

Economic And Emission Load Dispatch for The Nigerian Power System Using Improved Firefly Algorithm

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Abstract- It is of paramount importance for a power system comprising of many generating units to operate under an economic platform. However, effects of generation on the environment should also be considered alongside the cost of generation. This paper employs the improved firefly algorithm to solve the economic and emission load dispatch problem for the Nigerian power system. Valve-point loading effects are considered. The two objectives are combined to form one objective function with the use of weighting factors. The price penalty factor is applied on the emission function to ensure homogeneity of the objective function. Different values of weighting factors are applied to obtain the best. Comparison analysis is carried out between results obtained and other metaheuristic techniques; Genetic algorithm (GA), Particle Swarm Optimization (PSO) and conventional Firefly Algorithm (FA). From the simulations, it is observed that the improved firefly algorithm produces the best compromise between fuel cost and emission quantities.

Indexed Terms- Load dispatch, Firefly Algorithm, Price Penalty Factor, Generation

I. INTRODUCTION

Electrical energy is of paramount importance to every growing economy and the size of electrical power systems is increasing to meet the rapid increase in demand. But the rate of increase of the generating facilities is less than the rate of increase in power demand. Hence, it is necessary to operate the power system on an economic platform, to save cost of operation. This can be done through the application of Economic Load Dispatch (ELD) techniques. The ELD is a very important aspect of the power system. The purpose of the economic load dispatch is to determine the generation of various units in a plant such that the

total fuel cost is minimum and at the same time, the total demand and losses at any instance must be equal to the total generation. The common task in power system is to determine and provide an economic condition for generating units without violation of any of the system's constraints.

On the other hand, there are serious environmental concerns arising due to the pollution caused by toxic gases released from thermal units after combustion of fuel. Global warming which has been on the rise for decades is one of those negative effect caused by the emission of greenhouse gases (GHG) into the atmosphere. Greenhouse gases are those gases that allow the sun's energy to reach the earth's surface but prevent this heat from leaving the earth's surface thus leading to an increase in the earth's temperature and change in weather patterns. Some of these by-products of combustion include, Carbon dioxide (CO₂), Nitrogen oxides (NO_x), Sulphur dioxide (SO₂) and Particulate matter (PM).

With rapid increase in technological advancement, managing these dispatch problems simultaneously has been made possible. With the application of modern optimization techniques, the combined economic and emission load dispatch problem can be solved wherein the algorithm analyses the two aspects of the objective function and gives the dispatcher the best compromise.

II. RELATED WORK

In [1], the combined economic emission dispatch with Environment Based Demand Response using WU-ABC algorithm was carried out. The objective function was constructed in consideration of generation costs and pollutant emission. The emission function took the emitted quantities into account and converts their sum into operation costs through unit conversion, using a penalty factor. A multi-objective

algorithm called Broyden Fletcher Goldfarb Shanno based on Augmented Lagrangian (BFGS-AL) algorithm was applied to solve the economic and environmental load dispatch problem in [2]. The IEEE-30 bus test system was used to test the algorithm. The transmission line losses were considered in the optimization process but valve point loading effects were neglected. [3]. performed a simultaneous multi-area economic-environmental load dispatch modelling with thermal and wind turbines using Multi-Objective Particle Swarm Optimization. It was established that the unpredictable nature of wind generations makes the generation dispatch process highly complex. Thus, in the developed method, the storage and additional costs were defined in the objective function of the economic dispatch problem and the mean value of wind energy density was utilized. Transmission losses, generation limits and line carrying capacity were considered as constraints. A twelve-unit thermal power plant, two wind farms and three areas were considered and the efficiency of the proposed method was evaluated based on the simulation results on the IEEE 118 test bus system. The Biogeography Based Optimization (BBO) technique was proposed in [4]. to minimize fuel cost and emissions from thermal generating units. The results obtained by BBO were compared with the results obtained by different optimization techniques such as GA, PSO, EP and DE with respect to fuel cost, solution time and convergence criteria. [5]. presented an elitist technique, the second version of the non-dominated sorting genetic algorithm (NSAGII) to solve the DEED problem. Constraints considered were; valve point loading effect, ramp rate limits and prohibited zones. A fuzzy based membership function value assignment method was suggested to provide the best compromise solution. A ten-unit system was used to verify the effectiveness of the proposed approach. [6] presented an emission inventory of electricity generation from thermal plants in Nigeria. An emission factor approach was used in this study to quantify the emission of uncontrolled air pollutant discharged into the atmosphere from all existing thermal plants. The pollutants examined were carbon monoxides (CO), oxides of Nitrogen (NO_x), particulate matter, Sulphur dioxide (SO₂) and volatile organic compounds (VOCs). From the specific data, the study discovered that, the higher the production capacity, the higher the emission emitted.

