

Full Paper

**MULTI-OBJECTIVE OPTIMAL POWER DISPATCH FOR THE NIGERIAN POWER NETWORK**

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ABSTRACT

This paper solves the multi-objective optimal power dispatch problem with fuel cost and transmission loss as competing objectives. The elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) with the Nigerian 24-bus hydrothermal power system network data set have been used in this study. The better performance of the NSGA-II over both micro-GA and conventional GA approaches used in earlier studies on the Nigerian network has been demonstrated.

**Keywords-** Multi-Objective Evolutionary Algorithm, Economic dispatch, Loss formula, Non-dominated solution, Pareto-optimal

1. INTRODUCTION

Any solution approach to the classical economic dispatch (ED) problem seeks to determine the dispatch of generating units that satisfies the load demand at minimum generating cost, subject to the satisfaction of different constraints on the power system operation. Economic power system operation is influenced by the operating efficiency of generating units, fuel and operating costs, and transmission losses. According to da Silva and de Carvalho Costa (2003), transmission losses take a considerable part of the system cost, in general taking about 4% of the produced energy and in Brazil, these losses are estimated at about half a billion dollars annually. Hence, to enhance efficiency in power transmission, real power losses incurred during transmission must be minimized and a way to do this is to incorporate minimization of losses as an objective during the optimization process. A more realistic ED problem considering the transmission loss can be formulated as a multi-objective problem optimizing both the generation cost and the transmission loss.

Many strategies have been adopted to obtain an optimal solution for power system multi-objective optimization problems. Dhillon et al. (1993) and Chang et al. (1995) used the weighted sum method whereby weights are assigned to each of the multiple objectives before they are summed in order to create a composite objective function; El-Ela and Abido (1992) and Yokoyama et al.

(1988) used the  $\epsilon$ -constraint method in which one objective function is taken as the function to be optimized and the rest of the objectives are treated as constraints by limiting each of them within certain pre-defined limits. These preference-based approaches require specification of weighting coefficients or pre-defined limits which affect the quality of solutions obtained. Also, as common with analytical methods, several runs have to be performed in order to obtain different and acceptable non-dominated solutions for the decision maker to choose from.

Fonseca and Fleming (1999), Deb (2001) and Knowles et al. (2008) have shown that multi-objective evolutionary algorithms (MOEAs) overcome these shortcomings of classical optimization approaches. They don't require specification of weighting parameters. Their population-based nature also makes it possible for them to yield multiple Pareto-optimal solutions in a single run. Different formulations of the multi-objective optimal power flow problem have been solved using different MOEAs (Al-Hulail (2004), Ah-King et al. (2004), Abido and Bakhshwain (2005) and Abido (2006)).

In this study, the elitist Non-Dominated Sorting Genetic Algorithm (NSGA-II) is used to solve the multi-objective electric power dispatch problem with both fuel cost and transmission losses as objectives for minimization. It extends the work on economic load dispatch in the Nigerian power system presented by Bakare et al. (2005) by considering minimization of real power loss as an additional objective. The trade-off between generation cost and transmission loss is obtained and it is shown that this approach is able to find better generation cost than was obtained by either the micro-GA ( $\mu$ GA) or conventional GA (CGA) approach.

2. PROBLEM STATEMENT

The multi-objective economic power dispatch problem with transmission loss minimization as an added objective seeks to minimize two competing objective functions, fuel cost and real power transmission loss, while satisfying equality and inequality constraints imposed by physical limitations of the power system.

2.1. Problem Objectives

*Minimization of Fuel Cost:* The total generation cost,  $F(P_G)$ , curves are represented by quadratic function given by

$$F(P_G) = \sum_{i=1}^N a_i + b_i P_{G_i} + c_i P_{G_i}^2 \tag{1}$$

where  $N$  is the number of generating units;  $a_i$ ,  $b_i$ , and  $c_i$  are the cost coefficients of the  $i^{th}$  generator, and  $P_{G_i}$  is the real power

output of the  $i^{th}$  generator.  $P_G$  is the vector of real power output of generators and defined as

$$P_G = [P_{G_1}, P_{G_2}, \dots, P_{G_N}]^T \quad (2)$$

*Minimization of Transmission Loss*- The real power loss,  $P_L$  during transmission can be calculated as a function of  $P_G$  by using the B-loss coefficients obtained for the network. i.e.

$$P_L(P_G) = P_G^T [B] P_G + P_{G_1}^T B_0 + B_{00} \quad (3)$$

where B,  $B_0$  and  $B_{00}$  are the generalized loss formula coefficients.

