Multiobjective Optimization to schedule The Economic Operation of Colombian Atlantic Coast under insulation conditions from National Land

JOHANNA AMAYA
Universidad del Norte
Industrial Engineering Department
Km. 5 Vía Pto., Barranquilla
COLOMBIA

LUCENY GUZMAN
Universidad del Norte
Mathematics Department
Km. 5 Vía Pto., Barranquilla
COLOMBIA

YEZID DONOSO
Universidad del Norte
System Engineering Department
Km. 5 Vía Pto., Barranquilla
COLOMBIA

Abstract: This paper shows the application of evolutionary algorithm (SPEA) to determine the economic operation of power subsystem of Colombian Atlantic Coast considering only the generators units of this region of the country; this can be the solution when failures in the National Transmission System occur which disconnect the Caribbean coast from the rest of national land. The evaluate objective functions were: Power Production Costs and Losses on Transmission Lines. Performance of this algorithm was compare with the results obtained using traditional method E - Constraint. and that are shown in graphics of Pareto Optimal fronts in two dimensions. In addition, we develop an heuristic which determine the schedule to one specific operation day looking for the combination that minimize start, stop and generation costs in each stage. The main contributions of this paper are: the multiobjective model, the develop and solution of algorithm with computational complexity in polynomial time and contribution to energetic sector in Colombia.

Key–Words: Multiobjective Optimization, evolutionary algorithm, economic dispatch, losses of power, starts and stops costs,generation costs.

1 Introduction

The economic operation of a power system is a process which involve the generation and supply of potency. This process its so important to recover and obtain profits over the investment. In Colombia, this activity is in charge of National Dispatch Center (NDC), this organism schedule the generation to cover total expected demand using the most economic available resources of different enterprizes keeping in mind technical y electrical constraints [1].

Under unusual conditions of public order like civilian stoppage, and cases special conditions which demand security at working of National Interconnected System, NDC determine actions to keep the operation of NDC safety.

The Atlantic Coast through its generators has the capacity to provide big part of demand of the entire country, even it can supply itself; the problem is that the prices of generation are so hight because the generators transform thermic energy. However in emergency situation when Atlantic Coast where disconnected from de rest of the country, its possible overcome putting in action supply ourselves.

This work seeks a solution to problem of power planning of the region in abnormal conditions like it was describe before, having in mind Multiobjective Optimization.

To solve the problem, it were considered ten stations of Atlantic Coast (Termocandelaria, Termocartagena, Sabanalarga, Ternera, Tebsa, Termoflores, Nueva Barranquilla, Fundación, SantaMarta y Guajira) with six units of thermic energy generation.

The objective of this problem is to find the best solutions, in terms of operation conditions of the six available generators, which let supply hour demand of the Caribbean region in a specific day, satisfying every operation condition of system, keeping power losses in transmission lines and minimizing costs. In that way, our objective is center in the following aspects:

1. Choose among the available generators the best combination which minimize costs y satisfy define constraints to provide daily demand.

2. Determine the work sequence of selected generators, let us satisfying demand in each stage minimizing star, stop and generation cost.

Initially, it will be minimize two functions: Cost to produce Power and Losses on Transmission lines. The minimization of these functions leads to choose a subset of n generators, $n \leq 6$ from there will find the best combination x_i to generate in each of K daily stage . This selection is carry out in terms of minimal star, stop and generation costs.

The best set of points which describe the multi-objective optimization problem it will look for using different tools, since an heuristic to develop an evolutionary algorithm based on *Strength Pareto Evolutionary Algorithm* **(SPEA)**[5].

This paper is organized as follows: In section 2, we show mathematical formulation of the problem, exposing some concepts related to development of the solution. In section 3, we suggest the multiobjective evolutionary algorithm, in section 4 the experimental results and its analysis are expose, finally, in section 5 this paper is conclude.

2 Mathematical Formulation Problem

2.1 Multiobjective problem

The multiobjective optimization problem related in this paper is defined in the following way:

Optimize
$\mathbf{y} = f(\mathbf{x}) = (f_1(\mathbf{x}), f_2(\mathbf{x}))$
Where:
$\mathbf{x} = (x_1, ..., x_n)$ represents decision vector $n = 6$
$\mathbf{y} = (f_1(\mathbf{x}), f_2(\mathbf{x}))$ represents objective vector
$f_1(\mathbf{x}) =$ Power Production Costs
$f_2(\mathbf{x}) =$ Losses on Transmission Lines.
$x_i =$ represents the power of generator i,
$i = 1, ..., 6$

In multiobjective context [3] it says that a vector $\mathbf{x}$ domains another $\mathbf{x}'$ if at least is so good or better like the other in every objectives.