III. ECONOMIC AND EMISSION LOAD DISPATCH

a. Economic Model

The economic dispatch (ED) problem is represented as a non-linear expression with valve-loading effects and is subject to equality constraints of power balance and inequality constraints of plant upper and lower bounds.

Minimize

$$F(P_{Gi}) = \sum_{i=1}^{NG} (a_i + b_i(P_{Gi}) + c_i(P_{Gi})^2) + |d_i * \sin(f_{s1}(P_{Gi}^{min} - P_{Gi}))| \quad \dots (1)$$

Subject to:

$$\sum_{i=1}^{NG} (P_{Gi}) = P_D + P_L \quad \dots (2)$$

Where

$$P_L = B_{00} + \sum_{i=1}^{NG} B_{0i}(P_{Gi}) + \sum_{i=1}^{NG} (P_{Gi}) (B_{ij}) (P_{Gj}) \quad \dots (3)$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad \dots (4)$$

Where NG is the number of thermal generating units, F(P_{Gi}) is the total fuel cost, P_{Gi} is the real power output of unit i, a_i, b_i, c_i, e_i f_i are the fuel cost coefficients. P_D is the total demand; P_L is the transmission line losses. P_{Gi}^{Min} and P_{Gi}^{Max} are the lower and upper bounds of the ith unit respectively. The first constraint (2) which is called power balance constraint is an equality constraint and while the second constraint (4) is the inequality constraint denoting the thermal unit's operational limits.

b. Emission model

The emissions released by the thermal generating plants as a result of the combustion of fossil fuel to the environment to be considered in this paper are CO₂, SO₂, NO_x and PM. And they have very adverse effects on the ecosystem. It is also worth noting that the quantity of emission produced depends on; the type of fuel used, control devices installed, age of machines and amount of electricity generated.

$$E_{Gi} = \sum_{i=1}^{NG} (\alpha_i + \beta_i(P_{Gi}) + \gamma_i(P_{Gi})^2) + \lambda_i * \exp(\delta_i P_{Gi}) \quad \dots (5)$$

E(P_{Gi}) is the quantity of emissions produced in Kg/hr, while α, β, γ, ξ, λ, δ are the emission coefficients.

a. Combined economic and emission model

The price penalty factor h_i , is integrated for the various emissions accounted for in this work so as to come up with a single and homogenous objective function. The weighting factor (w) is also introduced in the objective function. The weighting factor defines the relative importance of one component of the objective function with respect to the other. It is dimensionless and ranges from 0-1.

$$F_{Ti}(P_{Gi}) = wF(P_{Gi}) + (1 - w)h_i * E(P_{Gi}) \quad \dots (6)$$

Where F_{Ti} is the total cost in N/hr, h_i is the price penalty factor in N/kg to ensure homogeneity of the objective function.

b. Price penalty factors

The price penalty factor is formulated by taking the ratio of the fuel cost and the emission value in the corresponding generators and is given as follow;

$$h_i = \frac{F(P_{Gi})}{E(P_{Gi})} \quad \dots (7)$$

Four different price penalty factors are considered in this paper

i. The Max-Max Price Penalty Factor

$$h_i = \frac{F(P_{Gi})^{Max}}{E(P_{Gi})^{Max}} \quad \dots (8)$$

ii. The Max-Min Price Penalty Factor

$$h_i = \frac{F(P_{Gi})^{Max}}{E(P_{Gi})^{Min}} \quad \dots (9)$$

iii. The Min-Max Price Penalty Factor

$$h_i = \frac{F(P_{Gi})^{Min}}{E(P_{Gi})^{Max}} \quad \dots (10)$$

iv. The Min-Min Price Penalty Factor

$$h_i = \frac{F(P_{Gi})^{Min}}{E(P_{Gi})^{Min}} \quad \dots (11)$$

IV. METHODOLOGY

The metaheuristic algorithm considered in this work is the Improved Firefly Algorithm (IFA) which developed by modifying the traditional Firefly Algorithm formulated by Yang Xhe-She in 2008. The fundamental principles on the traditional firefly was formulated are;

- i. All fireflies are unisex and they move towards more attractive and brighter ones regardless of their sex.
- ii. The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a

brighter or more attractive firefly than a particular one, it will then move randomly.

