Australian Journal of Basic and Applied Sciences, 5(8): 52-60, 2011
ISSN 1991-8178

Application of Genetic Algorithm for Generation Expansion Planning Considering Renewable Technologies

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Abstract: In this paper, a model for generation expansion planning (GEP) is presented. The proposed model is able to present a clear perspective to government to investment in generation. Renewable technologies have been considered to meet some limits in fuel and environmental emission but adding these technologies to power system will increase the costs. On the other hand, the main objective of planner in generation expansion procedure is decreasing the investment cost. So the GEP problem will be a complex problem especially in large power systems. Genetic Algorithm (GA) is used as a strong intelligent optimization tool to solve GEP problem and meeting its objective along with constraints. Finally, the feasibility of this approach is demonstrated using a case study.

Key words: Genetic algorithm, generation expansion planning, renewable technologies.

INTRODUCTION

Generation expansion planning (GEP) is defined as the problem of determining which, where, and when new generation units should be constructed over a long range planning horizon, to satisfy the expected energy demand. The GEP problem is considered difficult to solve for some reasons resulted from the uncertainty associated with the input data, such as forecasts of demand for electricity, economic and technical characteristics of new evolving generating technologies, construction lead times, and governmental regulations (A. G. Kagiannas, 2004). The aim of a traditional power generation planning has been to provide an adequate supply of electrical energy at minimum cost (Swisher J.N., 1997). Since non-linearity and complexity of GEP problem, a various approaches has been presented to solve and optimization that in traditional environment (J. Zhu, 1997). To cope with the Kyoto Protocol, the policy that the amount of poisonous gas emission is limited under some standard level has been made. Therefore, the environment problem is also becoming a more and more important factor that should be considered in generation expansion for utility companies (N.X. Jia, 2000; N.X. Jia, 2001; W.M. Lin, 2004; W. Xing, 2003). Another issue more relevant to consider nowadays when planning the expansion of electric systems, is the high uncertainty in fossil fuel prices and their increasing trend (IEA, 2004). Despite the attractiveness of generation units that use gas to produce electricity, because they are cleaner and cheaper than the other fossil fuel technologies (oil and coal), the risks of high and uncertain costs of this fuel type have to be considered in the planning process.

It is known that renewable energy such as wind, hydro, solar, and geothermal are relatively expensive and limited in availability. However, to mitigate the environmental impacts to the planet and the risk of depending only on few sources of energy, there is an increasing interest in renewable energy sources (S. Awerbuch, 2004). The alternative of producing more electricity from nuclear sources is also reconsidered by some decision makers (C.E. Escobar, 2003).

This paper studies the multi-period GEP problem which is a large and complex problem especially for a power system with large number of generation units. Genetic Algorithm is used as an optimization tool for solving this complex and non-linear problem. Finally Type and capacity of generation units for each period are determined.

Multi-period Generation Expansion Planning Model:

A. Objective Function:

The generation-transmission supply chain is represented as a network $G = (N, A)$, where N is the set of the nodes and A is the set of transmission lines. The $I \in N$ is a node (a point of demand and/or supply of energy), and the arc $(i, j) \in A$ is a transmission line, $q \in \Theta$ is a generation unit and $K \in F$ is a fossil fuel. T

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is the set of periods in the planning horizon where $t \in T$ is a time period.Some decision variables are present in the GEP model: θ_i is the voltage phase angle at node i; g_{iqt} is the generation amount (MW) of unit type q at node i in period t; n_{iqt} is the number of new units of type q at node i in period t; X_{iqt} is the additional capacity (MW) of unit type q at node i in period t; ΔXl_{ijt} is the additional transmission capacity (MW) in arc (i,j) in period t; l_{ijt} is the number of new circuits on arc (i,j) in period t; u_{kt} is the imported fuel (units) of type k in period t.

In this model, objective is the minimization of government cost which consists of investment and operation costs of generation, transmission cost and cost of imported fuel. In the following, we provide a detailed description of each part.

