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A Study of EHO-FF Algorithms for Optimal Distribution Energy Resources Sizing.

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Abstract: The advent of the Smart Grid idea has presented a significant obstacle in the power industry. The smart grid now mostly consists of distributed power that integrates renewable energy resources. Demand Side Management (DSM) adapts to fluctuating demand by letting customers choose their own power generation options. By limiting demand & maximising resource allocation for power generation, DSM enables customers to access power at a reduced cost. Developing a hybrid evolutionary algorithm for DSM that accurately monitors smart grid real power loss is the main goal of this study. This method will be useful for reactive power optimisation, or RPO. Improving the power grid network's energy efficiency and voltage profile under various load situations is the goal of the proposed effort.

Keywords: Smart Grid, Demand Side Management, Distributed Energy Resources, Reactive Power Optimisation, hybrid evolutionary algorithm, PSO

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INTRODUCTION

The smart grid environment has seen a significant growth in the penetration levels of Distributed Energy Resources (DERs) into the existing system. A system's DG units can be located and sized with the help of optimisation techniques, which allow for their best utilisation within predetermined boundaries and constraints. The main goal of this research is to develop a DSM hybrid evolutionary algorithm that can precisely monitor actual smart grid power loss; this will help with Reactive Power Optimisation (RPO). Improving the power grid network's energy efficiency and voltage profile under various load situations is the goal of the proposed effort.

PROBLEM FORMULATION

The RPO takes into account operational and physical limitations in addition to the formulae for reactive and active power balance at each bus. Minimising power loss (Ploss), as shown in Equation (1), is its goal function.

$$min(P^{loss}) = \sum_{i \in S} \sum_{j \in S} V_i V_j G_{ij} cos\theta_{ij} \quad \ldots\ldots\ldots (1)$$

The magnitude of bus i's voltage is Vi;, bus j's voltage is Vj, & conductance between buses i & j is Gij. The total number of branches in the network is denoted by S, and the voltage angle between buse si and j is θij. As shown in Equations (2) and (3), the power balancing equation limitations at each bus i are demonstrated.

$$\begin{cases} P_i^G - P_i^L - P_i = 0; & i \in S^G \\ Q_i^G - Q_i^L - Q_i = 0; & i \in S^G \end{cases} \quad \text{.........} (2)$$

$$\begin{cases} -P_i^L - P_i = 0; & i \in S^L \\ Q_i^C - Q_i^L - Q_i = 0; & i \in S^L \end{cases} \quad \text{.........} (3)$$

Reactive power generation output limitations, static VAR compensator capacity limits, allowable voltage magnitude operating ranges (excluding slack bus), and transformer tap position constraints are detailed in Equation (4).

$$\begin{cases} \min(Q_i^G) \le Q_i^G \le \max(Q_i^G); & i \in S^G \\ \min(Q_i^C) \le Q_i^C \le \max(Q_i^C); & i \in S^C \\ \min(V_i) \le V_i \le \max(V_i); & i \in S^G \cup S^L \\ \min(T_l) \le T_l \le \max(T_l); & l \in S^T \end{cases} \quad \text{.......}(4)$$

Where,

$$\begin{cases} P_i = V_i \sum_{j \in S} V_j (G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}) \\ Q_i = V_i \sum_{j \in S} V_j (G_{ij} cos\theta_{ij} - B_{ij} sin\theta_{ij}) \end{cases} \quad \text{...............}(5)$$

In this case, Bij represents the mutual susceptibility of buses i and j. Bus angles, load bus voltage magnitude, generator bus reactive power, & slack bus real power generation are all examples of state variables in an RPO, while generator bus voltage magnitude, shunt capacitor/reactor output, and transformer ratios are examples of control variables. This classification is standard in optimisation problems. The system's buses are supposed to be in the following order: slack, generator, & load (with load buses containing shunt capacitors/reactors coming previous in the sequence for easier expression). Equation (6) gives the state variable vector (X) based on this order,

$$X = [P_1^G, Q_1^G, \dots, Q_m^G V_{m+1}, \dots, V_n \theta_2, \dots, \theta_n]^T \quad \text{......} (6)$$

Another thing that Equation (7) describes is the control variables, which are U.,

$$U = [V_2, \dots, V_m Q_{m+1}^C, \dots, Q_{m+r}^C T_1, \dots, T_k]^T \quad \text{......} (7)$$

With the RPO's focus on optimising the voltage profile & reactive power, certain limitations that were formerly part of the ideal power flow have been eliminated. These constraints pertain to the actual power line flow & slack bus's real power generation. We know how to generate active power. In practical terms, the transformer and shunt capacitor/reactor ratios are discrete variables, and the penalty function is a good way to deal with these variables.

