Application of Genetic Algorithms in Colombian Interconnected Power System Operative Planning

Jaime A. Valencia V., Universidad de Antioquia *Member IEEE*, Walter M. Villa, Esteban Velilla, Universidad de Antioquia *member IEEE,* Giovanni Marín A., Empresas Públicas de Medellín*,* José I. Gutiérrez, Mónica M. Montoya

***Abstract*— Each interconnected electric system has to define its operating mode and how expansion and operation planning are made. This paper presents the first phase of the work of implementing a tool with application to Colombian power system operative planning. The tool uses genetic algorithms to optimize the cost functions that arise in which the elements of the system are the variables that can be operated to reduce losses and fulfill the operation restrictions. Tests results with IEEE systems and two fitness functions proposed by the authors are presented in this work; from those results is estimated the computing time needed to evaluate the Colombian system.**

Keywords- Genetic algorithm, Fitness function, Operative electrical planning, power systems.

I. Introduction

Given the current electricity market and the deregulation of electric power systems, the economic operation, safe and quality of generation and transmission resources in the system has become a priority for companies involved in the operative planning. In this process the hydro and thermal generation for a given demand scenario, considering technical and operative restrictions of the transmission system are used.

The deregulated electricity market, in its competitive environment has provoked power electric systems often operating near its maximum power capability, which has brought as a consequence the operation of transmission grids on its transfer limits. Additionally, the unavailability of transmission grids for attacks in some countries, the environmental restrictions and the cost of ways rights, which makes unviable the construction of new lines, have made that power systems operate with overcharged lines while others are undercharged, with the outcome of "loop flows" between different voltage levels, with high operative restrictions in dynamic and stationary state, with mandatory generation for electric security of expensive resources than others available.

This impacts the electrical system operation and is reflected on operative overprices charged to final user and in an inadequate use of the existent infrastructure, driving it to an accelerated wear and an additional maintenance, which together impact society and those companies participating in deregulated schemes. In this highly restrictive Electric Power System (EPS) operation arise diverse problematic situations that literature has addressed with a wide variety of methodologies. The operation state in or near its transfer limits has been called Congestion [1]. Those transfer limits may be based of diverse nature phenomena: stationary state, dynamic stability, voltage stability and even reliability criteria to meet demand. Independent of the market scheme, planning new work or using optimally existent resources is considered congestion management. It can be then handled congestion in power systems in three different time instances: Expansion Planning; Operation Planning and Operation.

For Expansion Planning of EPS it has been proposed diverse deterministic and non deterministic optimization strategies [2-5]. Deterministic strategies (e.g. those based on sensitivity) proposed in literature for expansion of EPS are difficult to implement and they do not give explicit information of the location of new works, their exact cost and how it will be set on the system. Thus, pretending to take those proposals to Operation Planning of EPS and Operation of EPS is unlikely.

In the Operation Planning of EPS, previous to execution of generation dispatch, or a programmed topological change, it is evaluated the system operation and is established if the dispatch in the existent grid and for the demand condition, fulfils security criteria. From there it can be established generation dispatch, security generation, taps position on transformers, reactors connection-disconnection, condensers or lines modifications. To achieve an optimal technical combination of those parameters is not an easy job for the analyst and is usually carried out by trial techniques based on the analyst system knowledge. It is not guaranteed, by doing so, obtaining an optimal operation state, associated to the computational and engineer high cost. A non-optimal coordination can lead to operative overprices which are paid by the final user. In the world wide exist the preoccupation of having ancillary tools in decision making capable of establishing operation guides in real time [6].

From that point of view it will be desirable an Operation Planning tool that permits the establishment of exact solutions for dynamic and stationary state problems, for example in stationary state reactive resources could be coordinated, such as condensers, reactors and tap changers in transformers that guaranties voltage levels, charge in lines and even voltage stability, minimizing reactive re-dispatches.

