac{loss)_{withoutDG} - loss)_{DG}}{loss)_{withoutDG}} \tag{6}$$

where

F_{loss}	System power loss
$loss)_{withoutDG}$	power loss without DG
$loss)_{DG}$	power loss with DG

The multi objective function is used with different weight can be expressed as follow:

$$\text{Min OF}, OF = w_1\left(\frac{1}{F_{PDG}}\right) + w_2(F_{loss} + F_v) \tag{7}$$

where $w_1 + w_2 = 1$ are positive constant weight for all terms to achieve the performance calculation consider $w_1 = w_2 = 0.5$ as all terms have the same importance with the same weight percentage.

The objective function (OF) in (7) is minimized with different operational constraints to satisfy the electrical requirements for distribution network. In this paper the optimization process are considered the losses and protection coordination as the main constraint.

2.4. System constraints

The total power loss reduction and voltage profile enhancement are the main constraints for the proposed RFM problem to achieve the technical impacts which are described as the following:

a) Power balance equality constraints

$$\sum_{i=1}^{n} P_{DGi} = \sum_{i=1}^{n} P_{Di} + P_{lossi} \tag{8}$$

$$\sum_{i=1}^{n} Q_{DGi} = \sum_{i=1}^{n} Q_{Di} + Q_{lossi} \tag{9}$$

where

P_{lossi}, Q_{lossi}	Active and Reactive power loss at i-th buses
P_{DGi}, Q_{DGi}	DGs real power placed at bus i
P_{Di}, Q_{Di}	Load active and Reactive Power at node i

b)   Voltage constrains

$$|V_i^{min}| \le |V_i| \le |V_i^{max}| \tag{10}$$

The voltage limit for buses between (0.95 -1.05 pu).

2.5. Optimum Fuse-Recloser Coordination in the Presence of DGs Unit

The connection of DG in distribution system changes the direction of fault currents across each protection devices. So the coordination settings between all fuses and recloser are complicated especially in case of connecting multiple DG units in distribution systems. To achieve the correct operation between recloser and fuses in the presence of single/multiple DGs units, an evolutionary optimization technique is formulated with multiple objective functions with the same settings at certain coordination margin with and without DG. Therefore, the objective function of the optimization problem is established to minimize the operating times of all fuses and recloser with certain minimum coordination time interval between them.

$$\text{Min OF, OF} = \sum_{j=1}^{n} t_{rec} + \sum_{k=1}^{nfuse} t_{fuse} \tag{11}$$

subjected to the following constraints:

$t_{fuse} - t_{recfast} \ge \text{MRCM}/2$ (12)
$t_{recslow} - t_{fuse} \ge \text{MRCM}/2$ (13)
$t_{recslow} - t_{recfast} \ge \text{MRCM}$ (14)
$t_{fuse\,(k+1)} - t_{fuse(k)} \ge \text{MFCM}$ (15)
$\text{TMS}_{min} \le \text{TMS} \le \text{TMS}_{max}$ (16)

where

nfuse	Total number of fuses
$t_{recfast}$	Operating time of fast recloser
$t_{recslow}$	Operating time of slow recloser
MFCM	Min Fuse coordination margin
MRCM	Min. Recloser coordination margin
TMS_{min} and TMS_{max}	Min. and Max.Time multiplier setting

The coordination between fuse and recloser is classified based on the fault location and associated with the capacity and location of DG**.** For single DG connected at any location in the system, the fault current seen by recloser and fuse are defined as follow:

$$\text{IRecloser} = \text{I substation} \tag{17}$$

$$\text{I Fuse} = \text{I substation} + \text{IDG} \tag{18}$$

In this case, a high fault current detected by the fuse more than recloser. Thus, to avoid RFM problem, the fault current through the fuse is limited to a threshold value and the constraint can be written as follows.

$$\text{I}_{Fuse} \le \text{I}_{Fuse-margin} \text{ and } I_{Fuse-margin} = 10^{(log(t_{recfast})-b)/a} \tag{19}$$

The optimization algorithm search the optimal size and location of single and multiple DG units to satisfying the technical constraints using (8), (9) and (10), while the operating times of all fuses and recloser is minimized at this optimizing values of DGs obtained from first objective function and satisfying all constraints illustrated from (12) to (19).

The steps of the solution procedure to obtain optimum Recloser fuse settings are as follows:
Step1: Carry out base case load flow and short-circuit program
Step2: Calculate the fault currents via recloser and fuses.
Step3: Select the pickup current of recloser using (2)

Step4: Select currents require in the optimum recloser fuse coordination form.

Step5: Set the Parameter of Whale optimizer algorithm.

Step6: Apply WOA program to obtain the optimum size and location of single/multiple DG added at bus location and go to Step (1)

Step7: Select the faulted bus and go to step (2)

Step8: Evaluate objective function using (4) and (8).

Step9: Obtain optimum setting of TMS for recloser and fuses constants (a , b).

