Multiobjective Optimization of Renewable Distributed Generation and Shunt Capacitor for Techno-Economic Analysis using Hybrid Invasive Weeds Optimization

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Abstract— *The techno-economic benefits of smart distribution grid enhanced through the integration of voltage control device and Renewable DG (RDG). In this research paper, a new optimization method called hybrid Invasive Weeds optimization proposed to solve the multiobjective optimization problem of minimizing power loss, cost of energy, and voltage deviation. Invasive Weeds optimization (IWO) and Artificial Bee Colony (ABC) are the new nature-inspired algorithms used to solve constrained optimization problems in distribution networks integrated with capacitor and RDG for both reactive and real power compesation. The optimum location of RDG and capacitor determined by using ABC algprithm and performance indices while the optimum size of RDG and capcitor found out by hybrid invasive weeds optimization..The results depict that the optimal RDG and capacitor reduce power losses by 14.4%, and cost by 22.4%. The effectiveness of proposed hybrid approach implemented in MATLAB and tested on IEEE 34-nodes and IEEE 37-nodes test feeder. The obtained results prove indetails the efficiency of the proposed approach to solve MOP problems.*

Keywords— **Invasive weeds optimization, renewable DG, ABC algorithm, HIWO, optimal power flow.**

1. INTRODUCTION

The needs of acceptable power quality, stability, and reliability in affordable create a climate for the penetration of renewable distributed generation in power distribution system of Thailand to enhance the desired performance. Usually, the power distribution networks are radial experiencing low X/R ratio, unidirectional of power flow, high power loss, voltage deviation, and voltage instability. Recently the cost of RDG has been reduced drastically due to the advanced technology [1]. Optimization techniques can use for deregulation of the power industry, by using the best allocation of multiple RDG units [2]. The advancement of RDG technology and the demand of the customers for reliable, affordable, and stable power supply has led to an increasing interest in RDG in power distribution networks [3]. However, issues related to reliability, stability, and variability have hindered the penetration of RDG units in power distribution grids [4]. Since RDG placement in on-grid critically affects the operation of the power distribution network.

To achieve improvement of voltage profile, power quality and reduction of power loss (enhanced performance) of radial power distribution network suitable sitting and size of RDG with shunt capacitor need to be provided. Since the integration of non-optimal size of RDG lead to complex operational situations in the power distribution network [5].

Under the current standard IEEE 1547, most of the RDG designed to operate at unity power factor [3], [6]. Conventional devices [7] such as switchable capacitors, voltage regulators and tap changers employed by different researchers for solving voltage regulation problem, but they are not fast enough to compensate for transient events [8]. Other technologies such as permanent magnet synchronous machines used in biomass power plants, gas power plant, and wind farm employed for controlling both real and reactive power [9]. However, sustainable energy supply such as solar PV farm and wind turbine farm is the most promising technologies for supply power at sub-transmission and distribution networks for techno-economic benefits. However, the drawbacks of using one type of RES are intermittent and variability which may not match with the load demand [10]. A hybrid approach of combining solar PV and wind turbine system, can efficiently complementary characteristics of each RES to improve reliability, power quality, and stability in the radial distribution system. Hence, the goal of this paper is optimal for hybrid RDG system for increasing techno-economic benefits.

Placement and sizing of DG were the best the best research topics for the past of three decades. The placement of RDG as single objective optimization carried out in various optimization techniques for finding MOO of DG in-line with minimizing power loss, operation cost, and maximization of profit. These methods include Improved Bat Algorithm [11-12], Particle Swarm Optimization (PSO) [13], Artificial Bee Colony (ABC) [14], Genetic Algorithm (GA) [15], and Analytical expression (AE) based heuristics [16-17]. The limitation of AE based heuristics is the inability to handle multiple objectives and multiple RDGs. In [15], GA introduced to address the optimal sizing and location

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of DG for voltage stability enhancement, and power loss reduction. Authors in [13] applied the PSO with improved differential evolution algorithm for the optimal sitting of DG in power distribution networks. The objective was a reduction of real power loss with the optimal real power of DG in RDS. From [14], results of optimal sizing and location using ABC and PSO were compared.