In [7-8] a compilation of the Artificial Intelligence techniques applied to power systems is made. In this references it can be seen the large number of applications proposed to solve problems in power systems. It has been

This work had been supported by Colciencias and XM as a researcher project "Optimization Methodology based on Genetic Algorithms for electrical Operational Planning", final report , 2009.
Authors are with the Group of Efficient Energy Management GIMEL, University of Antioquia, Medellín, Colombia (e-mail: gimel@udea.edu.co).
Jaime Valencia is a teacher in the electrical engineering program at University of Antioquia (e-mail: jvalenci@udea.edu.co).
Walter Villa (e-mail: retwal@gmail.com).

intensively worked with Genetic Algorithms (GAs) in problems related to electrical power systems (optimization problems with non-linear functions, non-convex search space and restrictions). In [9-11] an implementation of GAs in system expansion planning is presented, which shows its potential in combinatorial analysis in the optimal location of FACTS devices process. In [12] Bakare suggests a combination of GA and expert system trying to provide a strategy to assist the power system operator in the improvement of the system condition when voltage and line limits are violated, "emergency state". A conventional GA and a micro GA have been applied based in optimization criteria for voltage profile and losses, the results were compared and proved with an actual system [13]. For congestion management in electric power systems, [14-15] propose a tool for expansion planning based on GAs. For Optimal Power Flow execution it is suggested in [16] the use of an improved genetic algorithm with discrete and continuous control variables. It has been made comparisons of different optimization methods for the solution of the Optimal Power Flow problem with continuous and discrete variables as shown in [17-18], where the comparison is made between two methods of mathematical programming and two metaheuristics (an improved genetic algorithm and particle swarm). In [19] was presented a novel application of GAs with computational improvement to solve the reactive dispatch problem. In [20] is implemented a voltage profile and reactive power control for the Nigerian system by using a micro genetic algorithm. It has been worked evolutionary programming and adaptive genetic algorithm in reactive power dispatch [21-22]. In [23] is presented an improved genetic algorithm to solve the optimal reactive power dispatch and is the voltage dependent static charge model is included. In [24], conventional genetic algorithms and micro genetic algorithms are considered trying to find a time optimization.

II. Description of the operational planning problem

Planning available resources for generation and transmission should be done in an integrated way, with the aim of reducing operating costs in the system, and trying to meet security, reliability and quality service demand levels. Operational planning in the Colombian power system uses a functional and temporal decomposition [25]. The functional decomposition considers operational planning for network operation and energy planning. The decomposition provides a temporary period of 5 years for energy planning; median period of 5 weeks, an economic dispatch of 24 hours for operational planning. Operational planning of energy (long-term) is indicative, while operational electric planning and the economic dispatch is mandatory.

A. *Objective Function*

Two objective functions were tested to be implemented in the Colombian system. Load flow is required to calculate operative restrictions of EPS and its overall structure is shown in Figure 1.

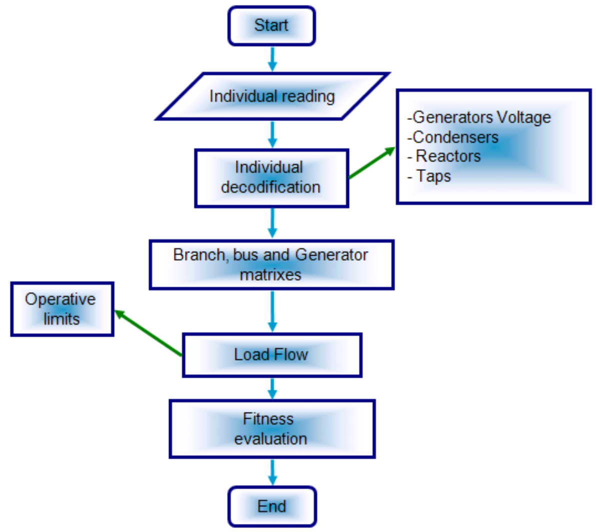

Figure 1. Flowchart of the fitness functions

Bus voltage and overload in the branches of the system (lines and transformers) were monitored to penalize constraints violations, thus the first fitness function proposed is:

$$F(x) = L(x)\mu_V V(x) + \mu_R R(x) \quad (1)$$

Where x represents the variables of optimization, V(x) and R(x) are subfeatures to include restriction violations of voltage in bus and flow in branches respectively. μ_V and μ_R are penalty constants. Both *V(x)* and *R(x)* are subfunctions that represent a penalty *P(x)*, which works based on the distance to the feasible area of the problem, each of these has the following form:

$$P(x) = \sum_j \max\{0, x_{\min,j} - x_j\} + \max\{0, x_j - x_{\max,j}\} \quad (2)$$

Where Xj, Xmin and Xmax are the optimization variables and their operational limits.