## 2.2. Constraints

*Generation Capacity Constraint*- The real power output of each generator is restricted by its lower and upper limits as follows.

$$P_{G_i}^{\min} \leq P_{G_i} \leq P_{G_i}^{\max}; \quad i = 1, \dots, N \quad (4)$$

*Power Balance Constraint*- The total power generated must be sufficient to satisfy the total load demand,  $P_D$  as well as the real power loss,  $P_L$  i.e.

$$\sum_{i=1}^N P_{G_i} - P_L - P_D = 0 \quad (5)$$

## 2.3. Multi-objective Formulation

The multi-objective economic dispatch problem with transmission loss minimization is therefore formulated as

$$\text{minimize}_{P_G} [F(P_G), P_L(P_G)] \quad (6)$$

$$\text{Subject to: } g(P_G) = 0 \quad (7)$$

$$h(P_G) \leq 0 \quad (8)$$

where  $g(P_G)$  is the equality constraint representing the power balance, and  $h(P_G)$  is the inequality constraint representing the generation capacity limits.

## 3. PRINCIPLE OF MULTI-OBJECTIVE OPTIMIZATION

Many real-world optimization problems are inherently multi-objective i.e. they involve simultaneous optimization of more than one objective function, which are often conflicting in nature. If such problems are formulated as single-objective problems, the obtained solution may look appealing in the absence of alternatives, but may be otherwise potentially far from what the decision maker may choose given a set of possibilities (Knowles et al., 2008).

Multi-objective optimization gives rise to a set of optimal solutions none of which can be said to be better than any other in terms of all the objectives. They are said to be non-dominated with

respect to one another and are called Pareto-optimal solutions. The curve joining these non-dominated solutions together is called the Pareto-optimal front. There are two basic goals in multi-objective optimization- first, to obtain a set of non-dominated solutions as close as possible to the 'true' Pareto-optimal front and second, to obtain as many diverse solutions as possible so that the decision maker has various alternatives to choose from.

## 4. PROPOSED APPROACH

### 4.1. Overview

Evolutionary algorithms (EAs) consist of a broad class of non-classical, unorthodox and stochastic search and optimization algorithms which includes genetic algorithms, evolutionary programming, evolutionary strategy and genetic programming. They mimic nature's evolutionary principles to drive their search towards an optimal solution. EAs are capable of finding multiple optimal solutions in a single simulation run. They are also less susceptible to the shape and continuity of the Pareto front.

In this study, the elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) is chosen because of its fast non-dominated sorting procedure, a fast crowded distance estimation procedure as well as its simple crowded-comparison operator.

### 4.2. Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II)

NSGA-II (Deb et al., 2002) is an elitist multi-objective evolutionary algorithm that uses a fast non-dominated sorting as well as an efficient crowding-distance assignment approach. It involves the creation of an initial random population of solutions  $P_0$  of size  $N$  which is sorted into different levels of non-domination. Each solution is assigned fitness equal to its non-domination level where level 1 is the best level. Binary tournament selection with a crowded tournament operator as well as recombination and mutation operators are then used to create an offspring population  $Q$  of size  $N$ .

The parent and offspring populations are combined and a non-dominated sorting is performed. Thereafter, solutions from better non-dominated sets are selected to propagate to the next generation, one set at a time until the population is filled. If the available population slots are not adequate to accommodate all solutions of a non-dominated set, a crowding strategy is used to identify solutions which reside in a less-crowded area. Fig. 1 shows the flowchart for NSGA-II.

## 5. NIGERIAN POWER SYSTEM NETWORK

Fig. 2 shows the Nigerian power system network which is a 24-bus, 330kV network consisting of four thermal generating units and three hydro stations. The parameters of the network are contained in a study by Haruna (2003). Bakare et al. (2005) developed the quadratic cost functions for the thermal units as the best curve fits to their actual operating cost data over a period of one year and the fuel cost coefficients so obtained are given in Table I. The B-loss coefficients for calculating power loss are as given by Wudil (2004). Power allocations to the hydro units were fixed *a priori* in conformity with the utility's operating practices.