Researchers found in [16] present a method for multiple DG sitting using an analytical method for loss reduction as an objective function. They compare the optimal size of four types of DG. The effectiveness of IA method compared to loss sensitivity factor using 33-node and 69-node RDSs. MOPSO algorithm presented by authors in [19] used to optimize sizing, and siting of multiple DGs in RDS. The proposed algorithm tested in IEEE 34-node and 69-node RDNs to improve the voltage magnitude, stability, reduced power losses, and enhanced the supply reliability. The drawbacks of these algorithms are declared insecure convergence properties, the complexity of algorithmic for a big network, and long execution time. Besides, the solution trapped into local minima. To overcome the drawback of these methods, researchers have successfully applied meta-heuristic algorithms such as ABC [20], FPA [22], IWO [23], [37] and HIWOPSO [27]. It is reported that meta-heuristic algorithms are more efficient than classical algorithms for solving the MOO problem.

The ABC algorithm [20] gave better results in term of iteration, quality of the solution, and convergence. However, IWO for power loss reduction in radial power system subjected to both voltage constraints and power transfer for the optimum sitting of DG performed in [23]. Authors in [24] present DE algorithm to determine optimal size and location of DG and shunt capacitor in power distribution system for minimum power loss and voltage profile improvement. The results analyzed in electricity benchmark of the 12-nodes power distribution network. However, results of inappropriate sitting and sizing of DG and capacitor shows a reduction of techno-economic benefits of the entire system operation.

In this study, an attempt of combine solar PV, a shunt capacitor, and permanent magnet synchronous wind turbine in distribution made as multiple RDG units in radial distribution network using Hybrid Invasive Weeds Optimization (HIWO). The RDGs that are capable of supplying both active and reactive power is the most effective for power loss reduction. Power loss minimization investigated by integrating multiple DGs and shunt capacitor. The problem of RDG placement to minimize energy losses has been solved by ABC algorithm [20] for two different load scenarios. Multiple RDG placements have been obtained by FPA [21], [25] to achieve an extreme reduction in annual energy losses in the radial distribution system. Distribution test networks such as IEEE 34-nodes and IEEE 37-nodes have been used to validate the effectiveness of proposed method.

This paper presents Hybrid Invasive Weeds Optimization (HIWO) and voltage stability index (VSI) for finding both optimal location and size of shunt capacitor and RDG in power distribution network. Hybrid technique of IWO and ABC adopted in this paper, has been proposed in [28], [29], while voltage stability index (VSI) adopted from [30]. IWO and ABC as new optimization algorithm used to diminish the problem of optimization considering reduction of total active power losses, the total operation cost, cost of energy loss, lower cost of electricity and voltage deviation in the rural community of Thailand. HIWO proposed to suit multi-objective problems due to its fast convergence performance and robustness. The results show that HIWO has better performance than the other algorithms in most of the functions. The obtained results analyzed and compared with recently published papers such as FPA [21], PSO [13], and GA [15] to confirm its notability

In Section 2, depicts modeling of renewable DG for optimal power flow. Deterministic power flow as a nonlinear multiobjective optimization problem with equality and inequality constraints analyzed in section 3 including problem formulation. In section 4 described ABC algorithm method while IWO as an intelligent optimization algorithm described in section 5 and section 6 shows the simulation results of the study. Finally, the main contributions of this paper summarized in Section 7.

2. MODELING OF RDG FOR OPTIMAL POWER FLOW

Wind turbine

In this research work, proposed wind turbine adapted from [21] and [31]. The parameters used are as follows: $Pnom$=600 kW, Vci=4 m/s, $Vnom$=16 m/s Vco=20 m/s. Fig. 1 shows the wind speed data used to calculate the power generated by the wind turbine generator in the deterministic OPF algorithm.

The power output of wind turbine in (1) and (2) considers two main factors, the wind speed and the power curve of the wind turbine. According to [20] the power curve of a wind turbine can be modeled using a function split into three different parts**:**

$$P_{wt} = \begin{cases} 0 & V \le Vci \\ YP_{norm} & V_{ci} \le V \le Vco \\ 0 & V > Vco \end{cases} \tag{1}$$

$$Y = \frac{V^2 - V_{ci}^2}{V_{norm}^2 - V^2{}_{ci}} \tag{4}$$

where $Pnom$, $Vnom$, Vci, *and* Vco *are* nominal active power, nominal speed of the wind turbine, cut-in wind speed turbine, and cut-out wind speed of the wind turbine, respectively. Pwt and V denoted power output of the wind turbine and wind speed respectively.

