Optimum Generation Mix for Malaysia's Additional Capacity Using Evolutionary Programming

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***Abstract*—Energy Commission Malaysia is targeting 4100 MW of power generation capacity via competitive bidding to replace capacity from the 1st generation Power Purchase Agreement (PPA) that will be retired from 2015 to 2017 and to cater for future demand growth. Malaysia's generation mix has been long time dependence on a single fuel. This over-dependency is not a good option for long-term energy sustainability and security. This has led Malaysia to find other alternative resources to generate electricity. Some possible options are: 1) coal, 2) nuclear and 3) renewable energy (RE). This paper proposes to determine optimum alternative resources of generation mix for Malaysia's additional capacity in 2015 using Evolutionary Programming (EP) at the least cost. The model takes into account characteristics associated with different technologies, such as the investment cost, the O&M cost, the fuel cost and the heat rate. This paper considers four new expansion candidates i.e. coal, natural gas, nuclear and renewable energy as the major power generation sources. Result shows that, the optimum generation mix for Malaysia's additional capacity in 2015 will be 67.9% is from coal, 22.51% from natural gas, 8.21% from nuclear and 1.25% from RE.**

Keywords*—*Optimum Generation Mix, Evolutionary Programming (EP), Nuclear, Economic Dispatch, Least Cost

I. INTRODUCTION

Malaysia has considered various efforts to create economic stability in order to attract outside investors to invest in various industry sectors. These efforts include developing a sustainable power generation sector to continuously supply electricity to industries at the least cost, reliable supply and minimum impact to the environment. It is very important to ensure the energy needs is sufficient in line with the economy as it continues to growth rapidly. High demand for electricity in the domestic and the commercial sector is growing in concomitant with Gross Domestic Product (GDP) growth in Malaysia. It was reported that the forecasted demand for electricity growth in 2012 increased to 3.7% compared to 3.2% in 2011 [1]. It was also reported that, in 2012, natural gas contributed to 52.7% of the power generation followed by coal, hydroelectric, oil and others sources by 38.9%, 7.3%, 1% and 0.2% respectively [2].

The electricity generation mix in Malaysia strongly relies on fossil fuels such as coal and natural gas which is not economically and commercially practical for long-term. In 1979, the government has formulated National Energy Policy 1979 to ensure the energy supplies are able to maintain its performance in term of non-contamination environmental with high security and efficiency. With respect to the rapid increase of production of the crude oil, a new policy i.e. National Depletion Policy 1980 was introduced to preserve the exploitation of natural oil reserve [3]. The over-reliance on oil as main resources, then has led the government to establish Four Fuel Diversification Policy 1981 to ensure the reliability of the energy that focused on four energy sources which is oil, natural gas, hydroelectric and coal [4]. As an effort to reduce the environmental impact of the conventional power plant, the government then introduced Five Fuel Diversification Policy in 2011 which include the Renewable Energy (RE) as the fifth fuel [5]. There are few other policies have also been introduced by the government to facilitate the other policies in Malaysia. These include Energy Policy which was imposed in 2010 to improve the energy security that focused on economic, environmental and social considerations.

There are three major utilities in Malaysia that play an important role to provide electrical power supplies which are Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn. Bhd. (SESB) and Sarawak Energy Berhad (SEB). In Peninsular Malaysia, in 2012, TNB supplied 11,462MW of electricity to consumers. SESB supplied 1,141MW of electricity in Sabah and it was 83% of the TNB Subsidiary. On the other hand, in Sarawak, SEB supplied 1,237MW. The electricity in Malaysia is mostly supplied by Independent Power Producers (IPPs) with 52% of the load and TNB with 48%. Table I shows the increased of total unit of electricity sold from 2009 to 2012.

