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Optimization of Distributed Generation in Micro Grid using a Hybrid Metaheuristic Technique

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ABSTRACT

This paper introduces a hybrid metaheuristic approach with eagle strategy (ES) and particle swarm optimization (PSO) technique to minimize the operation cost of a low voltage micro grid with renewable energy source (RES) such as photovoltaic (PV), micro turbine (MT), fuel cell (FC), wind turbine (WT), and battery, while satisfying the load demand and system operating constraints. The cost optimization problem is developed as a nonlinearly constrained mathematical problem to optimize the generation of DGs in the micro grid. The presented hybrid approach is validated on a low voltage micro grid and its better execution property is compared with the other metaheuristic techniques for example PSO, genetic algorithm (GA), adaptive modified PSO (AMSPO) and chaotic PSO (CPSO).

Key words: Distributed generation, Eagle strategy, Micro grid, Particle swarm optimization, Renewable energy sources.

1. INTRODUCTION

Electricity is one of the most greatly utilized forms of energy globally. Power production comes from a variety of technologies, and the primary sources have a general law that the application of a rotary motion to produce electricity through generators.

The goal of electrical power producing system is to produce the only energy required to be consumed at given period, by taking into account of various voltage levels to be supplied and the power loss related with the distribution and transmission systems. Due to the globalization of this resource, power demand has grown greatly, making it necessary to raise community awareness about the environmental impacts caused by large power production industries with regard to more conventional or centralized generation. In view of this, it led to various developments in micro grids, where a particular interest is given to decentralized or distributed generation (DG) [1]. Even though this form of DG has several advantages, some factors need to be taken into account.

By adding DG to a micro grid, a set of different operating conditions is imposed on the system such as power balance constraints, power generation limits, voltage limits, failure levels, harmonic distortions and network stability problem that severely impact the operation of the entire power systems if proper care is not taken [2].

The potential advantages of DG production depend on the position and size of the DG unit. The proper rating and placing of DG will results in condition that reduced energy losses and increased reliability level of the complete network. Nevertheless, the determination of the optimal position and rating of the generation unit is a complex job and it is necessary to computationally study about the parameter by taking into account that the unpredictability and intermittence associated with renewable energies [3].

The study underlying this option must be undertaken to minimize the operating cost of DG or other objectives in the functions of DG placement while satisfying the system constraints [4]. With the growing introduction of DG in the electricity grid, it's optimized planning and management in the distribution system will make it possible to introduce smart grids, which is of great interest today in the world electrical sector [5].

In this paper, a hybrid metaheuristic approach with eagle strategy (ES) [6]-[9] and particle swarm optimization (PSO) [7] technique so called ES-PSO algorithm to minimize the operation cost of a low voltage micro grid with renewable energy source (RES) such as photovoltaic (PV), micro turbine (MT), fuel cell (FC), wind turbine (WT), and battery, while satisfying the load demand and system operating constraints [10], [11]. The cost optimization problem is developed as a nonlinearly constrained mathematical problem to optimize the generation of DGs in the micro grid.

The reminder of this paper is organized as follows. Section 2 depicts the problem formulation for the operating cost optimization problem in a low voltage micro grid. The proposed hybrid metaheuristic approach with ES and PSO are illustrated in section 3. The simulation results of proposed hybrid metaheuristic technique (ES-PSO) used to solve the cost optimization problem in micro grid is depicted in section 4. Finally, section 5 summarizes the conclusion and advantages of the proposed hybrid method in solving the micro grid optimization problems.

2. COST OPTIMIZATION PROBLEM IN MICRO GRID

The operating cost optimization problem in a low voltage micro grid is specified as a mathematical problem to schedule the optimum generation output power of DGs in micro grid and appropriate ON or OFF status of DGs to minimize the micro grid's total operation cost while meeting the power demand and other technical constraints. The numerical modeling of this problem is formulated in the following sections.