## 6. RESULTS AND DISCUSSION

NSGA-II was applied to the Nigerian system with the fuel cost and transmission loss as optimization objectives. A total load demand of 2847.28 MW was considered. A population size of 100

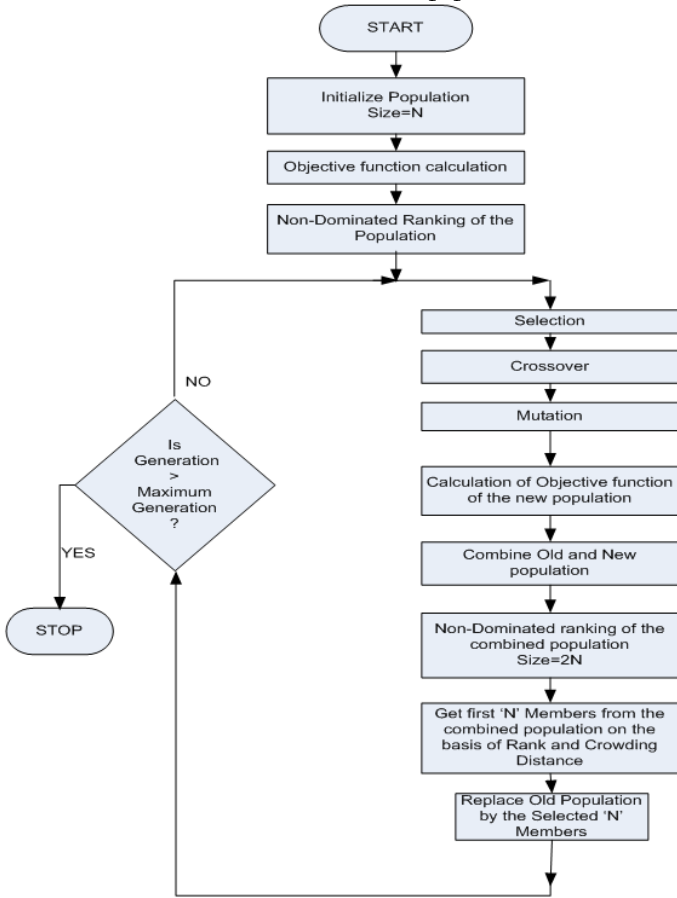


Fig.1 NSGA-II Flowchart

and a maximum number of generations of 1200 was used in the optimization run. Table 2 shows the generation schedule corresponding to the best fuel cost and the best transmission loss when the objectives were considered individually.

The first case considered minimizing the total fuel cost objective while the transmission loss is made part of the constraint equations. The result of this is shown in the second column of Table 2. The second ideal minimum considered the transmission loss as the objective function. Its value forms the third column of Table 2. Bakare et al. (2005) used both the  $\mu$ GA and CGA approaches to solve the minimum generation cost single-objective economic dispatch problem. A comparison of the generation cost returned by

these methods with those found by NSGA-II used in this study is presented in Table 3. NSGA-II was able to find solutions with lower generation cost than either the  $\mu$ GA or CGA. There is a saving of over ₦7,470.00 and ₦10,569.77.00 ₦/hr over the respective values returned by  $\mu$ GA and CGA. Thus NSGA-II converges to a better solution for fuel cost than these other methods.

Fig.3 shows the Pareto front generated by NSGA-II and it indicates the trade-off between fuel cost and transmission loss. These solutions are diverse in the objective space, so the power system decision makers have different solutions to choose from.

Table 1: Thermal Generator Cost Coefficients

Power Station	a (₦/hr)	b (₦/ΜW/hr)	c (₦/ΜW <sup>2</sup> /hr)	P <sub>G</sub> <sup>min</sup> (MW)	P <sub>G</sub> <sup>max</sup> (MW)
Sapele	6929.00	7.84	0.130	137.5	550.0
Delta	525.74	-6.13	1.200	75.0	300.0
Afam	1998.00	56.00	0.092	135.0	540.0
Egbin	12787.00	13.10	0.031	275.0	1100.0

Table 2: Ideal Minimum Solution with NSGA-II

	Fuel Cost (MW)	Transm. Loss (MW)
Egbin	1024.68	555.00
Sapele	284.70	365.68
Delta	75.00	45.00
Afam	177.05	540.00
Shiroro	490.00	490.00
Kainji	350.00	350.00
Jebba	450.00	450.00
Fuel Cost	100,070.23	122,667.66
Transm. Loss	28.32	2.59