Step10: Check all constraint and go to step (6)

Step11: Calculate optimum size and location to attain optimum recloser fuse coordination settings and print the results.

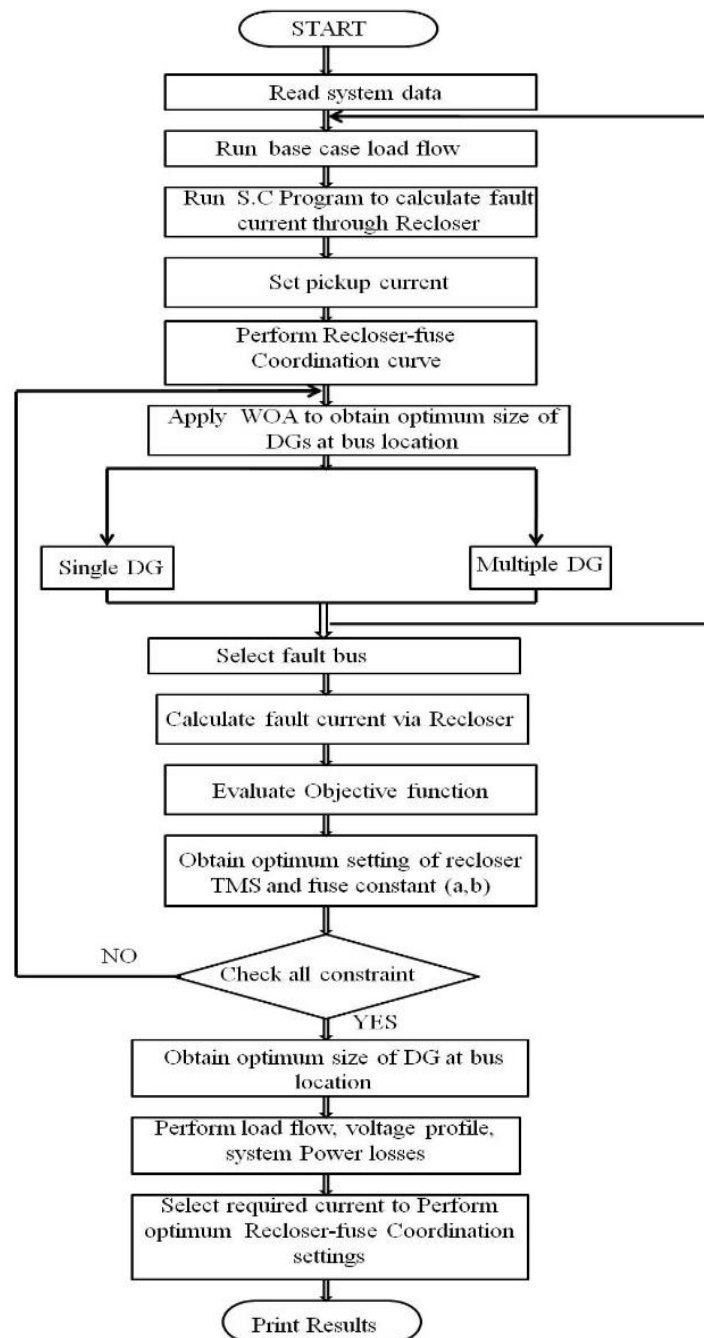The flow chart of the proposed algorithm is revealed in Figure 3.

Figure 3. Computational Procedure for proposed techniques

3.   WHALE OPTIMIZER ALGORITHM

When DGs are connected to the distribution feeder network, the fault current level is increased and RFM are occurs. Therefore, the coordination of protection scheme is formulated as an optimization problem to insure the sequence of operation is unchanged; thus, an Evolutionary Technique using Whale Optimizer Algorithm (WOA) is implemented to solve this problem.