2.1 Micro Grid Operating Cost

The micro grid's total operating cost is consists of the generating cost of DG, start-down or shut-up cost of DGs and the cost of power interchanged between the main grid and micro grid, in Euro cent (€ct). The objective of total operating cost minimization is directs at determining the optimal power flow from RESs to customer loads in a financial manner for 24 hour time horizon. The minimization of total operating cost of micro grid is derived as follows [3],

$$Min\ f=\sum_{t=1}^{T}\left\{\sum_{i=1}^{N_g}\left[u_i(t)P_{Gi}(t)B_{Gi}(t)+S_{Gi}\,|\,u_i(t)-u_i(t-1)|\right]+\sum_{j=1}^{N_s}\left[u_j(t)P_{sj}(t)B_{sj}(t)+S_{sj}\,|\,u_j(t)-u_j(t-1)|\right]+P_{Grid}(t)B_{Grid}(t)\right\} \quad (1)$$

where,

P_G is the output real power of DGs;

P_S is the charging or discharging power of batteries;

P_{Grid} is the active power exchanged between the utility grid and micro grid;

B_S and B_G are the bidding cost of batteries and DGs respectively;

B_{Grid} is the bidding cost of power exchanged between the utility grid and micro grid;

S_G and S_S denote the start-down or shut-up cost of batteries and DGs respectively;

The state variable X consists of real power output of DGs and batteries, and its ON or OFF status. The state variable X is expressed as [3],

$$X=\left[P_g,U_g\right]_{1\times 2nT} \quad (2)$$
$$P_g=\left[P_G,P_S\right]$$
$$n=N_g+N_s+1$$

where, T denotes 24 hour time horizon, P_g is the real power vector consists of output real power of all DGs and charge or discharge power of batteries; N_s and N_g are the number of battery units and DGs respectively; n is number of variables in state vector X; U_g is a status vector representing ON or OFF status of DGs for 24 hour time horizon. The vectors can be expressed as [3], [12],

$$P_G=\left[P_{G1},P_{G2},\ldots,P_{G,Ng}\right] \quad (3)$$
$$P_G=\left[P_{Gi}(1),P_{Gi}(2),\ldots,P_{Gi}(t),\ldots,P_{Gi}(T)\right];\ i=1,2,\ldots,N_g+1$$
$$P_s=\left[P_{s1},P_{s2},\ldots P_{s,Ns}\right]$$
$$P_{sj}=\left[P_{sj}(1),P_{sj}(2),\ldots,P_{sj}(t),\ldots,P_{sj}(T)\right];\ j=1,2\ldots,N_s$$

where, $P_{sj}(t)$ and $P_{Gi}(t)$ are the real power output of j^{th} battery and i^{th} DG unit at time t respectively.

$$U_g=\left[u_1,u_2,\ldots,u_n\right]=\left\{u_i\right\}_{1\times n}\in\{0,1\}; \quad (4)$$
$$u_k=\left[u_k(1),u_k(2),\ldots,u_k(t),\ldots,u_k(T)\right];\ k=1,2,\ldots,n$$

where, $u_k(t)$ is ON or OFF state of k^{th} DG at time t.

3. EAGLE STRATEGY WITH PARTICLE SWARM OPTIMIZATION ALGORITHM

3.1 Standard Particle Swarm Optimization Technique (PSO)

PSO algorithm is a stochastic optimization technique created in 1995 to diagrammatically model the characteristics of a troop of birds [7].

All particles store its own coordinate points in the problem exploration space that are colligated with the best fitness solution that has been found so far and is called $Particle_{best}$, $p_i = [p_{i1}, p_{i2}, \ldots, p_{in}]$.

The position of the particle is modified by including its updated velocity to its previous positioning and the updated velocity is expressed as,

$$v_{id}^{t+1}=\omega.v_{id}^{t}+\varphi_1(p_{gd}-x_{id}^{t})+\varphi_2(p_{id}-x_{id}^{t}) \quad (5)$$

where, v_i^{t+1} will be the new particle velocity; v_i^t and x_i^t is the previous velocity and position of the particle i, respectively.