Solar PV

The power output of the SPV shown in (3) dependent on the solar irradiance and ambient temperature of the site shown in (4) as well as the features of the module itself

[23]. The following equation used to determine the power output of the photovoltaic module *PV* [31]:

$$P_{pv} = \frac{P_{STC}T_S[1+\mu(T_C-25)}{1000}] \quad (3)$$

where *P_STC* is photovoltaic module maximum power at Standard Test Condition (STC) in Watts, *Is* is solar irradiance in (W/m2), μ is the coefficient (°C^{-1}), of solar PV, *Tc* is temperature (°C) of the photovoltaic cell determined as a function of solar irradiance and ambient temperature.

$$T_C = T_a + \frac{Is(T_{NOCT}-20)]}{800} \quad (4)$$

where *Ta* is ambient temperature (°C), *TOCT* is operating cell temperature (°C) of the Solar PV. Their performance characteristics are P_*STC*= 250 W,
µ = 00450C-1, T_NOCT=460C.

Hydropower

The mathematical formula depicted in (5) determine the power output of hydropower by Hermandez et al. 2012 [24] and Fuchs et al. 2010 [32] as follows:

$$P_h = \rho g H Q(t) \quad (5)$$

where *Ph* is hydraulic power produced at the shaft in MW, *p* is the density of water, *g* gravity due to gravity, *Q(t)* is the rate of water flow in meter cubic per second, *H* the sufficient head of water across the turbine.

Cost Analysis

Purchased actual power cost from the grid:

Purchase effective power cost from grid including losses is evaluated using (6) [33].

$$T_c = \sum_{t=1}^{t} PW^t E_d P_d T \quad (6)$$

where *PW* is the present worth, and it is expressed by (7), *t* is a planning period for five years, *Ep* is the electricity market price, *T* indicates time in hours and yr shows the year, *Pd* is the total real power demand, and it is a combination of total active power load (Pload) and real power loss (PLoss) of a network. It may be expressed using (7).

$$PW = \frac{1+\inf \quad R}{1+\text{int} \quad R} \quad (7)$$

Installation cost of Capacitor and RDG

Installation cost of shunt capacitor is a combination of capacitor purchase cost and fixed cost, and it can be evaluated using (8) while for DG expressed in (9). The possible standard sizes and individual purchase cost ($/kVAr) of shunt capacitor and $/MW of RDG are available in [33].

$$C_{inst} = \sum_{i=1}^{ncap} K_c^{inst} Q_{c,i} + K_c^f \quad (8)$$

$$RDG_{inst} = \sum_{i=1}^{NDG} RDG_{c,i} * K_{RDG}^{inst} \quad (9)$$

O&M cost of RDG and Capacitor

RDG O&M cost depends upon the real power supply by RDG to a system, and it can be calculated using (11).

$$RDG_{OM} = \sum_{T=1}^{YR}\sum_{i=1}^{NDG} PW^t * P_{DGi} * T * K_{RDG}^{OM} \quad (11)$$

Total annual cost saving

The total annual cost saving of a network is a difference between total annual cost before and after incorporation of RDG and shunt capacitor. It is evaluated using (12).

$$\%NS = \frac{T_C^{before} - (T_C^{after} + C_{Int} + I_{cost} + O_{cost})}{T_C^{before}} \quad (12)$$

where *NS* is Net Saving, *Tc_bef* and *Tc_aft* represent the purchase actual power cost from transmission grid before and after placement respectively, *Icost* is Installation cost of RDG, and *Cost* is Operation cost of RDG.

3. DETERMINISTIC OPTIMAL POWER FLOW

The MOPF problem can be formulated as follows [16]:

$$\min \; F(x,u) \quad (13)$$

subjected to

$$\begin{cases} g(x,u) = 0 \\ h(x,u) \le 0 \end{cases} \quad (14)$$

where *F* is the MOPF, *x* and *u* are vectors of state and control variables, respectively.

For distribution networks, the vector of dependent variables (*x*) shown in (15) consisting of:

- The active power of the electric grid *Pgr*
- Load node voltages,
- The reactive power *DG* units which are as PV nodes *QDG*;
- Branch flows *S*.

Therefore, *x* expressed:

$$x = [P_{gr}, V_L, S_l, Q]^T \quad (15)$$

where N_L, are number of PQ nodes and N_{PV}, are number of PV nodes.

