Integration of Multi-Renewable Energy Distributed Generation and Battery in Radial Distribution Networks

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Abstract— *In the modern world, power production and its efficient usage define the development of the country. In a distribution system of an electrical network due to the influence of load demand, fluctuation of voltage profile and high power losses are to be focused indeed. To avoid these technical problems in the power distribution grid, optimal placement and the appropriate size of Renewable Energy Distributed Generation (REDG) plays a vital role in the power distribution grid. The purpose of this paper is to implement an established hybrid optimization algorithm to place multiple REDGs with suitable power factor. Hybrid artificial bee colony (ABC) and Cuckoo Search Algorithm(ABC/CSA) algorithm employed to solve multi-objective problems of active power loss, cost of energy loss and reactive power loss by considering energy management constraints. The optimal locations of REDG found by voltage stability index (VSI) validated by ABC and sizing of REDG are found by ABC/CSA. The results achieved in this research work illustrate the successfully of proposed hybrid ABC/CSA to solve multiobjective problems. Simulated results validated in IEEE 33-nodes and 69-nodes systems and compared with optimization techniques reviewed in the literature.*

Keywords— **Artificial bee algorithm, renewable energy DG, CSA, VSI.**

1. INTRODUCTION

With the ever-increasing load demand, power losses and the continuous depletion of fossil fuels made the power industries to find the smarter way of meeting load demand. In this context, the massive penetration of REDG into power distribution grid (PDG) appears as one of the promising salient features of the smart grid. However, the integration of REDGs perturbs the power flow, investment cost, and cost of energy (COE). However, due to intermittent and irregular nature of wind turbine (WT) and solar PV, power from REDG makes grid management harder. So, voltage regulation, stability, power loss, and cost of energy are one of the significant issues to be addressed.

Optimum Solar PV and PMSG based WT takes the prominent position among all other sources due to its continuous availability and cost-effectiveness in operations. Proper incorporation of REDGs has several advantages of integrating REDGs in power distribution networks such as power loss reduction and voltage profile improvement [1-2]. However, improper placement of REDGs may lead to jeopardizing the system [3-4]. One of the significant challenges for REDGs presented in [5] is matching of the intermittent energy production with dynamic power demand. A solution is to a hybrid system of solar PV, battery energy storage, and WT, in power distribution grid for better performance of RDN [21] and improved with the integration of multiple RDGs [5].

Numerous optimization methods have been suggested in the literature for optimal placement and capacity of REDGs. However, classical optimization algorithms described in [29] characterized by discontinuing in non-linear and non-convex problems. Therefore, traditional optimization tools are not a flexible tool to be applied in complex search space and sensitive to initial points. The placement of REDG as single objective optimization carried out through various optimization techniques for power losses reduction, cost minimization, and voltage profile improvement. These techniques include [6], Particle swarm optimization (PSO) [7], the Genetic algorithm (GA) [8], Cuckoo Search Algorithm [9], BAT Algorithm [10] and analytical expression based heuristics [11]. However, the limitation of the single objective causes violation of system constraints [12] while limitation of analytical expression based heuristics inability to handle multiobjective and multiple REDG.

The REDG which is capable of injecting both active and reactive power is the most effective for power loss reduction. However, authors in [12-14] have investigated actual power loss by considering the integration of multiple REDGs with only one objective function. Multiobjective optimization problem (MOOP) has been solved by a single objective optimization using weight factor approach and through multiple objective optimization problems simultaneously [15-16]. Weight factor has in [17] been used to find optimal size of REDG. The location investigated by VSI compared with GA while the MOOP changed to the single objective by assigning a weight factor to the given three objective functions. The optimization was carried out by ABC after changing MOOP to a single objective. Unlike the

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majority of existing popular metaheuristic algorithms, hybrid ABC/CSA employed to solve multiobjective throughout the searching process for avoiding local stagnation (premature convergence).

A research study in [18] presented a multi-objective particle swarm optimization (MOPSO) algorithm to optimize sizing, and siting of REDGs, as well as the contract price of their generated power. The proposed method improved the voltage profile and stability, reduced power losses, and enhanced the supply reliability in the 33-nodes system. In [19], proposed a hybrid approach, which is a combination of analytical method and a heuristic approach to place multiple REDGs in 69-nodes.

The main contribution of this paper is to propose the hybrid ABC/CSA algorithm to optimally locate multiple REDG by considering optimal power factor, power output from REDG and node voltage constraints as well.

