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Hybrid Optimization Technique for Solving Economic Dispatch Problem: A Case Study of Nigerian Thermal Power System

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Abstract

Economic Dispatch Problem (EDP) is a power system optimization problem that is required to be solved accurately using an efficient optimization technique. Hybrid optimization solutions have provided better optimum results than either deterministic or non-deterministic optimization methods. The hybridization of both Particle Swarm Optimization (PSO) and Bat Algorithm (BA) to for Hybrid Particle Swarm Bat Algorithm (H-PS-BA) optimization technique for solving EDP of Nigerian 21 thermal generating station power system was carried out in this work. The result of the work revealed that H-PS-BA performed better and gave the best optimal generation costs when compared to other methods such as PSO, Interior Point Method and BA.

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1. Introduction

Fossil fuels are still largely depended upon for generating bulk electrical energy. The consumptions of these fuels are expected to be minimized because of their limited availability. Power generation are therefore dispatched based on the cost of generation aimed at reducing overall cost of generation since the cost of fuels have kept increasing [1]. Economic Dispatch (ED) is the process that determines the optimal coalition of outputs of participating generating

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units with the intention of minimizing the total fuel cost in a power system while load demands and other system constraints are satisfied [2]. ED is important due to scarce in generation resources, increase in generation costs and electrical energy demands [3].

The ED is an optimization problem termed Economic Dispatch Problem (EDP). Deterministic optimization techniques, such as Gradient and Lambda-Iteration methods, were the early traditional optimization methods used to solve EDP. These methods approximated costs as a quadratic function for generating units [4]. Deterministic methods failed to solve the problems accurately because the approximated cost function neglected the non-smooth, nonconvex and nonlinear characteristics of modern generating units [5]. Dynamic programming was later applied to solve EDP and the method was able to generate global solution for discrete and nonlinear cost functions of generating units because it placed no restrictions on the cost curve nature. However, the method has the limitation of 'curse of dimensionality' which becomes worse for large scale power systems resulting to high computational time [6, 7].

Optimization techniques such as Differential Evolution (DE), Particle Swarm Optimization (PSO), Bat Algorithm (BA), Genetic Algorithm (GA), Firefly Algorithm (FA), among others, are non-deterministic optimization techniques applied to solve EDP. These methods require little computational time and do not depend on assumption of convexity. The methods are fast and produce near global optimal solutions but global best solutions are not guaranteed [7].

The most successful trend in optimization, hybrid optimization, was brought about by the realization of the fact that no optimization method is perfect. Hybrid optimization combines two or more optimization methods with the aim of using the wealth of one method to conquer the limitations of the other methods [8]. Hybrid methods guarantee solutions with high quality, stable convergence and less computational time compared to separate techniques [9].

The PSO is a popular and successful non-deterministic optimization technique which is robust, simple and easy to implement but with the limitation of premature convergence and getting trapped at local optimum [10]. BA on the other hand, is a more effective method in exploiting global best for finding the possible best solution and it has the ability to escape being trapped at local optimum [11]. The detailed development of PSO and BA optimization algorithms can be obtained in Refs. [12, 13] respectively.

The PSO and BA combination to form a Hybrid Particle Swarm Bat Algorithm (H-PS-BA) optimization technique for solving the EDP of Nigerian Power System was carried out in this work. The EDP solutions of Nigerian power system have been carried out extensively using optimization methods such as GA, PSO, DE, FA, and Lambda-Iteration methods [14]. This research work bridges the gap of applying hybrid optimization technique to solve EDP of Nigerian power system which has not been reportedly applied.

2. Methodology

2.1. Economic Dispatch Problem

The EDP objective is minimization of total cost of generation while satisfying various operating conditions. The EDP finds real power generation for every generator in such a manner that the objective function, the total generation cost, as derived [15, 16] is

$$\min \mathrm{F}_{\mathrm{cost}} = \sum_{i=1}^{N_g} F_i(P_i). \tag{1}$$

The cost of operation when each generator generates a specific output is modelled as:

$$F_i\,(P_i) = a_i + b_i P_i + c_i\,P_i^2\,. \tag{2}$$

Equation (1) is then written as:

$$\mathrm{F_i}(P_i) = \sum_{i=1}^{\mathrm{N}_g} a_i + b_i P_i + c_i\,P_i^2, \tag{3}$$

where;

$a_i,\ b_i,\ c_i$ = i^{th} generating unit cost coefficient.

$\mathrm{F_i(P_i)}$ = ith generating unit cost function (in dollars/hour)

$\mathrm{P_i}$= i^{th} generating unit real power output (in MW)

$\mathrm{N_g}$ = total number of generators in the system.