Also, Vector of control variables (u) shown in (16) consists the following;

- The P of the DG units with nonrenewable energy sources PDG;
- Node voltage;
- Voltages at PV nodes V_{PV};
- Tap settings of Transformer t;
- Shunt VAR compensators Qc.

Therefore, the vector of control variables expressed as:

$$u = [V_{PV}, P_{DG}, Q_C, T]^T \tag{16}$$

where NNR, NPV, NT, and NC are a number of the non-renewable DG units, number of PV nodes (RDG units modeled as PV nodes), number of regulating transformers, and number of VAR compensators, respectively.

Multi-objective OPF

The multiobjective function of this work is to find the optimal size and location of RDG. The equation shown in (17) depicts the general objective of this paper as MOF which of the cost of energy loss, power losses and voltage deviation at load nodes:

$$\mathrm{F} = \mathrm{W_C C_{EL}} + W_V \sum_{i=1}^{NL} |1 - V_i| + W_p \sum_{i=1}^{N} P_L \tag{17}$$

where

$W_C + W_V + W_P = 1$
W_C Weight factor for the cost of energy loss
W_V Weight factor for voltage deviation
W_P Weight factor for power loss

Cost of energy losses (CEL) [34]

The mathematical equation shown in (18) was used to compute the annual cost of energy losses.

$$CEL = P_L * (K_p + K_e L_f * 8760)\$ \tag{18}$$

where
K_p Annual cost of power loss = 57.6923$/kW
K_e Cost of energy loss = 0.009615$/kWh
L_f Loss factor = 0.47

Real power loss

The total active losses of the system shown in (19) can be computed as follows

$$P_L = \sum_{k=1}^{N} G_k [V_i^2 + V_j^2 + 2|V_j||V_i| \cos(\delta_i - \delta_j) \tag{19}$$

where N is the total number of lines in the system; G_k is the conductance of the line 'k', V_i and V_j are the magnitudes of the sending end and receiving end voltages of tie line; are angles of the end voltages.

Economical Saving

By using the proposed method, net savings given by (20) and (21) were used to analyze economic saving in addition to its technical advantage

$$\begin{aligned} Netsaving &= (C_e * P_{Loss}^{Cap} * T) + (C_e * P_{Loss}^{RDG} * T) \\ &- (Cd * Nn) - (C_c * T_c) - (C_{RDG} * T_{RDG}) \end{aligned} \tag{20}$$

$$NS = EC / yr - (Cost_{inst} + Cost_{Pur}) - (Cost_{Op/year}) \tag{21}$$

where;
N_S Net saving
E_C Cost of total energy produced per year.
N_n The number of compesated nodes in the system
T_C The total capacity of the capacitor
T_{RDG} The total capacity of RDG
P_{Loss}^{RDG} The total power loss with RDG
P_{Loss}^{C} The total power loss with capacitor

Table 1: The parameter used for net savings [35]

S/N	Parameters	Value
1	Energy rate (Ce)	$0.06/kWh
2	Installation cost (Ccl)	$1000/each
3	Purchase cost (Cp)	$3.0/kVAr
4	Time (T)	8760

Table 1 depicts parameters used for analyzing economic benefits of the proposed research.

Voltage Stability Index (VSI)

Fig. 1 depicts the electrical equivalent of the radial power distribution system. The voltage Stability Index (SI) shown in (21) is one of the most significant indices that contribute to the security of the network. Fixing of the RDG units in the power distribution system have a tremendous positive impact on the voltage stability index. Chakraborty M. et al. in [20] have proposed a new VSI for determining the most sensitive node to voltage collapse. The value of VSI is given by (21).

$$VSI = |V_i|^4 - 4[P_r X_{ij} - Q_r R_{ij}]^2 - 4[P_r R_{ij} + Q_r X_{ij}]|V_s|^2 \tag{21}$$

The node at which VSI has the lowest value is prone to collapse. Therefore, to evade the possibility of voltage collapse, the VSI of all nodes determined at the base case and after placement of both shunt capacitor and RDG.