WOA is a nature-stimulated meta-heuristic optimization technique proposed in [27]. Population based WOA has the ability to keep away from local optima and find a global optimal result without any necessary replacement in methodology for solving different constrains or unconstraint optimization difficulties. WOA decreases the computational times for highly complicated problems. WOA emulate the behavior of different hunting humpback whales by encircling the victim which update its position to get the optimum solution based on exploitation phase and exploration phase. The mathematical procedures for WOA are illustrated in [27]. The flow chart of the suggested technique is illustrated in Figure 4.
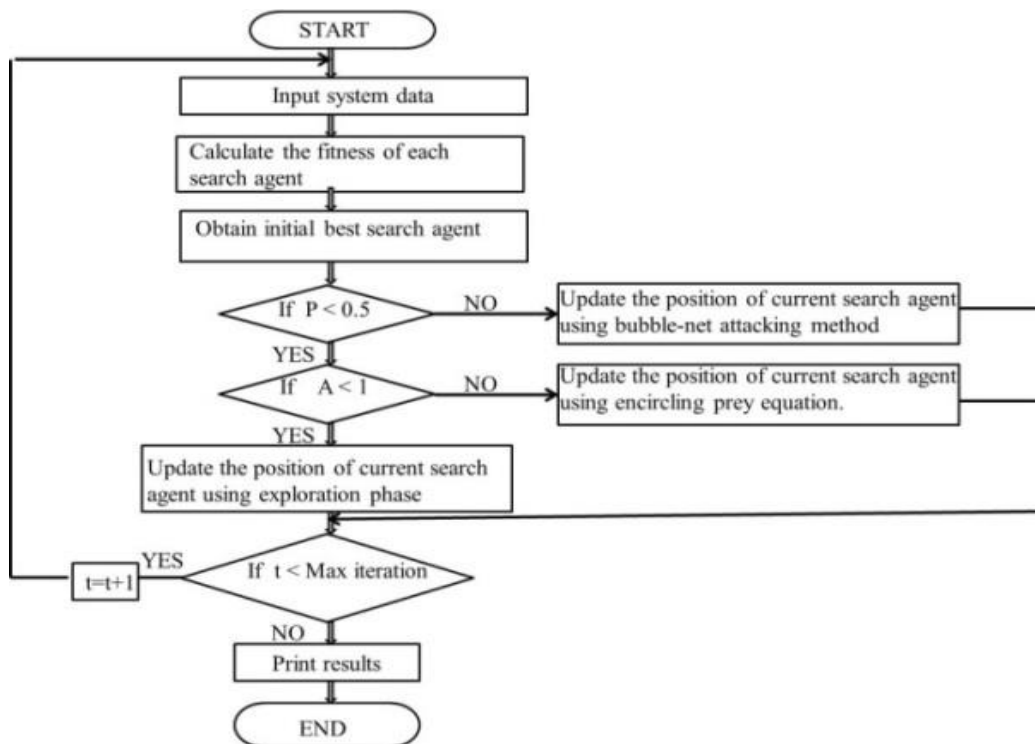

Figure 4. Flow chart of the Suggested WOA

4.   APPLICATION AND SIMULATION RESULT

The Simulation studies are performed on a standard IEEE 33 node test system [28]. The short circuit programs are developed according to Z-bus method to compute the maximum fault currents passing through each protective devices of the network. A load flow algorithm based on Bus-Injection to Branch-Current (BIBC) and Branch-Current to Bus voltage (BCBV) matrices is designed to compute the current setting of each protective element for radial distribution systems [29].

4.1.   IEEE 33 Node Test System

The single line diagram of the test system is revealed in Figure 5. The operating voltage is 12.66 kV feeding 17 commercial, 8 residential and 7 industrial loads. At the substation the short circuit level is supposed as 100 MVA. The total active and reactive load power in this system are 3.72 MW and 2.3 MVAR respectively [28]. The initial loss power in this system is 0.2022 MW and the lowest bus bar voltage is 0.9133 pu at node 18.

The proposed methodology is implemented in MATLAB R2013a to calculate the optimum sizes and location of DGs along the feeder to avoid the false tripping and miscoordination between fuse and recloser with minimum power loss and improve voltage profile. The short circuit program is executed based on the Z-bus method with and without the presence of DGs.

The test system shown in Figure 5 comprises one recloser and six fuses. Recloser is placed at the main feeders to protect it from temporary fault and also used as a backup protection for any persistent fault in the network. Fuses are placed downstream the recloser after each node to give a primary protection against persistent faults in each branch of the network. All fuses are located at each branch instead of lateral feeder to formulate a complete protection against any persistent fault in the main feeder. Thus, a total of proper seven sequences of the protective devices are achieved to avoid RFM problem for any fault in the system. The correct sequences are illustrated in Table 1.
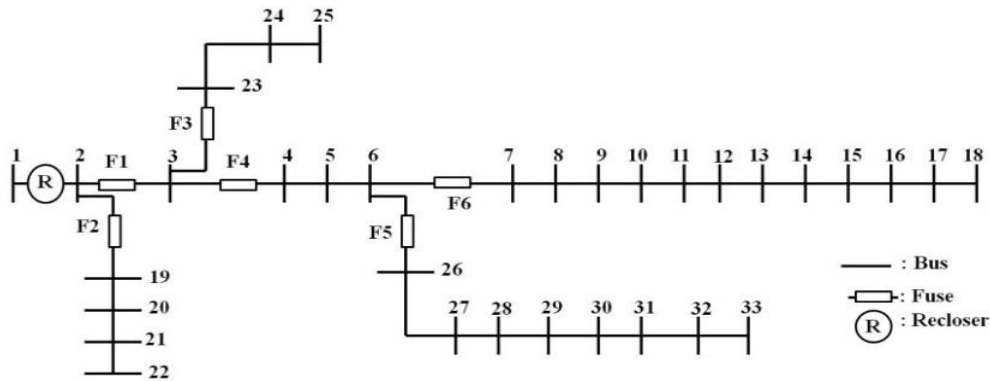