Congestion management solutions for power systems are suggested in [15]. The fitness function used here primarily aims to control the voltage node levels in the system and branch loads (lines or transformers), but also handle constraints on other variables such as voltage levels of particular nodes (which cannot operate in the conventional ranges of the nodes), branches with special capability, loop flows, stability of steady state voltage, small signal stability and control of losses.

The function described in [15] was change to the following:

$$f_f = \left[\prod_{i=1}^{\substack{Number\ of\\ nodes}} f_{VN}(i)\right] * \left[\prod_{j=1}^{\substack{Number\ of\\ branches}} f_{CR}(j)\right] * \left[f_{per}(s)\right] \quad (3)$$

Where fVN (i), fCR (j) and fper (s) represent subfunctions for node voltage i, branch load assessment in j and system losses assessment respectively, for an operational condition. The functions have the form shown in Figure 2.

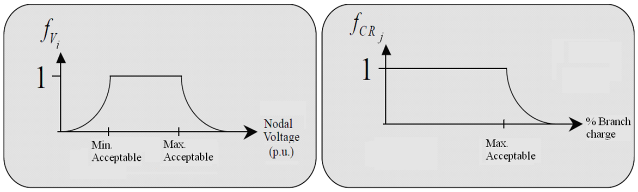

Figure 2. Performances of the voltages and branch load in the fitness function.

For example, the math expression for voltage subfunction is:

$$f_{VN} = e^{(-\lambda \cdot |(1-V_i)|-0.1)} \quad (4)$$

Where λ is called *lambdaV,* it defined as penalty factor of this function and allows to evaluate voltage constraints, in the same way, it was defined *lambdaF* and *lambdaP* for branch load and loss subfunctions respectively.

B. Variables of the Problem

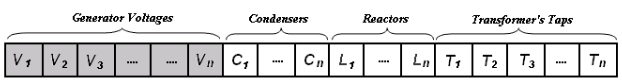

Figure 3. Chromosome implemented.

The chromosome selected is shows in figure 3 and is a compound for different variables as:

- Voltage generators vary in a range [0.95, 1.1] pu. Encoded between discrete [-10.10].
- The capacitors are made by steps, with a positive variation between [0, 10]. Each step corresponds to 5 MVAR.
- The reactors are made by steps, with a negative variation between [-10, 0]. Each step corresponds to 5 MVAR.
- The transformers taps vary in a range of [-10, 10].

C. Restrictions

The restrictions of the problem are handled directly in the cost function with penalty parameters that are defined heuristically. The information is taken from the load flow.

D. Test Systems

The IEEE test systems are used in this work because the elements that are available are very comparable to the Colombian power system. 118 and 300 IEEE nodes cases are of primary interest because they are large enough for comparison to the Colombian system which has about 700 nodes and similar devices.

III. GENETIC ALGORITHM

The Genetic Algorithms (GA) are algorithms inspired by the mechanisms of natural evolution and the genetic cross; they offer an adaptive search based on the “Darwinian” principle of reproduction and survival of individuals that best adapt themselves to environmental conditions, the principles of evolution and heredity allow to find the best individuals. These algorithms are designed to be used in those cases of large complexity where it is very difficult to use traditional methods of optimization [26-32].

The application of basic principles of genetics to mathematical optimization process begins with generating a random initial population that is a set of solutions. The fitness of each individual of the population is evaluated through an objective function, which is the function to be optimized. Each individual is represented by a string (chromosome) and each string has a code (genotype). The genotype is composed by a set of genes that represent a solution to the problem (phenotype). The better individuals are chosen considering the value of their fitness, those individuals will be the parents for the next generations (selection).

The evolution process occurs when a new population is formed, which is created by the genetic operators of reproduction and mutation. Reproduction or cross takes place when combining genes of selected individuals to form new individuals. Mutation occurs when in an individual or some of them from the new population, different genes change from those that were possessed by the selected individuals to reproduce. Mutation allows the GA to escape the minimum (maximum) locals. Both the crossover and the mutation of a gene are given accordingly to an established probability. The process of selection, crossover and mutation is repeated until it reaches a specific criterion that traditionally has been about carrying out a certain number of generations or when it is determined that the objective function is not substantially changed [7].