System Limitations

The MOPF subjected to the following constraints:

Equality constraints

The equality constraints (2) represent power balance and power flow equations. The power balance equation in a distribution network with DG units with renewable and nonrenewable energy sources expressed as follows:

The equality constraints represent the power flow equations, which are given below for ith nodes:

$$\begin{cases} P_G + P_{RDG} - P_D = \sum_{k=1}^{N} G_k [V_i^2 + V_j^2 - 2|V_j||V_i|\cos(\delta_i - \delta_j)] \\ Q_G + Q_{RDG} + Q_C - Q_D = \sum_{k=1}^{N} B_k [V_i^2 + V_j^2 - 2|V_j||V_i|\sin(\delta_i - \delta_j)] \end{cases} \quad (22)$$

Inequality constraints

Inequality expression in (23) is functional which comprise: voltage magnitude of nodes, reactive power capabilities of *RDG* and power flow limits in the branch. However, these constraints may describe the practicability region of the problem control variables such as *RDG* unit active power output limits, magnitude limits of *PV* node voltage, transformer tap setting limits and shunt *VAR* compensator.

PV nodes constraints (Generator):

Voltage and reactive power of ith node of generator lie between their upper and lower limits as given below:

$$\mathrm{V_{Gi}^{min}} \le \mathrm{V_{Gi}} \le \mathrm{V_{Gi}^{max}} \quad (23)$$

$$\mathrm{Q_{Gi}^{min}} \le \mathrm{Q_{Gi}} \le \mathrm{Q_{Gi}^{min}} \quad (24)$$

where in (28) depicts minimum and a maximum voltage of i^{th} generating units and in (29) present minimum and maximum reactive power of i^{th} generating units.

PQ nodes constraints:

The voltage magnitude for all load nodes expressed as**:**

$$\mathrm{V_{Li}^{min}} \le \mathrm{V_{Li}} \le \mathrm{V_{Li}^{max}} \quad (24)$$

where expression (22) depicts are the minimum and maximum load voltage of i^{th} unit.

Tap Setting of Transformer:

Tap settings of Transformer between upper and lower limit as given below:

$$\mathrm{T^{Min}} \le \mathrm{T} \le \mathrm{T^{Max}} \quad (25)$$

Shunt compensator constraints:

Shunt compensation is restricted by their limits as follows:

$$\mathrm{Q_{Ci}^{min}} \le \mathrm{Q_{Ci}} \le \mathrm{Q_{Ci}^{min}} \quad (26)$$

where an expression (26) depicts the min and max *VAR* injection limits of i^{th} shunt capacitor.

Constraints of RDG:

$$\begin{cases} 1.5MW \le P_{DG} \le 5.0MW \\ 0.5MWAr \le Q_{DG} \le 2.0MVAr \end{cases} \quad (27)$$

Reactive power (Q) of *RDG* supplementary to the *OF* as a quadratic penalty term [16]. The new expanded *OF* becomes:

$$F_p = F + \lambda_V \sum_{i=1}^{NL} (V_i - 1)^2 + \lambda Q_{DG} i = 1 \sum_{i=1}^{NPV} (Q_{DGi} - Q_{DGi}^{\lim})^2 + \lambda_S \sum_{i=1}^{N} (S - S_i^{\lim})^2 \quad (28)$$

where λ_V, λ_{QDG}, and λ_S defined as penalty factors, x_{lim} is the limit value of the dependent variable x and given as [21]:

$$\begin{cases} x^{\lim} = x^{\min} ....if.....x < x^{\min} \\ x^{\lim} = x^{\max} ....if........x > x^{\max} \end{cases} \quad (29)$$

4. METHODOLOGY

IWO Algorithm

IWO is the optimization algorithm developed by Mehrabian and Lucas in 2006. IWO is a novel ecologically inspired algorithm that mimics the process of weeds colonization and distribution [37]. Despite its recent development, it has shown successful results in some practical applications like optimization of optimal reactive power by using hybrid IWOPSO [36]. Each invading weed takes the unused resources in the field and grows to the flowering weed and produces new weed independently, as shown in Fig 1.

Steps of Invasive Weeds Optimization Algorithm:

Step 1: Initialization: As search space is taken, and a certain number of weeds are initialized randomly in the entire search space.

Step 2: Reproduction

The seeds produced by weeds increase linearly starting with worth fitness and ending with the best fitness.

$$s(i) = s_{\max} - abc(floor(\frac{s_{\max} * g_{best})}{g_{best} - g_{worst}}) \quad (30)$$

Step 3: Spatial dispersion

This step ensures the probability of dropping a seed in the remote area decreases nonlinearly.