The generating constraints are:

1. System Equality Constraints
   This is given by the following Eq. 4:

$$\sum_{i=1}^{N_g} P_i = P_D + P_{LOSS}, \tag{4}$$

   where;
   P_D = system total power demand.
   The transmission line loss equation is given as:

$$P_{Loss} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i B_{ij} P_j. \tag{5}$$

   The general loss formula that contains a linear term and a constant term known as Kron's Loss formula is given as [17];

$$P_{Loss} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i B_{ij} P_j + \sum_{i=1}^{N_g} B_{oi} + B_{oo}, \tag{6}$$

   where;
   B_{ij} =ith element of loss coefficient square matrix,
   B_{0i} = ith element of the loss coefficient vector,
   B_{00} =loss coefficient constant.
2. System Inequality Constraints
   The limits put on system components and operations are the system inequality constraints. The most important one is the power generation limits given as:

$$P_i^{min} \le P_i \le P_i^{max} \; i = 1, 2, ...Ng, \tag{7}$$

   where;
   P_i^{min}= minimum power limit,
   P_i^{max}= maximum power limit.

2.2. *Hybrid PSO-BAT Optimization Technique*

An embedded type hybrid optimization method, H-PS-BA was formulated and modeled to solve EDP of power systems. The H-PS-BA increased the diversity and avoid premature convergence of PSO by enhancing its ability for local search using the frequency tunning technique of BA at the velocity update stage of PSO. Each microbat, in the original BA, sends out a pulse with a frequency value, f_{min}, and variable wavelength as represented in equation (8).

$$f_i = f_{min} + \beta_i (f_{max} - f_{min}), \tag{8}$$

where;
f_{min}= minimum frequency of emitted pulse,
f_{max}= maximum frequency of emitted pulse,
β_i = a uniformly distributed random number in the range [0, 1],
f_i =frequency of the ith bath.

In the H-PS-BA, two different pulses were assumed to be sent out by each bat in two separate directions, one towards the best bat (solution) and the other towards a randomly chosen bat. The frequencies of these introduced pulses were updated as equations (9) and (10) respectively in the direction of bat and in the direction of random bat.

$$f_{i1} = f_{min} + (f_{max} - f_{min}) * \beta_{i1}. \tag{9}$$

$$f_{i2} = f_{min} + (f_{max} - f_{min}) * \beta_{i2}, \tag{10}$$

where;
f_{i1} = emission in the direction of best bat,

f_{i2} = emission in the direction of random bat,
f_{min} = minimum frequency,
f_{max} = maximum frequency,
β_{i1} and β_{i2} = random vectors between 0 and 1.

The velocity and position update equations of PSO is given in equation (11) and (12) respectively:

$$V_{in}^{j+1} = w\, v_{in}^{j} + c_1 r_1 \left(pbest_{in}^{j} - x_{in}^{j}\right) + c_2 r_2 \left(gbest_{n}^{j} - x_{in}^{j}\right). \tag{11}$$

$$x_{in}^{j+1} = x_{in}^{j} + V_{in}^{j+1}, \tag{12}$$

where;
v_{in}^{j+1} = i^{th} particle updated velocity in n-dimensional space,
w = inertial weight factor,
v_{in}^{j} = i^{th} particle velocity at jth iteration,
c_1, c_2 = acceleration coefficients,
r_1, r_2 =random numbers [0,1],
x_{in}^{j+1} = i^{th} particle updated position in n-dimensional space,
x_{in}^{j} = i^{th} particle position at iteration j.

Equation (11) is modified by introducing the cartesian distance between the bat position and local best position into the cognitive component of the equation and the cartesian distance between the best position and global position into the social component of the equation. The new velocity equation is given by equation (13).

$$V_i^{k+1} = w * V_i^k + \left(c_1 * \exp\left(-PBEST_i^2\right) * \left(pbest_i^k - x_i^k\right)\right) + \left(c2 * \exp\left(GBEST^2\right) * \left(gbest^k - x_i^k\right)\right). \tag{13}$$

Equation (12) ensures the removal of randomness in the velocity update and local and global bests were allowed to guide velocity and position updates. The H-PS-BA was finally developed by associating the pulse frequency of BA with the velocity update equation of PSO as given by equation (13) thereby ensuring the PSO ability to evade being trapped at local optimum.

$$V_i^{k+1} = w * V_i^k + \left(c_1 * \exp\left(-PBEST_i^2\right) * \left(pbest_i^k - x_i^k\right)\right) * f_{i1} + \left(c2 * \exp\left(GBEST^2\right) * \left(gbest^k - x_i^k\right)\right) * f_{i2}. \tag{14}$$