It has been noted that the RPO becomes an uncertain nonlinear programming issue due to the presence of multiple uncertain components in its input data. An interval, fuzzy integer, or even a random number can be used to depict this uncertainty. Because the RPO model is self-validated, the intervals used to characterise its uncertainties are selected for this study. It is easy to get the bound information on the uncertainty using engineering approaches. Transmission line parameter uncertainties, for example, pale in comparison to the uncertainty connected with active & reactive power changes. This study does not consider any other uncertainty besides active power generation & load demand (Cetai er al. 209). Equation (8) describes active power generation, and Equation (9) describes active power demand, for the sake of clarity.

$$[P_i^G(SL), P_i^G(SU)] for i \in S^G \ldots (8)$$

$$[P_i^L(SL), P_i^L(SU)] for i \in S^L \ldots\ldots\ldots (9)$$

The reactive power demand is evaluated 85 given by Equation (10),

$$[Q_i^L(SL), Q_i^L(SU)] for i \in S^L \ldots\ldots (10)$$

The slack & generator buses are thought to have predictable active and reactive power loads because they are mostly generated by power plants. Equations (11) through (13) restructure the RPO model following the development of the equilibrium equations including interval uncertainty.

$$\min f(X,U) = [f^L, f^U] \ldots\ldots\ldots (11)$$

$$h(X,U) = [h^L, h^U] \ldots\ldots (12)$$

$$min(g) \leq g(X,U) \leq \max(g) \ldots\ldots (13)$$

Here the interval functions are defined as f(X,U),h(X,U) & g (X, U), the interval of the real power losses is $[f^L, f^U]$ ¿ & interval vector of the power flow variation is represented as $[h^L, h^U]$. X & U, the state & control variable vectors, respectively, correspond to the RPO model's X and U. U is a real-valued vector in the suggested model since the excitation mechanism fixes the magnitude of the generators' voltages. Additionally, the output of the shunt capacitors/reactors must be coordinated manually with the transformer ratios. Given that its unregulated nature is present in interval input data, U is formed of interval values, unlike X. In addition, every time U is determined by combining the interval power flow equations, X is also determined by U; that is, for every U, there is an associated X. Naturally, the issue is resolved by applying the techniques of nonlinear programming issues including interval uncertainty. Deterministic RPO models utilise the linear approximation method with internal control. The suggested hybrid EHO-FF evolutionary algorithm is an improved way to get the intervals of the unknown power flow equations, which further improves its accuracy.

RESULTS AND DISCUSSION

The results of the simulation work are described in this section. On a platform consisting of an Intel (R) Core (TM) two CPU, 4GB RAM, and MATLAB 7.10.0 (R2014a), the code has been built to optimise reactive power in the smart grid by positioning DG units. The suggested work is tested against the benchmark systems of the IEEE 30 bus & the IEEE 57 bus to ensure its efficacy. The appendix provides a full single-line schematic of the IEEE 30 Bus system, including load and branch data. The 283.4 MW and 26.2 MVAr total loads of the six producing units & eight transmission networks that make up the IEEE 30 bus test system's 41 branches.

Voltage, power loss, active power, & reactive power tests are conducted on all transmission lines initially. DGs operate well at generator buses that employ a hybrid algorithm to boost distribution network voltage and decrease reactive power compensation loss. A number of meta-heuristic algorithms, including Bat & PSO, are employed to verify that the proposed hybrid method is effective.

A number of optimisation procedures were modelled in an effort to resolve the RPO issue; Table 1 displays the usual or selected values for the different parameters.

Table 1: Optimisation Algorithm Parameters

Algorithm /Parameter	EHO	FF	Bat	PSO
Max Generation	10	10	10	10
Alpha(α)	0.5	0.5	0.1	0.12 (C1)
Beta (β)	0.1	1	-	1.2 (C2)
Number Evaluations	100	100	100	50
Number of dimensions	6	3	6	6
Constant	2	1	2 (Pulse	(0.9)

Base Case Solution of IEEE 30 Bus Test System

The study's investigated IEEE 30 bus test system follows a typical 24-hour load pattern, as shown in Figure 1. Using the base case load data & Newton-Raphson approach, the load flow program is initially executed for the IEEE 30 bus system. Table 2 shows the load flow solution for each bus used in the test system. It contains the magnitude of the bus voltage, real power, & reactive power generation/load.