A solution $\mathbf{x}$ is optimal Pareto if doesn't exist another $\mathbf{x}^* \mid \mathbf{y}^* = f(\mathbf{x}^*)$ domain to $\mathbf{y} = f(\mathbf{x})$. The set of all Optimal Pareto Solutions is named Pareto Optimal Set and its image, Pareto Optimal Front.

2.2 Functions Definition

The functions to minimize are:

$$f_1(\mathbf{Q}) = \sum_{i=1}^{N} C_i Q_i \quad (1)$$

$$f_2(\mathbf{Q}) = \sum_{i=1}^{N}\sum_{i=1}^{N} Q_i B_{ij} Q_i + \sum_{i=1}^{N} B_{i0} Q_i + B_{00} \quad (2)$$

Where:

f_1 = Power Production Costs, represents the value of energy dispatched at Atlantic Coast during an specific day

$f_2 =$ Losses on Transmission Lines.(Mwh)

C_i = Production Cost of generator i. represents the price of offered power by generator i in energy share prices (In thousand pesos for Mwh)

$\mathbf{Q} = (Q_1, , , Q_N)$ Represents solution vector to suggested problem.

$Q_i =$ Professed Availability of Generator i.

N = Number of available generators to supply the Atlantic Coast demand.

The terms B are called loss coefficient, and are constants which were determine by features of the system.

Constraints:

$$Q^{\min} \leq Q_i \leq Q^{\max} \quad (3)$$

$$D \leq \sum_{i=1}^{N} Q_i \quad (4)$$

The minimization of those functions will lead to select a subset of n generators, $n \leq N$, from these we look for the best combination x_i to generate in each of K daily charge stages. This selection is done in terms of minimal generation costs, to do this it will calculate the next function:

$$F_{i*}(K) = \min_{\{x_j(K+1)\}} \{P_{i*}(K) + T_{ij}(K)\} \quad (5)$$

Where:

$P_{i*}(K) =$ Minimal generation cost of $x_i(K)$

The generation costs are related to costs which results from the fuel consumption

$T_{ij}(K) =$ Cost to pass from $x_i(K)$ to $x_j(K+1)$

Parameters B in the equation 2 are found from the power flow across suggested system, keeping in mind the features of lines (Length, Transport capacity, Positive, negative or zero sequence resistance, reactance, and zero susceptance, shape), of the generators (Net effective capacity, Absorbed and generate capacity, power factor, voltage, charge).

The next table shows the characteristics of each available generator unit to supply the Atlantic Coast demand.

Generator	Capacity (Mwh)	Q_{min}	Q_{max}
1	187	0	168
2	314	0	283
3	447	0	402
4	750	0	500
5	127	0	114
6	302	0	271

Table 1.

Generator	$P_v(Mwh)$	C_a	C_p	C_g
1	419.25	125.44	62.71	188.13
2	419.25	125.44	62.71	188.13
3	316.82	100.05	50.03	150.08
4	50.00	74.63	37.32	111.95
5	419.25	100.05	50.03	150.08
6	419.25	74.63	37.32	111.95

Table 2.

Q_{min} = Minimal generation capacity
Q_{max} = Maximal generation capacity
$P_v(Mwh)$ = Selling price for power unit $(\$/Mwh)$
C_a = Start Generator Cost $(\$/Mwh)$
C_p = Stop Generator Cost $(\$/Mwh)$
C_g = Generation Cost $(\$/Mwh)$

One of the main constraints of the system is related to losses of power on transmission lines, to that the operation range is between 20 and 25% of transmitted power.

Based on these characteristics will be generate the best set of points to describe the optimization multi-objective proposed problem using two supports tools, GAMS[10] and MOEA, both results will compare and will be choose from Pareto front obtained by each procedure a solution (combination of generators) to carry out the scheduling of the generation operation for one demanded day.

3 Proposed Algorithm

The proposed evolutionary algorithm is **SPEA;** its performance is based on search Pareto optimal solutions from initial population which is generated randomly and from an external population which is created based in concept of Pareto dominance. Each time that a non-dominates solution is found in initial population, this one is located on external population, so the last one is became elitist population. The assign of fitness values in both populations is according to kind of solution, if it is optimal, then has high probability to remain across different generations of created population. The most important characteristic of this algorithm is the implementation of clustering on elitist population, which let keep a set of best solutions.