In (5), $\varphi_1=c_1r_1$ and $\varphi_2=c_2r_2$, where c_1 and c_2 are two positive acceleration components called social and cognitive components, respectively; ω represents the inertia factor; r_1 and r_2 both are random coefficients uniformly distributed in on the interval $[0,1]$; d is the index of dimension; t is iteration number.

Then, the new particle position is expressed as,

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (6)$$

The PSO technique proves to be efficient in solving problems where the search space is continuous as a result of the position and velocity of the particle being updated [7].

3.2 Pseudo Code of PSO Algorithm

The pseudo code of PSO technique to solve minimization problem is given in Algorithm 1.

<u>Algorithm 1. PSO Pseudo code</u>

FOR each particle
Randomly initialize particle
END
DO WHILE
FOR each particle
Compute the objective value using (1).
IF the present objective value is lesser than the local best objective value Particle$_{best}$.
Update the Particle$_{best}$ value with the present objective value.
END
END
Choose the particle with the best objective value of all as G$_{best}$.
FOR each particle
Estimate the velocity of the particle according to (5).
Update the position of the particles according to (6).
END
WHILE not reaching the maximum iterations or minimum error criteria.
RETURN G$_{best}$.

3.3 Eagle Strategy (ES)

Eagle strategy is a two phase scheme, created by Yang, and Deb [6]. ES is propelled from the searching conduct of eagles that are flying arbitrarily in similarity to the Levy flights. It utilizes various artificial intelligent techniques that make local and global explorations for fitting diverse purposes.

3.4 Proposed ES-PSO

Since ES is a two stage scheme, it utilizes different metaheuristic techniques at different stages. In ES based metaheuristic techniques, the search process in optimization problem can utilize randomization by means of Levy flights. With regards to AI techniques, the so-called Levy distribution [6] is a continuous probability distribution of sum of N independently and identically non-negative random variable, whose property function is expressed in Fourier transform (FT) as [6]-[9],

$$F_N(k) = e^{-N|k|^{\beta}} \quad (7)$$

The inverse transform to obtain the Levy distribution L(s) is not straight forward, the integral not having analytical form as,

$$L(s) = \frac{1}{\pi}\int_0^{\infty} cos(\tau s) e^{-\alpha\tau^{\beta}}\, d\tau \qquad (0 < \beta \le 2) \quad (8)$$

Here L(s) is called the Lévy distribution with an index β.

For the subsequent stage, PSO technique is as the intensifier local exploration. PSO is a global search technique; it can be optimized without much of a stretch to do productive local exploration by constraining new feasible solutions around a new local search areas.

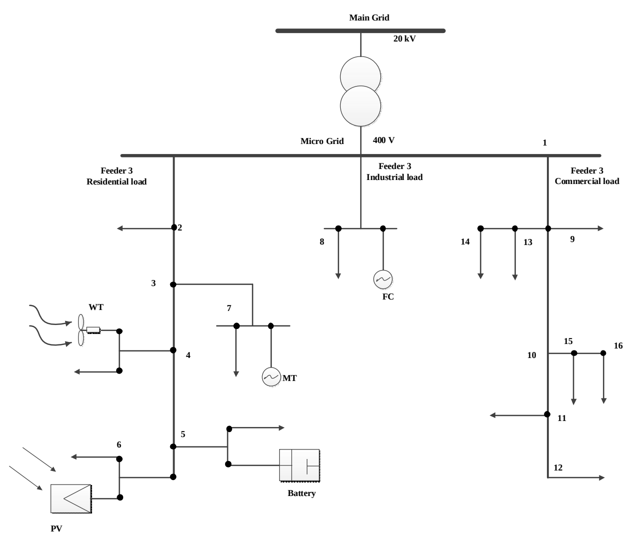

Figure 1: Low voltage micro grid

4. RESULT AND DISCUSSIONS

In this paper, the presented ES-PSO technique is employed to minimize the total operating cost of a low voltage micro grid as depicted in Figure 1 [3]. Furthermore, the problem is resolved in two different scenarios such as grid connected mode and islanded operation in order to gain better perceptive on the proposed ES-PSO technique.