Several studies indicate that a variety of intelligent algorithms shows different strength and weakness in solving optimal power flow problem (OPF). However, a combination of two algorithms can solve the OPF more efficiently. Hence, it acknowledged that the combination of CSA and ABC algorithm is one of the extreme promising meta-heuristic algorithms considering in this research paper. Moreover, the CSA and ABC algorithm demonstrates high competence and outperforms than other methods regarding fast convergence, accuracy, and simplicity in concept and ease of implementation. The rest of the paper is organized as follows: Section 2 describes the modeling of REDG units. Section 3, details about problem formulation. Section 4 introduces a methodology for integrating REDG and BES into radial distribution networks. Section 5, describes numerical results and discussions of IEEE 33 nodes and IEEE 69-node test distribution system. Finally, Section 6 summaries the contribution of the research work.

2. MODELING OF REDG UNITS

The grid-connected hybrid REDGs units.

Fig.1 below depicts the components of the hybrid system which comprises solar PV, wind turbine based on PMSG, and battery energy storage as REDG.

Wind turbine

For calculation of power output in wind turbine, two main factors must be known: the wind speed on a particular location and the power curve of the wind turbine. According to [22] the power curve of a wind turbine can be modeled using a function split into different parts***:***

$$\begin{cases} P_{WT} = \begin{cases} 0 & V<V_{Ci} \\ YP_{norm} & V_{Ci} \le V \le V_{norm} \\ 0 & V>V_{Co} \end{cases} \\ Y = \dfrac{V^2 - V_{Ci}^2}{V_{norm}^2 - V_{Ci}^2} \end{cases} \quad (1)$$

where *Pnom*, V*nom*, V*ci, and* V*co are* nominal power, wind speed, cut-in wind speed, and cut-out wind speed of the wind turbine, respectively, P*wt* is power output (in MW) of the wind turbine and *V is* the speed of the wind turbine.

For SCIG, the amount of consumed reactive power is uncontrolled because it varies with wind conditions. However, the reactive power supplied with a grid to a wind turbine (SCIG) causes additional transmission and distribution power losses which may cause instability of the system and even transient during switching. PMSG is preferred because of drawbacks of SCIG such as voltage instability. When the fault cleared, SCIG draws a significant amount of reactive power from the grid which may lead to further voltage variations.

In this paper, model type of wind turbine used available in [20]. The parameters of PMSG based wind turbine used to model the power curve are as follows: *Pnom*=600kW, V*ci*=4m/s, *Vnom*=16m/s *Vco*=20m/s. Fig. 1 shows the wind speed data used to calculate the power generated by the wind turbine generator in the deterministic optimal power flow algorithm.

Solar PV

The power in MW of the Solar PV depends on the technical parameters such as ambient temperature and solar irradiation [14], [22]. The expression (2) and (3) used to calculate the power output of the solar PV and average temperature of the cell [31].

$$P_{PV} = \frac{P_{STC} I_S}{1000}[1+\mu(T_C - 25)] \quad (2)$$

where:

- $P_{\_STC}$ is photovoltaic module maximum power at Standard Test Condition (STC) in Watts,
- *Is* is solar irradiance on the Solar PV surface (W/m2),
- μ is solar PV temperature coefficient for power
- *Tc* is photovoltaic cell (module) temperature *(°C).* The photovoltaic module temperature calculated as a function of solar irradiance and ambient temperature based on the module's nominal operating cell temperature (NOCT).

$$T_C = T_a + \frac{I_S}{1000}(T_{NOCT} - 20) \quad (3)$$

where

- *Ta* Ambient temperature (°C),
- T_{NOCT} Nominal operating temperature of solar PV

Sun module, SW 250 mono modules are used in this paper. Their performance characteristics are:

$P_{\_STC}$= 250W, μ=0045^{0}C^{-1}, $T_{\_NOCT}$ = 46^{0}C.

Figure 2 shows output characteristics of squirrel-cage induction generator (SCIG) based wind turbine.

Table 1: Parameters used in REDG

S/N	Parameter	Value
1	Power coefficient Cp	0.59
2	Air density ρ (kg/m^3)	1.225
3	Wind generator efficiency	0.85
4	Battery charge efficiency	0.95
5	The depth of discharge (DOD)	0.5

Power management strategies of REDG in PDG

Since both wind and PVs are non-conventional sources of power, it is highly desirable to incorporate energy storage into such hybrid power systems. Energy storage used to smooth out the power fluctuation from wind and solar and improve the voltage stability. When the power generated by WTs and PVs are more than the load demand, the surplus power will be stored in the storage batteries for future use. On the contrary, when there is any deficiency in the power generation of renewable sources, the stored power will be used to supply the load as shown in Fig.3. This will enhance the system stability and reliability. Charging and discharging of the battery at time steps is given in [23].