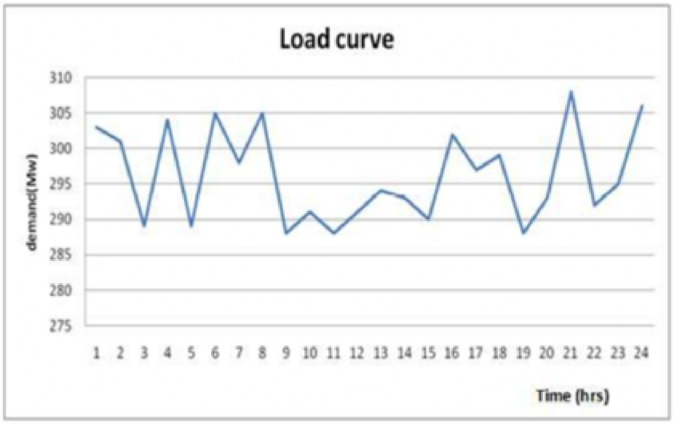

Figure 1: Daily load curve for IEEE 30 bus system

Table 2: Optimisation of an IEEE 30 bus system's load flow utilizing Newton-Raphson

Bus No	V (p.u)	Generation		Load	
		P(MW)	Q(MVAr)	P(MW)	Q(MVAr)
1	1.06	8.813	53.3257	134	0
2	1.043	21.7	59.646	46	50
3	1.0245	2.4	-1.2	0	0
4	1.0156	7.6	-1.6	0	0
5	1.0237	94.2	55	37	37
6	1.01	0	-31.335	0	0
7	1.0078	22.8	-10.9	0	0
8	1.0119	30	44.6	18	37.3
9	1.0373	0	0	0	0
10	1.028	5.8	36	0	19
11	1.0609	0	24.4	13	12.2
12	1.0564	11.2	-7.5	0	0
13	1.071	0	22.65	38	10.6
14	1.0392	6.2	-1.6	0	0
15	1.0309	8.2	-2.5	0	0
16	1.0367	3.5	-1.8	0	0
17	1.0251	9	-5.8	0	0
18	1.0175	3.2	-0.9	0	0
19	1.0128	9.5	-3.4	0	0
20	1.0158	2.2	-0.7	0	0
21	1.013	22.75	-11.2	0	0
22	1.01	0	-9.056	0	0
23	1.0133	3.2	-1.6	0	0
24	1.0028	8.7	1.9	0	4.3
25	1.0018	0	0	0	0
26	0.9838	3.5	-2.3	0	0
27	1.01	0	-1.738	0	0
28	1.0083	0	0	0	0
29	0.9899	2.4	-0.9	0	0
30	0.9782	10.6	-1.9	0	0
Total		297.663	153.944	286	170.4

Table 3 displays the power flow diagram and reactive and actual power losses for each transmission line in the IEEE 30 bus system. With base case load conditions, the reactive power line losses for the IEEE 30 bus system were 45.58MVAr & real power line losses were 11.463MW, as determined by the evaluation utilising the Newton-Raphson technique. Using the load flow solution, we can calculate the line flows & losses in each of the branches. Reactive power generation is to 53.944MVAr, while total active power generation is estimated to be 297.663MW. Tables 2 and 3 display the outcomes of the load generation balance equation for active & reactive power, total load, and line losses, respectively.

Table 3: Power flow & losses in an IEEE 30 bus system utilizing the Newton-Raphson model

From Bus	To Bus	P(MW)	Q(MVar)	From Bus	To Bus	P(MW)	Q (MVar)	Line losses	
								P (MW)	Q (MVar)
1	2	132.84	-8.231	2	1	-129.813	17.296	3.027	9.065
1	3	68.272	8.527	3	1	-66.367	-1.567	1.904	6.96
2	4	34.621	7.091	4	2	-33.967	-5.097	0.654	1.994
3	4	63.967	2.94	4	3	-63.45	-1.455	0.517	1.486
2	5	65.979	1.66	5	2	-64.089	6.281	1.89	7.94
2	6	47.512	5.613	6	2	-46.29	-1.903	1.222	3.709
4	6	56.063	-6.383	6	4	-55.694	7.666	0.369	1.283
5	7	-10.111	14.94	7	5	10.255	-14.576	0.145	0.365
6	7	33.352	-4.654	7	6	-33.055	5.566	0.297	0.912
6	8	18.91	-8.418	8	6	-18.859	8.595	0.05	0.176
6	9	19.939	-16.49	9	6	-19.939	17.825	0	1.335
6	10	13.79	-4.873	10	6	-13.79	6.002	0	1.13
9	11	-12	-11.665	11	9	12	12.2	0	0.535
9	10	31.939	5.628	10	9	-31.939	-4.566	0	1.062
4	12	33.754	-17.304	12	4	-33.754	20.644	0	3.341
12	13	-15	-10.123	13	12	15	10.533	0	0.41
12	14	8.458	2.468	14	12	-8.373	-2.29	0.085	0.178
12	15	20.156	7.441	15	12	-19.882	-6.903	0.273	0.538
12	16	8.941	3.937	16	12	-8.86	-3.768	0.081	0.17
14	15	2.173	0.69	15	14	-2.162	-0.68	0.011	0.01
16	17	5.36	1.968	17	16	-5.335	-1.91	0.025	0.058
15	18	6.838	2.005	18	15	-6.787	-1.901	0.051	0.103
18	19	3.587	1.001	19	18	-3.579	-0.984	0.008	0.017
19	20	-5.921	-2.416	20	19	5.935	2.442	0.013	0.027
10	20	8.202	3.294	20	10	-8.135	-3.142	0.068	0.151
10	17	3.673	3.912	17	10	-3.665	-3.89	0.009	0.023
10	21	21.408	11.809	21	10	-21.215	-11.394	0.193	0.415
10	22	6.646	2.755	22	10	-6.611	-2.683	0.035	0.072
21	23	-1.535	0.194	23	21	1.536	-0.194	0	0.001
15	23	7.006	3.078	23	15	-6.952	-2.968	0.055	0.11
22	24	6.611	3.748	24	22	-6.549	-3.65	0.063	0.097
23	24	2.216	1.561	24	23	-2.207	-1.542	0.009	0.019
24	25	0.055	2.792	25	24	-0.041	-2.768	0.014	0.025
25	26	3.546	2.368	26	25	-3.5	-2.3	0.046	0.068
25	27	-3.504	0.399	27	25	3.518	-0.374	0.013	0.026
28	27	16.808	0.026	27	28	-16.808	1.04	0	1.066
27	29	6.194	1.676	29	27	-6.105	-1.508	0.089	0.168
27	30	7.097	1.671	30	27	-6.93	-1.357	0.167	0.314
29	30	3.705	0.608	30	29	-3.67	-0.543	0.035	0.065
8	28	0.859	1.354	28	8	-0.858	-1.349	0.002	0.005
6	28	15.993	-1.188	28	6	-15.95	1.339	0.043	0.151
Total Loss								11.463	45.58