Selection was implemented by tournament, this process chose a number of *n* individuals and from those only the fittest is selected for the implementation of the subsequent operators. One point cross was used, in which from a cross probability a random position was chosen, and there it made an exchange between the sub-strings resulting from the division of two parents. The implemented mutation did not consider a probability but a percentage of genes to mutate. From the value of the percentage of genes to mutate was chosen at random the number of genes specified by the value, these genes are likely to vary between their maximum and minimum limits. Figure 4 describes the flow diagram of the programmed genetic algorithm.

The genetic algorithm is an unconstrained optimization technique; therefore mechanisms, have been designed, that allow the incorporation of important information about the violation of constraints within the fitness function, the most common way of considering constraints takes place through penalty functions that are included into the fitness function. For this work, a Matlab code of genetic algorithm was developed, with which the simulations were conducted and the results presented below.

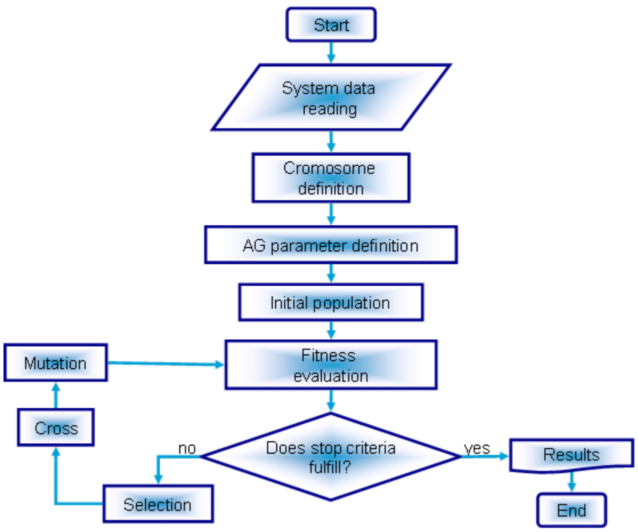

Figure 4. Methodology Flowchart

IV. SIMULATION RESULTS

Several tests were made to get the better penalty factor in each fitness function implemented in the software developed. The fitness functions are defined for specific constant values that guarantee the good performance in the results and the main criterion for selecting the best parameters was the lower losses complying with the restrictions of the system. In table I is presented the results for the case of 300 nodes of IEEE with the fitness functions number 1, (1). Which had defined two penalty factors: one for the voltages (rows) and other for the electrical power (columns), both variables had been evaluated in the same range 1 to 1000. The table I shows that the better parameters are 100 for the voltages and 1000 for the power penalty, where smaller values of constraints violation for voltage and power in the branches of the system were observed.

The fitness function number 2, (3) depend of three factors named lambdas (figure 2), this lambdas defined the curve of penalty through exponential function and these values depend on the number of nodes of the system, for that reason, in the Colombia case another test is required to calibrate these values. In table II is shown the lambda values that presented the lower losses and better fitness value in the case of 300 nodes, those are lambdaV = 0.1, lambdaF = 0,05 y lambdaP = 0,1.

With the objective of establishing an approximate computation time, it made several runs for AGs with large power system. Table III shows a series of results of optimization processes using the GA's tool developed and it includes the most important terms for its analysis.

Considering the computing time, many test were made to get information about the computing time needed to evaluate the real Colombia's case, the test consisted in evaluating different electrical systems (14, 30, 57 118 and 300 nodes) and different software with the genetic algorithm methodology implemented as GA_tool from Matlab, Flexga and the owner software developed called AG_UDEA. The figure 5 shows the results, if the Colombia case is approach to 700 nodes, a little extrapolation can be made to get the computing time around 600 seconds.

