European Journal of Molecular & Clinical Medicine

ISSN 2515-8260 Volume 08, Issue 02, 2021

Hybrid Cuckoo Search-Evolutionary Programming Technique for Distributed Generation and Battery Energy Storage Installation

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Abstract

Installation of distributed generation (DG) in distribution system has been favorable among them due to its great impact on power system operation. However, improper installation of DGs will lead to under-compensation or over-compensation phenomena. Thus, a reliable optimization technique is required to address this problem. This paper proposes a hybrid cuckoo search evolutionary programming (HCSEP) based technique for renewable energy distributed generation (REDG) and battery energy stored (BES) for loss and voltage stability control in power system. This technique integrates the operator in cuckoo search algorithm into the traditional evolutionary programming (EP) technique to alleviate the setback experienced in both traditional techniques. The proposed technique determines the optimal allocation and sizing of multi-units of DG and BES to address the loss minimization and voltage stability control. Validation on the proposed technique on the IEEE 30-Bus Reliability Test System (RTS) managed to produce convincing results and could be beneficial to the utility. Comparative studies conducted between the proposed HCSEP and the traditional EP highlight the superiority of the proposed HSCEP.

Keywords: Distributed generation, Hybrid Cuckoo Search Evolutionary Programming (HCSEP), Power Loss.

Introduction

Rapid population growth and developing industrial sector have witnessed the increasing number of power demand in the recent years [1]. Nevertheless, the current network may not be sufficient to satisfy the demand due to the rising crude oil. This would also be influenced by the deterioration of the grid system generation stations [2]. One of the challenges faced by the utilities is the provision of reliable power over high consumption periods. These high periods of consumption usually occur in the evening and at morning [3]. So, power plant owners have used their costly generator systems for a limited period to satisfy the high peak hour demand. High peak time consumption also causes system instability due to the overloading of the transmission and distribution lines [3]. Capacitor placement and distributed generation (DG) are the popular methods that usually used to imitate power losses problems in a system [5] - [8]. Power losses do not only contribute to monetary loss to the power provider, but it also gives a negative impact on power transfer by minimizing the effectiveness of power transmission. But most studies are more focusing on installation of DGs due to its significant impacts in terms of technical, economic, and operational characteristic change [9]. Distributed generation or also known as 'Embedded Generation' and 'Disperse Generation' are defined as small scale electricity generation that is capable to generate power from renewable energy in the range of 3-10,000 kW [10]. Energy storage systems have recently received a lot of attention due to the wide of distributed generation (DGs) usage. The combination of battery energy stored (BES) system with DGs can change the power system structure and made it accessible to a smart grid [4].

Although the DGs have a lot of benefits but the most difficulty in the placement of DGs is to determine the best location, size, and range of DG units in the system [11]. Losses in system with DGs could possibly be greater than the losses without DGs if DGs are installed at improper location and size. This situation is known as under-compensation. On the other hand, non-optimum allocation and sizing of DGs may also lead to over-voltage problem which is over-compensation phenomena. Thus, the improper installation of DGs can be solved by using optimization.

In addition, many researchers have developed fast and efficient approaches to minimize power loss, in order to contribute to the transmission system and boost network efficiency [12]. Numerous techniques can be used to determine the optimum locations and sizes of DGs such as Genetic Algorithm (GA) [13], Particle Swarm Optimization (PSO) [14], Artificial Immune System (AIS) [15], Tabu Search [16], Evolutionary Programming (EP) [17] and Cuckoo Search Algorithm (CSA) [18]. In this paper, an optimization technique that embeds Cuckoo Search Algorithm (CSA) into the frame of Evolutionary Programming (EP) algorithm is used to determine the optimal locations and sizes in power distribution system for losses and voltage stability control. The hybrid technique is termed as Hybrid Cuckoo Search Evolutionary Programming (HCSEP). The proposed technique has been tested on the IEEE 30-Bus RTS under several scenarios. Comparative studies have been conducted with respect to the traditional EP, resulting convincing findings. The proposed technique can be further applied in solving other problems with minor modification in the algorithm.

Materials and methods

This section presents the research methodology of the study. It describes the problem formulation, the proposed technique and other relevant mechanics of the algorithms.

Problem Formulation

Artificial Intelligence (AI) technique is used to identify the appropriate placement for DGs installation. The following sections present the detailed formulation and constraints of the DG optimization problem.

A. Objective function

The objective function in this study is to minimize the power losses in the system and the formula is given by:

$$O.F = \min(P_{loss}) = Min(\sum_{n=1} I^2 R) \tag{1}$$

where, O.F is the objective function, *I* and *R* are the magnitude of current and resistance of branch.