- iii. The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. The fireflies with lower brightness level moves to other ones with higher brightness level.

Each firefly corresponding to each optimal solution will own its brightness corresponding to the fitness function of the optimal solution. The action that the fireflies with lesser brightness will look for and get to other fireflies producing higher brightness level is similar to the newly produced solutions based on old solutions, with a better fitness function. Consequently, in firefly algorithm, each old solution can be produced several times depending on the comparison of its brightness with other ones. As a result, only one new solution of each old solution is kept based on the comparison of fitness function.

a. Distance

In calculating the distance between the considered solution i and another better solution to determine the radius, the best solution X_{Gbest} is recommended for calculating the radius as expressed below.

$$r_{ibest} = \sqrt{(X_i - X_{Gbest})^2} \quad \dots (12)$$

b. Attractiveness

The updated distance is employed to be substituted in another equation to determine the new attractiveness. Then the new position for the i^{th} considered firefly can be determined corresponding to the generation of a new solution of the i^{th} solution. The procedure of generating a new solution is carried out as;

$$\beta_r = \beta_0 * \text{Exp}(-\gamma r_{ij}^2) \quad \dots (13)$$

Where, r is the distance between any two fireflies, β_0 is the initial attractiveness at $r=0$, and γ is an absorption coefficient which controls the decrease of the light intensity.

c. Updated step size

The expression below used to generate the updated step size and obtain lower solution fitness than those of firefly algorithm.

$$\Delta X_{1ij} = X_{Gbest} - X_{GWorst} \quad \dots (14)$$

$$\Delta X_{2ij} = X_j - X_i + X_{r1} + X_{r2} \quad \dots (15)$$

The first updated step size ΔX_{1ij} is less than the second step size ΔX_{2ij} . The first facilitate exploitation by narrowing the search zone near old solutions while the second can expand exploitation (exploration) to avoid falling into the same solution.