Table 3: Comparison of Fuel Cost by  $\mu$ GA, CGA and NSGA-II

	NSGA-II (MW)	$\mu$ GA (MW)	CGA (MW)
Egbin	1024.68	1011.39	877.15
Sapele	284.70	173.28	194.64
Delta	75.00	111.18	106.49
Afam	177.05	261.43	371.13
Shiroro	490.00	490.00	490.00
Kainji	350.00	350.00	350.00
Jebba	450.00	450.00	450.00
Fuel Cost	100,070.23	107,540.00	110,640.0

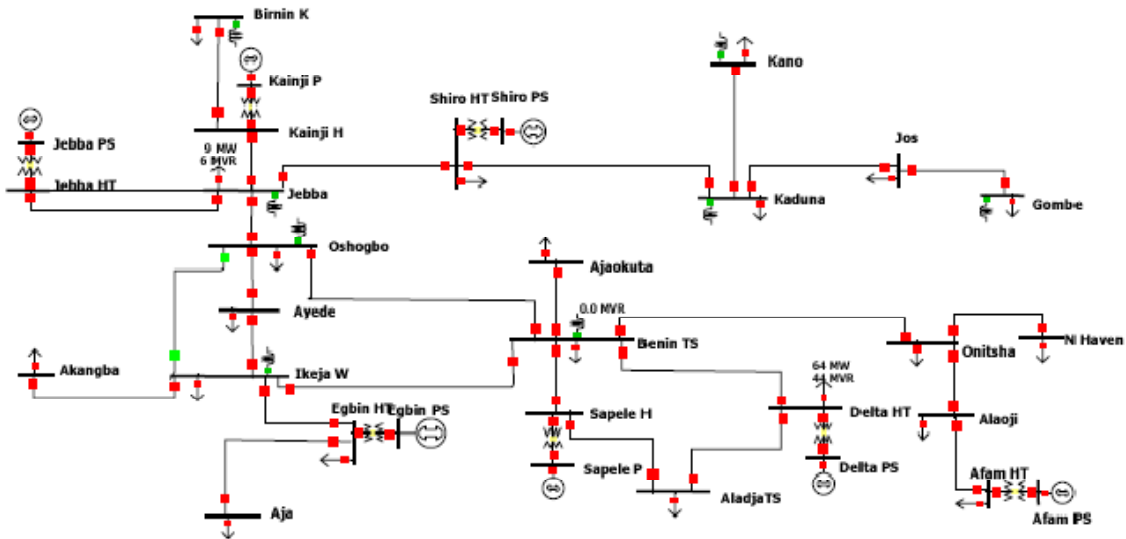


Fig.2 Nigerian Power System Network

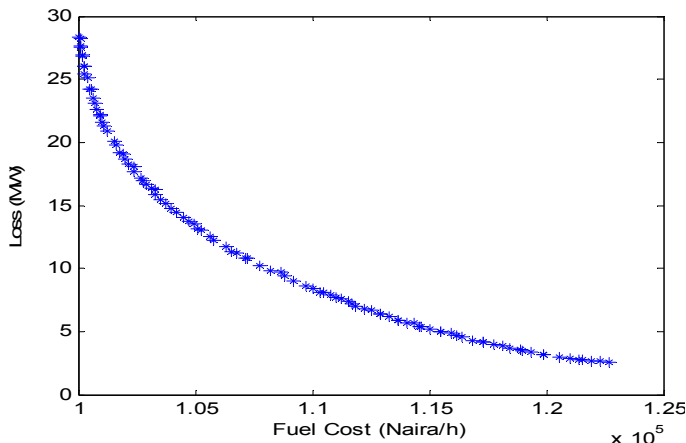


Fig.3 Trade-off between Fuel Cost and Transmission Loss

7. CONCLUSION

In this study, the elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) has been used in this study to solve the multi-objective power dispatch problem formulated for the Nigerian power system with both fuel cost and transmission loss as competing objectives. The results show the effectiveness of the NSGA-II in solving the problem, yielding different Pareto-optimal solutions which decision makers in the power system can choose from. The solutions found by NSGA-II also converge better than those found by micro-GA and conventional GA.

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