Figure 5. Single line diagram for 33-node test system

Table 1. Operating Sequences for the Protective Devices for Any Fault in the System

Seq. Number	Sequences Operation
1	R_{fm} - R_{sm}
2	R_{fm} – F_1 - R_{sm}
3	R_{fm} – F_2 - R_{sm}
4	R_{fm} – F_3 - F_1 - R_{sm}
5	R_{fm} – F_4 - F_1 - R_{sm}
6	R_{fm} – F_5 – F_4- F_1 - R_{sm}
7	R_{fm} – F_6 – F_4- F_1 - R_{sm}

4.2. Simulation Results

The optimum settings of TMSs for recloser and constants for all the fuses obtained using the proposed approach for the system with and without considering DG is presented according to some constraint to avoid RFM problem in addition system power loss reduction and voltage profile improvement. Multi-objective function is introduced to determine the location and size of DGs in the distribution system to minimize the total system loss and enhance voltage profile with maintaining coordination between recloser and fuse. The optimization process considers the protective device coordination, voltage profile and line loss as main constraint to achieve all proposed objective function. The proper settings of TMS parameter regard as recloser to operate for one fast trip to self clear the fault and operate as primary protection while one delayed trip for fuses are considered to operate as backup protection.

The values of minimum and maximum TMS for optimum coordination have been chosen between 0.2 and 5, respectively. The over load factor for the recloser set to 1.5 [30]. The coordination margin MFCM between the fuses have been chosen as 100 msec, while the coordination margin between recloser MRCM has been chosen as 200 msec. with these settings; the protective devices are completely coordinated.

Simulations results are performed in three different scenarios:
a) Without installing DG
b) With installing only one DG
c) With installing Multiple DG

The two scenarios (ii) and (iii) are implemented by applying the proposed optimization technique to achieve all the objective functions.

4.2.1. Without Installing DG

The output of the three-phase short circuit at different fault location without any DG is revealed in Figure 6. The operation setting of Recloser is based on extremely inverse characteristics that have the values

of A, B, P of 28.2, 0.1217, and 2 respectively as in [23]. The value of constant (a) for all the fuses has been considered to be the same as all fuses in the system are the same type [30]. The computational procedures for the conventional coordination between fuse and recloser are illustrated in [31]. With the optimum settings of TMS for recloser and constants of all fuses without installing DG, the coordination is obtained using time current characteristic as revealed in Figure 7.
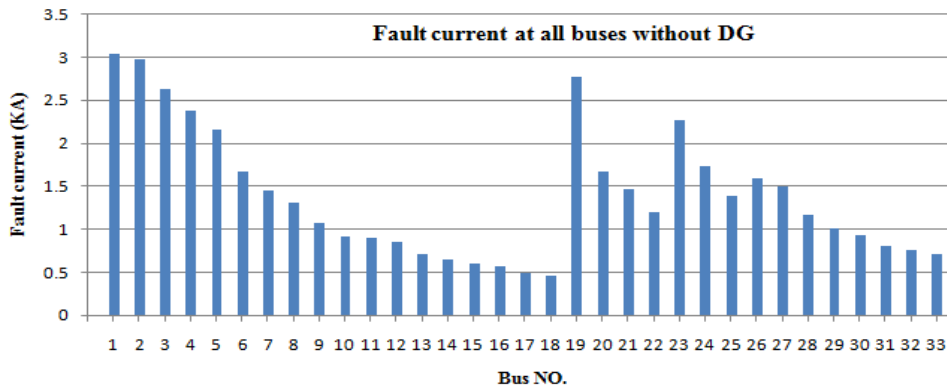

Figure 6. Fault current of the test system in different fault location without DG
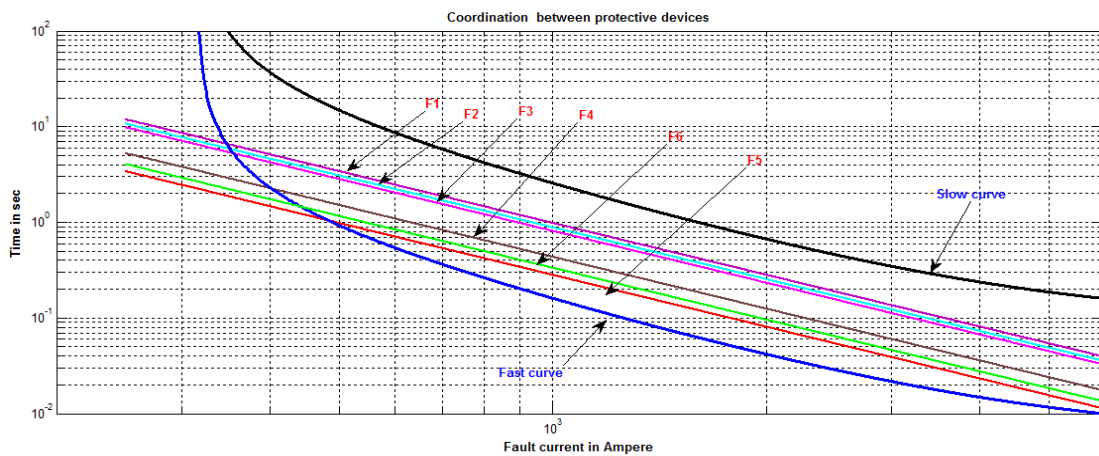