TABLE I. PARAMETERS EVALUATION IN THE FITNESS 1

Fitness	Loss (P/V)			
	1	**10**	**100**	**1000**
1	329,546	340,742	349,399	362,746
10	335,900	344,879	355,458	363,781
100	353,289	348,172	361,408	368,044
1000	365,199	362,320	369,404	379,826
Fitness	**∑Voltage to penalty (P/V)**			
	1	**10**	**100**	**1000**
1	3,155	0,339	0,003	4,08e-05
10	2,479	0,729	0,005	2,18e-04
100	2,791	0,583	0,188	5,82e-05
1000	1,879	2,479	0,704	0,532
Fitness	**∑Flow square to penalty (P/V)**			
	1	**10**	**100**	**1000**
1	0,683	0,295	0,687	1,231
10	0,099	0,148	0,109	1,117
100	0,042	0,047	0,070	0,032
1000	0,021	0,033	0,084	0,199
Fitness	**Value Fitness**			
	1	**10**	**100**	**1000**
1	333,385	344,424	350,384	364,018
10	339,369	353,656	357,034	365,166
100	360,273	358,734	387,216	371,311
1000	388,464	420,551	523,689	1111,65

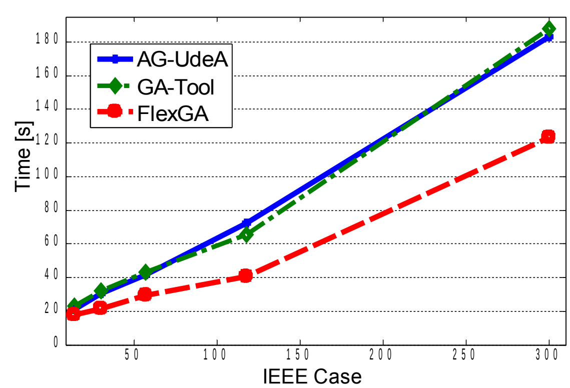

Figure 5. Computing time vs. nodes

TABLE II. PARAMETERS EVALUATION IN THE FITNESS 2

Fitness 2 Lambv = 0,1	Loss (lambF/lambP)		
	0,05	**0,1**	**0,15**
0,05	374,597	377,719	376,230
0,1	380,170	377,529	380,594
0,15	376,069	379,924	379,565
Fitness 2 Lambv = 0,1	**∑Voltage to penalty (lambF/lambP)**		
	0,05	**0,1**	**0,15**
0,05	4,33e-04	5,88e-05	4,31e-04
0,1	3,17e-04	0,176	0,356
0,15	0,180	0,005	0,179
Fitness 2 Lambv = 0,1	**∑Flow square to penalty (lambF/lambP)**		
	0,05	**0,1**	**0,15**
0,05	5,22e-05	0	8,52e-05
0,1	1,79e-06	0,058	0,092
0,15	0,045	4,28e-08	0,041
Fitness 2 Lambv = 0,1	**Value Fitness**		
	0,05	**0,1**	**0,15**
0,05	-0,999	-0,999	-0,999
0,1	-0,999	-0,972	-0,946
0,15	-0,968	-0,999	-0,969

TABLE III. RESULTS OF DIFFERENT SIMULATIONS FOR THE 300 NODES WITH THE FITNESS 1 USING DE GA TOOL DEVELOPED.

AG_UDEA, Case 300				
	Loss	**Voltage Penalty**	**Power Penalt y**	**Time [s]**
Test 1	370,76	2,22e-13	3,59	171,93
Test 2	363,46	2,22e-13	3,43	189,37
Test 3	361,54	0	1,43	195,09
Test 4	363,99	2,22e-13	0,51	185,51
Test 5	369,33	0	1,98	173,85
			Average time	**183,15**

The validation of the optimization algorithm of power system was done to assess operational strategy proposed by AGs, with other power flow program, it evaluated profile voltage in two cases, the first is the base case where there has not been modification at setting the system control elements up, and the second case is an optimized case in which the AGs had introduced changes with the objective of minimizing loss and controlling restriction violations.

In figure 6, it is presented the voltage profile for the two cases in the system of IEEE 57 bus, as shown there is a considerable improvement in the profile, when operational resources of the system are optimized. In this work, it was observed that for a larger system, the reduction of system loss is greater.

