Model of Long Term Electricity Generation Expansion Planning in Thailand by Load Demand Forecasting

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Abstract
This paper presents a mathematical model to an application of a least-cost generation expansion planning (GEP) problem in Thailand. Least-cost GEP problem is concerned with a highly constrained non-linear dynamic optimization problem that can only be solved by complete enumeration. The model consists of the cost function that minimizes the construction and operating costs. The genetic algorithm (GA) is employed for optimization algorithm to determine the types of generation which meet the forecasted demand within a pre-specified criterion over the planning horizon from 2007-2021. The proposed model indicates that 53% (47% natural gas, 2% lignite, and 4% turbine) of electricity must be supplied from the Electricity Generating Authority of Thailand (EGAT), and 47% purchased from private enterprises (40%) and neighboring countries (9%).

Keyword: Electricity generation expansion, Load forecasting, Optimization.

1. Introduction

The growth of population and industries reflect the increasing consumption of electricity around the world including Thailand. Because of technical and economical differences of the energy sources, generation expansion planning (GEP) is generally used to determine the best unit type for the additional power unit [1] and in decision-making activities in electric utilities. Least-cost GEP is used to determine the minimum-cost capacity addition plan that meets forecasted demand within a pre-specified reliability criterion over a planning horizon [2]. Costs have always been a very important factor in decision-making, especially between alternative energy sources and electricity generation technologies. The costs of power units consist of two groups: construction cost and operating cost including fuel and operating and maintenance (O&M) costs. All of the items in fuel and O&M costs affect the overall operating cost. An increase in regulatory actions is the major factor causing the escalation in O&M cost. However, these regulation-induced cost increases are partially offset by strong learning effects that cause O&M costs to fall. The escalation in capital addition costs is the result of increase in regulatory requirements and unit aging [3] the reliability of a unit, usually expressed as load factor, determines how much output it produces. As the load factor or output increases, the fixed costs can be spread and operating costs decrease. Insufficient operating performance is likely to result in higher operating costs. Costs, risks, and benefits of an energy source need to be evaluated against those of other energy sources. In general, national policy on energy should aim to implement systems ensuring diversity and security of supply [1]. To ensure the adequate electricity supply in the future, the Electricity Generating Authority of Thailand (EGAT) has establishes a policy called the Power Development Plan (PDP). This plan will be used to determine Thailand's electricity expansion in the next 15 years, starting from 2007 until 2021 [3]. In 2008, Thailand's electricity production is the following: 70% natural gas, 12.6% lignite, 8.2% imported coal, 4.7% hydro power, 1.9% purchase from Laos, 1.4% renewable energy, 1.2% fossil fuel [4]. However, in the future the domestic production of natural gas tends to be decreasing, as well as the increasing price according to the price of crude oil. This trend will accordingly affect the electricity production cost in the future. The main objective of the PDP in 2010 is to reduce greenhouse gas emissions from electricity generation sector [5]. To meet this objective, the proportion of renewable energy in electricity generation must increase. Bio-fuels, wind energy, solar energy, and hydro power are clean energy and environmentally friendly. The 15-year plan seems to be focused on clean energy, promoting alternative energy, and stimulating private investment to build small to medium scale power plants. The PDP 2010 also encourages to build 11 nuclear power plants within 20 years and to develop 23 coal power plants [6]. Therefore, the country must supply enough electricity to meet the demand by considering the existing power plants, the need for constructing new plants, as well as the plant expiration of each year during 2007 to 2021 [7]. The government main policy on energy is of expanding capacity to meet the energy demand and providing sufficient fuel for power generation [8]. This paper has focused on studying a suitable model of fuel proportion and power plants construction for long term electricity generation expansion planning in Thailand until the year 2021.

2. Electricity Generation Expansion

Generation expansion planning is an important planning activity for utility companies. Its basic objective is to determine the schedule for the construction of generation plants, the number and time of introduction for each new generation unit into production, and interconnecting links so that a reliable and economic supply for predicted load demands is ensured. The economic issue can be addressed by minimizing the expected sum of the investment and operation costs associated with each new generation unit under uncertain conditions. The reliability requirement is to ensure an adequate energy supply for predicted load demands under uncertain conditions. Sources of this uncertainty may come from future operating conditions, social and economic activities [9]. The electricity generation and supply under the Thai government is managed by three power utilities, i.e., the Electricity Generating Authority of Thailand (EGAT) responsible for generation and transmission, the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA) being the distribution bodies. Currently the national power system is divided into five areas including Northern region, Northeastern region, Southern region, Central region, and Metropolitan area. All of the existing power plants with the corresponding capacity and type of fuel used are obtained from EGAT [10-11].