Step 4: Competitive Exclusion

Fitter plants produce more seeds than fewer desirable plants, which tends to improve the convergence of the algorithm.

Step 5: Randomly initialized of the RDG and capacitor values (weeds values). The weeds with the highest fitness produce the maximum number of seeds and those with the lowest fitness produce minimal seeds. Seeds produced by the weed calculated by using (30)

Step 6: Now the generated seeds are added to the solution set, and the fitness value calculated for the combined set of weeds and seeds

Step 7: The population sorted in descending order of their fitness. Step 4-6 repeated until a maximum number of iteration reached.

Table 2: Controlled parameters for IWO

Parameters	Value
Max. Number of weeds	10
Total weeds in the population	100
Initial standard deviation	2
Final standard deviation	1e-3
Nonlinear modulation index	5

Artificial Bee Colony Algorithm

Artificial Bee Colony (ABC) algorithm, proposed by Karaboga for optimizing mathematical problems. ABC algorithm new swarm method that introduced by Karaboga in Turkey in 2005 [14], [20].

The ABC algorithm imitates the behaviors of bees in finding food sources and sharing the information with other bees. Since ABC is simple in easy to implement and has fewer control parameters. ABC algorithm is a combination of three types of honey bees namely employed bee, onlooker bee, and scout bee, where onlooker and scout bee considered as an unemployed bee. The employed bees' searches and exploits a food location while the onlooker bees wait in the hive. Then employed bee, share information with the onlooker bees regarding a food location.

Three control parameters used in the ABC based algorithm; the number of the food source which is equal to the number of onlooker bees, the value of limit and the MCN. In ABC, if a position cannot be improved further through a predetermined number of cycles, then that food font is assumed to be abandoned. The value of the predetermined number of cycles is an important control parameter of the ABC algorithm; this termed the limit for abandonment.

An optimization algorithm for ABC

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

$$X_{ij} = X_{minj} + rand(0,1)(X_{max,j} - X_{min,j}) \tag{31}$$

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

$$Fitness = \frac{1}{1 + Objective\_function} \tag{32}$$

Total Losses = Active Power Losses + Reactive Power Loss

Step-3: Produce neighbor solutions for the employed bees by using (39).

$$v_{ij} = x_{ij} + f_{ij}(x_{ij} - x_{kj}) \tag{33}$$

Step-4: Apply the acquisitive selection process between Xij and Vij. If all onlooker bees distributed, go to *Step 9*. Otherwise, go to next step.

Step-5: Determine the probability values $P_{(Xij)}$ for the solutions *Xij* using (40)

$$P(X_{ij}) = \frac{F(X_i)}{\sum_{i=1}^{n} F(X_i)} \tag{34}$$

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*.

$$X_{i,j}^{\max} = x_{\min,j} + rand(0,1)(x_{\max,j} - x_{\min,j}) \tag{35}$$

Step-8: If cycle = MCN, stop and print result. Otherwise, follow Step 3 as shown in Fig 2.

Table 2: Parameters of ABC in IEE 34 [20]

S/N	Parameters	Value
1	Limit	35
2	MCN	100
4	Food source	40

The Hybrid IWO and ABC Algorithm

From the two previous sections, it can be concluded that IWO and ABC have two different approaches for optimization. IWO offers good exploration and diversity, while ABC is an algorithm with reasonably deliberate and to the point movements in each iteration. In this section, we combine two algorithms and present a hybrid algorithm. In hybrid IWO/ABC algorithm, colonization is beginning in the same way as IWO. However, the weeds are located like the equations in ABC for flying bees. It means that after reproducing the weeds, the velocity updated and temporary position of weeds is estimated. Finally, these weeds distributed randomly same as the process used in IWO to construct the next population.

HIWO algorithm for solving MOO Problem

1. Generate random population of N0 solutions,
2. For *iter* = 1 to the maximum number of generations;
   a. Calculate fitness for each iteration;
   b. Set Pg as the best position of all individuals
3. Set Pi as the best position of the individual in comparison with its predecessors;
4. Computation of weeds, corresponding to its fitness,
5. For each weed S;
   a. Calculate the velocity;
   b. Update the position;
6. Randomly generated weeds over the search space with a normal distribution around the parent plant
7. Add the generated weeds to the solution set, W
8. Sort the population in ascending order of their fitness;
9. Truncate population of weeds with smaller fitness until $N = Pmax$ and then to Next iteration

The HIWO used to solve the optimal capacity and location problem by considering the following cases:

Case #1: allocation of a single RDG.