Investment and operational costs of generation units, and transmission cost:

$$f_1 = \sum_{t\in T}(1+d)^{-t}\left[\sum_{i\in N}\sum_{q\in\Theta}\left(IC_{iqt}\Delta X_{iqt} + GC_{iqt}g_{iqt}\right) + \sum_{(i,j)\in A} C_{ijt}\Delta Xl_{ijt}\right] \tag{1}$$

Where d is the discount rate, IC_{iqt} is the investment cost (\$/*MW*) of a unit of type q at node i in period t, GC_{iqt} is the generation (operation and maintenance) cost (\$/*MW*) of a unit of type q at node i in period t and C_{ijt} is the cost (\$/*MW*) for new transmission capacity in arc (i,j) in period t.- Cost of imported fuel:

$$f_2 = \sum_{t\in T}(1+d)^{-t}\left[\sum_{k\in F} V_{kt}u_{kt}\right] \tag{2}$$

Where V_{kt} is the cost (\$/*unit*) of imported fuel of type k in period t.The government cost is sum of these costs and fitness function can be defined as

$$Fitness = \frac{k}{f_1 + f_2 + penalty} \tag{3}$$

Where "*penalty*" is the penalty factor added if constraints aren't met. It is usually a big value depended on amount of violation from limits. k is a constant value used for refusing of small values for fitness function. Therefore, problem's objective is the maximization of fitness function or minimization of government cost with providing constraints.

B. Constraints:

In GEP, there are some constraints described as follows:

Power balance in each node, transmission capacity on each arc and generation capacity of each unit: optimal dc power flow is done using linear programming to meet these constraints

$$f_{arcijt} = El_{ijt}\gamma_{ij}(\theta_i - \theta_j) \tag{4}$$

$$El_{ijt} = El_{ij(t-1)} + l_{ijt} \tag{5}$$

$$\sum_{(j,i)\in A} f_{arcjit} - \sum_{(i,j)\in A} f_{arcijt} + \sum_{q\in\Theta} g_{iqt} = D_{it} \tag{6}$$

$$\left|f_{arcijt}\right| \le f_{arcijt\max} \tag{7}$$

$$g_{iqt\min} \le g_{iqt} \le g_{iqt\max} \tag{8}$$

Where El_{ijt} is the number of existing circuits on arc (i,j) in period t, γ_{ij} is the susceptance (pu) of a circuit on arc (i,j), and D_{it} is the load/demand (MW) at node i in period t. - Fuel demand for each fuel type k in period t: fuel used will be either from local markets (U_K), the domestic production (in corresponding units) of fuel type k in period t, or if necessary imported

$$\sum_{i\in N}\sum_{q\in J_k} W_q g_{iqt} \le u_{kt} + U_{kt} \tag{9}$$

Where W_q is the consumption of fuel (units/MW) for a unit of type q, and U_{kt} is the national available amount (corresponding units) of fuel type k in period t.- Maximum investment of generation units and transmission lines:

$$n_{iqt} \le Mn_{iqt} \tag{10}$$

$$l_{ijt} \le Ml_{ijt} \tag{11}$$

Here n_{iqt} , l_{ijt} are integer values, Mn_{iqt} is the maximum number of candidate units for addition of type q at node i in period t, and Ml_{ijt} is the maximum number of candidate circuits for addition on arc (i,j) in period t. - Minimum and maximum reserve for generation:

$$\sum_{i\in N} D_{it}(1+r_{\min}) \le \sum_{i\in N}\sum_{q\in\Theta} X_{iqt} \le \sum_{i\in N} D_{it}(1+r_{\max}) \tag{12}$$

$$X_{iqt} = X_{iq(t-1)} + MCG_q n_{iqt} \tag{13}$$

Where, r_{min} and r_{max} are a percentage of demand considered as minimum and maximum reserve in generation, MCG_q is the capacity (MW) of a unit of type q.- Environmental impact: the carbon dioxide emissions (CO_2) from fossil-fuel plants should be limited.

$$\sum_{t\in T}\left[\sum_{i\in N}\sum_{q\in\Theta} E_q g_{iqt}\right] < L_{co2} \tag{14}$$

Where, E_q is Tons of carbon dioxide (CO_2) emission per MW generated by a unit of type q, and L_{co2} is the CO_2 emission limit (TON) in planning horizon.