Optimising Efficiency utilising PSO for the IEEE 30 Bus System

In the current investigation of the 30 bus test system for IEEE compatibility, DG units are installed on generator buses. Specifically, DGI is located on bus 1, DG2 on bus 2, DG3 on bus 6, DG 4 on bus 3, DG5 on bus 22, & DG6 on bus 27. Figure 1 shows the varied load pattern that may be achieved by applying the PSO algorithm to determine the ideal size of distributed generation units (DG) installed at specific places. The PSO algorithm's evaluation of the base case line flows and losses is displayed in Table 4. Analysis of the PSO algorithm yielded real power line losses of 0.886 MW and reactive power line losses of 43.074 MV Ar for the IEEE 30 bus system under base case load conditions.

Table 4: PSO algorithm power loss & flow evaluation in IEEE 30 Bus system

From Bus	To Bus	P (MW)	Q (MVar)	From Bus	To Bus	P (MW)	Q (MVar)	Line losses	
								P (MW)	Q (MVar)
1	2	129.165	-7.282	2	1	-126.31	15.847	2.86	8.565
1	3	66.121	8.728	3	1	-64.332	-2.188	1.789	6.54
2	4	33.376	7.265	4	2	-32.765	-5.402	0.611	1.863
3	4	61.932	3.562	4	3	-61.446	-2.169	0.485	1.394
2	5	65.277	1.751	5	2	-63.427	6.022	1.85	7.773
2	6	45.952	6	6	2	-44.805	-2.519	1.147	3.48
4	6	54.702	-5.348	6	4	-54.352	6.565	0.35	1.216
5	7	-10.773	15.199	7	5	10.927	-14.81	0.154	0.389
6	7	34.037	-4.85	7	6	-33.727	5.8	0.309	0.95
6	8	18.799	-8.421	8	6	-18.749	8.596	0.05	0.175
6	9	18.062	-16.749	9	6	-18.062	17.959	0	1.21
6	10	12.714	-5.032	10	6	-12.714	6.019	0	0.987
9	11	-12	-11.666	11	9	12	12.2	0	0.534
9	10	30.062	5.502	10	9	-30.062	-4.56	0	0.942
4	12	31.909	-17.335	12	4	-31.909	20.395	0	3.06
12	13	-15	-10.107	13	12	15	10.517	0	0.41
12	14	8.179	2.536	14	12	-8.098	-2.368	0.081	0.168
12	15	19.032	7.521	15	12	-18.784	-7.033	0.248	0.488
12	16	8.498	4.023	16	12	-8.423	-3.866	0.075	0.157
14	15	1.898	0.768	15	14	-1.89	-0.76	0.009	0.008
16	17	4.923	2.066	17	16	-4.901	-2.015	0.022	0.05
15	18	6.749	2.069	18	15	-6.699	-1.968	0.05	0.101
18	19	3.499	1.068	19	18	-3.491	-1.051	0.008	0.016
19	20	-6.009	-2.349	20	19	6.023	2.376	0.014	0.027
10	20	8.291	3.229	20	10	-8.223	-3.076	0.069	0.153
10	17	4.108	3.809	17	10	-4.099	-3.785	0.009	0.025
10	21	18.029	11.596	21	10	-17.881	-11.277	0.148	0.319
10	22	6.547	3.12	22	10	-6.511	-3.047	0.035	0.073
21	23	0.381	0.077	23	21	-0.381	-0.077	0	0
15	23	5.726	3.224	23	15	-5.685	-3.143	0.04	0.081
22	24	6.511	3.49	24	22	-6.452	-3.398	0.059	0.092
23	24	2.867	1.62	24	23	-2.853	-1.592	0.014	0.028
24	25	0.605	2.59	25	24	-0.592	-2.567	0.013	0.023
25	26	3.546	2.368	26	25	-3.5	-2.3	0.046	0.068
25	27	-2.953	0.199	27	25	2.963	-0.181	0.009	0.018
28	27	16.253	0.014	27	28	-16.253	0.983	0	0.996
27	29	6.194	1.676	29	27	-6.105	-1.508	0.089	0.168
27	30	7.097	1.671	30	27	-6.93	-1.357	0.167	0.314
29	30	3.705	0.608	30	29	-3.67	-0.543	0.035	0.065
8	28	0.749	1.353	28	8	-0.748	-1.348	0.001	0.005
6	28	15.545	-1.208	28	6	-15.505	1.351	0.04	0.143
Total Loss								**10.886**	**43.074**