Figure 7. Time current characteristic curve of all protective devices

As in (3), with high value of constant b the operating time is high. From Table 2 the value of constant b for fuse 4 (F4) is higher than the value for fuses 7 (F5) and 8 (F6), while that value for fuse 2 (F2) is higher than that for fuses 3 (F43) and 4 (F4). Consequently, fuse 2 (F2) is higher than fuse 3 (F3). And thus, Fuse 4 (F4) is backup protection for fuses 5 (F5) and 6 (F6) and fuse 2 (F2) is backup protection for fuses 3 (F3) and 4 (F4). From Figure 7, the characteristic of the optimum values of all fuses are located between the operating times of recloser. Thus the sequences of operation in Table 2 are kept unchanged.

Table 2. Optimum Settings of Protection Scheme without DG

Recloser		Fuses		
Fast mode	Slow mode	Fuse No	Fuse Constant (a)	Fuse Constant (b)
		F1	-1.8	5.3919
		F2	-1.8	5.3465
Ip=320A	Ip=320A	F3	-1.8	5.3090
TMS=0.3	TMS=3.5125	F4	-1.8	5.0378
		F5	-1.8	4.8489
		F6	-1.8	4.9233

4.2.2. With Installing Only One DG

The DG units in this study are considered to be synchronous-type generators as they can cause miscoordination between recloser and fuse due to high contribution to fault currents [25]. All synchronous machine used are operates at unity power factor. The optimum setting of TMS for the recloser and all fuse constants have been considered in the presence of single and multiple DG units in the application of the presented methodology.

From the result the optimum size and location of DG that satisfy the coordination constraints between fuse and recloser for protection system is presented at bus 7 with rated power of 2.5434 MW and is operated at unity power factor. The short circuit capacity of DG is 25MVA.

The results of the optimal capacity of single DG at each bus location for the test system with considering technical impacts and protection coordination constraint are illustrated in Table 3. The optimizing value of DG is integrated to insure that when the fault occurs in any lateral feeders, the proper coordination between fuse and recloser is achieved.

In Table 3, the lowest value of power losses occurs with DG located at bus 7 with minimum power loss of 0.1037MW and reactive power loss of 0.0746 MVAR compared to other value due to including the protection coordination constraint in the multi-objective function.

The variation of voltage profile for the test system with and without the presence of DG unit using the presented algorithm is depicted in Figure 8. The three-phase short circuit at various locations with single DG unit located at bus 7 is revealed in Figure 9.

The time-current characteristic curves of the recloser and the fuses using their optimum coordination results obtained are depicted in Figure 10. Optimum settings of protection scheme in the presence of single DG unit shown in Table 4.

Table 3. Optimum Size of Single DG Achieving Protection Coordination

	Without DG	With one DG
DG location	------	7
Size (MW)	-------	2.5434
Loss (MW)	0.2022	0.1037
Qloss (MVAR)	0.1348	0.0746
Min.Voltage (pu)	0.9133	0.9512
Ifmax (KA)	3.0386	3.254

Table 4. Optimum Settings of Protection Scheme in the Presence of Single DG Unit

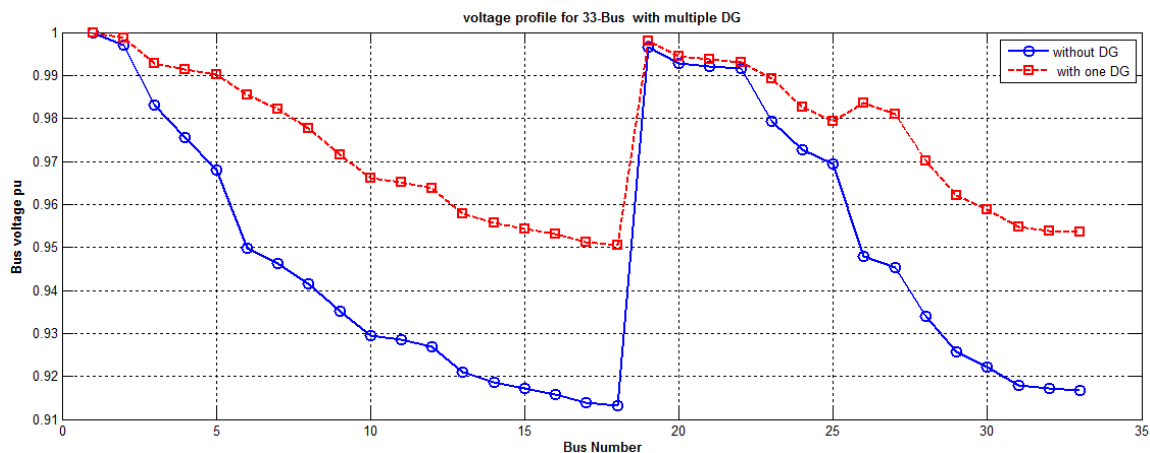| Recloser		Fuses		
Fast mode	Slow mode	Fuse No	Fuse Constant (a)	Fuse Constant (b)
		F1	-1.8	5.4912
		F2	-1.8	5.4723
Ip=320A	Ip=320A	F3	-1.8	5.4439
TMS=0.3	TMS=3.5220	F4	-1.8	5.3653
		F5	-1.8	5.1205
		F6	-1.8	5.2159