Electrical storage units generate expensive investment and operation cost with strong operation constraints. In this context, the objective is to reduce power loss and operation cost by managing the power flows in power distribution grid. It is optimization problem that consists of optimizing the use of energy storage and REDGs.

According to the sign convention, the of physics require the power balance in the system as follows:

1. When power from REDG is less than load demand and SOC is less than 1

$$P_{GRID} + P_{REDG} = P_D + P_{BES} \tag{4}$$

2. When power from REDG is less than load demand and SOC is equal to 1

$$P_{GRID} + P_{REDG} = P_D \tag{5}$$

The amount of generated power from REDG is limited, and the capacity of the REDG cannot be immediately increased to match the increase in demand. In this case, a dump load is required to dissipate excess energy produced and protect the batteries from overcharging. Therefore, having a power management strategy would be one of the main criteria to design such systems.

Based on algorithm given in Fig 4-6, the following cases (case 1- 4) considered in the simulation to apply power management strategies:

Case 1: Renewable sources provide sufficient generated energy, and the extra energy is used to charge a battery bank.

Case 2: Same as case 1 but the surplus energy generated by REDG is higher than the need to supply the load and the battery bank. Therefore, in this case, the surplus of power is consumed in a dump load.

Case 3: REDG fails to provide sufficient energy to meet the load. The priority, in this case, is to use the energy from BES rather than purchasing power from the slack bus in which could increase power loss. In this case, the shortage of power generation is supplied from a BES

Case 4: The power from the REDG is not sufficient to meet the demanded load, and the BES is also depleted. In this case, the power from the slack bus (for grid-connected) purchased to supply the load and to charges the batteries.

In Fig 4, show how charging algorithm takes place. While in Fig.5 describe a flow chart for discharging of BES. However, in both cases of charging and discharging BES, system constraints were considered and should be violated.

From scenarios which show charging and discharging algorithm for the battery, its mode of operation is given in Fig.4 and Fig.5 respectively. In Fig 5, running of diesel generator means power from conventional source of enrgy which is currently power of utility. However, the general hybrid system of solar PV, wind turbine, and the battery is given in Fig 3. The reason is to minimize power loss, purchased energy from the substation and cost of REDG which will be reflected in the cost of energy given to customers.

3. PROBLEM FORMULATION

The goal of the proposed multiobjective optimization is to minimize active and reactive power losses and hence reduce the cost of energy losses simultaneously[24]:

$$\min\ [P(x,u), Q(x,u), C_{EL}(x,u)] \tag{4}$$

subjected to

$$\begin{cases} g(x,u)=0 \\ h(x,u) \le 0 \end{cases} \tag{5}$$

where

P the multiobjective function

h the inequality constraints

g the equality constraints

x the state vectors of and

u the control variables, respectively.

The equation shown in (6) illustrate vector of state variables x:

$$x = [P_{Slack}, V_L, S_l, Q_G]^T \tag{6}$$

where:

V_L Voltage of load nodes

S_l Thermal limits of the line.

Q_G Generated Reactive power

Pslack Power at the slack bus

The equation shown in (7) illustrates a vector of control variables *u*:

$$u = [V_{PV}, P_{REDG}, T]^T \tag{7}$$

where:

V_{PV} Voltage at PV nodes

P_{DG} Power generated from REDG

T Tap setting of the transformer

The total active power losses

$$P=\sum_{k=1}^{N} G_k[V_i^2+V_j^2-2|V_i||V_j|\cos(\delta_i-\delta_j)] \tag{8}$$

where:

N Branches in the system;

G_k Conductance of the line '*k*,'

V_i, V_j Voltages magnitudes

δ The angle of the voltages.

The total reactive power losses

$$Q=\sum_{k=1}^{N} B_k[V_i^2+V_j^2-2|V_i||V_j|\sin(\delta_i-\delta_j)] \tag{9}$$

The optimal sitting of REDG with appropriate size will reduce losses and cost of energy losses.