4.1 Simulation Data

The forecasted market energy price for 24 hours is shown in Table 1 [3]. For scheduling of optimal set points to all DGs for both grid connected and islanded cases, all RESs are assumed to be operated for whole 24 hours i.e., status of all DGs are 1, therefore there is no start-down or shut-up cost for all DGs in these cases. The bids and limits of the DGs, BES and Grid are depicted in Table 2. The predicted power output of WT and PV are detailed in Table 3. To check the quality of the presented hybrid ES-PSO method, the simulation outcomes are compared with the existing algorithms developed in [3].

Table 1: Forecasted market price

Hour	Market price (€ct/kWh)
1	0.230
2	0.190
3	0.140
4	0.120
5	0.120
6	0.200
7	0.230
8	0.380
9	1.500
10	4.000
11	4.000
12	4.000
13	1.500
14	4.000
15	2.000
16	1.950
17	0.600
18	0.410
19	0.350
20	0.430
21	1.170
22	0.540
23	0.300
24	0.260

Table 2: The bids and limits of the DGs, BES and Grid

ID	Type	Bid (€ct/kWh)	Start-up / Shut-down (€ct)	P_{min} (kW)	P_{max} (kW)
1	MT	0.4570	0.96	6.00	30.00
2	FC	0.2940	1.65	3.00	30.00
3	PV	2.5840	0.00	0.00	25.00
4	WT	1.0730	0.00	0.00	15.00
5	BES	0.3800	0.00	-30.00	30.00
6	Grid	-	-	-30.00	30.00

4.2 Grid Connected Mode

In Table 4, all AI techniques such as GA, PSO, fuzzy self adaptive PSO (FSAPSO), adaptive modified PSO based on tent equation (AMPSO-T), adaptive modifies PSO based on logistic equation (AMPSO-L), chaotic PSO based on logistic equation (CPSO-L), chaotic PSO based on tent equation (CPSO-T), and the proposed ES-PSO are compared for 20 trails for the objective function shown in (1) [3]. For better comprehension of the ES-PSO execution, the convergence property of ES-PSO against the conventional PSO technique in minimizing the total operating cost of micro grid is depicted in Figure 2. Similarly, the optimal power generation of DGs, battery power and grid power using the proposed ES-PSO algorithm are tabulated in Table 5.

Table 3: Forecasted power output of WT and PV

Hour	PV output power (kW)	WT output power (kW)
1	0.0000	1.7855
2	0.0000	1.7855
3	0.0000	1.7855
4	0.0000	1.7855
5	0.0000	1.7855
6	0.0000	0.9142
7	0.0000	1.7855
8	0.1937	1.3017
9	3.7540	1.7855
10	7.5279	3.0854
11	10.4412	8.7724
12	11.9640	10.4133
13	23.8934	3.9228
14	21.0493	2.3766
15	7.8647	1.7855
16	4.2208	1.3017
17	0.5389	1.7855
18	0.0000	1.7855
19	0.0000	1.3017
20	0.0000	1.7855
21	0.0000	1.3017
22	0.0000	1.3017
23	0.0000	0.9142
24	0.0000	0.6124

4.3 Islanded Operation

In islanded operation, the micro grid is isolated from the main utility grid and all DGs including MT, FC, PV, WT and battery are operate to meet power demands. The convergence property of ES-PSO against the conventional PSO technique in minimizing the total operating cost of micro grid in islanded operation is depicted in Figure 3. Similarly, the optimal power generation of DGs and battery power in islanded mode using the proposed ES-PSO algorithm are tabulated in Table 6.