It is reported that, 4100 MW of IPPs generating capacity comprising combined cycle and open cycle gas fired power plants are due to expire between 2015 and 2020. These include YTL Power International Berhad, Powertek Berhad, Malakoff Port Dickson Power, Genting Sanyen Power Berhad, S.J Serdang and S.J Sultan Iskandar Pasir Gudang with capacity of 1170 MW, 434 MW, 436.4 MW, 762 MW, 625 MW and 729 MW respectively. With 4100 MW of new capacity coming on stream by 2017, it may be boom years in the power engineering business. It is important for the Energy Commissioner Malaysia to find an optimum generation mix strategy for the additional capacity considering other alternative resources such as nuclear and RE.

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TABLE 1 ELECTRICITY SUPPLIED BY TNB [6]

	Peninsular Installed Capacity (MW)	Total Units Sold (GWh)	Total Customers (million)	Total Assets (RM billion)
2009	11,530	87,780	7.59	71.4
2010	11,530	95,197	7.87	75.9
2011	11,530	97,888	8.11	79.1
2012	11,462	102,132	8.36	88.5
Half year 2013	11,462	52,129	8.47	88.3

There are several techniques have been proposed to determine the least cost optimal generation mix. Traditional approach to solve generation planning problem are based on mathematical programming method such as Linear Programming [6-8] and Dynamic Programming (DP) [9-11]. Other approach is based on Artificial Intelligence (AI) technique such as Evolutionary Computation (EC) programming which consists of several types i.e. Evolutionary Programming (EP) [12], Evolutionary Strategy (ES), Genetic Programming (GP) and Genetic Algorithm (GA) [13-15]. Recent techniques include Particle Swarm optimization (PSO), Bee Colony optimization (BCO) and Ant Colony optimization (ACO) [16].

Very limited study can be found to study generation mix for Malaysia. Among these works, the authors of [6] uses two-phase K-Best Dynamic Programming trade-off method to find the optimal generation mix planning for 2000 MW additional capacity and [17] uses General Algebraic Modeling system (GAMS) to determine a generation mix for Malaysia with less carbon emission. Both of the technique choose conventional optimization technique to solve Malaysia's generation mix problem.

This research proposes to find an optimum generation mix for 4100 MW Malaysia's additional generation capacity in 2015 using a modern optimization technique EP at least cost. The work considers new alternative resources such as nuclear and RE. This additional capacity is to replace the first IPP power generations that will be retired soon and to cater for the load growth.

II. POWER GENERATION TECHNOLOGY OPTIONS

In this paper, there are some generations technologies have been considered as candidates for generation expansion. The availability, the limitation and the challenge of each of the technologies is discussed in this section.

A. Natural Gas

One of the main sources in Malaysia is natural gas that is owned by Petronas Carigali Company. The natural gas is mostly reserved in Terengganu and Sarawak. However, the production of the natural gas has decreased about 10% because of the scattered of gas fields in the distribution [1]. For a long term it will be a challenge for the government to rely on natural gas for supplying energy.

B. Coal

Coal is one of the main sources that contribute to the supply of energy in Malaysia which is cheaper than natural gas. Main coal field in Malaysia is located in Sabah and Sarawak and most of the supply was imported from Indonesia, Australia and South Africa with 84%, 11% and 5% of coal supply respectively in 2011 [1]. However, in 2009 the availability of coal became worse when Indonesian government announced to limit the exports of the coal [18]. Furthermore, the coal supply is exposed to risks such as weather, political and competition in some developing countries like China and India [18]. Another issue is related to environmental risk due to carbon emission from the burned coal ashes. Moreover, coal has the highest carbon footprint among all the fossil fuel resources. The introduction of carbon tax and market for carbon trading in some countries has increased the cost of generating electricity from coal.

C. Hydroelectric Power

Other resources such as hydroelectric power (HEP) plant can be found in Temenggor, Kenyir and Bakun.. The constructions of the hydroelectric involve large high areas that have water resources to generate energy. It also requires high cost due to complex design and operation of the dams. Although Malaysia has abundance of hydro potential, most of the hydropower potential is situated in the Borneo and not in the peninsular [19]. Hydro potential for Peninsular Malaysia is limited due to the flat terrain and political constraint. Therefore, this generation technology is not considered as expansion technology in this paper. Furthermore, developing a new hydropower plant requires support from the State Government which is not easily obtained [20].