Cost of total energy losses

$$C_{EL}(\$) = P_{Loss}E_{rate}T \tag{10}$$

E_{rate} Energy rate in $/kWh

T Time duration in hours (=8760)

Ploss Total power loss in kW

System Constraints of the Networks

The minimization problem subjected to the following equality and inequality constraints

Equality constraints

The equality constraints (11) represent ideal power balance and power flow equations. The power balance equation in a PDG with REDG units expressed as follows:

Power Flow Equation Limits

The equality function constraints (11) present the power flow equations,

$$\begin{cases} P_S+P_{REDG}-P_D=\sum_{k=1}^{N} G_k[V_i^2+V_j^2-2|V_i||V_j|\cos(\delta_i-\delta_j)] \\ Q_S+Q_{REDG}-Q_D=\sum_{k=1}^{N} B_k[V_i^2+V_j^2-2|V_i||V_j|\sin(\delta_i-\delta_j)] \end{cases} \tag{11}$$

where

Ps Active power purchased from the substation

Qs Reactive power purchased from the substation.

Inequality constraints

Inequality constraints of the system in (12-16) are the functional operating constraints containing generator output limits, load nodes constraints, power factor, and penetration level of REDG. However, these constraints may define the feasibility region of the state and control variables such as active power limits of RDG unit, transformer tap setting limits, voltage magnitude limits of load node, & PV node, and shunt VAR compensator.

Generator output Limits:

Generator voltage and reactive power of i^{th} node lie between their upper and lower limits as given below:

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max} \tag{12}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \tag{13}$$

where, expression in (12) describes the minimum and a maximum voltage of i^{th} generating units. The equation is shown in (13) present minimum and maximum reactive power of i^{th} generating units. Expression in (14) is the minimum and maximum load voltage of i^{th} node.

Load node constraints:

$$V_{Li}^{min} \ge V_{Li} \le V_{Li}^{max} \tag{14}$$

Power factor

$$pf_{min} \le pf \le pf_{max} \tag{15}$$

Penetration of REDG

$$0 \le S_{REDG} \le S_{Load}^{max} \tag{16}$$

In this research work, Inequality constraints of the dependent variables are load nodes voltage magnitudes, and reactive power and REDG units. The new expanded objective function becomes:

$$\begin{cases} F_P=F+\lambda_V\sum_{i=1}^{NL}(V_i-1)^2+\lambda Q_{DG}\sum_{i=1}^{NPV}(Q_{DGi}-Q_{DGi}^{lim})^2 \\ +\lambda_S\sum_{i=1}^{N}(S-S_i^{lim})^2 \end{cases} \tag{17}$$

where, λ_V, λ_{QDG}, and λ_S are defined as penalty factors.

Voltage stability Index (VSI)

The voltage stability index (VSI) in (18) calculated for all of the nodes, since the nodes with max voltage stability index near to 1 are prone to voltage instability, and it is essential to distinguish weak nodes. A node with VSI near to zero is more stable than other above 0.5.

$$\mathrm{VSI} = \frac{4X}{V_i^2}\left(\frac{P_j^2}{Q_j} + Q_2\right) \leq 1 \quad (18)$$

Table 2. Limits of Control Variable

Variable	Limits
Generator voltage	0.95 - 1.05
P_{REDG}(MW)	1.5 - 4
Q_{REDG}(MVAR)	0.5-2
P_{BES}	0.5 - 2

4. METHODOLOGY

Artificial Bee Colony Algorithm

Artificial Bee Colony (ABC) algorithm was proposed by Karaboga for optimizing mathematical problems. Artificial bee colony or just known as the ABC optimization is one of the new optimization introduced by authors in [19], [25]. The computation for optimizes multiple REDG units described in Fig. 7.

An optimization algorithm for (ABC)

Step 1: Initialize the food-source locations *Xi* (solutions population), The *Xi* form is as follows:

$$X_{ij} = X_{min} + \mathrm{rand}(0.1)(X_{max,j} - X_{min,j} \quad (19)$$

Step 2: Calculate the nectar amount of the population using their fitness values using

$$\mathrm{Fitness} = \frac{1}{1 + \mathrm{objective\_function}} \quad (20)$$

Total Losses = P_Loss + Q_ Loss

Step 3: Produce neighbor solutions for the employed bees by using (20).

$$V_{ij} = X_{ij} + f_{ij}(X_{ij} - X_{kj}) \quad (21)$$

Step 4*:* Apply the acquisitive selection process between *Xij* and *Vij*. If all onlooker bees distributed, go to *Step* 8. Otherwise, go to next step.

