Minimization of Power Losses With Different Types of DGs Using CSA

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Abstract: Proper allocation of DGs in distribution network is important from all the aspects like technical, economical and environmental. In this paper, Crow search algorithm (CSA) technique has been proposed to find the optimal size and location of multiple DGs of different types to reduce the active power loss of the distribution network (DN). The proposed method has only two parameters to be tuned while other metaheuristic optimization methods discussed in the literature have more than two tunings parameter. Parameter tuning plays a very important role to reach the global optimal value. The proposed method is tested on 33 bus and 69 bus test system and the obtained result is compared with improved analytical (IA) and particle swarm optimization (PSO) method. The proposed method gives better results compared to existing PSO and IA methods.
Keywords: Distributed Generation, Crow search algorithm, Power System optimization

1. Introduction

The growth of any country is determined by the per capita consumption of energy. In developing countries energy crisis is a main concern for the economic growth. Mainly, there are two types of energy available on the earth. One is called conventional energy and other is known as nonconventional or renewable energy. Because of the limited availability and disadvantages of conventional energy resources, renewable energy sources (RES) are getting popular. Renewable energy sources like solar, wind geothermal and biomass are abundantly and freely available in the nature. These sources are used either in off grid mode or on grid mode. RES such as solar energy is getting day by day popular because of the ease of technology and policy implementation. The conversion of energy from the solar is based on the photoelectric effect. It is most widely used technology all over the world. By using the solar panels solar energy is converted to DC electricity. Output electrical energy produced from the solar photovoltaic (SPV) module depends on the several factors some of them are mounting of the modules whether it is fixed or mounted or inclined, local climatic condition, solar radiation approaching on the surface. The renewable energy resources are becoming a boon to the developing world where the necessity of electrical energy is increasing day by day. There are many types of renewable energy resources among them the solar energy is the superlative. Though photovoltaic (PV) cell has some limitations of high capitation cost, lower conversion efficiency, partial shading and seasonal energy production, it has seized the attention of many researchers because of its special virtues. The special virtues include costless source and maintenance free system. These systems are also pollution free that is environmental contamination is reduced to the minimum of zero percentage. The gap between PV power generation and the load demand is fulfilled by using batteries. Solar, biomass, wind, geothermal i.e. renewable energy sources have negligible impact on the green house gas emissions and these are known as Distributed generation (DG) sources. In literature DGs are mainly classified in four categories depending on the terminal characteristics:

Type-1 DG: It is Capable of injecting only real power (P) to the system

Type-2 DG: It is capable of injecting only reactive power (Q) to the system.

Type-3 DG: It is capable of injecting P and Q both to the system.

Type-4 DG: It is capable of injecting P and taking Q from the system.

The high incursion of DG resources on the distribution network has started many challenges to distribution network such as increasing losses, voltage fluctuation and low voltage stability etc.[1]. The high penetration of DG on distribution network can have either positive or negative impact depending on the operating uniqueness and the DG characteristics. Poor voltage profile and power loss is the main concern in developing countries; therefore it becomes necessary to place the DGs of appropriate size at optimal location.

Different optimization algorithm has been reported in the literature. In [2] authors has proposed one of the accurate technique, Particle swarm optimization (PSO) to allocate the different types of DGs in distribution network but this method has four settings parameters to run the algorithm. [3] Discusses about the allocation of DG using Genetic algorithm (GA) method, this method has six settings parameters and only type-1 DG is discussed. In [4, 5] authors have presented crow search optimization (CSO) algorithm for allocation of DG which has two settings parameters but only type-1 DG is considered for the study. Paper [6] presents parameter independent Teaching learning based optimization (TLBO) algorithm to find the optimal allocation of DG, this method discusses about the type-1 DGs only. In all the papers [7-13] authors have proposed different optimization methods for allocation of DG but none of the author have proposed allocation for all the types of DG and all the methods have more than two settings parameters. Paper [25-29] discusses about the CSA method and other concepts to find the allocation of solar PV but it is limited to the one location only. Setting parameters of the algorithm play a very important role in optimization. It is very difficult to set parameters for global optimal solution. This paper contributes CSA method for all the types of DG allocation which has only two settings parameters and easy to tune for global optimal value. CSA method has been given by Alireza Askarzadah [14]. This algorithm has been used in many areas [15-18] which proves the superiority of the algorithm. The optimal location and sizing of DG in radial distribution systems using CSA for all the types of DGs has not been reported in literature till now which motivates to develop CSA method to determine the location and size of DG. The Results is compared with other technique which proves the superiority of CSA. The remaining sections are as follows: Section 2 discusses about problem formulation Section 3 proposed methodology section 4 test systems and result in the last Section 5 we discuss about the conclusion.

2. Problem Formulation:

Finding the optimal allocation of DG in DN is a constrained nonlinear optimization problem. Where the size of the DG is a continuous variable and location of the DG is a discrete variable. In this work the Bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) method of load flow analysis is used for the study purpose and the details about BIBC and BCBV is given in[19].

2.1 Objective Function

Power loss (P_L) of the radial distribution network is considered for the optimization subject to the constraints.

$$\min(P_L) = \min\left(\sum_{i=1}^{n} \frac{P_i^2+Q_i^2}{|V_i|^2}\right) R_i \tag{1}$$

Where P_i and Q_i are active and reactive power flow of the branch i respectively. R_i; Resistance of the branch i, V_i; voltage of the bus i and n; total number of buses of the system

2.2 Constraints:

i. The size of the DG varies between minimum value ($DG_{i,min}$) of zero and maximum value ($DG_{i,max}$) of 100 percent of total load of the system as the case may be

$$DG_{i,min} \leq DG_i \leq DG_{i,max} \tag{2}$$

ii. Voltage at each bus should be within permissible limit i.e. ± 0.05.

$$0.95 p.u. \leq V_i \leq 1.05\, p.u. \tag{3}$$

iii. Power flow equations should match.

$$P_j = |V_j| \sum_{k=1}^{n} |V_k||Y_{jk}| \sin(\delta_j - \delta_k - \theta_{jk}) \tag{4}$$

$$Q_j = -|V_j| \sum_{k=1}^{n} |V_k||Y_{jk}| \cos(\delta_j - \delta_k - \theta_{jk}) \tag{5}$$

$$P_j = P_{DGj} - P_{Dj} Q_j = Q_{DGj} - Q_{Dj} \tag{6}$$

Where V_k is voltage at bus k, $Y_{jk}\ and \theta_{jk}$; admittance magnitude and angle between bus j and k respectively, δ_j; phase angle of bus j, δ_k; phase angle of bus k.