D. Renewable Energy

Renewable energy (RE) is a source that provides an alternative supply to the generation mix in Malaysia. Examples of RE include biomass, biogas, solar, wind and geothermal. RE uses energy that produces by nature (such as sun, wind and wave) to generate electricity. RE is environmental friendly resource and it has high potential to reduce carbon emission and eliminate pollution. However, the energy produced by RE is smaller compared to other sources. Generating electricity from RE involves high cost as RE uses high end technology to convert solar energy to electricity. Yet, RE is still considered in this case study as it has high potential to contribute to sustainable generation mix.

E. Nuclear

Nuclear is another possible option for Malaysia's generation mix as it is capable to produce large amount of energy and reduce carbon emission from the conventional power generation. Nuclear uses uranium and plutonium as fuels to generate energy [21]. Nevertheless, nuclear investment cost is costly; the operation of nuclear power plant is complex as well as dangerous as it forms a radioactive waste which is hazardous to public [16]. Major arguments that relate to the nuclear are due to its limited raw material supply (Uranium) and nuclear power plant requires specially-trained engineers to operate the plant safely [13]. Despite of its complex engineering design and stringent safety requirement, nuclear is considered in this paper as alternative resources for Malaysia's future generation mix.

III. EP-BASED GENERATION MIX MODEL

A. *Generation Mix Optimization Model*

The objective of this paper is to find an optimum generation mix for the 4100 MW additional generation capacity at the most economical costs-effective way. These costs include investment and operation costs as follows;

Objective function:

$$TotC = \min \Sigma \{FCi(Xi) + VCi(Xi)\} \qquad (i=1,\ldots,n) \quad (1)$$

The optimization is subject to some constraints such as, 1) the total capacity of the new generation must greater or equal to 4100 MW, 2) capacity of nuclear is between 300 MW to 800 MW, 3) capacity of coal is between 2000 MW to 3000 MW, 4) capacity of gas is between 500 MW to 1000 MW and capacity of RE is between 20MW to 80MW. These are shown in equation 2 to equation 6 as below:

$$\Sigma \{X_{ni} + X_{ci} + X_{gi} + X_{rei}\} \geq T \qquad (i=1,\ldots,n) \quad (2)$$

$$300MW \leq X_{ni} \leq 800MW \qquad (i=1,\ldots,n) \quad (3)$$

$$2000MW \leq X_{ci} \leq 3000MW \qquad (i=1,\ldots,n) \quad (4)$$

$$500MW \leq X_{gi} \leq 1000MW \qquad (i=1,\ldots,n) \quad (5)$$

$$20MW \leq X_{rei} \leq 80MW \qquad (i=1,\ldots,n) \quad (6)$$

The fixed and variable costs are calculated using equations below:

$$FC_i = X_i \, IC_i \qquad (i=1,\ldots,n) \quad (7)$$

$$VC_i = \Sigma \, MC_i \, Ltis \, Ps \qquad (i=1,\ldots,n) \quad (8)$$

where,

n : Number of unit of the power generation
$TotC$: Total cost of the system
X_i : Decision variable for generation type i for each type of generation sources $[X_{ni}, X_{ci}, X_{gi}, X_{rei}]$
FC_i : Fixed cost of the system
VC_i : Variable cost of the system
T : Target capacity
X_{ni} : Decision variable for nuclear
X_{ci} : Decision variable for coal
X_{gi} : Decision variable for natural gas
X_{rei} : Decision variable for renewable energy
IC_i : Investment cost of the system
MC_i : Marginal cost of the system for generation type i
$Ltis$: Load produced by generating unit i at segment s
Ps : Period of time of segment s

B. *Economic Dispatch*

Economic dispatch is a short term determination of the optimal output of a number of electricity generation facilities to meet the system load at the lowest possible cost. Economic dispatch is modeled in the EP-based generation mix model to calculate the power dispatch by the generating unit in the system and production cost of each unit. The economic dispatch is performed for each segment of the load duration curve (LDC) of each year. Fig. 1 shows a six-segment discretized additional 4100 MW LDC used in this project.