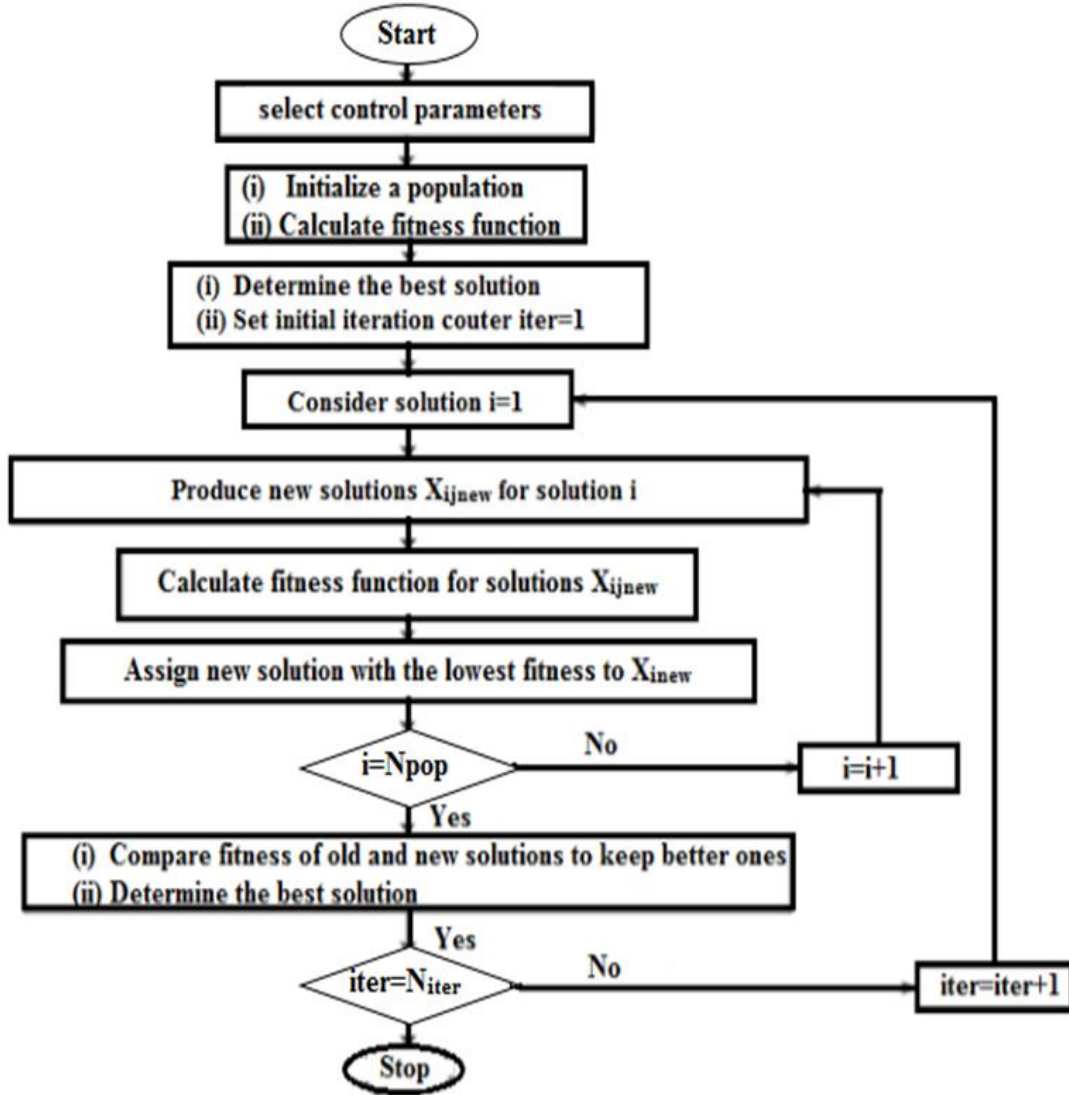
d. Movement

The movement of a firefly i which is attracted by a more attractive (brighter) firefly j is given by the following equation. A normal distribution is used

instead of the uniform distribution to calculate the new position of the firefly in order to diversify the search zone.

$$X_{i+1} = X_i + \beta_0 * \text{Exp}(-\gamma r_{ij}^2) * (X_{Gbest} - X_i) + \alpha * (\text{rand} - \frac{1}{2}) \dots (10)$$

Figure 1 below is a pictorial representation of the improved firefly algorithm.



Source: Thang *et al.* (2018)

Figure 1: Flow chart of improved firefly algorithm

V. RESULTS

Table 1: Price Penalty Factor

S/N	Price penalty Factors	Output (MW)
1	Max-Max	2,691.3

2	Max-Min	2,632.0
3	Min-Max	2,619.4
4	Min-Min	2,658.0

Table 2: Allocations for different weighting factors at 2500MW

S/N	Station	Economic load dispatch ($\omega=1$)	Emission load dispatch ($\omega=0$)	Economic and emission load dispatch ($\omega=0.5$)
1	Aes	177.4065	71.5626	129.8278
2	Afam IV	258.1022	245.3162	183.3824
3	Egbin	125.3582	303.7513	207.4987
4	Trans-amadi	26.7065	8.4995	25.5607
5	Afam IV-V	94.6528	67.1295	238.6688
6	Alaoji	75.9200	38.9051	66.3851
7	Delta II-III	59.3777	105.4157	69.6705
8	Delta V	128.6891	208.8580	24.7536
9	Geregu Nipp	122.1612	141.9726	123.4706
10	Geregu	436.7304	94.1582	178.0919
11	Ibom	94.8273	63.8323	48.5313
12	Ihovbe Nipp	111.3352	104.2751	99.5892
13	Okapi	329.7748	469.1502	263.2501
14	Olorunsogo	12.3263	11.0114	116.5018
15	Omoku	28.2853	16.9417	52.3552
16	Omotosho Nipp	67.7819	39.8051	184.7741
17	Omotosho	30.1313	164.6205	166.6340
18	Rivers ipp	146.1202	125.4725	103.2351
19	Sapelle st	36.2059	34.0823	135.4553
20	Sapelle gt	189.8729	201.5683	35.6168
21	Olorunsogo Nipp	31.0035	94.0427	113.0447
	Fuel cost (N/hr)	3,596,200	3,835,000	3,791,000
	CO ₂ (Kg/hr)	120,480.0	114,930.0	117,960.0
	NO _x (Kg/hr)	293.7548	280.2163	287.7033
	SO ₂ (Kg/hr)	21.6968	20.6968	21.2416
	PM (Kg/hr)	14.0275	13.381	13.7333