3. Proposed Methodology:

Crow search algorithm has been implemented to get the optimal allocation of all types of DGs, BIBC and BCBV method has been used to determine the required objective. Brief explanation of the CSA is given in the following sections:

3.1 CSA technique:

CSA is a nature inspired population based meta-heuristic optimization algorithm given by Alireza Askarzadah in the year 2016 to solve the constrained engineering optimization problem. If we compare the performance of CSA with other intelligent optimization methods the solution obtained by CSA is better [14]. This method has been implemented to find the optimal sizing and location of the DG system. The crows are the most intelligent birds in nature. Ratio of brain and body of crow is very good comparing to other birds. The motivation of the algorithm is rooted in the cleverness behavior of the crows. The evolutionary process is given as hiding and recovery of extra food. The crow flock and optimization process have many similarities. In crow flock each crow hides their surplus food to certain place (hiding place) of environment and retrieves the food from that place when it is desired. Other crows of the flock chase each other to steal the superior food but it is not an simple task since if a crow knows that one more crow is following it goes to another place to make fool. From optimization point of view Crows are searchers, Environment is the search space, each position is feasible solution, quality of food is fitness function and the best food is global solution of optimization problem[14].

Mathematically, the position of crow in a d-dimensional search space is defined by a vector

$$X^{j,iter} = [X_1^{j,iter}, X_2^{j,iter}, \dots\dots\dots\dots.., X_d^{j,iter}];\ j = 1,2,\dots\dots N\ \&\ iter = 1,2,\dots\dots\dots, iter_{max} \quad (7)$$

Each crows has its hiding place (memory) and memory of crow in a d-dimensional search space is defined by a vector

$$m^{j,iter} = [m_1^{j,iter}, m_2^{j,iter}, \dots\dots\dots\dots.., m_d^{j,iter}];\ j = 1,2,\dots\dots N\ \&\ iter = 1,2,\dots\dots\dots, iter_{max} \quad (8)$$

where $m^{j,iter}$ is the position of hiding place of crow j and best position of crow j obtained so far.

Let us suppose crow i want to follow crow j for better food source in this scenario two cases are possible:

Case1: Crow j is unaware that crow i is following and in this case crow i will reach to the hiding position of crow j. The new position of crow i is given by:

$$X^{i,iter+1} = X^{i,iter} + r_i \times fl^{i,iter} \times (m^{i,iter} - X^{i,iter}) \quad (9)$$

Where $X^{i,iter+1}$ is the modified position of the crow i; r_i a random number with uniform distribution between 0 and 1; $fl^{i,iter}$ flight length of crow i at iteration $iter$; $AP^{j,iter}$ awareness probability of crow j at iteration $iter$.

Case 2: Crow j knows that crow i is following to make him fool he will update to some random position in the search space.

Both cases can be written as:

$$X^{i,iter+1} = \begin{cases} X^{i,iter} + r_i \times fl^{i,iter} \times (m^{i,iter} - X^{i,iter}), & r_j > AP^{j,iter} \\ a\ random\ position, & otherwise \end{cases} \quad (10)$$

After each iteration, the position and memory of crows are updated. The size of DG is taken between 0 to 100 percent of the total load (continuous) of the system. In CSA algorithm the maximum number of iteration and population size of the crows are fixed. The initial position and memory of the ith crow has been considered as X_i and m_i respectively and they are given by eqn. (7) and (8).

3.2 CSA approach for location and sizing of DG

The CSA approach used for solving the optimal placement and size of multiple DGs of different types to minimize the active power loss takes the following steps:
Step1: Input the flock size (N), Number of decision variable (d), maximum number of iterations, flight length and awareness probability.

Step2: Initialize the position and memory of the crows. For the flock size N and decision variable d the size of the search space i.e. crow position and position of the food i.e. memory matrix is $N \times d$.

$$\text{Crows position}(X) = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_d^1 \\ x_1^2 & x_2^2 & \dots & x_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ x_1^N & x_2^N & \dots & x_d^N \end{bmatrix} \quad (11)$$

$$\text{Memory}\ (m) = \begin{bmatrix} m_1^1 & m_2^1 & \dots & m_d^1 \\ m_1^2 & m_2^2 & \dots & m_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ m_1^N & m_2^N & \dots & m_d^N \end{bmatrix} \quad (12)$$

Table 1: Size of the search space in different cases

Type of system	Number of DG		
	1 DG	2 DG	3 DG
Type-1	$N \times 2$	$N \times 4$	$N \times 6$
Type-2	$N \times 2$	$N \times 4$	$N \times 6$
Type-3	$N \times 3$	$N \times 6$	$N \times 9$

The location is an integer value initialized between 2 to 33 (for 33-bus system) and 2 to 69 (for 69-bus system) while size is a continuous value initialized between 1 to 100 (for both 33 and 69 bus systems). Initially the value of m is equal to X, because crows have no experience in starting.

Step 3: Calculate the active power loss (fitness function) for each crow position using BIBC and BCBV method of load flow analysis. This step is required to check the quality position of each crow.

Step 4: Generate new position of the crows in the search space which is obtained by eq. (10) and check the boundary violations given in eq. (2) and (3).

Step 5: Calculate the fitness function for each crow position (generated in step 4) using BIBC and BCBV method and find the fitness value for each position.