Table 4: Comparison results for 20 trials

Algorithm	Worst Solution (€ct/day)	Average (€ct/day)	Best Solution (€ct/day)	SD
GA	304.5889	290.4321	277.7444	13.4421
PSO	303.3791	288.8761	277.3237	10.1821
FSAPSO	291.7562	280.6844	276.7867	8.3301
CPSO-T	286.5409	277.4045	275.0455	6.2341
CPSO-L	281.1187	276.3327	274.7438	5.9697
AMPSO-T	275.0905	274.9821	274.5507	0.321
AMPSO-L	274.7318	274.5643	274.4317	0.0921
ES-PSO	**274.1995**	**273.9292**	**273.8766**	**0.084**

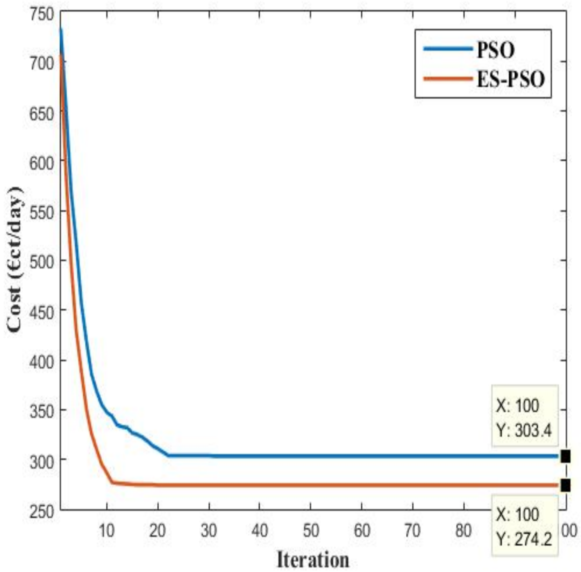

Figure 2: Convergence property – Grid connected mode

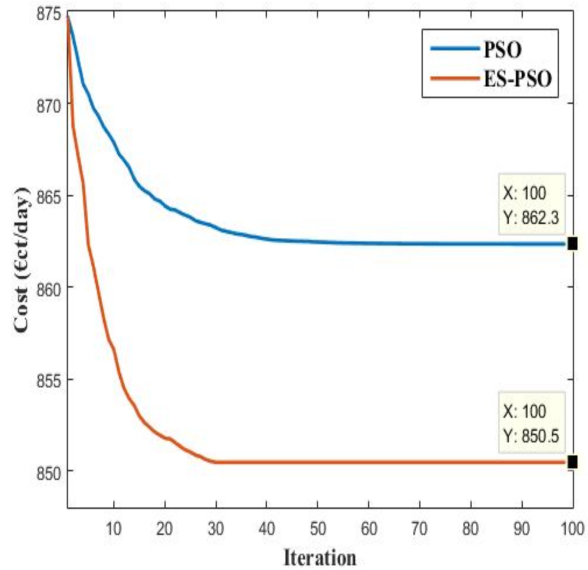

Figure 3: Convergence property – Islanded operation

Table 5: Optimal power output of DGs, battery and grid

T (h)	P_L (kW)	DG units, Battery and Grid - Output Power (kW)					
		MT	FC	WT	PV	Battery	Grid
1	52.000	6.0000	30.000	1.7855	0.0000	-15.785	30.0000
2	50.000	6.0000	30.000	1.7855	0.0000	-17.785	30.0000
3	50.000	6.0000	30.000	1.7855	0.0000	-17.785	30.0000
4	51.000	10.653	30.000	1.7855	0.0000	-21.439	30.0000
5	56.000	6.0000	30.000	1.7855	0.0000	-11.785	30.0000
6	63.000	17.648	29.999	0.9142	0.0000	-15.562	30.0000
7	70.000	14.949	24.919	1.7855	0.0000	-1.6540	30.0000
8	75.000	6.0000	30.000	1.3017	0.1937	13.4549	24.0497
9	76.000	30.000	30.000	1.7855	3.7540	30.0000	-19.5395
10	80.000	30.000	30.000	3.0854	7.5279	30.0000	-20.6133
11	78.000	28.786	30.000	8.7724	10.441	30.0000	-30.0000
12	74.000	21.622	30.000	10.413	11.964	30.0000	-30.0000
13	72.000	14.183	30.000	3.9228	23.893	30.0000	-30.0000
14	72.000	21.335	29.998	2.3766	21.049	27.2403	-30.0000
15	76.000	30.000	30.000	1.7855	7.8647	30.0000	-23.6502
16	80.000	30.000	30.000	1.3017	4.2208	30.0000	-15.5225
17	85.000	30.000	30.000	1.7855	0.5389	30.0000	-7.3244
18	88.000	12.706	30.000	1.7855	0.0000	30.0000	13.5079
19	90.000	6.0000	30.000	1.3017	0.0000	22.6983	30.0000
20	87.000	20.673	30.000	1.7855	0.0000	30.0000	4.5406
21	78.000	30.000	30.000	1.3017	0.0000	30.0000	-13.3017
22	71.000	30.000	30.000	1.3017	0.0000	30.0000	-20.3017
23	65.000	6.0000	30.000	0.9142	0.0000	-1.9143	30.0000