El scheme of the algorithm is:

- **Representation of solutions, Initial Population and External Population**

  Each solution to optimization problem was represented like a row vector:

  $\left(Q_1, \ Q_2, \ Q_3, \ Q_4, \ Q_5, \ Q_6. \right)$ The initial population with size N is created randomly by generating 6 random numbers $r, (0 \leq r \leq 1)$. Like we have limits of operation of six generators units, members of row vector are given by: $Q_i = (Q_{\max} - Q_{\min}) * r \quad i = 1, ...6$. Values $Q_i \quad i = 1, ...6$. selected must satisfy constraints of the system, those are: $Q_{\min} \leq Q_i \leq Q_{\max}$, $1140 \leq \sum_{i=1}^{6} Q_i \leq 1175$. To create elitist population it was used concept of Pareto dominance trying to minimize objective functions. Each gene in created population was compare with another, so the solution that give low values for both objective functions was included to an external population.

  Next, appear the heuristic which created initial population and first external population.

- **Clustering**

  It was applied clustering technique to reduce size of external population (Elitist) until a value smaller N, be $\overline{N} = 10$.This technique compare Euclidean distances between solutions, and put into a set that are closer in pairs, if a cluster have three or more solutions, it is calculated the centroid and the solution closer to this is the representation of the cluster.

- **Selection and Fitness Function**

  Process of selection is carried out with intention to choose the best individuals from both considered populations to apply on them crossover and mutation operators to create the population for next generation.

  To the elements of elitist and initial population it was calculated fitness function. For elitist population with the expression

$$f_i = \frac{1}{S_i} \tag{6}$$

Where:

$$S_i = \frac{n_i}{N+1} \tag{7}$$

Figure 1: Pareto Fronts comparison

n_i = Number of elements form initial population which solution i, from external population, domain.

N = Size of initial population.

And for initial population fitness is calculated with the expression:

$$f_i = 1 + \sum S_i \tag{8}$$

To Each solution was associate a probability according to:

$$P_i = \frac{f_i}{\sum f_i} \tag{9}$$

The solutions were ranking by fitness and it was calculated accumulated probability. It was improve roulette wheel operator to choose the ones which will cross and mute and create population to next generation.

It was processed 5 generations, with final results and best solutions was created Pareto optimal front which was compare with front given by analytical solution.

- **Multiobjective Evolutionary Proposed Algorithm: pseudecode**

  The pseudecode shows SPEA at its general way

  On proposed algorithm, selection non dominance procedures, clustering, fitness and crossover and mutation operators were implemented like [5]

4 Experimental Results

The solutions obtained to solve the multiobjective proposed problem were gotten by consecutive running of **SPEA** algorithm to get the results. With these results we construct following graphic where it is compare Pareto optimal front from SPEA versus Pareto optimal with numerical solution

According to that graphic, possible solutions from ideal front (GAMS) are better in distribution in feasible area fulfilling constraints, while real front (SPEA) it is consider more discrete in distribution but if we consider analytical solution like a NP Hard Problem, SPEA Algorithm give us a good approximation reducing its complexity to polynomial processing time.

For a detail analysis of the evolutionary algorithm performance in determining the Optimal Pareto Front, a study of the results was necessary. The results obtained by the algorithm and the e-restriction method were analyzed and compared, and the error between the estimations was calculated. For this was necessary first to determine the Euclidian distance existing between a point given by SPEA and the closest point to the Pareto Front given by the numerical method.

Next, the estimated error was calculated using the Norm between the points. The following calculations were made in order to estimate the error:

E-restriction method point: (x_1, y_1)

SPEA algorithm point: (x_2, y_2)

Estimated Error: $\frac{\sqrt[2]{(x_2-x_1)^2+(y_2-y_1)^2}}{\sqrt[2]{(x_1^2+y_1^2)}}$

According to this formula, the maximum value for error was 0,085% and the minimum value was 0,004%. This let us conclude that the values obtained by the evolutionary technique are a very good approximation to the results obtained by the analytical (e-restriction) method.

From the study of the solutions it can be concluded that the solutions given by the analytical method is more exact, but we have to keep in mind that this method requires the convexity of the functions. The analytical method is more difficult to use when the complexity of the functions increases, while the evolutionary algorithm adjust easily to any kind of problem.

4.1 Testing Problem

Now we take any solution **Q** from Pareto front obtained by SPEA and another obtained by GAMS to carry out the operation generators scheduling; this requires knowledge of demand to a consider day and the number of stages according with peaks of demand during the day.