Step 6: If the fitness function value of the new position is better than fitness function value of the memorized position the crow updates it's memory by the new position otherwise remain in previous position. Crow updates their memory as follows:

$$m^{i,iter+1} = \begin{cases} X^{i,iter+1} & f(X^{i,iter+1}) < f(m^{i,iter}) \\ m^{i,iter} \quad \text{a random position,} & otherwise \end{cases} \quad (13)$$

where $f(.)$ is the objective function value.

Step 7: Check the termination criterion (maximum iteration) is reached. Now the best position of the memory in terms of the objective function value gives the optimal location and size of DG.

4. Test Systems and result:

Two different test systems and three different types of multiple DGs have been used to test the CSA method proposed in this paper. Three different types of DG's are Type-1, Type-2, and Type-3. This method is implemented in Matlab version 2017 a. The CSA parameters selected for solving the optimization are: N =100, Maximum number of iteration ($iter_{max}$) =500, Flight length (fl) =0.2, Awareness probability (AP) =2.5 and 50 independent runs [14]. These values are selected on experience basis for better result and convergence. Bus 1 is considered as the reference bus. From economical point of view maximum number of DG taken is three. Statistical analysis of each system is carried out to check the robustness of the algorithm.

4.1 *33-bus system:*

IEEE-33 bus system is taken for the study purpose. Active power, reactive power and total load power of the system is 3.72 MW, 2.3 MVAr and 4.4 MVA respectively [20] . This system has 32 numbers of branches and 33 numbers of buses. The base loss of the system is 210.96 KW.

4.1.1 *Type-I DG placement*

Table 2 shows the optimal location and size of multiple DGs by CSA approach. For single DG system, optimal size of the DG is 2.59 MW and optimal location is 6 and for two DG system, total optimal size of the DG is 2.01 MW and optimal locations are 13, 30. For three DG system, total optimal size of the DG is 2.83 MW and optimal locations are 13, 24, 30. The result obtained from the CSA is compared with PSO [21] and fast analytical method (IA) [22]. For single DG, Table 2 shows better result than IA. The size of DG obtained from CSA is better compare to PSO and IA method. For 2 DG units, power loss reduction and DG size by CSA and PSO is same but it is better than IA method. For 3 DG units, power loss reduction of CSA and PSO method is approximately same but it is better than IA while DG size obtained from CSA is less compare to PSO method but it is more than IA method. The statistical data of the CSA method shows robustness of the method for type-1 system. Table 8 shows the voltage characteristics of the system. Therefore result obtained from CSA methods give equal or better result compare to PSO and IA method.

4.1.2 *Type-II DG placement*

Table 3 shows the optimal location, size, power loss, reduction in loss and statistical data of multiple DGs placed in the system. From the table 3 maximum and minimum percentage reduction loss of the system is 28.26 and 34.47 respectively. Minimum reduction is obtained for single DG placement while maximum is for 3 DG. The minimum and maximum voltage variation is 0.9319 p.u. and 1 p.u. respectively. Statistical data shows the robustness of the proposed method for type-2 system. As DG inserted in the system increases, power loss of the system decreases and percentage system power loss increases.

4.1.3 *Type-III DG placement*

Optimal location, size, and power factor of multiple DG placement for type-3 system is obtained in table 4 and corresponding voltage profile in table 8. Result from the proposed method is compared with PSO[21] and IA[22] method. For single DG placement optimal size, location, DG size and percentage reduction in loss for proposed method is approximately same as PSO and IA method. For position of two and three DG in the system result from the CSA method gives improved performance than IA but lower performance than PSO method.

4.2 *69-bus system:*

The second system is a 69-bus system having active power load of 3.80 MW, reactive power load of 2.70 KVAr and total load of 4.7 MVA [23]. Total branches and buses in the system is 68 and 69 respectively. 50 independent runs are performed to study the statistics of the algorithm for different type of DGs. The base case loss of the system is 225 kW.

4.2.1 *Type-I DG placement*

Optimal location, size, power loss, percentage reduction in loss and statistical analysis of multiple DGs are obtained and given in table 5. From the results maximum and minimum percentage reduction in loss is 68.41 and 62.62 respectively. Maximum and minimum voltage is 0.9806 p.u. and 1 p.u. respectively. It is found that optimal location and size obtained from the proposed method is same as PSO but reduction in loss obtained from the CSA method is better than PSO.

4.2.2 *Type-II DG placement*

Table 6 shows different values obtained using CSA optimization method. Maximum and minimum percentage reduction in loss is obtained as 32.44 and 34.87 respectively. Maximum and minimum voltage is obtained as 1 p.u. and 0.9329 p.u. respectively. As the number of DG inserted in the system increases reduction in loss increases and power loss decreases.

4.2.3 *Type-III DG placement*

Optimal location, size, power loss, reduction in loss and statistics of multiple DGs are obtained using CSA optimization method and it is given in table 7. Table 7 gives maximum and minimum percentage reduction in loss as 89.71 and 97.9 respectively. Voltage profile of the system lies between 0.9723 to 1 p.u. respectively. Result from the proposed technique is compared with PSO method. This method gives equal result as PSO.

Flow chart for the location and sizing of DG:

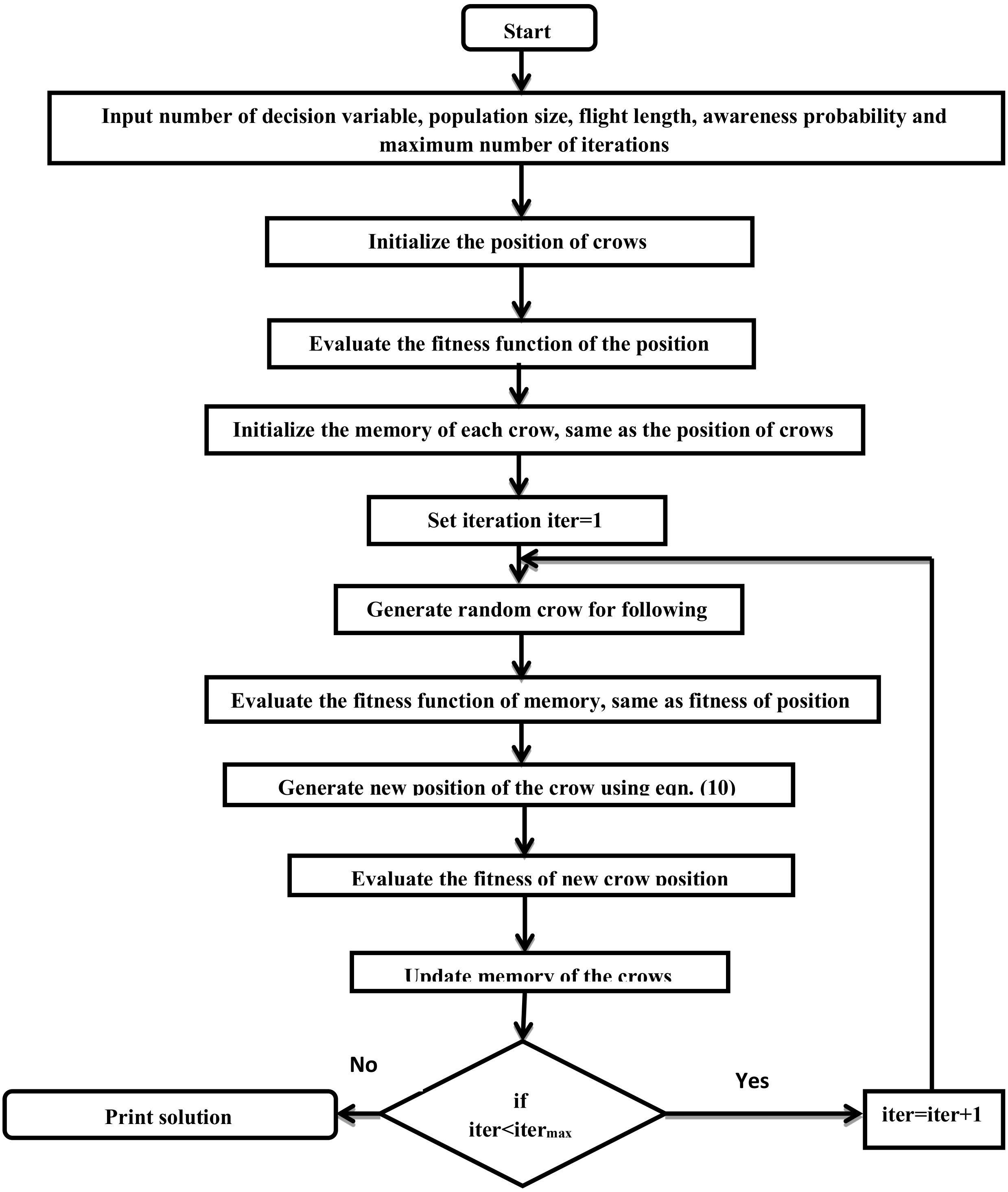

Fig.1: Flow chart for optimal allocation of DGs

Table 2: Optimal values forType-1 System

No. of DG	Method	Optimal location	Optimal size MW	Total DG Size MW	Power Loss (kW)	Reduction in loss (%)	Statistics			
							Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	CSA	6	2.58	2.58	111.03	47.38	111.03	111.03	111.03	1.92e-09
	IA[22]	6	2.60	2.60	111.10	47.38	NA			
	PSO[24]	6	2.59	2.59	111.03	47.38	NA			
2 DG	CSA	13 30	0.85 1.16	2.01	87.17	58.69	87.167	87.169	87.168	2.35e-05
	IA[22]	6 14	1.80 0.72	2.52	91.63	56.61	NA			
	PSO[24]	13 30	0.85 1.16	2.01	87.17	58.69	NA			
3 DG	CSA	13 24 30	0.76 1.03 1.04	2.83	72.79	65.46	72.79	72.96	72.80	2.31e-03
	IA[22]	6 12 31	0.90 0.90 0.72	2.52	81.05	61.62	NA			
	PSO[24]	14 24 30	0.77 1.09 1.07	2.93	72.79	65.50	NA			

Table 3: Optimal values for Type-2 System

No. of DG	Optimal Location (Bus No.) &	Optimal Size (MVAr)	Total DG Size MVAr	Power Loss (kW)	Reduction in loss (%)	Statistics			
						Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	30	1.26	1.26	151.38	28.26	151.38	151.38	151.38	5.53e-10
2 DG	12 30	0.47 1.06	1.53	141.84	32.78	141.84	141.86	141.84	1.09e-04
3 DG	13 24 30	0.39 0.54 1.04	1.97	138.27	34.47	138.27	138.36	138.29	6.86e-04

Table 4: Optimal values for Type-3 System

No. of DG's	Method	Optimal location	Optimal Size MVA	Optimal power factor	Total Size MVA	Power Loss (kW)	Reduction in loss (%)	Statistics			
								Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	CSA	6	3.107	0.82	3.107	67.87	67.85	67.87	67.87	67.87	2.36e-06
	IA[22]	6	3.107	0.82	3.107	67.9	67.82	NA			
	PSO[21]	6	3.035	0.82	3.035	67.9	67.82	NA			
2 DG	CSA	13 30	0.93 1.557	0.90 0.73	2.487	28.51	86.49	28.51	28.90	28.56	0.013852
	IA[22]	6 30	2.195 1.098	0.82 0.82	3.293	44.39	78.98	NA			
	PSO[21]	13 30	0.914 1.535	0.82 0.82	2.449	28.6	86.44	NA			
3 DG	CSA	14 24 30	0.439 0.632 0.779	0.91 0.90 0.71	3.514	11.77	94.42	11.77	14.48	12.92	0.23042
	IA[22]	6 30 14	1.098 1.098 0.768	0.82 0.82 0.82	2.964	67.87	67.85	NA			
	PSO[21]	13 24 30	0.863 1.188 1.431	0.91 0.90 0.71	3.482	67.9	67.82	NA			