B. Equality Constraint

$$\sum_{i=1}^{n} P_{DG,i} + \sum_{i=1}^{n} P_{G,i} = P_{demand} + P_{loss} \tag{2}$$

C. Inequality Constraints

$$P_{loss\_DG} < P_{set} \tag{3}$$

$$L_{DGi,min} \leq P_i \leq L_{DGimax} \tag{4}$$

$$L_{Bat,min} \leq P_i \leq L_{Bat,max} \tag{5}$$

$$P_{DGi,min} \leq P_i \leq P_{DGimax} \tag{6}$$

$$P_{Bat,min} \leq P_i \leq P_{Bat,max} \tag{7}$$

$$V_{i,min} \leq V_i \leq V_{I,max} \tag{8}$$

Where, P_{loss_DG} is the losses after installing DGs, P_{set} is the losses before installing DGs, P_{demand} is the total load demand in the system, P_{loss} is the total system loss, $P_{DGi,min}$ and $P_{DGi,max}$ are the minimum and maximum active power of DG which depends on the type of energy resources used, $P_{Bat,min}$ and $P_{Bat,max}$ are the minimum and maximum power level of battery energy stored (BES). Following the IEEE standard, the voltage levels are required to be maintained between 0.95 p.u. and 1.05 p.u. respectively.

Sizing of Distributed Generation

The sizing of DG mainly depends on the type of energy resources used while the type of power to be compensated depends on the type of distributed generation. The reactive output power of the distributed generator is determined using equation below:

$$X_i = -P_{DG} \tag{9}$$

$$Q_{DG} = 0.5 + 0.04 \times {P_{DG}}^2 \tag{10}$$

Fast Voltage Stability Index (*FVSI*)

Voltage stability is a continuous issue in power system despite numerous studies conducted several decades ago. Voltage failure and contingency analysis caused by line outage in power system was evaluated using a voltage stability index. One of the popular techniques, used in various studies is a line-based voltage stability indexed termed as Fast

Voltage Stability Index (*FVSI*). *FVSI* proposed by [10,19, 21], ensures that the system can be loaded securely on the bus. The line that gives an index value (*FVSI*) closest to 1.00 in voltage stability analysis is considered the most critical line of the system which can lead to the entire system instability. Voltage instability can lead to a voltage failure in the system, whereby the voltage decreases to an unacceptable, low value. Heavily loaded, faulted, or having a shortage in reactive power is usually the cause of voltage collapse. The mathematical representation for *FVSI* can be written as;

$$FVSI = \frac{4|Z|^2 Q_2}{|V_1|^2 X} \quad (11)$$

where, X is line reactance in p.u., Z is line impedancep.u., V_1 is the sending end voltage and Q_2 is reactive power at the receiving end.

Evolutionary Programming (EP)

Evolutionary Programming is known for its fast operation toachieve an optimal solutionwithin a short time. In most cases, EP has been proven superior in terms of fast computation to reach an optimal solution, especially in power system and the number of EP iterations is usually less than 10 iterations [21]. EP works based on several important operators namely, initialization, fitness calculations, mutation, combination and tournament/selection. One of the unique things working with EP is in terms of its ability to converge to an optimal solution. It is also worth to mention that EP is a simple technique to understand and work with, for the beginners. The applications of EP have been very broad as can be referred to numerous publications.

Cuckoo Search Algorithms (CS)

Cuckoo Search Algorithms, an evolutionary algorithm was proposed by Yang and Deb in 2009. This technique was based on the behavior of cuckoo species where they usually lay their eggs in other bird species nest and basically follow three principles [22].

- Each cuckoo lays one egg (new solution) at one time and dump it randomly in any chosen host nest amongfixed number of host nests which is available at that time.
- The best nests which consist of best quality of eggs will be considered to the next solution.
- The number of host nest is fixed, and the probability of host bird notice the foreign egg, $Pa \in [0, 1]$. The host bird can either abandon the nest or it can simply throw away the foreign eggs.

Cuckoo Search faced a phase known as iterative phase which consists of two random walks.
a) Levy Flights Random Walk
b) Biased or Selective Random Walk

After the random walks, the best nest (solution) is selected based on best fitness value between new generated solutions by Selected Random Walk and current solution by Levy Flights Random Walk.

Levy Flights Random Walk

Levy Flights is used to generate new solution with the step size is drawn from a Levy distribution. Levy Flights Random Walk can be written as:

$$X_{g+1} = X_g + \alpha \otimes Levy\ (\beta) \quad (12)$$

where α is step size. Levy (β) is a random number and can be drawn from a Levy distribution:

$$Levy\ (\beta) \sim u = t^{-(1+\beta)} \quad (13)$$

where, β is a constant with value 1.5.

Biased or Selective Random Walk

It is generally used to generate new solution if the current solution is out from the probability fraction. It can be formulated as [22]

If $u_\alpha > P_a$ then

$$X_{i,j,g+1} = X_{i,j,g} + u(X_{p,j,g} - X_{q,j,g}) \quad (14)$$

Otherwise,

$$X_{i,j,g+1} = X_{i,j,g} \quad (15)$$

Where p and q is p^{th} and q^{th} are solution in population respectively. While j is j^{th} dimension of solution. u or $u\alpha$ are random number in the range defines as $[0,1]$ and P_a is the probability fraction.