Step 5: Determine the probability values *P(Xij)* for the solutions Xij using (28)

$$P(X_{ij}) = \frac{F(X_i)}{\sum_{i=1}^{N} F(X_i)} \quad (22)$$

Step 6*:* Produce the new solutions *Vi* for the onlookers from the solutions xi, depending on *Pi* apply the greedy selection process between *Xij* and *Vij*.

Step 7: Determine the abandoned solution for the scout bees, if it exists, and replace it with an entirely new solution using equation and evaluate them as indicated in *Step 2*.

$$X_{i,j}^{new} = X_{min,j} + \mathrm{rand}(0,1)(X_{max,j} - X_{min,j}) \quad (23)$$

Step 8: If cycle = MCN, stop and print result. Otherwise, follow *Step 3.*

Table 3. Parameters of ABC in IEE 34 System

S/N	Parameters	Value
1	Population	20
2	Generation	80
3	Scaling factor	0.9
4	Crossover rate	0.5
5	Decision variable	4
6	K_P in \$/MW	150
7	K_E in \$/kWh	0.06
8	K_{REDG} in \$/MVAR	5

Table 4. Weight factor used for simulation

Cases	*Kp*	*Kq*	*Ke*
1	1	0	0
2	0.5	0.5	0
3	0.4	0.3	0.3

From Table 4, the sum of weight factor (*Kp*, *Kq*, and *Ke*) should be equal to one.

Cost of REDG, Cost of Energy Losses and Saving

The cost of REDG determined by the following formula

$$C(P_{REDG}) = aP_{REDG}^2 + bP_{REDG} + c \quad (24)$$

where

a = 0.25

b = 20;

c = 0;

From equation (24), cost of the REDG varies proportionally to the size of the REDG. However, cost of electrical energy shown in Table 5-8 reflects the total cost of the system including cost depicted in (24) above. However, a,b, and c are the cost coefficient of REDG with values adapted from [26] as shown above.

Fitness function for maximum saving

Fitness function for maximum saving considering the cost of REDG is given in (25). The sizes corresponding to maximum saving are required for designing optimal REDG.

$$S = K_P \Delta P + K_E \Delta E - K_{REDG} S_{REDG} \quad (25)$$

S Saving in \$/year

Kp Factor of convert power losses to \$

K_E Factor of converting energy losses into \$

K_{REDG} Cost of REDG in dollars per MVA

S_{REDG} Capacity of REDG in MVA

ΔP Reduction in peak power loss

ΔE Reduction in energy losses

The negative value of S calculated from (25) indicate saving is negative. However, REDG corresponding to maximum fitness gives the optimal size at i^{th} location in PDG.

Proposed Hybrid ABC/CS Algorithm

The suggested structure of proposed method utilizes a hybrid ABC and CSA. The objectives considered in proposed framework minimize apparent power losses and reduce the cost of energy losses. Based on multiobjective function VSI and ABC employed for optimal allocation of REDG with suitable size obtained by ABC/CSA. The algorithm of suggested method is shown in Fig 8. While convergence of the proposed method shown in Fig.9.

The proposed hybrid ABC/CSA optimization algorithm shown in Fig 7 combines the behavior of the artificial bee colony (ABC) and cuckoo search algorithms (CSA). In the suggested structure, an artificial intelligence technique is applied for the placement and sizing of multi REDGs to enhance the performance of power distribution grid. The detail description of the proposed hybrid ABC/CSA is adapted from [30].

5. SIMULATION RESULTS AND DISCUSSION

The effectiveness of ABC/CSA tested on IEEE 33-nodes and IEEE-69-nodes systems [26-27]. From the modeling of REDG, the following were notices during simulation. Maximum wind speed Vw =5.2m/s, average wind speed Vm =2.0m/s, solar radiation G = 410W/m^2, Gm = 245W/m^2, rated of solar PV is 1000W/m^2. Assumed that solar PV equipped with 96% power converter. Peak load = 5.89MW, with a load factor of 0.87. Inline with data given above, size of BES estimated to suit the intermittent of REDG with variable load at the optimal location of REDG.

Results for 33-nodes test system using ABC/CSA with VSI at case # 3

Fig. 10 shows a single line diagram of the 22.4kV, 33-nodes test radial distribution system. It has one feeder with four different laterals, 32 branches and a total peak load of 3715kW and 2300kVAr. The total power loss of the system at the base case system is 221.20 kW and 143.7kVAr before installation of REDG into the system. With installation of REDG at unity power factor, real and reactive power losses were 107.5kW and 64.1kVAr respectively. Penetration of REDG at 0.9 pf real and reactive power losses become 54.18kW and 32.59kVAr respectively with REDGs at nodes 28 and 31.