Data for Electricity generation expansion as follows: (Table 1-3)

1) National energy policy (Plan PDP2007)
2) System capacity electric current and past
3) Forecasted demand of electricity in long run consists of demand of electric power MW (for new constructing planning, Forecasted demand of electricity) Unit; 1 Unit = 1 kWh (for fuel supply and purchase planning and forecasted demand under PDP show in table 1)
4) Fuel show in table 2 and 3
5) Different types of power plants as alternative contained in the plan
    - 700 MW coal-fueled power plant
    - 700 MW natural gas power plant
    - 230 MW gas turbine power plant
    - 1,000 MW nuclear power plant
6) Requirement on Electricity Stabilization
    - Reserve electricity is no less than 25% of overall production capacity
    - Gas Turbine power plant generates the electricity not exceeding 10% of overall production capacity.
    - Nuclear power plant generates the electricity not exceeding 10% of overall production capacity.
    - Buying from IPP must not exceeding 36% of overall production capacity
    - Buying from SPP must not exceeding 3,600 MW, maximum sale
    - Ratio for imported electricity
    - Buying from a country must not exceeding 13% overall production capacity

Table 1: Forecasted demand of electricity under PDP 2007

Year	Maximum Electric (MW)	Electric Power (GWh)
2007	22,586	148,073
2008	23,957	156,335
2009	25,225	164,774
2010	26,635	173,835
2011	27,996	182,618
2012	29,629	193,258
2013	31,384	204,844
2014	33,216	216,949
2015	35,251	230,370
2016	37,382	244,365
2017	39,560	258,657
2018	41,795	273,387
2019	44,082	288,404
2020	46,481	304,154
2021	48,958	320,376

Note: From 2008 forwards, net generation excluded station service.

Table 2 : Constructing and Generating Data by Fuel Used

Type (j)	Unit Size (MW)	Operating Hours (h/yr)	Life time (yr)	Available Cap. Factor	Escalation rate
Nat. Gas	700	5,000	25	0.90	0.02
Coal	700	8,760	30	0.90	0.06
Lignite	550	8,760	30	0.90	0.06
Gas Turbine	230	1,500	20	0.98	0.02
Nuclear	1,000	8,760	60	0.85	0.09
SPP	260	5,000	-	0.98	0.00
IPP	260	5,000	-	0.98	0.00
Import	270	5,000	-	0.98	0.00

Table 3 : Constructing and Generating Cost by Fuel Used

Type (*j*)	Construction cost (Baht/kW)	Unit cost (Baht/kWh)	Operating Cost (Baht/kWh yr)
Nat. Gas	24,718	1.50	7,500
Coal	52,700	1.00	8,760
Lignite	52,700	0.53	4,643
Gas Turbine	14,858	6.75	10,125
Nuclear	104,958	0.53	14,560
SPP	-	1.00	2,600
IPP	-	1.00	2,600
Import	-	1.00	2,700

3. Genetic Algorithm

The genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. A fitness function is used to evaluate individuals, and reproductive success varies with fitness. Recently, a global optimization technique using GA has been successfully applied to various areas of power system such as economic dispatch unit commitment, reactive power planning and power plant control. GA-based approaches for least-cost GEP have several advantages. Naturally, they can not only treat the discrete variables but also overcome the dimensionality problem. In addition, they have the capability to search for the global optimum or quasi optimums within a reasonable computation time. However, there exist some structural problems in the conventional GA, such as premature convergence and duplications among strings in a population as generation progresses [11].

Step 1: Randomly generate an initial population M(0)
Step 2: Compute and save the fitness u(m) for each individual m in the current population M(t)
Step 3: Define selection probabilities p(m) for each individual m in M(t) so that p(m) is proportion to u(m)
Step 4: Generate M(t+1) by probabilistically selecting individuals from M(t) to produce offspring via genetic operators
Step 5: Repeat 2 until satisfying solution is obtained

The paradigm of GAs described above is usually the one applied to solve most of the problems presented to GAs. Though it might not find the best solution, more often than not, it would come up with a partially optimal solution.

4. Problem Formulation

4.1 General Proposition

In Thailand, the electric power comes from various sources; the Electricity Generating Authority of Thailand (EGAT) where a variety of fuel are used, purchased from private organizations, and imported from neighboring countries. These alternatives were the matters to be determined which type of fuel suits the production capacity best in leverage of the production capacity. Table 4 showed general propositions for various power plants. The most appropriate number of power plants that produces the overall minimum cost which includes construction and operating expenses that may vary depending on volume of electricity produced (fuel expenses). The most appropriate number of power plants that produces the overall minimum cost which includes construction and operating expenses that may vary depending on volume of electricity produced (fuel expenses) [2].