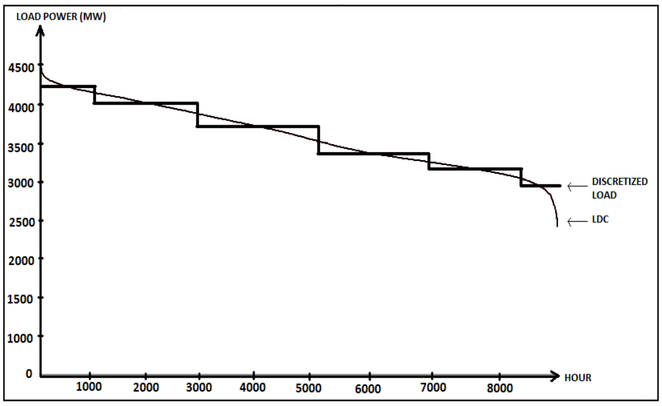

Fig. 1 Load Duration Curve

The economic dispatch is modeled as an optimization problem in which the total yearly operating cost is minimized:

$$\min \left\{ \sum_{s=1}^{S} \sum_{i=1}^{I} \left(MCb_i \; p_{i,s} \; d_s \right) \right\} \quad (9)$$

The objective function is subject to several constraints:

$$\textstyle\sum_{j=1}^{J} p_{j,s} = pd_s \quad (10)$$

$$p_j^{min} \leq p_{j,s} \leq p_j^{max} \quad (11)$$

where pd_s is the system demand at segment s, P_j^{min} and P_j^{max} is minimum and maximum output power of the generating unit.

The first constraint is enforced so that the selected generation meets the load demand of segment s; as in equation (10). Each of generating unit is also constrained by its minimum stable generation and the maximum capacity that can be supplied as in equation (11).

IV. EVOLUTIONARY PROGRAMMING (EP)

The objective of EP technique is to optimize fitness which can be represented using mathematical equations either to minimize or maximize the fitness. In this study, the objective function is to minimize the total cost of the generation mix. There are a several phases in EP techniques as explain in the following sections:

A. Initialization Phase

The initialization phase or also known as pre-optimization phase is where the random number is generated that represents the variables to control the objective function. In this case study, the variables are X_n, X_c, X_g and X_{re} which represent the capacity of nuclear, coal, natural gas and RE respectively. The constraints of each variable are set in this phase. The command used to generate random numbers is as follows:

$$Xi = rand(x, y) * A + B \quad (12)$$

where: x : no of row
y : no of column
A : the offset
B : the minim

Twenty populations of random numbers are generated to meet the constraints that have been set earlier. Sets of variables that met the constraints are classified as acceptable populations or identified as acceptable installed capacity. Then the acceptable populations are loaded into pool populations. For each population, the variable and fixed costs are calculated. The variable cost is determined by performing economic dispatch for each segment of the LDC. On the other hand, the fixed cost is equal to investment cost ($/MW) multiplied by the generation installed capacity in MW.

B. Fitness Phase

Fitness is the equation or the function to be optimized. It can be either a single mathematical equation or a set of sub-program. In this study, the objective function is to minimize the total cost i.e. investment and operation costs of the generation mix.