24	56.000	16.869	30.000	0.6124	0.0000	-21.481	30.0000

Table 6: Optimal power output of DGs and battery

T (h)	PL (kW)	DG units and Battery - Output Power (kW)				
		MT	**FC**	**WT**	**PV**	**Battery**
1	52.000	8.825	30.000	1.786	0.000	11.390
2	50.000	6.000	30.000	1.786	0.000	12.215
3	50.000	10.263	30.000	1.786	0.000	7.951
4	51.000	6.000	30.000	1.786	0.000	13.214
5	56.000	8.856	30.000	1.786	0.000	15.359
6	63.000	6.148	30.000	0.914	0.000	25.938
7	70.000	11.692	30.000	1.786	0.000	26.523
8	75.000	16.061	30.000	1.302	0.194	27.443
9	76.000	14.723	29.994	1.786	3.754	25.743
10	80.000	22.295	29.999	3.085	7.528	17.093
11	78.000	15.507	29.999	8.772	10.441	13.280
12	74.000	18.088	30.000	10.413	11.964	3.535
13	72.000	7.736	30.000	3.923	23.893	6.448
14	72.000	10.812	30.000	2.377	21.049	7.762
15	76.000	8.807	30.000	1.786	7.865	27.543
16	80.000	18.355	29.997	1.302	4.221	26.126
17	85.000	22.676	30.000	1.786	0.539	30.000
18	88.000	26.215	30.000	1.786	0.000	30.000
19	90.000	28.698	30.000	1.302	0.000	30.000
20	87.000	25.215	30.000	1.786	0.000	30.000
21	78.000	16.698	30.000	1.302	0.000	30.000
22	71.000	15.815	30.000	1.302	0.000	23.883
23	65.000	20.603	30.000	0.914	0.000	13.483
24	56.000	6.000	30.000	0.612	0.000	19.388

5. CONCLUSION

In this paper, hybrid metaheuristic approach with eagle strategy (ES) and particle swarm optimization (PSO) technique has been presented to minimize the operation cost of a low voltage micro grid with renewable energy source (RES) such as photovoltaic (PV), fuel cell (FC), micro turbine (MT), wind turbine (WT), and battery, while satisfying the load demand and system operating constraints. The presented hybrid approach has been analyzed on a typical micro grid and its better execution property has been compared with PSO, GA, AMSPO and CPSO. The simulation results indicated that the proposed hybrid ES-PSO technique has a superior performance in solving the micro grid optimization problems and also it has fast convergence properties when compared to other metaheuristic techniques.

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