Genetic Algorithm:

Standard genetic algorithm is a random search method that can be used to solve non-linear system of equations and optimize complex problems. The base of this algorithm is the selection of individuals. It does not need a good initial estimation for sake of problem solution. In other words, the solution of a complex problem can be started with weak initial estimations and then be corrected in evolutionary process of fitness (A. Raie and V. Rashtchi, 2002). The standard genetic algorithm manipulates the binary strings which may be the solutions of the problem. The genetic algorithm generally includes three fundamental genetic operators of reproduction, crossover and mutation. These operators conduct the chromosomes toward better fitness (Raie and Rashtchi, 2002; Jalilzadeh, 2008). Although binary codification is conventional in genetic algorithm, but real and decimal coded genetic algorithms have been also used to solve some problems in (Raie and Rashtchi, 2002) and (Jalilzadeh, 2008) respectively. In this paper, decimal coded genetic algorithm is used to solve the GEP problem because random variables are integer parameters. In this method crossover can take place only at the boundary of two random variables. Mutation operator selects one of existing random variables in chromosome and then changes its value randomly according to its characteristic and limits. Reproduction operator, similar to standard form, produces each chromosome proportional to value of its objective function. Therefore, the chromosomes which have better objective functions will be selected more probable than other chromosomes for the next population (Elitist strategy) (A. Raie and V. Rashtchi, 2002; S. Jalilzadeh, 2008).

Ga Application:

The flowchart of the proposed approach is abstracted in Fig. 1.

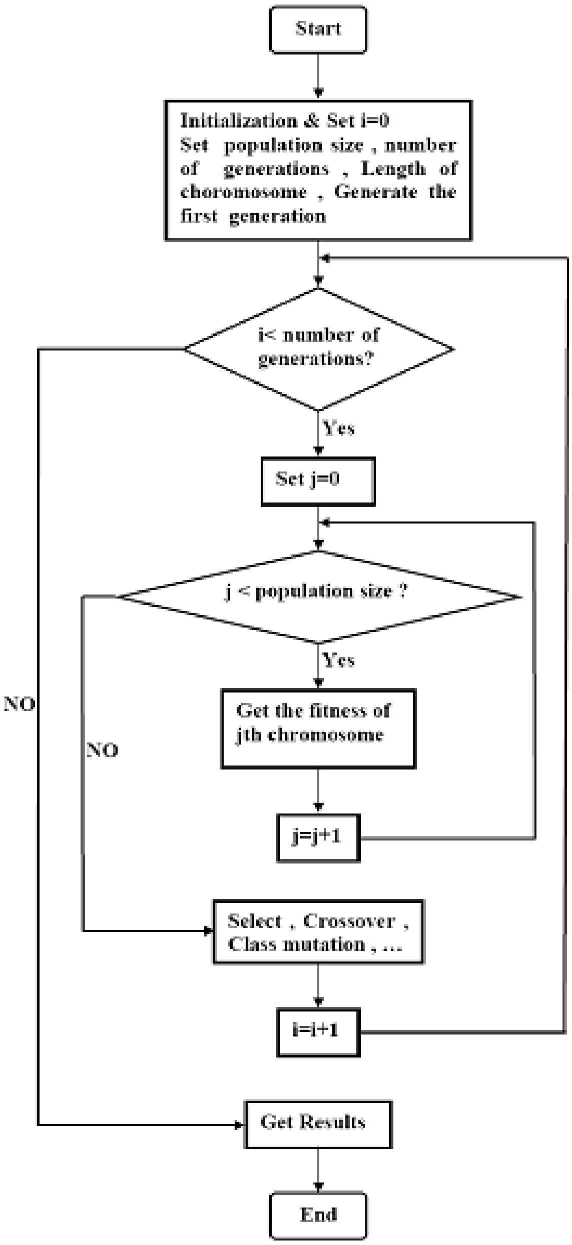

Fig. 1: The flowchart GA approach.

The proposed approach to solve generation expansion planning is based on GA. In this method, the chromosome is defined as an array of random variables as Fig. 2.