In Table 5, we can see the total real power loss that was computed with and without the deployment of DG utilising the PSO algorithm. Assessing reactive & real power losses for every load scenario follows the optimal sizing of DG units. Real power losses average 11.85 MW when DG is not implemented and 9.66 MW when it is. The results indicate that after DGs are placed in the designated places with the right size, real power loss is decreased.

Table 5: Evaluate power losses with DG in an IEEE 30 Bus system with variable load demand using

the PSO technique.

Hour	DG1 (MW)	DG2 (MW)	DG3 (MW)	DG4 (MW)	DG5 (MW)	DG6 (MW)	Total real power loss before DG placement (MW)	Total real power loss after DG placement (MW)
1	166	61	22	19	10	25	11.39	9.2
2	180	29	20	30	10	32	11.78	9.62
3	162	50	21	11	10	35	11.39	9.79
4	165	42	24	27	10	36	11.19	8.26
5	141	53	23	24	10	38	11.19	8.08
6	177	44	16	19	10	39	11.78	9.95
7	171	39	23	12	13	40	14.6	12.37
8	181	32	17	17	18	40	14.6	12.49
9	157	39	16	17	20	39	11.78	9.5
10	170	22	15	23	23	38	11.65	9.58
11	134	43	24	25	25	37	11.19	7.29
12	129	58	27	16	27	34	11.39	7.36
13	168	36	18	14	28	30	11.39	9.27
14	144	44	22	25	30	28	11.46	7.74
15	147	42	17	31	28	25	11.19	7.98
16	161	55	16	20	27	23	11.78	9.01
17	178	36	22	16	23	22	11.39	9.55
18	170	43	22	25	19	20	11.39	8.98
19	180	39	15	20	15	19	14.6	13.91
20	192	35	22	16	10	18	11.39	10.97
21	187	62	20	11	10	18	11.46	10.57
22	177	32	22	34	10	17	11.19	9.43
23	184	42	20	24	10	15	11.65	10.6
24	186	55	19	24	10	12	11.65	10.38
Average							11.85	9.66

Bat Algorithm for Optimal DG Unit Sizing in IEEE 30 Bus Systems

Similarly to how the Bat algorithm was used for the PSO method, this one is used to find the ideal size of DG units to be put at specific locations in order to accommodate different load patterns, as seen in Figure 1. According to Table 6, the line losses for the base case load scenario of the IEEE 30 bus system, as determined by the Bat method assessments, are 34.389 MVAr and 8.556 MW. Table 7 displays the outcomes of calculating power losses for every load scenario following the installation of appropriately sized DG units. Average real power losses are 11.4592 MW when DG is not used, and they decrease to 7.3971 MW when DG is used. Using this method for optimal DG unit sizing led to the conclusion that DG put with suitable sizing at the specified sites reduces average real power loss. Moreover, when all potential loads are considered, the Bat algorithm is found to reduce reactive & actual power losses on average compared to the PSO algorithm's results.