Table 5: Optimal values for Type-1 System

No. of DG	Method	Optimal Location	Optimal Size (MW)	Total DG Size MW	Power Loss (kW)	Reduction in loss (%)	Statistics			
							Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	CSA	61	1.82	1.82	83.19	63.03	83.19	83.19	83.19	1.56e-08
	PSO[24]	61	1.87	1.87	83.37	63.01	NA			
2 DG	CSA	17 61	0.52 1.77	2.29	71.66	68.15	71.66	71.7	71.66	5.65e-03
	PSO[24]	17 61	1.78 0.53	2.31	71.68	68.14	NA			
3 DG	CSA	11 17 61	0.50 0.39 1.72	2.61	69.42	69.15	69.42	71.32	69.97	2.74e-02
	PSO[24]	11 17 61	0.46 0.44 1.70	2.60	69.54	69.09	NA			

Table 6: Optimal values for Type-2 System

No. of DG	Optimal Location	Optimal Size (MVAr)	Total DG Size MVAr	Power Loss (kW)	Reduction in loss (%)	Statistics			
						Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	61	1.328	1.328	152.01	32.44	152.01	152.01	152.01	3.51e-9
2 DG	17 61	0.36 1.273	1.633	147.85	34.29	147.85	147.87	147.85	1.44e-04
3 DG	11 20 61	0.397 0.233 1.244	1.874	146.54	34.87	146.54	147.36	146.68	5.63e-03

Table 7: Optimal values for Type-3 System

No. of DG's	Method	Optimal location	Optimal Size MVA	Optimal power factor	Total Size MVA	Power Loss (kW)	Reduction in loss (%)	Statistics			
								Best (kW)	Worst (kW)	Mean (kW)	Std. Dev.
1 DG	CSA	61	2.24	0.81	2.24	23.15	89.71	23.15	23.15	23.15	4.43e-05
	PSO[21]	61	2.22	0.81	2.22	23.20	89.7	NA			
2 DG	CSA	18 61	0.63 2.14	0.84 0.81	2.77	7.21	96.8	7.21	8.79	7.48	0.21937
	PSO[21]	17 61	0.63 2.13	0.82 0.81	2.76	7.20	96.8	NA			
3 DG	CSA	11 22 61	0.59 0.42 2.06	0.93 0.76 0.81	3.07	4.51	98	4.51	7.88	5.77	0.74894
	PSO[21]	11 18 61	0.60 0.46 2.06	0.83 0.81 0.81	3.12	4.61	97.9	NA			

5. Conclusion:

A new optimization technique to solve the optimal allocation of multiple DGs of different types for minimization of active power loss in distribution network is discussed in this paper. Proposed scheme is implemented on 33 and 69 bus system. The obtained result is compared with existing methods like PSO and IA method. It is seen that for all type of DG proposed method gives better result than IA method and roughly equal result to PSO method. This method is easy to implement compare to PSO method as it has only 2 parameters while PSO has 4 parameters to control. If parameters are not controlled properly it will lead to local optimal value. To check the robustness of the method Statistical data has been analyzed. This paper implements single objective function taking constant load to find the solution. In future multi-objective function and time varying load and generation can be taken into consideration for finding the solution. Researchers and planners may find this study useful by implementing it.