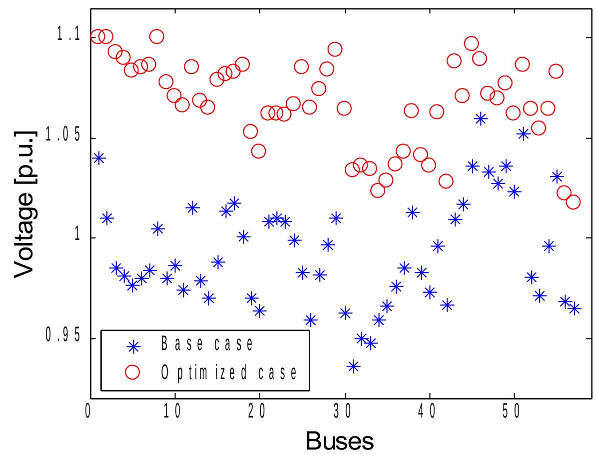

Figure 6. Voltage profile of IEEE 57 bus, base case vs. optimized case.

V. CONCLUSIONS

Genetic algorithms are shown as a good tool to obtain reliable and applicable solutions for the operational planning of electric system. The next phase of this work is to apply this methodology to Colombian case which is approach to 700 nodes.

Two optimization functions were presented, but it is possible to offer more features to control the number of operations and include the cost of each operation and to adapt to the operating hours of planning time as a planned release in the Colombian system.

In order to get good results with the GAs is needed to adapt to the specific problem of planning electric operating through the implementation of appropriate selection of initial population and set of genetic operators.

To get fewer losses is necessary to establish appropriate penalty factors without violating the restrictions defined by the operating limits.

The optimization methodology implemented follows the guidelines established for operation where for starters it seeks to meet the operating limits and then it seeks to optimize system losses, to fulfill this requirement it should be used large penalty factors in order to give priority to these restrictions.

The computational time of AGs are great for the implementation in the operational planning, so it has proposed work next stage on the application of parallel computing tools, both software and hardware, the objective is reducing computational time.

VI. ACKNOWLEDGMENT

The authors would like to acknowledge the contribution and support of engineer RAMON ALBERTO LEON CANDELA who works for XM-Expertos en Mercados of Colombia.

VII. REFERENCES

[1] R.D. Christie, B.F. Wollenberg, and I. Wangensteen. "Transmission management in the deregulated environment", Proceedings of the IEEE, vol. 88, pp. 170 -195, Feb. 2000.

[2] T. Orfanogianni, and R. Bacher, "Steady-state optimization in power systems with series FACTS devices", IEEE Transactions on Power System,, vol. 18, pp. 19- 26, Feb. 2003.

[3] L. Yunqiang and A. Abur, "Static security enhancement via optimal utilization of thyristor-controlled series capacitors", IEEE Transactions on Power Systems, vol. 17, pp. 324 –329, May. 2002.

[4] L. Yunqiang and A Abur, "Improving system static security via optimal placement of thyristor controlled series capacitors (TCSC)", IEEE Power Engineering Society Winter Meeting, 2001. Vol: 2 , pp. 516 – 521, 28 Jan.-1 Feb. 2001

[5] R. Rajarman, F. Alvarado, A. Maniaci, R. Camfield and S. Jalali, "Determination of location and amount of series compensation to increase power transfer capability", IEEE Transactions on Power Systems, vol. 13, pp. 294-300, May.1998.

[6] U.S.-Canada Power system Outage Task Force," Final report on the August 14, 2003 blackout in the United States and Canada: Cause and recommendations" April. 2004.

[7] Bansal R.C., "Optimization Methods for Electric Power Systems: An Overview". International Journal of Emerging Electric Power Systems, Vol. 2, No 1, 2005.

[8] Warwick. K., Ekwue A. and Aggarwal. R. "Artificial Intelligence Techniques In Power Systems". IEE Power Engineering Series, 1997.

[9] Gerbex, S. Cherkaoui, R. and Germond, A.J. "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms", IEEE Transactions on Power Systems, vol. 16, pp. 537-544, Aug. 2001.

[10] Gerbex, S. Cherkaoui, R. and Germond, A.J. "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms", IEEE Transactions on Power Systems, vol. 16, pp. 537-544, Aug. 2001.

[11] Cai L.J.; Erlich I. and Stamtsis G., "Optimal Choice and Allocation of FACTS Devices in deregulated Electricity Market Using Genetic Algorithms". IEEE PES. Power Systems Conferences and Exposition, Vol. 1, 2004.

[12] Bakare G.A; Krost G., "Removal of overloads and Voltage Problems in Electric Power Systems Using Genetic Algorithm and Knowledge Base". IEE Power System Management and Control, 17-19 April, 2002.