4.2 Requirements

1) Requirement on Electricity Stabilization
2) Mass productivity for all types of fuels meets the demand of power consumption) P_t (at any session.
3) Mass productivity for all types of fuels meets the demand of electric power) E_t (at any session.

Table 4 : Scenarios Analysis for Power Plants

Unit type	Years (2007-2021) 1	2	3	…	T
1	X_{11}	X_{12}	X_{13}	…	X_{1T}
2	X_{21}	X_{22}	X_{23}	…	X_{2T}
3	X_{31}	X_{32}	X_{33}	…	X_{3T}
…	…	…	…	…	…
J	X_{J1}	X_{J2}	X_{J3}	…	X_{JT}

where j = type of fuels used for electric generation ($j = 1, 2, 3, \ldots, J$)
t = year for constructing the power plant ($t = 1, 2, 3, \ldots, T$)
X_{ij} = number of power plants using the fuel j in year t

4) Production Development Plan 2007-2021 requirements
5) Electricity reserve production capacity must not less than 25% of overall production capacity
6) Increased production capacity should not exceed the maximum production capacity for each type of fuel at any session.
   - Gas turbine power plant generates the electricity not exceeding 10% of overall production capacity.
   - Nuclear power plant generates the electricity not exceeding 10% of overall production capacity.
   - Buying from IPP must not exceeding 36% of overall production capacity.
   - Buying from SPP must not exceeding 3,600 MW, maximum sale
   - Ratio for imported electricity
   - Buying from a neighboring country must not exceeding 13% overall production capacity

5. Mathematical Model

The mathematic model developed was aimed to figure out the optimal number of the power plants that generates the overall minimum cost as well as the maximum reliability under the requirements and policies. The total cost is the sum of construction cost and operating cost. The constraints include capacity constraints, reliability constraints, and operating constraints. The equation for mathematic model is written as follows;

Objective Function:

$$\text{Min Cost} = \sum_{j=1}^{J}\sum_{t=1}^{T}(C_{jt}x_{jt} + f_{jt}y_{jt}) \;;\; x_{jt} \in I^{+} \quad (1)$$

Constructing cost for power plant *j* at time t is below

$$C_{jt} = C_{j0}[(1-e_j)(1+i)]^{-t} r_{jt} \quad (2)$$

$$j = 1, 2, 3, \ldots, J \qquad t = 1, 2, 3, \ldots, T$$

Constructing cost for each year included the following payback factors.

$$r_{jt} = \frac{\sum_{k=0}^{T-t} L_j - k}{L_j(L_j+1)/2} \quad (3)$$

$$j = 1, 2, 3, \ldots, J \qquad t = 1, 2, 3, \ldots, T$$

Transaction cost depends on the production volume as below.

$$f_{jt} = f_{j0}[(1-e_j)(1+i)]^{t} \quad (4)$$

$$j = 1, 2, 3, \ldots, J \qquad t = 1, 2, 3, \ldots, T$$

where x_{it} = number of power plant type *j*, constructed at time *t*

C_{jt} = initial constructing cost for the power plant *j*

x_{jt} = number of power plant type *j*, constructed at time *t*

f_{jt} = operating cost for the power plant *j* at time *t*

y_{jt} = accumulated power of the power plant *j* at time *t*

L_j = lifetime of power plant *j*

f_{j0} = initial operating cost for the power plant *j*

e_j = escalation rate for power plant *j*

i = interest rat

The objective function in (1) is subject to the following constraints.

Equation of Constraint 1: represents the adequacy of electricity production volume and demand of power consumption (P_t) plus electricity reserves (m) at each year in case of new construction, it included the natural gas, coal, lignite, gas turbine, and nuclear power plant In case of buying, it included SPP, IPP, and import shown in Table 5 and 6.

$$\sum_{j=1}^{5}\sum_{t=1}^{t} a_{jt}x_{jt}u_j + \sum_{j=6}^{8} a_{jt}x_{jt}u_j \geq P_t(1+m) \quad (5)$$

$$j = 1, 2, 3, \ldots, J \qquad t = 1, 2, 3, \ldots, T$$

where a_{jt} = feasibility factors for the power plant *j* at time *t*

u_j = unit size of power plant

P_t = consumption demand (MW)

m = minimum power reserves (%)

Table 5 : Forecast of Electricity Demand plus Electricity Reserves 25%, 20%, and 15%

$P_t(1+m)$	m=0.15	m=0.20	m=0.25
2008	25,320	26,420	27,521
2009	26,319	27,463	28,608
2010	27,526	28,723	29,920
2011	28,848	30,102	31,356
2012	30,558	31,886	33,215
2013	32,416	33,826	35,235
2014	34,352	35,845	37,339
2015	36,494	38,081	39,668
2016	38,724	40,408	42,091
2017	41,018	42,802	44,585
2018	43,384	45,270	47,156
2019	45,802	47,794	49,785
2020	48,328	50,429	52,530
2021	50,923	53,137	55,351