Proposed Hybrid Cuckoo Search Evolutionary Programming (HCSEP)

Hybrid Cuckoo Search Evolutionary Programming abbreviated as HCSEP is proposed where the mutation process in CS is embedded into the original EP algorithm. In this study, HCSEP is implemented in order to minimize the total losses and stabilize the voltage profile in transmission system by determining the optimal location and sizing of the renewable energy distributed generation (REDG) and battery energy stored (BES). The flowchart of the proposed HCSEP is shown in Figure 1 and the algorithm is explained as follows:

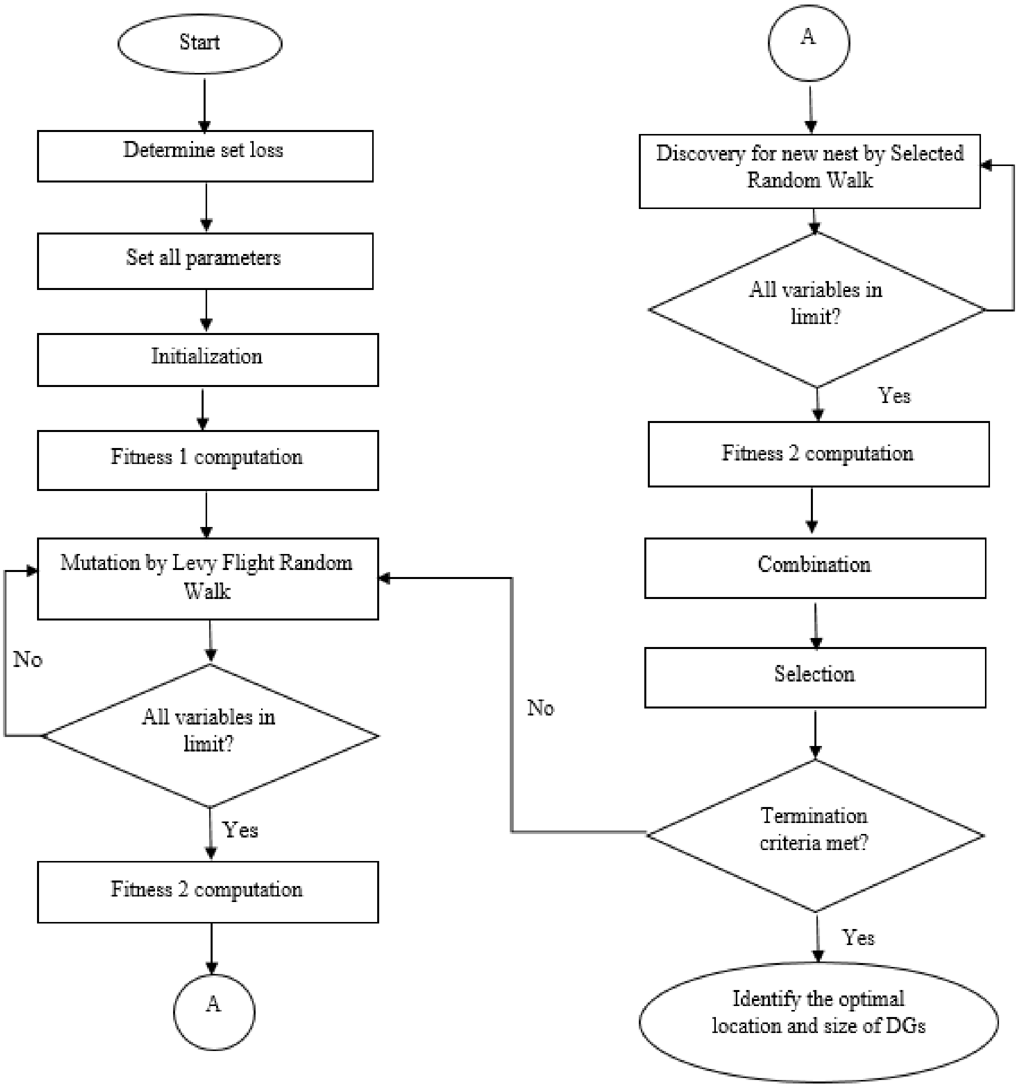

Figure 1: Flowchart of HCSEP

Step 1: *Determination of P_{set}*:Perform the load flow of IEEE 30-Bus RTS without any DGs placement. Define the total power loss of the system and calculate *FVSI*. The total loss is known as $P_{set.}$

Step 2: *Set parameters*: Initialize all the parameters such as number of population (n=20), maximum number of iterations (*Max_Iter*=100), upper and lower boundary of location and size of DGPV, WTDG, BES and probability (P_a=0.25).

Step 3: *Initialization*: In this process, 20 individuals of input variables; location, real power, reactive power of DGs and size of BES are randomly generated within specific limits by using (4)-(8). These candidates are known as parents and denoted as X_1. X_1 for reactive power can be determined by using equation (10) while $X_{1_location}$and X_{1_PDG} form are as follow:

$$X_i = rand^*(UB - LB) + LB \qquad (15)$$

Step 4: *Fitness 1 computation*:Fitness calculation is the process where the equation/function is to be optimized. In this study, the objective function which is to be minimized is the power losses; which will be used as the fitness function. The total losses can be determined by running the load flow while index can be calculated through the *FVSI* calculation. The value of fitness function famed based on equation (1).