In this string, there are 2 different groups of random variables. Where *n* is number of new units, *l* is number of new circuits.

$$|T| \times (|N| \times |\Theta| + |A|) \tag{15}$$

n_{11t}	n_{12t}	$\cdots$	n_{iqt}	l_{1t}	l_{2t}	$\cdots$	l_{jt}

Fig. 2: chromosome structure to solve GEP.

Case Study:

The proposed method is applied using Interconnected Grid Mexican Power System (see Fig. 3), at the level of areas. The input data is based on the information of (Meza, 2006) as follows.

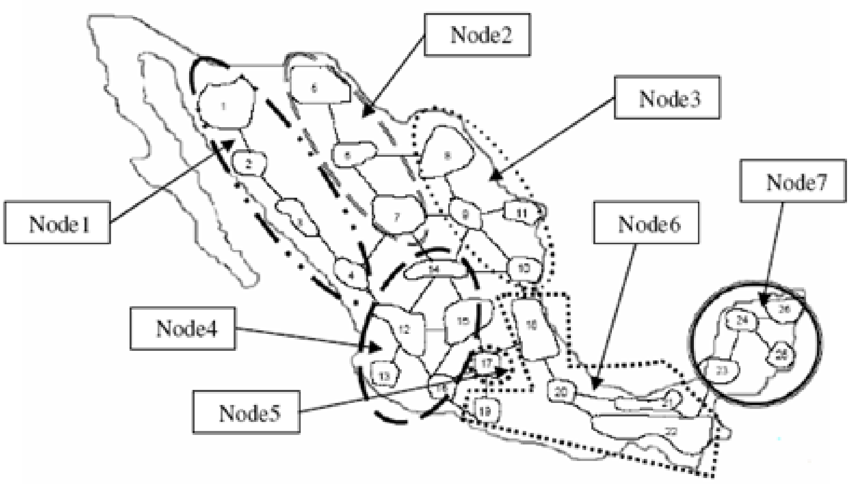

Fig. 3: Interconnected Mexican Electric System (IAMES).

The planning horizon (2005-2014) consists of five biannual periods within the time horizon. The base year is 2004, and the existing capacity in the system, peak load and reserve are respectively 41443 MW, 36037.39 MW, and %15. This system is formed by 7 nodes (areas), 7 arcs, 8 types of generation units, and four types of fuel. Generation technology options for capacity additions include: conventional steam units, coal units, combined cycle modules (CC), nuclear, gas turbines (TG), wind farms, geothermal and hydro units. The types of non-renewable fuel are: coal, gas, oil, and uranium (For more information, please refer to tables (2) to (7) in the appendix).

CO_2 emission limit is 46000 TON in planning horizon. Minimum and maximum amounts of reserve in each period are %5 and %15 of peak load in that period and discount rate is %5.

Load duration curve (LDC) for each area is considered as Fig. 4. In this curve the horizontal axis is scaled based on biannual period of time and the vertical axis is scaled based on the maximum load in the second year of each biannual period.

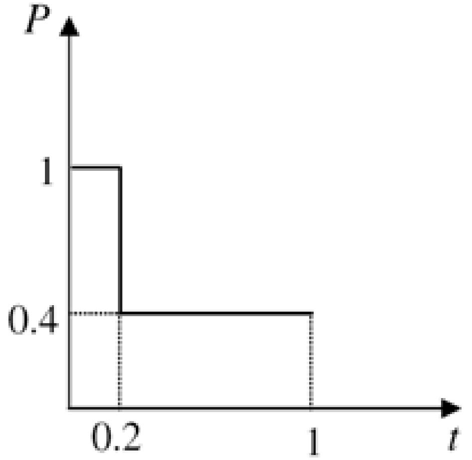

Fig. 4: LDC for each biannual period.

Some parameters are defined for the planning horizon as follows:
*u*cost: total expense of government which is the sum of investment cost for new units and new transmission

lines, generation costs and cost for imported fuel.
fixcu: government expense to provide the investment cost for new units.
ECO2: amount of CO_2 emission.
fuel cost: cost of the imported fuel.
Genetic algorithm with following parameters is used to solve GEP problem.
Population size: 50
Mutation rate (P_m): 0.01
Crossover rate (P_c): 0.9
The GA converged in 1500 iteration.
Computer: PC, Pentium 4, CPU 2.8 GHz, RAM 512 MB
The average of running time per cycle: 5 sec.