Table 6: IEEE 30 bus power flow and losses under bat algorithm

From Bus	To Bus	P (MW)	Q (MVar)	From Bus	To Bus	P (MW)	Q (MVar)	Line losses	
								P (MW)	Q (MVar)
1	2	96.602	1.486	2	1	-95.007	3.291	1.595	4.777
1	3	54.533	10.019	3	1	-53.296	-5.499	1.237	4.52
2	4	30.724	7.168	4	2	-30.203	-5.579	0.522	1.589
3	4	50.896	6.88	4	3	-50.564	-5.927	0.332	0.953
2	5	59.35	0.948	5	2	-57.821	5.474	1.529	6.423
2	6	42.232	6.942	6	2	-41.254	-3.973	0.978	2.969
4	6	50.189	-0.739	6	4	-49.898	1.751	0.291	1.012
5	7	-8.379	15.765	7	5	8.52	-15.41	0.141	0.355
6	7	31.589	-5.577	7	6	-31.32	6.405	0.269	0.827
6	8	15.679	-8.466	8	6	-15.642	8.597	0.037	0.131
6	9	16.118	-16.735	9	6	-16.118	17.811	0	1.077
6	10	11.404	-5.029	10	6	-11.404	5.85	0	0.82
9	11	-11	-11.708	11	9	11	12.2	0	0.492
9	10	27.118	5.689	10	9	-27.118	-4.914	0	0.775
4	12	22.978	-18.088	12	4	-22.978	20.068	0	1.979
12	13	-30	-8.332	13	12	30	9.542	0	1.21
12	14	8.908	2.251	14	12	-8.815	-2.058	0.093	0.193
12	15	22.043	6.904	15	12	-21.728	-6.284	0.315	0.62
12	16	10.828	3.589	16	12	-10.718	-3.358	0.11	0.23
14	15	2.615	0.458	15	14	-2.601	-0.445	0.014	0.013
16	17	7.218	1.558	17	16	-7.177	-1.462	0.041	0.096
15	18	7.819	1.794	18	15	-7.755	-1.664	0.064	0.131
18	19	4.555	0.764	19	18	-4.542	-0.737	0.013	0.026
19	20	-4.958	-2.663	20	19	4.968	2.683	0.01	0.021
10	20	7.224	3.508	20	10	-7.168	-3.383	0.056	0.125
10	17	1.83	4.355	17	10	-1.823	-4.338	0.007	0.017
10	21	16.613	11.84	21	10	-16.479	-11.551	0.134	0.289
10	22	7.055	2.568	22	10	-7.017	-2.489	0.038	0.078
21	23	-1.021	0.351	23	21	1.021	-0.351	0	0
15	23	8.31	2.434	23	15	-8.24	-2.294	0.07	0.141
22	24	7.017	3.176	24	22	-6.952	-3.076	0.064	0.1
23	24	4.019	1.045	24	23	-3.997	-1	0.022	0.044
24	25	2.25	1.677	25	24	-2.235	-1.652	0.014	0.025
25	26	3.546	2.368	26	25	-3.5	-2.3	0.046	0.068
25	27	-1.31	-0.717	27	25	1.313	0.721	0.002	0.005
28	27	17.956	0.076	27	28	-17.956	1.14	0	1.217
27	29	7.569	1.816	29	27	-7.438	-1.57	0.131	0.247
27	30	9.075	1.858	30	27	-8.805	-1.351	0.269	0.507
29	30	5.038	0.67	30	29	-4.975	-0.549	0.064	0.12
8	28	1.642	1.354	28	8	-1.639	-1.345	0.003	0.009
6	28	16.362	-1.127	28	6	-16.317	1.285	0.045	0.158
Total Loss								**8.556**	**34.389**

Table 7: Bat algorithm investigation of IEEE 30 Bus variable load demand power losses with DG.

Hour	DG1 (MW)	DG2 (MW)	DG3 (MW)	DG4 (MW)	DG5 (MW)	DG6 (MW)	Total real power loss before DG placement (MW)	Total real power loss after DG placement (MW)
1	170	57	18	23	10	25	11.19	9.21
2	173	45	29	12	10	32	11.19	9.03
3	137	55	29	23	10	35	11.46	8.02
4	159	58	31	10	10	36	11.65	8.7
5	153	54	20	14	10	38	11.39	9.33
6	199	23	16	18	10	39	14.6	13.92
7	164	37	29	15	13	40	11.19	8.43
8	156	54	26	11	18	40	11.78	8.5
9	129	56	19	25	20	39	11.46	7.91
10	119	56	31	24	23	38	11.14	6.38
11	154	42	18	12	25	37	11.46	9.05
12	151	42	18	19	27	34	14.6	11.33
13	158	35	27	16	28	30	14.6	10.89
14	109	72	29	25	30	28	11.19	6.12
15	124	70	28	15	28	25	11.65	7.49
16	179	25	23	25	27	23	11.14	8.57
17	152	61	29	10	23	22	11.65	8.57
18	166	53	19	22	19	20	11.14	8.89
19	166	38	35	15	15	19	11.78	9.37
20	158	67	19	21	10	18	11.39	9.56
21	156	63	32	29	10	18	11.14	7.57
22	192	32	28	13	10	17	11.46	10.86
23	162	56	24	28	10	15	11.19	8.84
24	170	64	22	28	10	12	11.14	8.93
Average							11.77	8.98