Table 5. Results of 33-nodes at a unity power factor

	Without REDG	SFLA [27]	ABC/CS
REDG Location	-	30	28
BESS Location	-	-	28
REDG size MW	-	1.54	1.25
P_{BESS} size MW	-	-	0.64
P loss kW	221.4	125.16	107.5
Q loss kVAr	143.7	98.16	64.1
Vmin	0.91	0.94	0.95
Cost of EL \$	19641.4	10067.59	55135.3
Cost of P_{REDG} \$/MWh	-	31.10	25.4

Table 6. Results of 33-nodes at 0.9 power factor with REDG

	SFLA [27]	ABC/CS
REDG Location	30	28, 31
REDG size MW	1.74	2.34
P loss kW	78.43	54.18
Q loss kVAr	58.97	32.59
Vmin	0.95	0.97
Cost of EL \$	6,308.92	4,105.02
Cost of P_{DG} \$/MWh	35.17	41.22
Cost of S_{DG} \$/MVA	38.88	46.08

Results for 69-nodes test system using ABC/CSA with VSI

A single line illustration of the 12.66 kV, shown in Fig.11, has 69-nodes test radial distribution system. It has one feeder with eight laterals, 68 branches, a total peak load of 3800kW and 2690kVAr and its corresponding active and reactive power loss are 224.93 kW and 102.11kVAr before installation of REDG into the system respectively. With the installation of REDG at unity power factor, real and reactive power losses were 52.76kW and 37.92kVAr respectively. Penetration of REDG at 0.9 pf real and reactive power losses become 48.11kW and 27.34kVAr respectively with REDGs at nodes 50 and 22.

Table 7. Results of 69-nodes at a unity power factor

	With REDG	SFLA [27]	ABC/CS
REDG Location	-	61	50,22
REDG size MW	-	1.88	1.99
P loss kW	225.56	83.22	52.76
Q loss kVAr	102.11	40.57	37.92
Vmin	0.90	0.96	0.971
Cost of EL $	18,101.7	6,694.25	3,971.23
Cost of P_{REDG} $/MWh	-	37.69	50.68

Table 8. Results of 69-nodes at 0.9 power factor with REDG

	SFLA [27]	ABC/CSA
Location of REDG	61	50, 22
REDG size MW	1.57	2.20
P loss kW	57.92	48.11
Q loss kVAr	46.47	27.34
Vmin	0.964	0.977
Cost of EL $	40.16	32.14
Cost of S_{DG} $/MVA	44.44	52.04

Both real and reactive power losses in radial distribution get reduced with the insertion of hybrid REDG. The particular results of 33-nodes and 69-nodes are shown in Table 5-8 respectively**.** Wind turbine based on PMSG help to improve the performance of radial distribution system efficiently than the wind turbine DFIG by supply apparent power. Since the voltage variation and high power losses in PDG mostly are caused by unbalanced of reactive power.

6. CONCLUSION

Optimal power flow in PDG is an optimizing tool for power system operation analysis and energy management. Use of multiobjective simultaneously become more critical because of its capability of dealing with various objective functions. Hence, in this paper, ABC/CS and VSI have been used to determine the size and location of REDG in the PDG respectively. The obtained optimal size REDG used to improve voltage profile, power losses reduction and cost of energy loss in the power distribution grid. Proposed hybrid ABC/CSA compared with SFLA based metaheuristic OPF techniques with different parameters both in IEEE 33-nodes and IEEE 69-nodes. The simulation results support the integration of REDG and BES in the PDG.

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NOMENCLATURE

RES	Renewable Energy source
Q_{DG}	Reactive power from DG
VSI	Voltage stability index
Qi	Reactive power flow from ith node
Pi	Active power flow from ith node
ABC	Artificial bee colony
DG	Distributed generation
REDG	Renewable Energy Distributed Generation
V_i	Voltage at i^{th} node
Vmax	Maximum voltage of ith node (p.u)
Vmin	Minimum voltage of ith node (p.u)
Ps	Active Power from the substation
Qs	Reactive power from the substation
V_j	Voltage at j^{th} node
PMSG	Permanent Magnet Synchronous Generator

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