C. Mutation Phase

Mutation phase is the phase to generate offspring or children from the parent populations. There are various techniques available to perform the mutation process. In this paper Gaussian Mutation Technique is chosen. The Gaussian's formula is shown below:

$$x_{i+m,j} = x_{i,j} + N[0, \beta(x_{jmax} - x_{jmin})] \quad (13)$$

where: $x_{i+m,j}$: offspring
$x_{i,j}$: parents
β : search step
x_{jmax} : max parents
x_{jmin} : min parents
f_{max} : max fitess

Syntax in MATLAB is as follows:

$$z1 = 0.0005 * (x_{max} - x_{min}) * (\frac{output_{fit1(i,1)}}{ymax}) \quad (14)$$

$$[sat1] = Gauss\_EP1(Z1) \quad (15)$$

$$x_{new} = x + imag(sat1) \quad (16)$$

where equation 15 is Gaussian Mutation Function and equation 16 is new children/offspring.

D. Combination Phase

After the new offspring have been generated, the parent and the children are combined in the combination phase. The number of rows now becomes double as the parent and the offspring are combined in series.

$$combination = \frac{parents}{offsprings} \qquad 2m\ x\ n = \frac{m\ x\ n}{m\ x\ n}$$

E. Selection Phase

In selection phase, the survivors are determined. The sets of variables are ranked according to their fitness value. There are two types of sorting; 1) ascending and 2) descending order. In this study, the fitness value is ranked in the ascending order.

F. New Generation Definition Phase

New generation definition displays the new sets of variables from the fitness function that have been optimized.

G. Convergence Test Phase

Convergence test is to determine the stopping criterion of the simulation. If the difference between the maximum fitness and minimum fitness is zero, the solution is said converge and the simulation stops. The value of accuracy was set to 0.0001as shown in the equation below:

$$f\_max - f\_min < 0.0001 \quad (17)$$

V. SIMULATION AND RESULTS

The proposed EP based generation mix model has been tested for 4100 MW Malaysia's additional capacity. Table 2 shows data of the expansion candidates which includes maximum and minimum power of the generating capacity and fixed and variable costs.

TABLE 2 EXPENSION DATA FOR EP-BASED GENERATION MIX

Parameters	Unit	Coal	Natural Gas	RE	Nuclear
Pmax	MW	3000	1000	80	800
Pmin	MW	2000	500	20	300
Fixed Cost	$/MW	1,175,000	452,000	2,775,000	1,810,000
Variable Cost	$/MWh	15	30	50	10

The values of twenty random numbers or installed capacity generated in the initialization phase for each candidate units are shown in Table 3.

TABLE 3 INSTALLED CAPACITY BEFORE OPTIMIZATION (MW)

No.	Nuclear, Xn (MW)	Coal, Xc (MW)	Natural Gas, Xg (MW)	Renewable Energy, Xre (MW)	Total capacity (MW)
1	696.10	2421.76	957.87	96.76	4172.49
2	775.11	2694.83	658.55	22.76	4151.25
3	525.27	2689.21	874.08	26.71	4115.27
4	342.22	2817.30	934.35	51.98	4145.85
5	623.87	2649.12	865.86	56.07	4194.92
6	764.69	2780.23	540.56	82.06	4167.54
7	705.79	2644.32	689.30	62.63	4102.04
8	737.97	2350.73	969.50	64.01	4122.21
9	657.52	2494.17	889.53	92.30	4133.52
10	649.05	2666.34	769.56	73.32	4158.28
11	619.27	2695.95	849.94	22.69	4187.85
12	420.35	2637.71	978.85	74.09	4111.00
13	631.00	2770.29	675.11	53.29	4129.69
14	734.97	2582.25	770.37	41.18	4128.77
15	730.99	2768.85	583.63	99.19	4182.66
16	587.33	2498.09	950.43	87.61	4123.47
17	756.07	2675.39	734.23	28.32	4194.01
18	448.67	2995.39	666.05	24.96	4135.07
19	354.58	2905.13	766.89	86.06	4112.66
20	603.93	2780.18	668.79	79.30	4132.20

These twenty populations are the sets of variables that met the maximum and minimum power of generating capacity constraints and the minimum total capacity required in the system as set earlier. This can be seen in Table 3 that the capacity of nuclear is between 300 MW to 800 MW, the capacity of coal is between 2000 MW and 3000 MW, natural gas is between 300 MW to 800 MW and RE is between 20 MW to 80 MW. All the twenty population has total installed capacity greater than 4100 MW. The highest total installed capacity that randomly generated in the initialization phase is 4194.92 MW.