The H-PS-BA optimization solution algorithm for EDP of power systems is as follows:

Step 1: Initialize PSO parameters. Read power system data. The EDP dimension is the number of participating generators. The particles are generated between P_{max} and P_{min} haphazardly. The ith particle, for N number of units is represented as:

$$P_i = \left[P_{i1}, P_{i2}, P_{i3}, ..., P_{iNg}\right]. \tag{15}$$

Step 2: Generate initial velocities of the particles randomly in the following range:

$$[-V_i^{\max}, V_i^{\max}]. \tag{16}$$

Step 3: The objective function values of the particles are evaluated using EDP objective function. These evaluated values are set as the P_{best}.

Step 4: Choose the best value among the P_{best} as the G_{best}.

Step 5: The new velocities for all the dimensions in each particle are calculated using the hybridized velocity updating equations.

Step 6: Check the constraints violations for the minimum and maximum values of the velocities.

if

$$v_i^{new} > v_i^{\max}. \tag{17}$$

$$v_i^{new} = v_i^{\max}. \tag{18}$$

and if

$$v_i^{new} < v_i^{\min}. \tag{19}$$

$$v_i^{new} = v_i^{\min} . \tag{20}$$

Step 7: The position of the generators in the particles is updated using the following Equation:

$$P_i^{new} = P_i + V_i^{new} . \tag{21}$$

Step 8: The objective function values are determined for the updated positions of the particles. If the new value is better than the previous P_{best}, the new value is set to P_{best}.
Step 9: Update G_{best} of the population.
Step 10: Repeat Step 4 to Step 10 until the maximum number of iterations

3. Result and Discussions

H-PS-BA optimization technique was developed to solve the EDP of Nigerian 21 thermal generators of the power system. The generators cost coefficients and the limits are shown in Table 1. The H-PS-BA algorithm was implemented using MatLab 2018a on an Intel Core i5 HP laptop computer with a RAM of 4GB and a speed of 1.90 GHz. The solution to the EDP of this Nigeria power system considered the system transmission loss and both the equality and inequality constraints of the system. The results obtained were compared with results obtained from other works using the same data set and system equality and inequality constraints. Table 2 shows the results of EDP solution using the H-PS-BA optimization technique for load demands of 2500 MW and 3500 MW respectively. The table also shows the results of EDP of the system from literate using IPM, PSO and BA optimization techniques obtained from [18, 19, 20] respectively.

Table 1. Limits and Cost Coefficients of Nigerian 21 Thermal Generators [19].

S/No.	Name of Station	a	b	c	P_{min} (MW)	Pmax (MW)
1	Egbin ST (Gas)	0.0000109	0.0284	3.92	118	1100
2	Sapele ST	0.0000591	0.0226	8.10	33	223
3	Delta II-III	0.0000757	0.0326	6.47	10	110
4	Delat IV	0.0000743	0.0334	9.85	22	434
5	Geregu	0.000201	0.0313	1.25	14	450
6	Omotosho	0.0000514	0.0312	4.70	29	480
7	Olorunsogo	0.0000294	0.0313	2.80	10	293
8	Afam IV-V	0.0000384	0.0289	2.03	24	453
9	Sapele GT NIPP	0.0000105	0.0227	5.60	30	373
10	Alaoji NIPP	0.0000200	0.0332	3.00	34	87
11	Geregu NIPP	0.0000223	0.0314	1.00	94	272
12	Olorunsogo NIPP	0.0000287	0.0313	1.70	31	422
13	Omotosho NIPP	0.0000179	0.0313	2.64	20	225
14	Ihovbe NIPP	0.0000200	0.0294	1.00	91	120
15	Okpai	0.0000126	0.0286	4.53	100	475
16	Afam VI	0.0000115	0.0286	8.00	45	656
17	AES	0.0000133	0.0286	4.30	51	242
18	Omoku	0.0000442	0.0314	1.30	3	65
19	Ibom	0.0000189	0.0312	4.60	10	101
20	Trans Amadi	0.0000315	0.0311	1.00	4	31
21	Rivers IPP	0.0000215	0.0318	6.00	20	160

The optimal distributions of the total load demands and the system losses among the twenty-one participating generators are shown for different optimization techniques. The total costs of generation for 2500 MW load demand on the system are 81.8411 ₦/h, 83.8384 ₦/h, 163.3070 ₦/h and 170.8845 ₦/h for H-PS-BA, PSO, IPM and BA optimization techniques respectively. The result showed that H-PS-BA optimization technique performed better than PSO, IPM and BA optimization techniques by 2.38%, 49.89% and 52.11% respectively. It can be observed that H-PS-BA optimization technique produced the least total cost of generation and hence the best total generation cost

Table 2. Results of EDP Solutions.