Step 5: *Mutation*:Generate offspring solution; $X_{mutate}$by using Levy Flight Random Walk which is formulated in equations (12)-(13).

Step 6: *Limit check*:Check the generated offspring's value. The value must in range specified in equations (4)-(7). Step 5 is repeated if the values are not desired the limit.

Step 7: *Fitness 2 computation*:Perform load flow analysis and determine the power loss and the index for the offspring population. These losses will be the second fitness of the algorithm.

Step 8:*Discovery for new nest*:Generate new solution if the current solution is out from the probability fraction, $P_a \leq 0.25$ by using equations (14) to (15).

Step 9: *Limit check:*Check the value of generated new solution. The value must in the range specified in equations (4) to (7). Repeat step 8 if the values are not the desired limit.

Step 10: *Fitness 2 computation*:Perform load flow analysis and determine the power loss and index for new nest solution. These losses will override the previous data and become the second fitness of the algorithm.

Step 11: *Combination*:The process where the parent's solution and offspring solution are combined in series (by rows).

Step 12: *Selection*:The combination of parents and offspring are then conducted and rearranged in ascending order based on their fitness value. Only 20 best candidates are selected from this population.

Step 13: *Convergence Test*:The stopping criterion of HCSEP is determined by evaluating the difference between maximum fitness and minimum fitness to be less than 0.0001. The 0.0001 value can be changed depending on the required accuracy. The lower this value, the higher the accuracy is. The general equation is given as below:

$$diff = F_{MAX} - F_{MIN} \leq 0.0001 \qquad (17)$$

The optimization process is repeated from step 5 to 9 if the diff does not achieve the desired value;typically is 0.0001.

Step 14: *Identify the optimal location and sizing of DGs*and thebatteries:The minimum power loss in the best 20 similar optimal individuals are determined as the optimal location and sizing of DGs(REDG) and the batteries (BES).

Results and discussion

The standard IEEE30-Bus RTS is used as the test specimen for the validation process to determine the optimal location and sizing of DG and BES using the proposed HCSEP technique. In this section, the unit of DGs were varied for each DG types when the reactive loading was increased at certain bus. Table 1 tabulates the results for losses of the system before injecting DG and BES. Reactive load was gradually increased from 20 MVar to 50 MVAR at chosen load buses to show the effect of losses due to the high demand. Bus 13 (Scenario 1) and Bus 20 (Scenario 2) were chosen for the reactive load increment. Based on the losses, Bus 13 and Bus 20 represented the healthy and the weak buses in the system. From the table, the power loss in the system increases accordingly as the reactive load value was gradually increased, one at a time at both buses. The trends for both scenarios (i.e. for bus 13 and bus 20) are quite consistent, where losses are increased with the reactive load increment. The loss value in the system at reactive load value of 20

MVAR at bus 13 was originally 17.6156 MW. This value increases to 17.8251 MW with gradual increase in the reactive load until 50MVar. We may see that the increment is acceptably high. On the other hand, when reactive power load at bus 20 was increased from 20 MVar to 50MVar; the loss increases from 18.2559 MW to 20.9820MW. This implies a drastic increase in the power transmission loss due to the reactive power load increment at bus 20. Apparently, bus 20 is more sensitive than bus 13 when load increment was subjected to the system. Several cases are considered in terms of number of DG and battery to be installed into the system.

Table 1: Value of Power Loss before DGs and BES Injection

Chosen load bus for load stress	Reactive Load (MVar)	Losses (MW)
13	20	17.6156
	30	17.8251
	40	17.8251
	50	17.8251
20	20	18.2559
	30	18.8699
	40	19.7678
	50	20.9820

Case 1: Optimal Location and Sizing for single unit of DGPV and BES

Table 2 and Table 3 tabulate the results of the optimal location and sizing for single unit of PVDG and BES, solved using EP and HCSEP with reactive power loading variation subjected to Bus 13 (Scenario 1) and bus 20 (Scenario 2). In scenario 1, at Q_{d13}=30 MVar; the installation of single unit of DGPVand BES at buses 8 and 5 with optimal sizing of 0.9223 MW and 29.9881 MW had reduced the power losses up to 74.12% from the original value using HCSEP.Using EP, the losses have been reduced to only 61.52% at the same reactive loading condition. Bus 29 and 5 are identified as the optimal location for DGPVand BES with size of 0.8685MW and 13.7356MW respectively.