Like testing exercise we take a day with the next characteristics:

Level of power required to satisfy Atlantic Coast during a day is 1150 Mwh, including 22,3% of losses level, this is, 940 Mwh real demand and 210 Mwh of power losses. This amount is distributed in 8 stages like this:

Stage	Hour	Demand
1	6:00-9:00	130
2	9:00-12:00	109
3	12:00-15:00	239
4	15:00-18:00	130
5	18:00-21:00	319
6	21:00-24:00	84
7	24:00-3:00	69
8	3:00-6:00	70

Table 3.

Results given for heuristic for solution of GAMS are:

Stage	Cost	Generators	Power
1	410497	4	130
2	335862	4	109
3	746359	4	237,302
		6	1,698
4	923455	6	91,074
		3	38,926
5	1727660	3	169653
		5	108831
		1	40,516
6	664449	1	84
7	1254240	1	12,839
		2	56,161
8	627110	2	70
Total	6689630		

Table 4.

Results given for heuristic for solution of SPEA are:

Stage	Cost	Generators	Power
1	410497	4	130
2	335862	4	109
3	335862	4	239
4	1296630	4	8,875
		6	56,8931
		3	64,2319
5	1764980	3	171,591
		5	111,734
		2	35,6744
6	664449	2	84
7	1254240	2	32,4381
		1	36,5619
8	627110	1	70
Total	6689630		

Table 5.

Based on this results we can say that operation scheduling minimizing costs, is optimal for both cases, although that depends of generators available capacity and operation constraints.

Although in both cases we cover entire demand with the same cost of generation, for combination obtained by GAMS it release 1,62 Mwh of free capacity, while to SPEA solution free capacity is 14,985 Mwh let us conclude that solution of Gams satisfy the objective to operate generators and use almost 100% of availability capacity and getting better cost of power buying in energy share.

Thus, the objective to specify the operation schedule for one demand day in Caribbean Colombian Coast under insulation conditions from the rest of national land having in mind working cost of available generator units, demand to provide and the most important thing, working with acceptable power losses level according to effort of enterprisers to get better situation.

5 Conclusions

In this paper it was presented technique to optimize multiple objectives implementing evolutionary algorithm SPEA.

The chosen multiobjective problem as reference is process to economic operation of power systems for Colombian Caribbean Coast under insulation conditions. To compare results of evolutionary algorithm, the model was solved using CPLEX of GAMS.

According to GAMS and SPEA results, we can proof that both tools have good capacities to found solutions closer to Pareto optimal, keeping in mind that in some cases one y better than the other, but the difference among solutions is no significant to choose one.

The front gotten it is an economic tool to improve in sector energetic enterprisers. For example, if the shown scene become true and the supply is required, companies have information on time to determine which units must operate, what will be its contribution and know the cost to this situation carried out.

Finally, it can state that apply multiobjective evolutionary algorithms to solve proposed problem represent an efficient tool because provide a different view making decisions to give to anyone an optimal solutions set and the feasible area to operate.

For future works we propose adding and complete operational constraints to obtain better results keeping in mind technical conditions of another elements which belong to the system and give a global view to mentioned problem.

References

[1] www.creg.gov.co (Comisión Reguladora de Energia y Gas Home Page)

[2] Grainger, John y Stevenson William. Análisis de Sistemas de Potencia. Mc Graw Hill, México. 1994. Capítulo 13.

[3] Arroyo J y Armetano V. Un Algoritmo genético para problemas de Optimización o Combinatoria Multiobjetivo, XXXIII Simposio Brasilero de Pesquisa Operacional. Campos do Jordao- SP. Noviembre, 2001.

[4] Pinedo, Michael. Scheduling: Theory, Algorithms and Systems. Prentice Hall, 2da Edicion (2001)

[5] Deb K. (2001). Multiobjective Optimization Using Genetic Algoritms. John Wiley & Sons, Chichester, UK

[6] Alvarado,C; Herazo, I; Ardila, C; Donoso, Y. Aplicación de NSGA-II y SPEA-II para la Optimización Multiobjetivo de Redes Multicast. Ingeniería y Desarrollo, Número 17. Pag. 28-53

[7] Jaller, M; Hernandez, K; Cervantes, E; Donoso, Y; Paternina, C. Application of Evolutionary Algorithm Techbiques in Multi-Objective Optimization of the Plastic Injection Process.

[8] Amarillo, N; Almeida, C; Barán, B. Optimización Multiobjetivo para la Ubicación de Locutorios de Cabinas Telefónicas. 2004

[9] Pinedo, Michael, Xiuli Chao. Operations Scheduling with applications in Manufacturing and Services. McGraw-Hill/Irwin; Bk&Disk edition (1998)

[10] www.gams.com