As shown in Fig. 5, Genetic algorithm is converged in 1500 iterations. Number of new units for addition in each node and number of new transmission lines is presented in table (1) in planning periods. These new lines are determined according to the growing of electricity demand and generation to meet the power flow equations.

Fig. 6 shows that amount of CO_2 emission is decreased along the running of program to meet CO_2 constraint.

Table 1: New generation units and Transmission lines addition.

period	Units									Lines		
	node	Steam	CC	TG	Coal	Nuclear	GEO	Wind	Hydro	Origin	Destine	Number
1	1									1	2	1
	2									1	4	1
	3									2	3	
	4									3	6	
	5									4	5	
	6							3		6	5	1
	7									6	7	1
2	1							3	2	1	2	
	2		1							1	4	
	3								2	2	3	1
	4			1			1		2	3	6	
	5								1	4	5	1
	6						1	3	2	6	5	
	7									6	7	
3	1							3	2	1	2	
	2	1								1	4	
	3			1	1				2	2	3	
	4						1		2	3	6	
	5								1	4	5	
	6				1	1	1	3	1	6	5	
	7			1						6	7	
4	1							3	2	1	2	
	2			1						1	4	
	3		1		1				2	2	3	
	4		1	1	1		1		2	3	6	
	5								2	4	5	
	6		1				1	3	2	6	5	
	7			1						6	7	
5	1							3		1	2	
	2		1	1						1	4	
	3								2	2	3	
	4						1		2	3	6	1
	5									4	5	
	6						1	2	2	6	5	
	7		1	1						6	7	

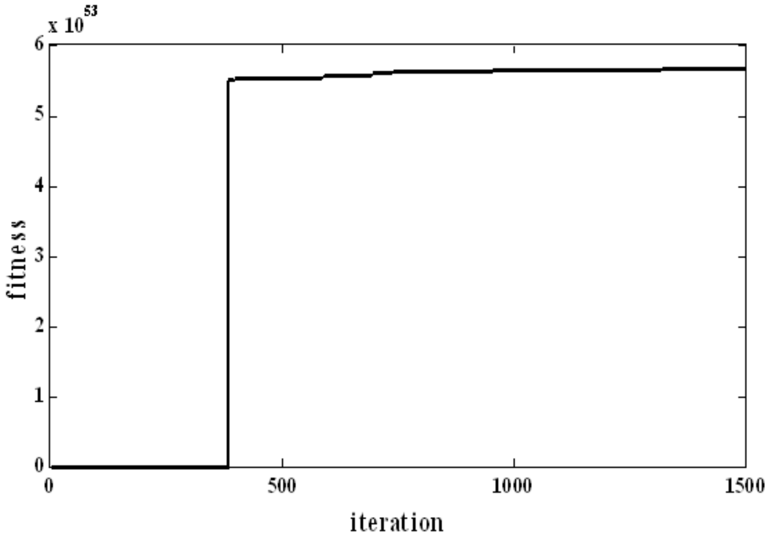

Fig. 5: Fitness variation versus GA number of iterations.

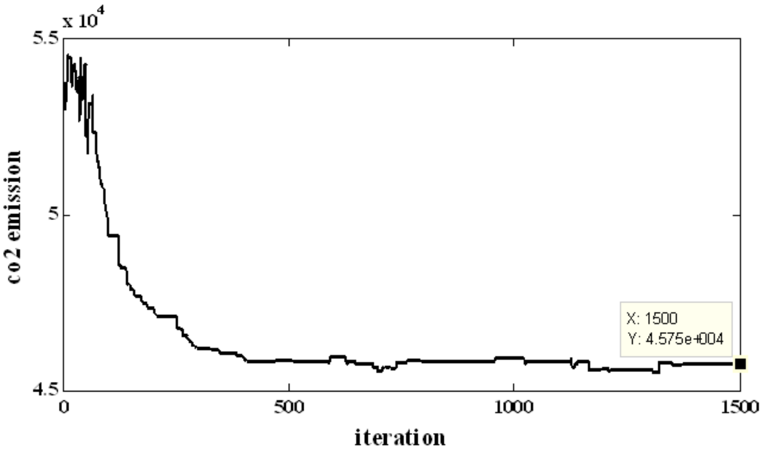

Fig. 6: CO_2 emission versus GA number of iterations.