Table 2: Loss reduction for optimal location and sizing of single DGPV and BES for load variation at bus 13 – Scenario 1

Technique		HCSEP				EP			
Load Stress (MVAR)		20	30	40	50	20	30	40	50
Loc DGPV		5	8	5	5	5	29	16	5
Loc BES		24	5	21	21	24	5	5	23
DGPVSize (MW)		0.981	0.9223	0.5191	0.9924	0.8083	0.8685	0.4931	0.6883
BES Size (MW)		23.2998	29.9881	22.9558	29.9933	28.0019	13.7356	27.4945	16.9414
Loss (MW)	Without DGPV	17.6156	17.8251	17.8251	17.8251	17.6156	17.8251	17.8251	17.8251
	With DGPV	5.3242	4.6131	4.9704	4.6631	5.1504	6.8583	6.4749	6.1929
Loss (%)		69.78	74.12	72.12	73.84	70.76	61.52	63.68	65.26
FVSI		0.16	0.1538	0.1531	0.1533	0.159	0.1532	0.1509	0.1477

Table 3: Loss reduction for optimal location and sizing of single DGPV and BES for load variation at bus 20 – Scenario 2

Technique		HCSEP				EP			
Reactive load (MVAR)		20	30	40	50	20	30	40	50
Loc DGPV		5	5	5	8	5	14	7	5
Loc BES		8	8	8	5	14	8	9	25
DGPV Size (MW)		0.1683	0.7393	0.0089	0.975	0.4755	0.4057	0.3766	0.8165
BES Size (MW)		27.2142	23.5287	19.6136	29.0712	23.404	14.7631	29.0547	28.832
Loss (MW)	without DGPV+BES	18.2559	18.8699	19.7678	20.982	18.2559	18.8699	19.7678	20.982
	with DGPV+BES	4.5087	5.2075	6.2215	7.5876	6.6889	13.0401	13.487	8.99
Loss (%)		75.3	72.4	68.53	63.84	63.36	30.89	31.77	57.15
FVSI		0.1619	0.2161	0.2857	0.3639	0.1597	0.2195	0.2829	0.3627

The results for Scenario 2 are tabulated in Table 3, where reactive power loading was gradually increased from 20 MVar to 50 MVar at bus 20. From the table the proposed HCSEP technique managed to remarkably reduce high loss, worth 75.3%. at Q_{d20}=20 MVar. On the other hand, EP only managed to achieve 63.36% loss reduction as can be referred to Table 3. The locations for DGPV and BES installation are buses 5 and 8 with the corresponding values of 0.1683 MW and 27.2142 MW solved using HCSEP. EP identified bus 5 and bus14 with 0.4755 MW and 23.404 MW for the sizing of the DGPV and BES respectively.The *FVSI* value has also been reduced using both techniques. Results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Case 2: Optimal Location and Sizing for 2-unit DGPV and single BES

In this case, 2 units of DGPV and single BES were installed in the system. Table 4 and Table 5 tabulate the results of installing 2 DGPV and single BES in the system with increasing load at bus 13 (Scenario 1) and bus 20 (Scenario 2). From Table 4, at Q_{d13}=50MVar, the system has experienced unhealthy mode indicated by high transmission line losses worth17.8251MW. With the installation of 2 units of DGPV and a BES, HCSEP managed to reduce the total transmission loss from 17.8251 MW to 3.1636 MW, indicating 82.25% loss reduction. This requires 2 DGPVsto be installed at buses 5 and 8 with an additional BES to be installed at bus 21. The corresponding sizing for the DGPVs are 0.8747 MW and 0.2746 MW. The sizing for the BES is 29.9166 MW. The identified locations for the DGPVs and BES, solved using EP are buses 5, 2 and 7 respectively. The corresponding sizing for the DGPVs and BES are 0.0555 MW, 0.0143 MW and 21.7146 MW. This has caused a loss reduction of 73.08%. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Table 4: Loss reduction for optimal location and sizing of 2 DGPV and single BES for load increment at bus 13 – Scenario 1

Technique		HCSEP				EP			
Reactive load (MVAR)		20	30	40	50	20	30	40	50
Loc DGPV 1		5	8	8	5	5	4	17	5
Loc DGPV 2		15	5	21	8	3	5	3	2
Loc BES		8	10	5	21	19	6	5	7
DGPV 1 Size (MW)		0.2458	0.787	0.1117	0.8747	0.9176	0.3775	0.3014	0.0555
DGPV 2Size (MW)		0.1915	0.6316	0.9106	0.2746	0.3619	0.8165	0.6142	0.0143
BES Size (MW)		29.997	29.9711	27.5177	29.9166	29.1013	27.8405	17.2687	21.7146
Loss (MW)	without DGPV+BES	17.6156	17.8251	17.8251	17.8251	17.6156	17.8251	17.8251	17.8251
	with DGPV+BES	3.4057	3.5897	3.6936	3.1636	5.0867	5.2474	6.2256	4.7978
Loss (%)		80.67	79.86	79.28	82.25	71.12	70.56	65.07	73.08
FVSI		0.1639	0.1557	0.1521	0.1677	0.1603	0.1493	0.1512	0.1477