Table 3: Optimal Allocation for 4000MW, 5000MW and 6000MW

S/N	POWER STATION	4000MW	5000MW	6000MW	P _{min} (MW)	P _{max} (MW)
1	AES	113.6603	79.6189	242	51	242
2	AFAM IV	361.6687	607.9682	656	45	656
3	EGBIN ST(GAS)	739.1405	742.3478	1100	118	1100
4	TRANS AMADI	27.6949	12.5828	19.7	4	31
5	AFAM IV-V	288.4527	381.4889	453	24	453
6	ALAOJI NIPP	74.3535	66.2961	58.9	34	87
7	DELTA II-III	104.6354	71.7715	19.7	10	110
8	DELTA IV	299.0367	380.6842	434	22	434
9	GEREGU NIPP	223.759	216.2418	271.9	94	272
10	GEREGU	291.3757	342.2282	450	14	450
11	IBOM	53.2629	195.8447	90.8	10	101
12	IHOVBE NIPP	103.4197	111.1956	112.3	91	120
13	OKPAI	275.0243	430.1614	475	100	475
14	OLORUNSOGO	182.9223	267.3707	293	10	293
15	OMOKU	45.5589	36.6957	64.2	3	65
16	OMOTOSHO NIPP	143.3603	192.8875	225	20	225
17	OMOTOSHO	348.2408	461.2613	480	29	480
18	RIVERS IPP	97.7694	90.4353	160	20	160
19	SAPELE (ST)	149.445	134.6193	223	33	223
20	SAPELE GT(NIPP)	186.2521	319.888	373	30	373
21	OLORUNSOGO NIPP	223.4018	398.657	422	31	422