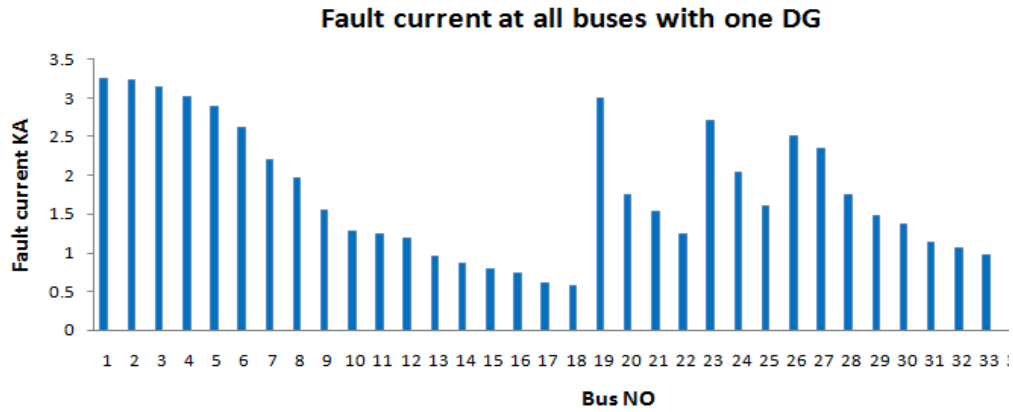Figure 8. Voltage profile without and with only one DG located @ bus 7

Figure 9. Fault current of the test system in different location with single DG unit
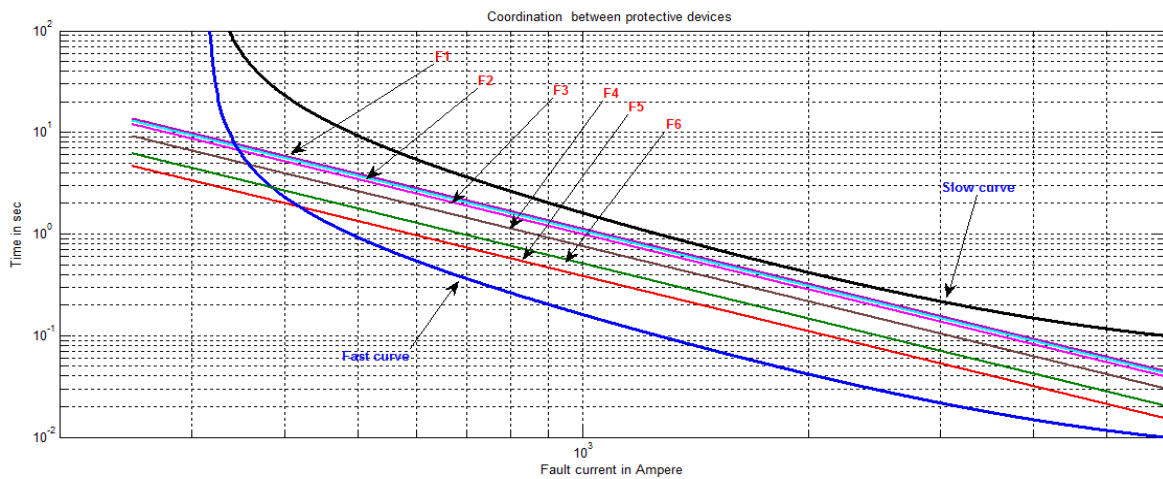

Figure 10. Time current characteristic of all protective devices after adding one DG

4.2.3. With Installing Multiple DG

From the result the optimum sizes and location of DG that achieve all objective function is presented at buses 7, 16 and 25 with rated output power of 1.6923 MW, 0.4523 MW and 0.5361 MW, respectively, with unity power factor. The optimum sizes and locations of the DGs units that achieve the technical impacts and the coordination margin between recloser and fuse are depicted in Table 5.

Table 5 shows that after inserting one DG unit, the reduction in system power loss is reduced to 48.7% compared with that without DG units and the minimum bus voltage is improved. The system power loss is reduced with adding two DG and with three DG units to 54% and 57.27%, respectively. DG can cause enhancement of system voltage condition. However, the short circuit level is increased with increasing the number of DG units.