[13] Krost, G. Bakare, G.A., "A genetic algorithm based approach for improvement in voltage profile and real power loss minimization". International Conference on Electric Power Engineering, PowerTech Budapest, 1999.

[14] G. Marín, "Manejo de la congestión de sistemas eléctricos de potencia en esquemas deregulados.", Tesis de maestría, Universidad Autónoma de Nuevo León, 2003.

[15] Marín G. and Ramirez, J.M., "Alleviating Congestion Of An Actual Power System By Genetic Algorithms." Proceedings of IEEE Power Engineering Society. General Meeting, Denver, Colorado, USA June 2004, Pag 2134-2142.

[16] Bakirtzis A. G., Biskas P.N. Zouumas C. and Petridis V.," Optimal power Flow by Enhanced Genetic Algorithm". IEEE TRANS. On Power Systems. Vol. 17, No. 2, May, 2002.

[17] P.N. Biskas; N.P. Ziogos A. Tellidou; C.E. Zoumas; A.G. Bakirtzis and V. Petridis., "Comparison of two Metaheuristics with Mathematical Programming Methods for the solution of Optimal Power Flow". IEE Proceeding Gener. Transm. Distrib., Vol 153, No 1, January, 2006.

[18] El Metwally, M.M.; El Emary, A.A.; El Bendary, F.M.; Mosaad, M.I.; "Optimal power flow using evolutionary programming techniques". 12th International Middle-East Power System Conference, 2008. MEPCON 2008.

[19] [19] Bakare G. A., Aliyu U. O., Krost G., and Venayagamoorthy G. k.," Computacional Enhancement of Genetic Algorithm via Control Device Pre- Selection Mechanism for Power System Reactive Power/Voltage Control". IEEEPower Society General Meeting, Vol. 3, July, 2003.

[20] Bakare G. A., Venayagamoorthy G. k and Aliyu U. O." Reactive Power and Voltage Control of the Nigerian Grid System Using Micro-Genetic Algorithm" IEEE Power Society General Meeting, Vol. 2 July, 2005.

[21] Q. H Wu J. Ma., "Power System Optimal Reactive Power Dispatch Using Evolutionary Programming". IEEE Trans. On power Systems, Vol. 10, No 3, 1995.

[22] Cao Y.J., Wu Q. H.,"Optimal Reactive Power Dispatch Using an Adaptive Genetic Algorithm" International Conference on Genetic Algorithms in Engineering System: Innovations and Application, Galesia, 1997.

[23] Ma J.T., Lai L. L., "Application of Genetic Algorithm to Optimal Reactive Power Dispatch Including Voltage-Dependent Load Models". IEEE International Conference on Evolutionary Computation, Vol 1, 1995.

[24] Bakare G. A., Aliyu U. O., Venayagamoorthy G. K., Shu'aibu Y. K., "Genetic algorithms Based Economic Dispatch with Application to Coordination of Nigerian Thermal Power Plants". Power Engineering Society General Meeting, 2005.

[25] Resolución CREG 025/1995, Ministerio de Minas y Energia, Colombia, 1995.

[26] Holland Jonh H. "Adaptation in Natural and Artificial Systems", University of Michigan Press, Ann Arbor, Michigan, 1975.

[27] Goldberg David E.; "Genetic Algorithms in Search, Optimization and Machine Learning"; Addison-Wesley Publishing Company, Inc.; USA; 1989.

[28] Lee, Kuwang; El-Sharkawi, Mohamed, "Modern Heuristic Optimization Techniques, Theory and Application to Power Systems" IEEE press, Wiley, New Jersey, 2008.

[29] Coello Coello Carlos A.; "Introducción a la Computación Evolutiva (Notas de Curso)"; CINVESTAV-PIN; México; Mayo 2007.

[30] Zalzala A.; Fleming P., "Genetic Algorithms in Engineering Systems", Control Engineering Series 55, 1997.

[31] Cavalcanti M. A.,"Algoritmos Genéticos: Principios y aplicaciones", Núcleo de Pesquisa en Inteligencia Computacional Aplicada, 1996.

[32] Man, K.; Tang K.; Kwong S., "Genectic Algorithms: Concepts and Applications", IEEE Trans. On Industrial Electronic, Vol. 43, No.5 October, 1996.