The results for Scenario 2, where load increment was subjected to bus 20 are tabulated in Table 5. From the table, at Q_{d20}=30MVar the total transmission loss in the system is 18.8699 MW.With the installation of 2 units of DGPV and a BES, HCSEP managed to reduce the total transmission loss from 18.8699 MW to 4.6438 MW. This leads to75.39% loss reduction. This requires 2 DGPVsto be installed at buses 21 and 8 with an additional BES to be installed at bus 5. The corresponding sizing for the DGPVs are 0.9902 MW and 0.9603 MW. The sizing for the BES is 29.7877 MW. The identified locations for the DGPVs and BES, solved using EP are buses 30, 5 and 19 respectively. The corresponding sizing for the DGPVs and BES are 0.0603 MW, 0.559 MW and 18.8699 MW. This has caused a loss reduction of 71.15%. Comparing the results obtained using HCSEP is superior than EP, indicated by higher loss reduction. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Table 5: Loss reduction for optimal location and sizing of 2 DGPV and single BES for load increment at bus 20 – Scenario 2

Technique		HCSEP				EP			
Reactive load (MVAR)		20	30	40	50	20	30	40	50
Loc DGPV 1		15	21	5	21	28	30	28	27
Loc DGPV 2		5	8	30	5	5	5	5	2
Loc BES		8	5	8	8	18	19	7	5
DGPV 1 Size (MW)		0.4626	0.9902	0.5748	0.1998	0.3513	0.0603	0.4945	0.6869
DGPV 2Size (MW)		0.8681	0.9603	0.4514	0.8121	0.3072	0.559	0.6503	0.1051
BES Size (MW)		24.5663	29.7887	23.1407	29.4704	28.562	23.089	13.1235	21.547
Loss (MW)	without DGPV+BES	18.2559	18.8699	19.7678	20.982	18.2559	18.8699	19.7678	20.982
	with DGPV+BES	4.076	4.6438	5.2767	5.9478	6.0228	5.4436	7.3212	9.3901
Loss (%)		77.67	75.39	73.31	71.65	67.01	71.15	62.96	55.25
FVSI		0.159	0.2125	0.2848	0.3585	0.1549	0.2124	0.2862	0.3651

Case 3: Optimal Location and Sizing for 2-unit WTDG

In Case 3, studies were conducted to see the impact of DG and battery installation. In this case, WTDG is type 4 DG which is capable to supply real power but consuming reactive power. Table 6 tabulates the results for loss reduction for optimal location and sizing of 2 WTDG and single BES for load increment at bus 13.From the table, at Q_{d13}=40MVar the total transmission loss in the system is 17.8251 MW. With the installation of 2 units of WTDGand a BES, HCSEP managed to reduce the total transmission loss from 17.8251 MW to 3.7991 MW. This leads to 78.69% loss reduction. This requires 2 DGPVsto be installed at buses 5 and 21 with an additional BES to be installed at bus 15. The corresponding sizing for the DGPVs are 2.4858 MW, 0.7472 MVar and 2.4836 MW, 0.7467 MVar. Apparently, WTDG will have both the real and reactive power values. The sizing for the BES is 29.9759 MW. The identified locations for the DGPVs and BES, solved using EP are buses 19, 7 and 6 respectively. The corresponding sizing for the WDTGs are 1.0826 MW, 0.5469 MVar and 1.2943 MW, 0.567 MVar.The sizing of BES is 24.4729 MW. This has caused a loss reduction of 39.9%. Comparing the results using both techniques, HCSEP is superior than EP, indicated by higher loss reduction. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Table 6: Loss reduction for optimal location and sizing of 2 WTDG and single BES for load increment at bus 13 – Scenario 1

Technique	HCSEP				EP			
Reactive load (MVAR)	20	30	40	50	20	30	40	50
Loc WTDG 1	5	5	5	5	26	19	19	15
Loc WTDG 2	21	21	21	8	21	8	7	24
Loc BES	8	8	15	7	5	17	6	8
WTDG 1 Size (MW)	2.4646	1.3915	2.4858	2.4841	0.8611	0.9284	1.0826	2.4526
WTDG 2 Size (MW)	2.04	1.9029	2.4836	2.4553	1.8629	1.0008	1.2943	0.9365
WTDG 1 Size (MVAR)	0.743	0.5774	0.7472	0.7468	0.5297	0.5345	0.5469	0.7406
WTDG 2Size (MVAR)	0.6665	0.6448	0.7467	0.7411	0.6388	0.5401	0.567	0.5351
BES Size (MW)	27.1109	26.7095	29.9759	29.9752	22.7312	29.9248	24.4729	25.6417
Loss (MW) without WTDG+ BES	17.6156	17.8251	17.8251	17.8251	17.6156	17.8251	17.8251	17.8251
with WTDG+ BES	2.9631	3.0232	3.7991	3.2051	4.9331	9.5491	10.7136	9.7078
Loss (%)	83.18	83.04	78.69	82.02	72	46.43	39.9	45.54
FVSI	0.1834	0.175	0.1812	0.1351	0.185	0.148	0.1458	0.1550

Table 7: Loss reduction for optimal location and sizing of 2 WTDG and single BES for load increment at bus20 – Scenario 2