The variation of voltage profile for the test system before and after adding multiple values of DG units using the applied technique is depicted in Figure11. The short circuit current at each bus locations with multiple DG units is revealed in Figure 12.

Table 5. Optimal Allocation of DG Achieve Protection Coordination Along the System

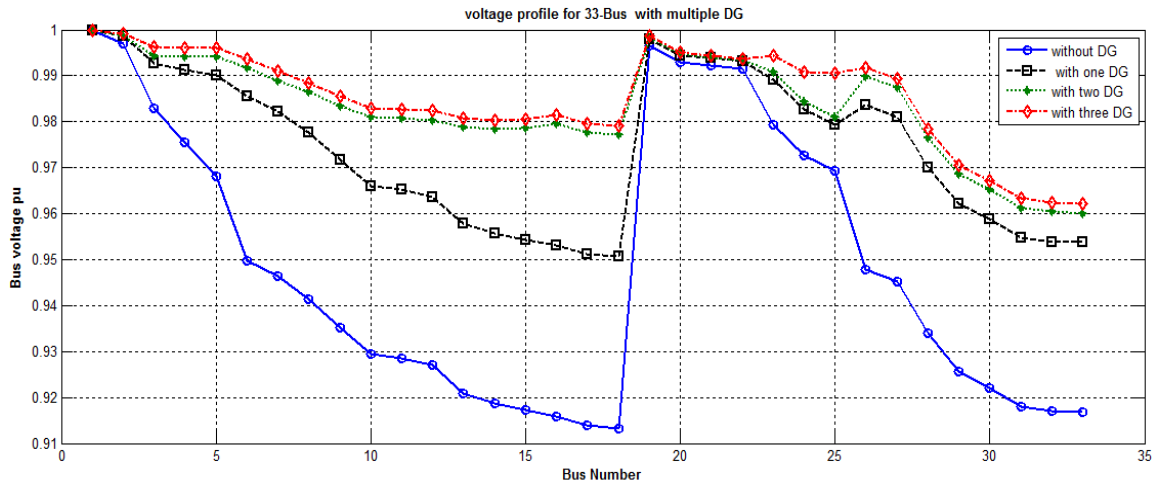|	Without DG	With one DG	With Two DG		With Multiple DG unit		
Bus location	------	7	7	16	7	16	25
Size (MW)	-------	2.5434	1.8979	0.5196	1.6923	0.4523	0.5361
Loss (MW)	0.2022	0.1037	0.0930		0.0864		
Qloss (MVAR)	0.1348	0.0746	0.0658		0.0612		
Min.Voltage (pu)	0.9133	0.9512	0.9601		0.9622		
I_{fmax} (KA)	3.0386	3.254	3.287		3.406		

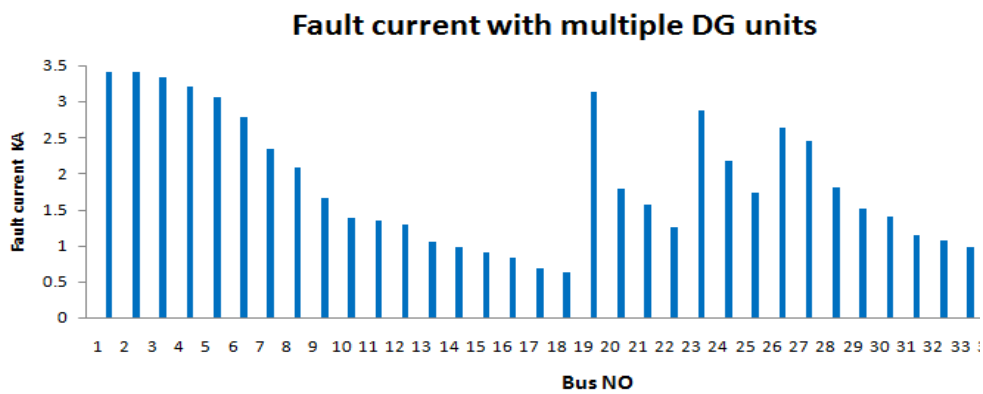Figure 11. Variation of Voltage profile without and with multiple DG units

Figure 12. Fault current of the test system in different location with Multiple DG

From Table 6, it is observed that in the presence of single DG and multiple DGs, the fuse constant b for fuse 6 (F6) is higher than that for fuses 7(F7) and 8 (F8), while the constant b for fuse 3 (F3)is higher than those for fuse4 (F4) and 5 (F5) and the constant b for fuse 2 (F2) is higher than those for fuse3 (F3). Thus, fuse (F6) provides backup protection to fuses 4 (F5) and 5 (F5) while fuse (F6) provides backup protection to fuses 7 (F7) and 8 (F8) and then fuse 2(F2) provides backup protection to fuse3 (F3). Further, from Figure 10 and Figure 13, it is observed that the optimum coordinated characteristics of the fuses are located between the operating times for fast and slow modes of operation for the recloser. Therefore, the operating sequences depicted in Table 1 are properly achieved.