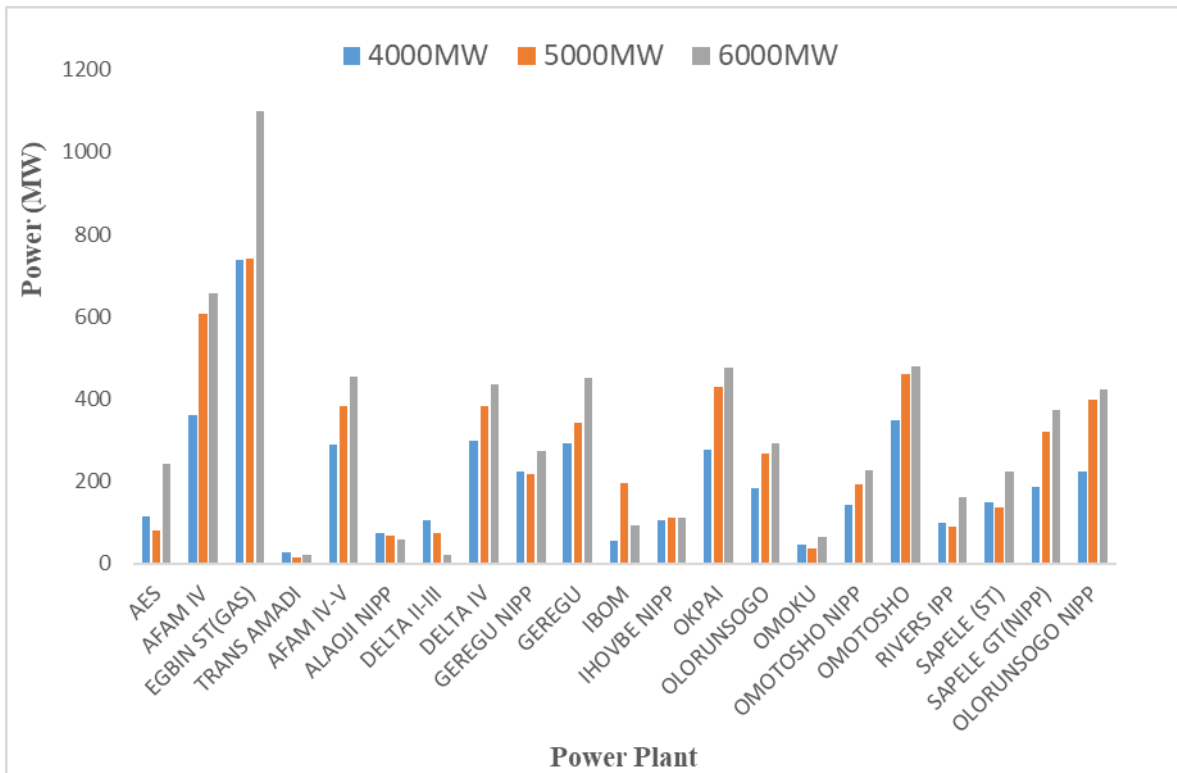


Figure 1: Optimal Allocation for 4000MW, 5000MW and 6000MW

Table 4: Comparison of optimization techniques at 2500MW

S/N	POWER PLANT	GA	PSO	FA	IFA
1	AES	55.9580	149.7333	136.6588	129.8278
2	AFAM IV	179.8223	541.3950	231.9705	183.3824
3	EGBIN ST(GAS)	190.4600	121.1194	212.1059	207.4987
4	TRANS AMADI	15.1567	28.6643	8.0199	25.5607
5	AFAM IV-V	59.3641	61.4773	193.6141	238.6688
6	ALAOJI NIPP	45.3778	34.1192	64.8705	66.3851
7	DELTA II-III	38.5311	61.1993	48.7584	69.6705
8	DELTA IV	53.9457	22.0000	116.3625	24.7536
9	GEREGU NIPP	268.7952	140.0508	188.1534	123.4706
10	GEREGU	450.0000	287.0630	112.8001	178.0919
11	IBOM	51.5232	42.7905	46.7341	48.5313
12	IHOVBE NIPP	97.2412	91.0000	96.8972	99.5892
13	OKPAI	163.7388	177.8049	259.5216	263.2501
14	OLORUNSOGO	229.8148	293.0000	66.2876	116.5018
15	OMOKU	31.8288	40.5393	40.7786	52.3552
16	OMOTOSHO NIPP	129.8019	163.8632	130.4197	184.7741
17	OMOTOSHO	162.4469	240.6234	117.4623	166.6340
18	RIVERS IPP	156.0696	27.4589	127.2110	103.2351
19	SAPELE (ST)	222.1271	33.0000	92.7675	135.4553
20	SAPELE GT(NIPP)	109.8957	30.0000	219.9624	35.6168
21	OLORUNSOGO NIPP	31.0000	40.8583	108.9694	113.0447
	Total Power (MW)	2690.1	2,627.7	2,620.3	2,619.1
	CO ₂ (Kg/hr)	119.110	118.520	118,240.0	117,960.0
	NO _x (Kg/hr)	288.3211	287.9433	287.7321	287.7033
	SO ₂ (Kg/hr)	22.2974	22.1822	21,3122	21.2416
	PM (Kg/hr)	14.2284	13.7899	13.7543	13.7333
	Fuel Cost (N/hr)	4,569,200	4,240,900	3,907,000	3,791,000

CONCLUSION

The economic and emission load dispatch was successfully carried out using the improved firefly algorithm on the Nigerian Power System to ascertain allocations of the thermal power plants. Different price penalty factors were applied and the Min-Max penalty factor produced the optimal results. Three weighting factors ($\omega=0$, $\omega=0.5$, $\omega=1$) were used and the best compromise was achieved with $\omega=0.5$. The results obtained satisfies all the constraints under consideration as seen in Table 3. Different optimization techniques were used to compare the results and the IFA was found to be the best in terms of minimal fuel cost and emissions released into the atmosphere.

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