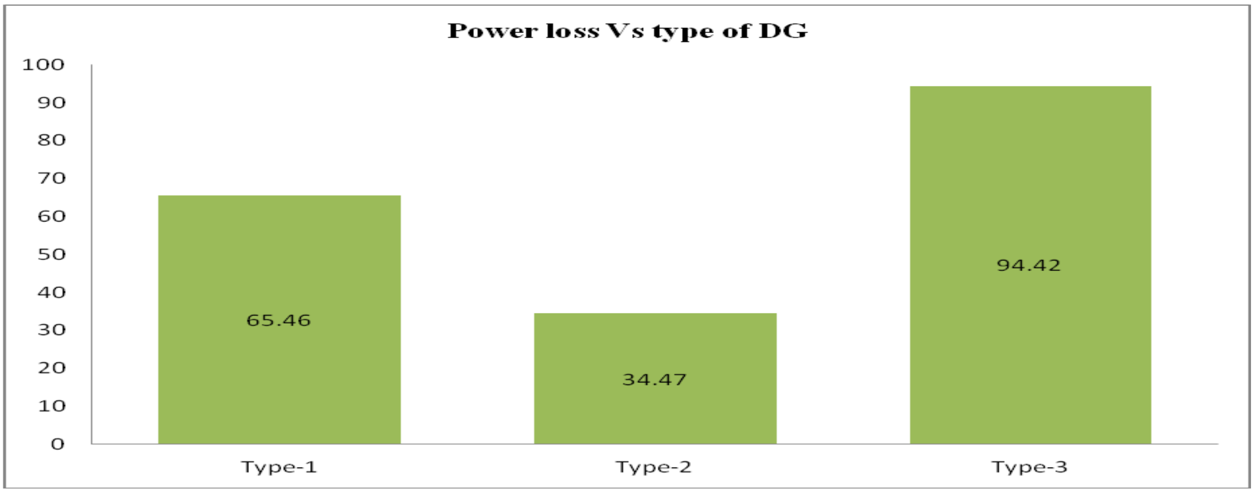

Fig.2: Power loss vs. type of DG for 3 DG system in 33-bus system

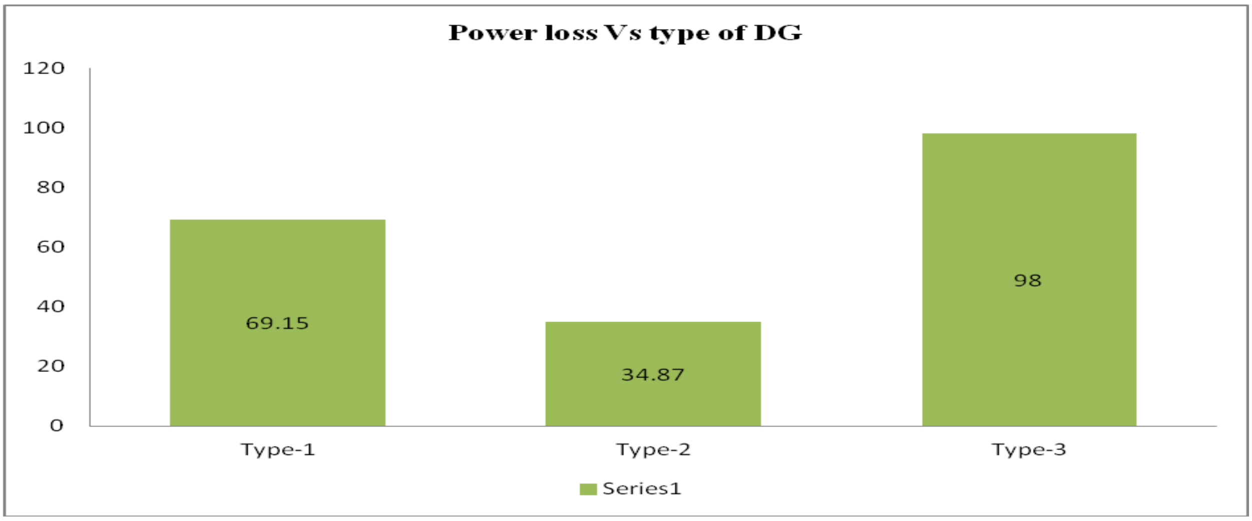

Fig.3: Power loss vs. type of DG for 3 DG system in 66-bus system

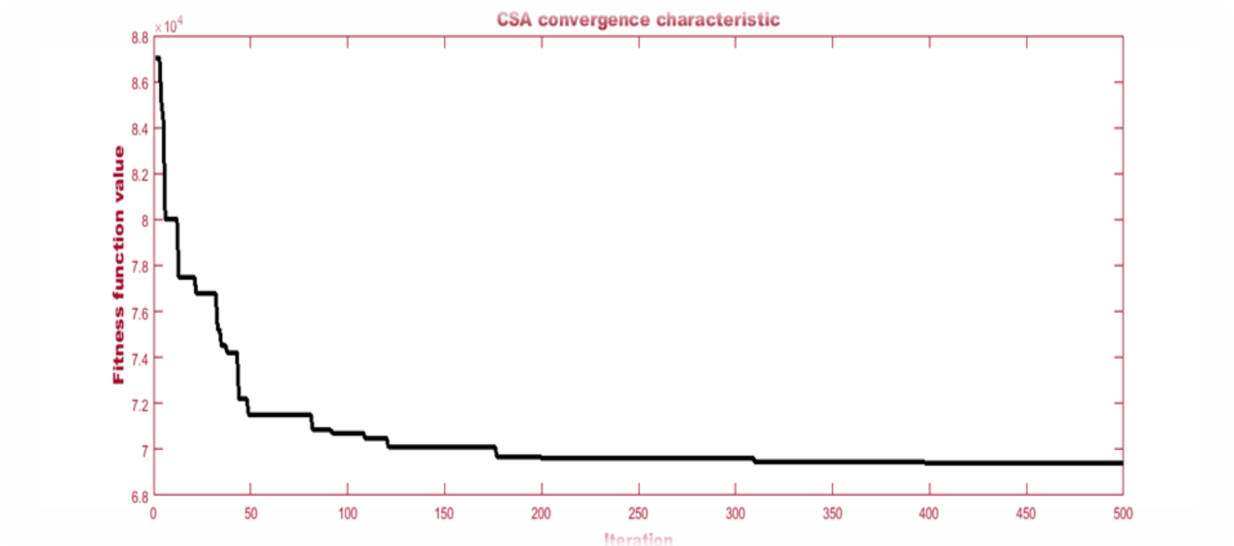

Fig.4: Convergence characteristics for three DG, type-1, 33-bus system

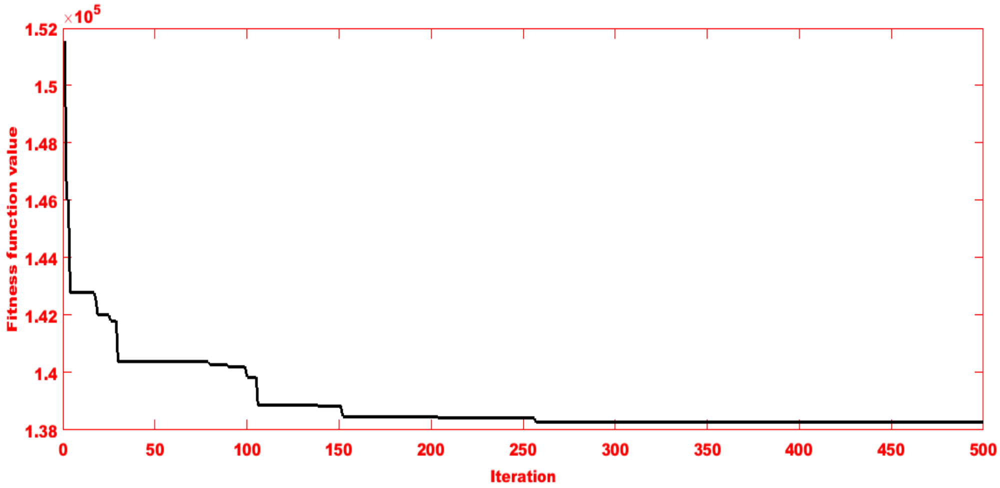

Fig.5: Convergence characteristics for three DG, type-2, 33-bus system

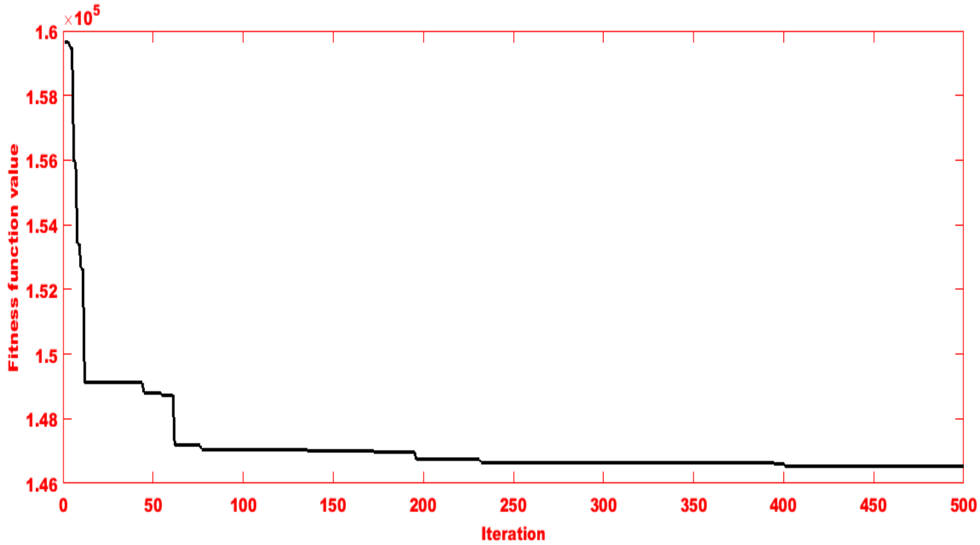

Fig.6: Convergence characteristics for three DG, type-3, 33-bus system

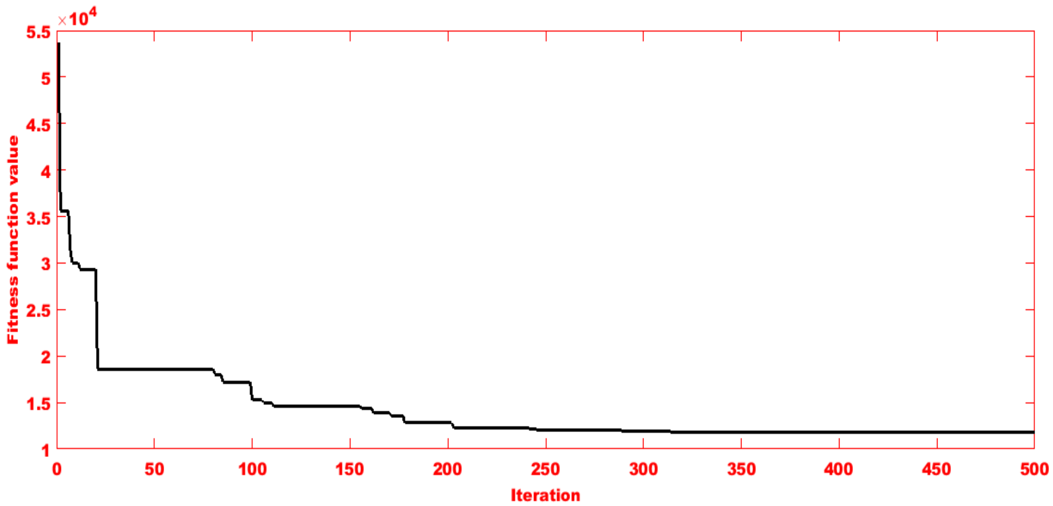

Fig.7: Convergence characteristics for three DG, type-1, 69-bus system

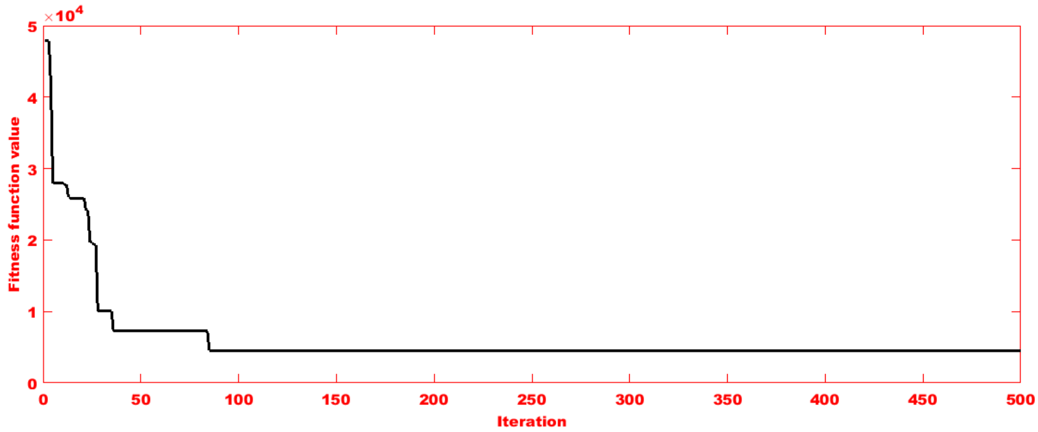

Fig.8: Convergence characteristics for three DG, type-2, 69-bus system

Table 8: Voltage profile for 33-bus system

DG Type	Minimum voltage	Bus No.	Maximum voltage	Bus No.
No DG	0.9038	18	1.0000	1
Type-1	0.9581	33	1.0000	1
Type-2	0.9289	18	1.0000	1
Type-3	0.9940	22	1.0091	13

Table 9: Voltage Profile for 69-bus system

DG Type	Minimum voltage	Bus No.	Maximum voltage	Bus No.
No DG	0.9092	65	1.0000	1
Type-1	0.9783	1	1.0000	1
Type-2	0.9329	65	1.0000	1
Type-3	0.9904	27	1.0000	1

References

[1] G. Pepersman, J. driesen, D.Haeseldonckx, R.Belmans and W.D. haeseleer, “Distributed generation: definition, benefits and issues. Energy policy” , vol. 33(6), pp. 787-798, 2005.