Hybrid EHO-FF Method for the Sizing of DG Units in an IEEE 30 Bus System

The proposed hybrid evolutionary algorithm integrates the EHO and FF algorithms to mimic the PSO & Bat algorithms. It is now being used in the IEEE 30 bus test system that accounts for DG placement for various load patterns. Total line losses assessed using the suggested hybrid algorithm are 7.60 MW and 30.674 MV Ar, as shown in Table 8, which displays the power flow & losses in the transmission lines utilising the proposed method.

Table 8: Power consumption and losses in an EHO-FF algorithm-based IEEE 30 bus system

From Bus	To Bus	P (MW)	Q (MVar)	From Bus	To Bus	P (MW)	Q (MVar)	Line losses	
								P (MW)	Q (MVar)
1	2	93.942	2.231	2	1	-92.434	2.288	1.509	4.519
1	3	50.31	10.705	3	1	-49.246	-6.815	1.064	3.89
2	4	26.863	8.126	4	2	-26.441	-6.869	0.412	1.257
3	4	46.846	8.197	4	3	-46.561	-7.381	0.284	0.817
2	5	52.423	0.222	5	2	-51.231	4.788	1.192	5.01
2	6	37.457	8.191	6	2	-36.672	-5.808	0.785	2.383
4	6	46.163	0.871	6	4	-45.917	-0.015	0.246	0.856
5	7	-5.969	16.472	7	5	6.104	-16.13	0.135	0.34
6	7	29.137	-6.416	7	6	-28.904	7.131	0.233	0.716
6	8	13.587	-8.497	8	6	-13.557	8.603	0.03	0.106
6	9	14.414	-13.351	9	6	-14.414	14.12	0	0.77
6	10	10.839	-3.074	10	6	-10.839	3.745	0	0.67
9	11	-13	-11.613	11	9	13	12.2	0	0.587
9	10	27.414	9.129	10	9	-27.414	-8.275	0	0.853
4	12	19.239	-16.996	12	4	-19.239	18.489	0	1.522
12	13	-38	-10.11	13	12	38	12.05	0	1.94
12	14	9.556	2.582	14	12	-9.448	-2.357	0.108	0.225
12	15	24.298	8.596	15	12	-23.904	-7.82	0.394	0.776
12	16	12.185	4.751	16	12	-12.04	-4.447	0.145	0.305
14	15	3.248	0.757	15	14	-3.225	-0.736	0.023	0.021
16	17	8.54	2.647	17	16	-8.479	-2.503	0.061	0.143
15	18	8.393	2.243	18	15	-8.317	-2.088	0.076	0.155
18	19	5.117	1.188	19	18	-5.1	-1.153	0.017	0.034
19	20	-4.4	-2.247	20	19	4.408	2.263	0.008	0.016
10	20	6.656	3.069	20	10	-6.608	-2.963	0.048	0.106
10	17	0.524	3.305	17	10	-0.521	-3.297	0.003	0.009
10	21	18.868	11.978	21	10	-18.704	-11.624	0.164	0.354
10	22	6.405	9.259	22	10	-6.317	-9.079	0.087	0.18
21	23	-4.046	0.424	23	21	4.048	-0.42	0.002	0.004
15	23	10.536	3.813	23	15	-10.418	-3.575	0.118	0.239
22	24	6.317	0.024	24	22	-6.272	0.046	0.045	0.07
23	24	3.17	2.395	24	23	-3.149	-2.353	0.02	0.041
24	25	0.722	-0.093	25	24	-0.721	0.095	0.001	0.002
25	26	3.546	2.369	26	25	-3.5	-2.3	0.046	0.069
25	27	-2.825	-2.464	27	25	2.841	2.493	0.015	0.029
28	27	16.131	0.043	27	28	-16.131	0.938	0	0.981
27	29	6.194	1.676	29	27	-6.105	-1.508	0.089	0.168
27	30	7.097	1.671	30	27	-6.93	-1.357	0.167	0.314
29	30	3.705	0.608	30	29	-3.67	-0.543	0.035	0.065
8	28	1.557	1.349	28	8	-1.554	-1.341	0.003	0.008
6	28	14.612	-1.188	28	6	-14.576	1.315	0.036	0.126
Total Loss								**7.601**	**30.674**

In Table 9, we can see the results of simulating the ideal DG unit sizing for each load pattern using the suggested EHO-FF method. We also analyse the line losses that occur after DG placement at the selected sites (generator bus). The suggested hybrid EHO-FF algorithm decreases average power loss to 11.4592 MW without DG placement & 7.3971 MW after DG placement, in comparison to PSO and Bat algorithms.