S/No.	Power Station	Loads on Power System (MW)							
		H-PS-BA		PSO		IPM		BAT	
		2500	3500	2500	3500	2500	3500	2500	3500
1	Egbin ST (Gas)	118.00	797.80	118.00	387.53	369.03	501.26	496.53	605.55
2	Sapele ST	33.00	33.00	33.00	33.00	109.14	139.91	34.98	185.88
3	Delta II-III	110.00	10.00	110.00	20.30	18.84	44.12	10.00	98.91
4	Delat IV	22.00	81.62	22.00	434.00	22.43	39.12	22.00	84.17
5	Geregu	14.00	296.10	385.17	328.47	108.12	199.79	191.27	360.24
6	Omotosho	166.86	335.51	67.34	100.93	40.01	76.69	320.84	181.14
7	Olorunsogo	10.00	293.00	206.36	129.43	72.27	134.12	10.06	232.20
8	Afam IV-V	156.64	49.32	84.64	116.62	38.82	61.82	24.00	156.30
9	Sapele GT NIPP	166.00	373.00	30.00	39.52	372.82	372.98	101.87	140.67
10	Alaoji NIPP	87.00	81.94	55.81	42.81	50.43	86.94	34.00	44.40
11	Geregu NIPP	252.51	272.00	94.00	94.00	97.34	171.25	94.00	136.93
12	Olorunsogo NIPP	111.11	73.62	31.00	413.10	66.93	135.21	31.02	418.43
13	Omotosho NIPP	203.32	20.00	20.00	171.65	118.89	207.96	183.65	194.21
14	Ihovbe NIPP	119.63	120.00	91.43	108.10	119.65	119.97	92.14	93.23
15	Okpai	475.00	100.00	475.00	475.00	116.47	163.95	128.10	113.47
16	Afam VI	45.00	297.43	563.65	280.72	281.17	462.63	480.91	74.85
17	AES	242.00	56.12	51.00	51.00	241.44	241.96	193.03	171.65
18	Omoku	3.00	26.47	3.00	65.00	44.58	64.92	3.00	8.73
19	Ibom	101.00	10.00	48.00	67.80	100.55	100.96	24.61	53.38
20	Trans Amadi	31.00	11.86	4.09	4.55	30.70	30.97	4.00	8.65
21	Rivers IPP	48.44	160.00	20.00	154.31	100.17	159.68	20.00	137.12
Total Power Generated (MW)		2513.07	3518.17	2513.45	3517.54	2519.80	3516.20	2511.74	3513.67
Total Cost (₦/h)		81.8411	118.0722	83.8384	132.4931	163.3070	200.6663	170.8845	210.8092
Power Loss (MW)		15.07	18.17	13.45	17.54	19.80	16.21	11.74	13.67

compared to other mentioned method. It is also revealed that H-PS-BA method produced total system transmission loss with a value of 15.07 MW for 2500 MW power demand when PSO gave a system loss of 13.45 MW and IPM gave a system loss of 19.80 MW.

The total costs of generation obtained were 118.0722 ₦/h, 132.4931 ₦/h, 200.6663 ₦/h, and 210.8092 ₦/h for H-PS-BA, PSO, IPM and BA optimization techniques respectively when the total system load considered is 3500 MW. The result showed that H-PS-BA optimization technique performed better than PSO, IPM and BA optimization techniques by 10.88%, 41.16% and 77.92% respectively. The system losses obtained were 18.17 MW, 17.54 MW and 16.21 MW for H-PS-BA, PSO and IPM respectively. It can be observed that H-PS-BA produced the least optimal cost of generation compared to the other methods and it also gave the highest transmission loss.

4. Conclusion

A hybrid optimization technique, H-PS-BA, was developed and applied to solve the EDP of Nigerian 21 thermal generators power system. The H-PS-BA overcame the problem of PSO getting trapped at local optimum by using the frequency tunning technique of BA at the velocity update stage of PSO. This was achieved using the frequency tunning of BA to enhance PSO local search ability. Results of the application suggested that H-PS-BA performed better than other optimization approaches such as PSO, IPM and BA, it was compared with, by providing the best optimum total cost of generation. It can be concluded that H-PS-BA is a better optimization tool for solving EDP of power systems.

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