Case #2: allocation of single RDG and capacitor

Case #3: allocation of multiple RDGs only

Case #4: allocation of multiple RDGs and capacitors

Table 3: Weighted factors value Control variable

Scenario	Wp	Wv	Wc
1	1	0	0
2	0.8	0.1	0.1
3	0.6	0.2	0.2
4	0.4	0.2	0.4
5	0.2	0.4	0.4
6	0.1	0.4	0.5

Table 4. Control Variables

Parameters	34-Nodes	37-Nodes
V	0.95 - 105	0.95-1.05
Q_C (MVAr)	1.5 - 8	1.5 - 8
P_{RDG} (MW)	1 - 5	1 - 5
Q_{RDG} (MVAr)	0.5 - 2	0.5 - 2
T	0.95 – 1.05	0.95 – 1.05

5. SIMULATION RESULTS AND DISCUSSION

IEEE-34-Nodes System Results

The IEEE 34 node test feeder shown in Fig. 6 is an actual feeder located in Arizona and characterized by long, lightly loaded, multiple three and single-phase laterals and unbalanced distribution feeder with operating voltages of 24.9 kV. The line data and node data for this system is given in [24]. The total real power of RDS is a 4636.5kW and reactive power of is 2873.5 kVAr. The real and reactive power losses of RDN at the base case is 220.8 kW and 63.9 kVAr respectively. The cumulative voltage deviation of the base case is 1.16. Table 4 shows control variable used in this research study.

In Table 5 depicts performance analysis of IEEE 34 nodes with power losses reduced to 14.4%. In contrast, the voltage magnitude seems to be within the range of 0.95 to 1.0 in scenario number 4 shown in Table 3. Fig.3 and Fig.4 depict convergence characteristics of IWO and ABC respectively on solving MOO problem.

Table.5: Performance Analysis of IEEE-34-Nodes

Parameter	Case 3	Case 4
P_{RDG} (MW) (node)	2.2 (28)	1.61 (18) 1.82 (30) 1.58 (10)
Capacitor MVAr (node)	-	1.28(26) 1.02(21)
Ploss (kW)	493.68	167.27
Qloss (kVAR)	270.00	46.49
|Vmin| in p.u	0.93	0.95
|Vmax| in p.u	0.99	1.00
VSI	0.178	0.04
CVD	0.968	0.22
% Ploss reduction	9	14.4
CEL ($/Year)	716,830.24	337,614.18

Results using different Methods in IEEE-34-Node

The simulated results in Table 9 compared with GA [14], particle swarm optimization (PSO) [15] and Flower Pollination Algorithm [11], and GA method [17].

Table 6. Simulation Results of 34-Nodes

Parameters	GA [14]	PSO [15]	FPA[11]	HIWO
Vmin	0.947	0.951	0.932	0.951
Vmax	0.994	0.997	1.010	1.020
VSI.min	0.861	0.801	-	0.882
VSI.max	0.979	0.980	-	0.994
Ploss(MW)	0.169	0.168	0.173	0.167
Qloss(MVAr)	0.051	0.049	0.055	0.046
Net saving %	17.891	15.57	-	38.84

From the given Case 1 to Case 4, only two cases considered for comparison which good results based on techno-economic benefits as shown in Table 5 for IEEE 34 nodes and Table 8. However, based on scenarios shown in Table 3, only scenario number 4 shows promising results in both test system, i.e. that is the IEEE 34-nodes and IEEE 37-nodes system.

IEEE-37-Nodes System Results

The problem of placement and sizing of the shunt capacitors and RDG has been solved for the unbalanced IEEE 37-nodes. However, the distribution network under study in modified IEEE-37 nodes system shown in Fig. 5 adapted from Tanzania. System interconnected at slack bus number 5290 (Kiyungi 33kV). The network parameters and related data found in [11]. VSI used for the placement of the RDGs and shunt capacitor. The first three nodes considered as an optimum place for RDG. The node numbers chosen as per VSI are 35, 26, 29, 37, 18, & 11. The outcome leads to two locations for RDG and two locations for capacitor placement, which are nodes 35 & 268 and 34 & 31 respectively with maximum capacitor ratings depicted in Table 8 with scenario number four shown in Table 3.