[2] S. Kansal, K. Vishal and T. Barjeev, “Optimal placement of different type of DG sources in distribution networks”, International Journal of Electrical Power and Energy systems, vol. 53, pp. 752-760, 2013

[3] D. Singh and K. Verma, “GA based optimal sizing & placement of distributed generation for loss minimization”, International Journal of Electrical Computer Engineering, vol. 2(8), pp. 556-562, 2007.

[4] A.K. Pandey and S. Kirmani, “Optimal location and sizing of hybrid system by analytical crow search optimization algorithm”, International Transactions on Electrical Energy Systems,e12327, 2020

[5] A.K. Pandey and S. Kirmani, "Multi-Objective Optimal Location and Sizing of Hybrid Photovoltaic System in Distribution Systems Using Crow Search Algorithm", International Journal of Renewable Energy Research, vol. 9(4), pp. 1681-1693, 2019.

[6] B. Mohanty and S. Tripathy, "A teaching learning based optimization technique for optimal location and size of DG in distribution network", International Journal of Electrical systems and information technology, vol. 3(1), pp. 33-44, 2016.

[7] M.H. Moradi, M.J. Abedini and E. Systems, "A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems", International Journal of Electrical Power and Energy Systems, vol.34(1), pp. 66-74,2012.

[8] M.F. Akorede, H. Hizam, I. Aris and M.Z.A. Kadir , "Effective method for optimal allocation of distributed generation units in meshed electric power systems", IET Generation, Transmission & Distribution, vol. 5(2), pp. 276-287, 2011.

[9] P.Gareth, H. Antonio, P. PierluigiSiano and A. RobinWallace,"Hybrid GA and OPF evaluation of network capacity for distributed generation connections". Electric Power Systems and Research, vol.78(3), pp. 392-398, 2008.

[10] N. Acharya, P. Mahat and N. Mithulananthan, "An analytical approach for DG allocation in primary distribution network", International Journal of Electrical Power Energy Systems, vol. **28**(10),pp. 669-678, 200

[11] M. Gandomkar, M. Vakilian, and M.J.E.P.C. Ehsan, "A genetic–based tabu search algorithm for optimal DG allocation in distribution networks", Electric power components and systems, vol.33(12), pp. 1351-1362, 2005.

[12] K.H. Kim,Y.J. Lee , S.B. Rhee, S.K. Lee and S.K. You," Dispersed generator placement using fuzzy-GA in distribution systems". in IEEE Power Engineering Society Summer Meeting. 2002.

[13] H. Mori and Y. Goto. "A parallel tabu search based method for determining optimal allocation of FACTS in power systems", in PowerCon 2000. 2000 International Conference on Power System Technology. Proceedings (Cat. No. 00EX409). 2000.

[14] A. Askarzadeh, "A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm",Computers Structures, vol. 169, pp. 1-12, 2016.

[15] M. Lakshmi and A.R. Kumar. Engineering, "Optimal Reactive Power Dispatch using Crow Search Algorithm", International Journal of Electrical, vol. 8(3), 2018

[16] D.Gupta, S.Sundaram, A. Khanna, A. E. Hassanien,V. H. C. Albuquerque, "Improved diagnosis of Parkinson's disease using optimized crow search algorithm". Computers & Electrical Engineering, vol. 68,p p. 412-424, 2018

[17] D. Oliva, S. Hinojosa, E. Cuevas, G. Pajares, and J.Gálvez, "Cross entropy based thresholding for magnetic resonance brain images using Crow Search Algorithm", Expert Systems with Applications, vol.79, pp. 164-180, 2017

[18] A.Y. Abdelaziz and A. Fathy, "A novel approach based on crow search algorithm for optimal selection of conductor size in radial distribution networks", Engineering Science Technology, vol. 20(2): p. 391-402, 2017.

[19] J.H. Teng, "A direct approach for distribution system load flow solutions", IEEE Transactions on power delivery, vol. 18(3), pp. 882-887, 2003.

[20] M.A. Kashem, V. Ganapathy, G.B. Jasmon and M.I. Buhari, "A novel method for loss minimization in distribution networks," in International Conference on Electric Utility Deregulation and Restructuring and Power Technologies. Proceedings (Cat. No. 00EX382). 2000.

[21] S. Kansal, V. Kumar and B. Tyagi, "Hybrid approach for optimal placement of multiple DGs of multiple types in distribution networks", International Journal of Electrical Power Energy Systems, vol. 75, pp. 226-235, 2016.

[22] D.Q. Mithulananthan, "Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, vol.. 4, pp.60. 2013.

[23] M. Baran, and F.F. Wu, "Optimal capacitor placement on radial distribution systems", IEEE Transactions on power Delivery, vol. 4(1), p p. 725-34, 1989.

[24] S. Kansal and V.K., Barjeev Tyagi, "Optimal placement of different type of DG sources in distribution networks", Electrical Power and Energy Systems, 21 May 2013.

[25] A. K. Pandey and S. Kirmani, "Efficient Approach for DG Placement and Size in Medium Voltage Distribution Systems," 2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018, pp. 127-131

[26] M. Saleh, Y. Esa, N. Onuorah and A. A. Mohamed, "Optimal microgrids placement in electric distribution systems using complex network framework," 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), San Diego, CA, 2017, pp. 1036-1040.

[27] Y. Tominaga, M. Tanaka, H. Eto, Y. Mizuno, N. Matsui and F. Kurokawa, "Design Optimization of Renewable Energy System Using EMO," 2018 International Conference on Smart Grid (icSmartGrid), Nagasaki, Japan, 2018, pp. 258-263.

[28] T. Sakagami, Y. Shimizu and H. Kitano, "Exchangeable batteries for micro EVs and renewable energy," 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), San Diego, CA, 2017, pp. 701-705.

[29] P. Mazidi, G. N. Baltas, M. Eliassi and P. Rodríguez, "A Model for Flexibility Analysis of RESS with Electric Energy Storage and Reserve," 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), Paris, 2018, pp. 1004-1009.