The fixed cost, variable cost and the total cost for each randomly set capacity generated in Table 3 are then calculated as shown in Table 4 below:

TABLE 4 FIXED COST, VARIABLE COST AND TOTAL COST (RM)

No.	Fixed Cost (RM)	Variable Cost (RM)	Total Cost (RM)
1	4,806,980,688	341,503,186	5,148,483,874
2	4,930,186,099	335,233,674	5,265,419,773
3	4,579,757,794	341,466,161	4,921,223,955
4	4,496,322,476	353,535,630	4,849,858,107
5	4,788,895,102	347,631,125	5,136,526,227
6	5,122,904,178	337,838,296	5,460,742,475
7	4,869,907,119	331,794,864	5,201,701,984
8	4,713,681,652	333,039,422	5,046,721,075
9	4,778,954,585	338,062,351	5,117,016,937
10	4,859,045,424	341,696,690	5,200,742,115
11	4,735,745,485	346,901,075	5,082,646,560
12	4,508,186,039	345,511,850	4,853,697,890
13	4,850,240,644	338,722,988	5,188,963,633
14	4,826,927,437	334,035,550	5,160,962,987
15	5,115,546,999	341,310,826	5,456,857,826
16	4,671,051,415	339,820,740	5,010,872,156
17	4,922,528,905	341,705,150	5,264,234,055
18	4,702,008,818	347,440,004	5,049,448,823
19	4,640,779,914	348,619,889	4,989,399,803
20	4,882,177,248	340,242,534	5,222,419,782

The optimum generation mix for 4100 MW additional generation capacity after the EP simulation is converged is shown in Table 5. It is seen that, coal has the highest capacity with 2814.73 MW followed by natural gas with 932.97 MW, nuclear with 340.55 MW and RE with 51.63 MW. The total cost for the optimum generation mix is RM 4,488,772,214. This optimum cost is much lower than the cost obtained in the initialization phase as shown in Table 4.

TABLE 5 INSTALLED CAPACITY AFTER OPTIMIZATION (MW)

Nuclear, Xn (MW)	Coal, Xc (MW)	Gas, Xg (MW)	RE, Xre (MW)	Total capacity (MW)	Total cost (RM)
340.55	2814.73	932.97	51.63	4145.50	4,488,772,214

Fig. 2 shows the percentage of optimal generation mix for Malaysia's additional 4100MW according to fuel types, where 67.9% are from coal, 22.51% from natural gas, 8.21% from nuclear and 1.25% from renewable energy.

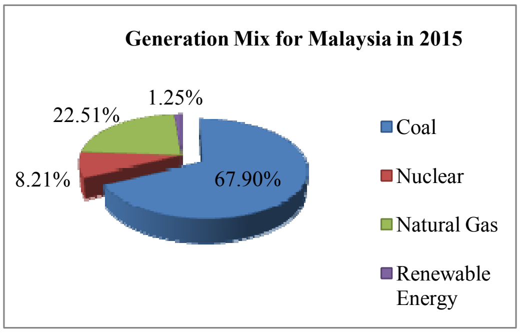

Fig. 2 Optimize generation mix in 2015

VI. CONCLUSIONS

In this paper, Evolutionary Programming technique has been used to determine optimum generation mix for Malaysia's additional capacity. Four different power generation technologies i.e. nuclear, coal, natural gas and RE have been used as the candidates for expansion. Result shows that the optimal generation mix for Malaysia additional capacity will be coal with 67.90%, natural gas with 22.51%, nuclear with 8.21% and RE with 1.25%.

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