Performance of the system before and after installation of RDG are shown in Table 7 and Table 8.

Table.7: Performance of scenario one in IEEE-34-Nodes

Parameters	Without RDG	With RDG
P_{RDG}(MW) Node)	-	1.61 (18) 1.82 (30) 1.58 (10)
Power loss (kW)	290.31	199.89
CEL ($)/year	964,145.52	508,655
Δ VD	0.15	0.01
% loss reduction	-	14.4
Shunt capacitor kVAr (node)	-	1.08 (26) 1.02 (21)

Table.8: Performance analysis of IEEE-37-Nodes in scenario one, case four

Parameters	Without RDG	With RDG
P_{RDG} (MW) (Node)	-	1.24(28) 1.52 (35)
Power loss (kW)	367.89	170.89
CEL ($)	4534.78	1049.41
Δ VD	0.27	0.03
% loss reduction	-	26.92
Shunt capacitor kVAr (node)	-	1104(34) 1010(31)

The Optimal sitting and sizing of single RDG in RDs network using proposed method revealed that the best location of the RDG and capacitor in the network depend on network configuration, load, and technology of renewable energy source to be used. The power loss reduced to 0.167MW as against the initial value of 290.3kW with a reduction also in voltage deviation to 0.004 from 0.155 depicted in Table 8.

The variation of voltage drop for the base case is shown in Fig.7 and Fig 8 forgiven 34-nodes and 37-nodes distribution networks respectively. Different scenarios were considered to obtain the optimal site and size of both capacitor and RDG. Additional to that, voltage, transformer tap changer, and power from RDG considered as constraints. Evaluation of case 1 to case 4 with consideration of scenarios of 34-nodes is shown in Fig. 9 while for 37-nodes is shown in Fig 10 respectively. It shows that simultaneously optimization of power loss, voltage deviation and energy losses gives better results on both sizes of RDG and location.

Economical Saving

By using the proposed method in addition to its technical advantages, an economic saving or benefit obtained after 15 years. The worth of the saving of reduction purchased energy for IEEE 34-nodes, and 37-node systems are $14,096,064 and $21,203,100, respectively. Also, ultimate benefit including the total costs of energy losses for a 34 and a 37 nodes systems are $337,614.18 and $, 1,049.41 respectively as shown in Table 5 and Table 7. The total combination of wind turbine and solar PV Generator brings to the total net present cost (TNPC) value of $891,995 that is lower than the TNPC of $2,578,224 for the hybrid renewable system consisting of hydropower generator, solar PV generator, wind turbine generator, converter and battery storage.

6. CONCLUSION

In this paper, the IWO and ABC algorithm has been implemented into presented case studies considering the IEEE-34-nodes and IEEE-37-nodes distribution system. Both VSI and ABC have been used to identify the potential nodes for sitting RDG and shunt capacitor. HIWO used to solve MOO problem considering both voltage and power constraints. The results show that the proposed method achieved better in power loss reduction, saving of cost of energy loss, and less voltage deviation when compared with other existing techniques. Hence, the proposed method can able to implement for any distribution system to enhance voltage profile and conclude that the proposed method of sizing and sitting of RDG and capacitor is suitable for techno-economic benefits. The obtained results via the proposed HIWO method is preferable regarding the excellence of the solution and the computational efficacy.

ACKNOWLEDGMENT

Authors would like to express our sincere gratitude to the management of the Suranaree University of Technology-Thailand for providing excellent infrastructure facilities and encouragement which have made this research possible.

NOMENCLATURE

RES	Renewable Energy source
RDG	Renewable distributed generation
Qc	Capacitor reactive power
Qdg	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
IWO	Invasive weeds optimization
FPA	Flower pollination algorithm
DG	Distributed generation
Vi	Voltage at ith node
Tc	Total purchase power from the grid
Vi^{max}	maximum voltage of ith node (p.u)
Vi^{min}	minimum voltage of ith node (p.u)
Ps	Active Power from the substation
Qs	Reactive power from the substation
Vj	Voltage at jth node
V_L	Voltage at load node
Ep	Electricity market price
Ta	Ambient temperature
P_W	Present worth
C_{EL}	Cost of energy loss
L_{COE}	Levelised cost of energy
T_{NPC}	Total Net Present Cost
MOPF	Multiobjective Power Flow
PV	Photovoltaic

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