Technique	HCSEP				EP			
Reactive load (MVAR)	20	30	40	50	20	30	40	50
Loc WTDG 1	7	5	8	20	8	15	26	12
Loc WTDG 2	8	20	20	5	24	9	17	20
Loc BES	5	8	5	8	19	5	5	5
WTDG 1 Size (MW)	1.3534	1.8507	2.4212	2.4954	1.7077	0.8689	2.4371	0.7999
WTDG 2 Size (MW)	2.4394	2.1659	2.4355	2.2888	1.6647	0.6046	1.3292	1.8359
WTDG 1 Size (MVAR)	0.5733	0.637	0.7345	0.7491	0.6166	0.5302	0.7376	0.5256
WTDG 2Size (MVAR)	0.738	0.6876	0.7373	0.7095	0.6108	0.5146	0.5707	0.6348
BES Size (MW)	27.9569	29.9988	29.9748	23.1823	22.0145	12.5583	22.272	27.8751
Loss (MW) without WTDG	18.2559	18.8699	19.7678	20.982	18.2559	18.8699	19.7678	20.982
with WTDG	4.119	3.5637	4.1512	3.7925	10.2154	7.4286	7.3512	5.6233
Loss (%)	77.44	81.11	79	81.92	44.04	60.63	62.81	73.2
FVSI	0.1508	0.1846	0.1785	0.1852	0.1506	0.2147	0.2843	0.2057

Table 7 tabulates the results for loss reduction for optimal location and sizing of 2 WTDG and single BES for load increment at bus 20 (Scenario 2). From the table, at Q_{d20}=40 MVar the total transmission loss in the system is 19.7678 MW. With the installation of 2 units of WTDG and a BES, HCSEP managed to reduce the total transmission loss from 19.7678MW to 4.1512 MW. This leads to 79.0% loss reduction. This requires 2 WTDGs to be installed at buses 8 and 20 with an additional BES to be installed at bus 5. The corresponding sizing for the WTDGs are 2.4212 MW, 0.7345MVar and 2.4355 MW, 0.7373MVar. Apparently, WTDG will have both the real and reactive power values. The sizing for the BES is 29.9748 MW. On the other hand, the identified locations for the WTDG and BES, solved using EP are buses 26, 17 and 5 respectively. The corresponding sizing for the WDTGs are 2.437 MW, 0.7376MVar and 1.3292 MW, 0.5707MVar. The sizing of BES is 22.272 MW. This has caused a loss reduction of 62.81%. Comparing the results using both techniques, HCSEP is superior than EP, indicated by its higher loss reduction. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Case 4: Optimal Location and Sizing for 3-unit WTDG and single BES

In Case 4, further studies were conducted to see the impact of 3 units of WTDG and single BES. Tables 8 and 9 tabulate the result of power loss reduction through the installation of 3 units of WTDGs and single BES. Load increment involving Bus 13 (Scenario 1) and Bus 20 (Scenario 2) are considered again in this study.

Table 8: Loss reduction for optimal location and sizing of 3 WTDG and single BES for load increment at bus13 – Scenario 1

Technique		HCSEP				EP			
Load Stress (MVAR)		20	30	40	50	20	30	40	50
Loc WTDG 1		30	21	7	8	11	25	2	15
Loc WTDG 2		21	15	8	5	5	21	5	27
Loc WTDG 3		8	5	5	24	13	5	24	5
Loc BES		5	8	21	21	21	17	7	27
WTDG 1 Size (MW)		1.3577	0.7166	1.1379	0.8124	1.4694	2.4872	1.1861	2.075
WTDG 2Size (MW)		2.0581	1.1412	0.8967	2.2588	1.2127	2.3524	0.6463	2.2763
WTDG 3Size (MW)		2.4091	2.307	2.1398	2.0604	1.208	1.5091	1.2278	2.1254
WTDG 1 Size (MVAR)		0.5737	0.5205	0.5518	0.5264	0.5864	0.7475	0.5563	0.6722
WTDG 2Size (MVAR)		0.6694	0.5521	0.5322	0.7041	0.5588	0.7213	0.5167	0.7073
WTDG 3Size (MVAR)		0.7322	0.7129	0.6831	0.6698	0.5584	0.5911	0.5603	0.6807
BES Size (MW)		27.4743	29.9559	29.9194	19.3296	18.1055	17.6022	14.3688	25.2463
Loss (MW)	without WTDG	17.6156	17.8251	17.8251	17.8251	17.6156	17.8251	17.8251	17.8251
	with WTDG	2.6947	2.5008	2.3969	2.7914	4.9666	4.3572	4.2657	5.2345
Loss (%)		84.7	85.97	86.55	84.34	71.81	75.56	76.07	70.63