Table 6. Optimum Settings of Protection Scheme in the Presence of Multiple DG

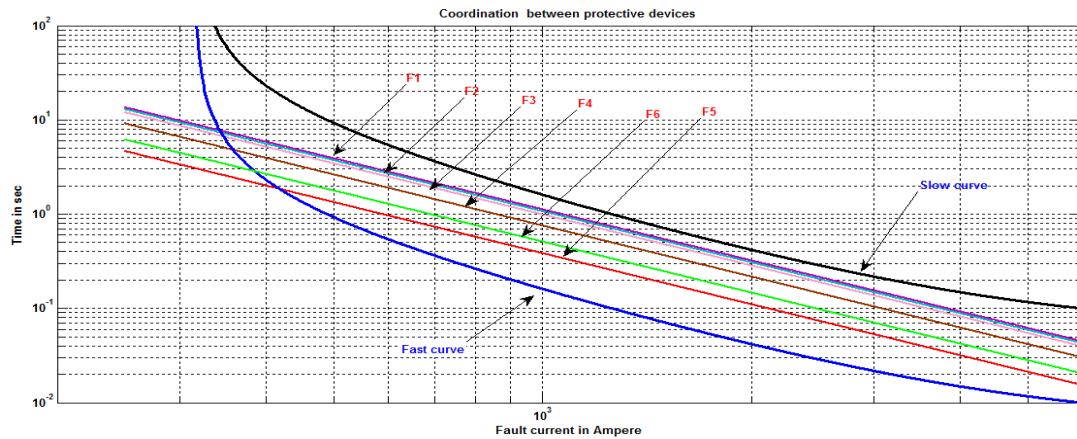| Recloser		Fuses		
Fast mode	Slow mode	Fuse No	Fuse Constant (a)	Fuse Constant (b)
		F1	-1.8	5.4500
		F2	-1.8	5.4296
Ip=320A	Ip=320A	F3	-1.8	5.3961
TMS=0.3	TMS=3.5295	F4	-1.8	5.2783
		F5	-1.8	4.9846
		F6	-1.8	5.1080

Figure 13. Time current characteristic of all protective devices after adding multiple DG

4.3. Comparison Results between Proposed and Other Methodology

Table 7 shows the comparison between the proposed methodology and other methods called GA, PSO and IPM. The optimum coordination between recloser and fuse using all methods is obtained in case of installing single and multiple DG units. From Table 7, the results obtained from WOA has the total minimum operating time compared with that obtained from GA, PSO and IPM in case of installing single and multiple DG units.

Thus the proposed WO algorithm has the superiority in solving RFM problem with maximum technical impacts such as minimizing power loss and improving system voltage when compared with GA, PSO and IPM.

Table 7. Comparison between Different Optimization Methods

| | Methods | Recloser TMS | | Fuse const. (a) | F1 | F2 | Fuse const.(b) | | | | Total Operating time (sec) |
		Slow	Fast				F3	F4	F5	F6	
GA	Single DG	0.5	9.253	-1.801	14.937	15.526	14.256	15.326	13.931	15.126	**13.1927**
	Multiple DG	0.5	9.945	-1.527	12.521	13.404	11.908	13.204	12.600	13.004	**16.9746**
PSO	Single DG	0.5	7.717	-2.183	18.261	17.949	17.698	17.751	17.163	17.541	**11.5539**
	Multiple DG	0.5	7.638	-2.102	17.623	17.066	16.751	16.844	15.463	16.633	**12.3626**
IPM [16]	Single DG	0.5	7.632	-2.179	18.134	17.912	17.349	17.712	16.836	17.512	**10.3660**
	Multiple DG	0.5	7.628	-2.095	17.292	16.971	16.519	16.771	15.300	16.571	**10.8034**
WOA	Single DG	0.3	3.522	-1.800	5.4912	5.4723	5.4439	5.3653	5.1205	5.2159	**7.95780**
	Multiple DG	0.3	3.5295	-1.800	5.4500	5.4296	5.3961	5.2783	4.9846	5.1080	**8.00150**

5. CONCLUSION

This paper introduces two multi objective optimization problems. The first associated with RFM problem to minimize the sum of operating time of all fuses and recloser and the second is consider many technical benefits such as voltage profile enhancement and system power loss reduction. The single set is sufficient to maintain the correct operation of recloser and fuses with and without the presence of a single and multiple DGs in the distribution system. The obtained results reveal that the optimizing value of DG units is maintained the coordination between recloser and fuses with suitable constraint. Whale optimizer algorithm is applied to compute the optimal size and location of single/multiple DG to enhance voltage profile and minimize power loss with some constraints to avoid RFM problem. Simulation results approved that the robustness of the WOA compared to the other techniques for solving RFM problem with minimizing power loss and enhancing system voltage.

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