EHO-FF Algorithm with a Hybrid Approach for Optimal DG Unit Sizing in IEEE 57 Bus Systems

The proposed hybrid approach, which integrates the EHO and FF algorithms, is now being used by the IEEE 57 bus test system that includes DG placement for different load patterns (as shown in Figure). Table 10 shows the results of the evaluation of the appropriate DG unit sizing for each load pattern and real power losses. Results from the suggested hybrid EHO-FF algorithm outperform those from the PSO and bat algorithms.

Table 9: A proposed algorithm for DG power loss analysis in IEEE 30 bus systems with variable load demand.

Hour	DG1 (MW)	DG2 (MW)	DG3 (MW)	DG4 (MW)	DG5 (MW)	DG6 (MW)	Total real power loss before DG placement (MW)	Total real power loss after DG placement (MW)
1	175	57	20	16	10	25	11.78	7.77
2	180	44	21	14	10	32	11.19	7.99
3	162	36	22	24	10	35	11.39	7.2
4	179	38	24	17	10	36	11.19	7.77
5	166	31	21	23	10	38	11.14	6.9
6	164	38	28	26	10	39	11.65	7.18
7	172	35	24	14	13	40	11.14	6.82
8	164	41	18	24	18	40	11.14	6.59
9	145	26	33	25	20	39	11.65	6.64
10	160	35	23	12	23	38	11.14	7.57
11	150	40	22	14	25	37	11.14	6.2
12	157	37	23	13	27	34	11.39	6.98
13	139	59	23	15	28	30	11.19	6.63
14	143	47	20	25	30	28	11.46	5.82
15	158	32	20	27	28	25	11.46	7.51
16	164	48	22	18	27	23	11.19	7.21
17	151	53	26	22	23	22	11.14	6.13
18	166	47	36	11	19	20	11.46	6.71
19	170	42	21	21	15	19	11.65	7.65
20	175	48	20	22	10	18	11.46	8.05
21	199	31	26	24	10	18	11.14	7.71
22	176	48	28	13	10	17	11.19	8.63
23	188	54	16	12	10	15	11.14	8.65
24	185	50	20	29	10	12	14.6	11.22
Average							**11.4592**	**7.3971**

Table 10: Power losses with DG for variable load demand in IEEE 57 bus system using proposed algorithm

Hour	DG1 (MW)	DG2 (MW)	DG3 (MW)	DG4 (MW)	DG5 (MW)	DG6 (MW)	DG7 (MW)	Total real power loss DG before placement (MW)	Total real power loss after DG placement (MW)
1	322	251	56	47	168	242	75	26.67	21.74
2	387	243	56	54	175	232	98	27.80	22.87
3	207	251	47	34	123	188	52	19.80	14.87
4	222	267	27	23	213	256	48	22.40	17.47
5	482	313	54	42	212	263	125	25.52	20.59
6	467	332	68	12	264	412	186	30.41	25.48
7	421	314	83	76	218	423	325	31.47	26.54
8	472	301	327	54	243	421	222	32.80	27.87
9	425	337	65	121	221	531	477	31.23	26.30
10	498	325	87	423	245	476	427	34.52	29.59
11	485	376	78	132	254	497	374	33.16	28.23
12	467	371	260	65	234	446	322	32.23	27.30
13	503	321	145	164	243	397	296	29.06	24.13
14	432	324	72	169	236	497	487	30.20	25.27
15	504	328	42	219	243	490	289	28.30	23.37
16	465	345	65	251	256	498	412	29.32	24.39
17	512	264	53	345	198	398	325	28.50	23.57
18	476	286	92	56	174	402	448	27.03	22.10
19	367	312	176	84	265	398	185	24.28	19.35
20	426	413	21	52	296	316	110	26.05	21.12
21	395	364	62	15	287	425	61	26.08	21.15
22	328	304	52	14	256	328	67	25.33	20.40
23	289	254	46	18	176	272	38	22.19	17.26
24	276	231	43	11	176	213	78	22.51	17.58
Average								27.78	22.85

CONCLUSION

The suggested hybrid method outperforms the state-of-the-art methods and is supported by appropriate outcomes in a comparison of optimisation algorithms used for DG unit optimal sizing in IEEE 30 bus & IEEE 57 bus test systems. Because of this, we can say that the suggested hybrid algorithm improves performance for different types of power sector loads and is more effective at reactive power optimisation for optimally sizing distributed generation in smart grid environments. A novel hybrid EHO-FF method for optimising DG units deployed at indicated locations was described & developed by Muthukumaran et al. (2021). We discuss the test systems that incorporate all operative limitations and use a 24-hour load pattern to solve the objective function that has been formulated.

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