$$u\cos t = 4.3914\times10^{10}(\$) \qquad fixcu = 3.1481\times10^{9}(\$)$$

$$ECO2 = 4.5750\times10^{4}(TON) \qquad fuel\cos t = 1.0775\times10^{6}(\$)$$

Total expense of government, government expense for constructing of new unit, amount of CO_2 emission and cost of imported fuel are presented. The program has provided all of the constraints.

The renewable technologies are added at their maximum because of fuel and CO_2 emission limits. Low cost and high availability of fuel (gas), low environmental emission and reasonable operation and investment costs of CC technology motivates planning program to use this type of units in higher percentage than other fossil fuel technologies.

Conclusion:

This paper demonstrates the effectiveness of genetic algorithm as an intelligent method to solve non-linear and complex problems such as GEP. Generation expansion planning is formulated in this paper by considering some limitations in providing required amount of fuel and CO_2 emission. These constraints are met by adding renewable technologies to power system. But the planning program still uses fossil fuel units for expansion because of their lower cost. A large scale power system is considered to study the performance of proposed approach. Obtained results show that the proposed approach is able to present a methodology for expanding generation units along with meeting fuel and environment emission constraints in multi period.

Appendix:
Input Data:

Table 2: Existing capacity (MW) by technology in the base year.

Node	Steam	CC	TG	Coal	Nuclear	GEO	Wind	Hydro
1	2092	496						898
2	1035	1535						
3	1265	3218	1488	2600				66
4	3466	577	597	2100		190		2783
5		1989	1449					292
6	2380		1930		1365	40		6120
7	150	1045	277					

Table 3: Type of units.

	TYPE	Capacity (MW)	Fuel	*Wt* consume	Units	*Et* CO2 E	I_{it}(*$/KW*)Invest	O&M (*$/MW*)
1	STEAM	350	Oil	1.54	Barrel	0.795	166	494064
2	CC	560	Gas	7.00893	Mbtu	0.359	80	525600
3	TG	184	Gas	10.43537	Mbtu	0.508	60	630720
4	COAL	350	Coal	0.46587	TON	0.957	260	252288
5	NUCLEAR	1506	Nuclear	2.68000	GR	0	386	105120
6	GEO	230	Steam	0	TON	0	212	191318.4
7	WIND	100	Wind	0	NO	0	200	52560
8	HYDRO	200	Water	0	NO	0	180	252288

Table 4: Peak load (MW) in each period.

Node	2006	2008	2010	2012	2014
1	2873	3140	3473	3821	4135
2	3216	3542	3941	4382	4832
3	6673	7363	8293	9352	10511
4	7412	8302	9344	10423	11493
5	8762	9453	10298	11196	12069
6	6187	6890	7743	8617	9558
7	1229	1391	1604	1816	2072

Table 5: Fuel types.

Fuel	Units	U_k (*Units*)Capacity	V_k (*$/Units*) Import Cost
Oil	Barrel/day	1742.27460	26.75
Gas	Mbtu/day	42630.45704	4.70
Coal	Ton/year	16800	33
Nuclear	GR	1000	2.1

Table 6: Economical components.

Parameter	Rate (%)
Investment inflation	3
Operation inflation	5
Fuel inflation	4
Transmission inflation	3

Table 7: Inter-area links in the base yearOrigin.

Origin	Destine	X_{ij}(*MW*)Capacity	Fixed C(*$/KW*)	Length (Miles)
1	2	300	3.903	176
1	4	320	3.903	252
2	3	260	3.903	215
3	6	1000	3.903	231
4	5	2900	3.903	232
6	5	3800	3.903	280
6	7	435	3.903	296

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