In Table 8, at Q_{d13}=40 MVar the total transmission loss in the system is 17.8251 MW. With the installation of 3 units of WTDGand a BES, HCSEP managed to reduce the total transmission loss from 17.8251 MW to 2.3969 MW. This leads to 86.55% loss reduction. This requires 3 WTDGto be installed at buses 7, 8 and 5 with an additional BES to be installed at bus 21. The corresponding sizing for the WTDGs are 1.1379 MW with 0.5518MVar, 0.8967 MW with 0.5322 MVar and 2.1398 MW with0.6831 MVar. Apparently, WTDG will have both the real and reactive power values. The sizing for the BES is 29.9194 MW. The identified locations for the 3 DGPVs and BES, solved using EP are buses 2, 5, 24 and 7 respectively. The corresponding sizing for the WDTGs are 1.1861 MW with 0.5563MVar, 0.6463 MW with 0.5167 MVar and1.2278 MW with 0.5603MVar. The sizing of BES is 14.3688 MW. This has caused a loss reduction of 76.07%. Comparing the results using both techniques, HCSEP is much superior than EP, indicated by the higher loss reduction. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Table 9: Loss reduction for optimal location and sizing of 3 WTDG and single BES for load increment at bus20 – Scenario 2

Technique	HCSEP				EP			
Load Stress (MVAR)	20	30	40	50	20	30	40	50
Loc WTDG 1	8	20	21	5	5	11	5	21
Loc WTDG 2	5	8	20	30	26	19	27	13
Loc WTDG 3	7	5	5	20	21	5	16	5
Loc BES	21	7	8	8	24	15	13	18
WTDG 1 Size (MW)	0.6123	2.4623	1.3197	2.4939	2.2295	1.0868	1.5627	1.9372
WTDG 2Size (MW)	2.4978	2.4128	2.4975	2.4962	1.5283	2.1179	1.3253	0.7376
WTDG 3Size (MW)	1.356	2.473	0.8755	2.4917	1.2803	1.7727	2.4753	0.8263
WTDG 1 Size (MVAR)	0.515	0.7425	0.5697	0.7488	0.6988	0.5472	0.5977	0.6501
WTDG 2Size (MVAR)	0.7496	0.7329	0.7495	0.7492	0.5934	0.6794	0.5703	0.5218
WTDG 3Size (MVAR)	0.5735	0.7446	0.5307	0.7484	0.5656	0.6257	0.7451	0.5273
BES Size (MW)	20.857	29.9973	29.9769	21.5545	19.3855	28.0932	21.5132	23.9374
Loss (MW) without WTDG	18.2559	18.8699	19.7678	20.982	18.2559	18.8699	19.7678	20.982
with WTDG	2.9608	2.9033	2.7162	3.0617	4.427	5.2645	7.7119	6.9685
Loss (%)	83.78	84.61	86.26	85.41	75.75	72.1	60.99	66.79
FVSI	0.1431	0.1726	0.1913	0.1799	0.1546	0.2013	0.2921	0.3511

Table 9 tabulates the results for loss reduction for optimal location and sizing of 3 WTDG and single BES for load increment at bus20 – Scenario 2. From this table, at Q_{d20}=40 MVar the total transmission loss in the system is 19.7678 MW. With the installation of 3 units of WTDGand a BES, HCSEP managed to reduce the total transmission loss from 17.8251 MW to 2.7162 MW. This leads to 86.26% loss reduction. This requires 3 WTDGto be installed at buses 21, 20 and 5 with an additional BES to be installed at bus 8. The corresponding sizing for the WTDGs are 1.3197 MW with 0.5697MVar, 2.4975 MW with 0.7495 MVar and 0.8755 MW with0.5307MVar. Apparently, WTDG will have both the real and reactive power values. The sizing for the BES is 29.9769 MW. The identified locations for the DGPVs and BES, solved using EP are buses 5, 27, 16 and 13 respectively. The corresponding sizing for the WDTGs are 1.5627 MW with 0.5977MVar, 1.3253 MW with 0.5703MVar and 2.4753 MW with 0.7451MVar. The sizing of BES is 21.5132 MW. This has caused a loss reduction of 60.99%. Comparing the results using both techniques, HCSEP is much superior than EP, indicated by the higher loss reduction. The results for other reactive loading conditions can be referred to the same table. It is also observed that the system is maintained its stability indicated by low *FVSI* values in all reactive load conditions.

Conclusions

This paper has presented Hybrid Cuckoo Search Evolutionary Programming (HCSEP) Based Technique for Renewable Energy Distributed Generator (REDG) and Battery Energy Stored (BES) for Loss and Voltage stability control in power system. In this study, different optimal REDG types and BES have been installed into the system for loss control in power system. It can be concluded that a large number of DG units and types of REDG that provide reactive power like WTDG improve further minimized power losses in the system compared to a single unit of DG and DGPV type. The proposed HCSEP technique provides better results in determining the location and sizing of DGs and BES to minimize power losses compare to EP technique. Voltage stability of the system are also under control indicated by the *FVSI* value being maintained at lower than unity. This implies that the installation of REDG and BES in one scheme to the power system is worth to reduce loss and maintain voltage stability in a power system.

Acknowledgements

The authors would like to acknowledge the Ministry of Education, Malaysia (MOE) for the financial support of this research. This research is supported by MOE under Fundamental Research Grant Scheme (FRGS) with project code: FRGS/1/2018/TK04/UKM/02/7.

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