Feasibility factors were taken into consideration. Production capacity for each type of power plant increased with operating machine time as follows;

$$a_{jt} = a_{j0}(1-0.007)^{t} \qquad (6)$$

$$j = 1, 2, 3, \ldots, J \qquad t = 1, 2, 3, \ldots, T$$

where a_{j0} = feasibility factors for the power plant *j*

Equation of Constraint 2: represents the adequacy of electricity production and demand of power consumption at each year.

$$\sum_{j=1}^{J} y_{jt} \geq E_t \;;\; t = 1, 2, 3, \ldots, T \qquad (7)$$

where y_{jt} = power consumption at each year

E_t = electricity demand

Equation of Constraint 3: represents the restrictions on electricity production capacity for each type of fuels used to produce the electricity.

$$\sum_{t=1}^{T} a_{jt} x_{jt} u_j \leq Cap_{jt} \qquad (8)$$

$$t = 1, 2, 3, \ldots, T \qquad j = 4, 5$$

where $j = 4$ is gas turbine power plant, production capacity is not exceeding 10% of overall production capacity, $P_t \times (0.1)$ MW

$j = 5$ is nuclear power plant, production capacity is not exceeding 10% of overall production capacity, $P_t \times (0.1)$ MW

Table 6 : Production Capacity for Each type of Power Plant

Year	Nat Gas	Coal	Lignite	Gas turbine	Nuclear
0	0.9000	0.9000	0.9000	0.9800	0.8500
1	0.8937	0.8937	0.8937	0.9731	0.8411
2	0.8874	0.8874	0.8874	0.9663	0.8381
3	0.8751	0.8751	0.8751	0.9528	0.8264
4	0.8689	0.8689	0.8689	0.9396	0.8149
5	0.8629	0.8629	0.8629	0.9396	0.8149
6	0.8568	0.8568	0.8568	0.9330	0.8092
7	0.8508	0.8508	0.8508	0.9264	0.8036
8	0.8449	0.8449	0.8449	0.9200	0.7979
9	0.8389	0.8389	0.8389	0.9135	0.7923
10	0.8331	0.8331	0.8331	0.9071	0.7868
11	0.8272	0.8272	0.8272	0.9008	0.7813
12	0.8215	0.8215	0.8215	0.8945	0.7758
13	0.8157	0.8157	0.8157	0.8882	0.7704
14	0.8100	0.8100	0.8100	0.8820	0.7650

Note: SPP, IPP, and Import provided stable production capacity.

Equation of Constraint 4: represents the restrictions on electricity production capacity for each type of fuels used to produce the electricity shown in Table 7.

$$a_{jt} x_{jt} u_j \leq Cap_{jt} \qquad (9)$$

$$t = 1, \ldots, T \qquad j = 6, 7, 8$$

where $j = 6$ is SSP, buying from SPP must not exceeding 3,600 MW, maximum sale offer

$j = 7$ is IPP Buying from IPP must not exceeding 36% of overall production capacity $P_t \times (0.36)$ MW

$j = 8$ is import from only one neighboring country must not exceeding 13% overall production capacity $P_t \times (0.13)$ MW

Table 7 : Requirements on Electricity Stabilization 10%, 13%, and 36% of Consumption Demand

	$P_t(0.10)$	$P_t(0.13)$	$P_t(0.36)$
2008	2,202	2,862	7,926
2009	2,289	2,975	8,239
2010	2,394	3,112	8,617
2011	2,509	3,261	9,031
2012	2,657	3,454	9,586
2013	2,819	3,664	10,148
2014	2,987	3,883	10,754
2015	2,987	3,883	10,754
2016	3,173	4,125	11,424
2017	3,367	4,377	12,122
2018	3,773	4,904	13,581
2019	3,983	5,178	14,338
2020	4,202	5,463	15,129
2021	4,428	5,757	15,941

6. Result of Case Study

Based on the mathematic model and information mentioned above, when testing was performed using the Lingo program, number of new power plants and volumes of buying from IPP, and SPP, and import shown in Table 8.

Number of new power plants and volumes of buying from IPP, and SPP, and import shown in Table 8 were calculated as production capacity (See Table 9). Total production capacity of old and new power plants by time shown in Table 10 must be greater than forecasted figures of power consumption under the PDP2007.

The results have shown that during the year 2008-2021, the Electricity Generating Authority of Thailand (EGAT) must supply 53% of the electricity (47% natural gas, 2% Lignite, and 4% gas turbine) and purchase the rest (from small enterprise 7%, large enterprise 31%, and neighboring countries 9%

Table 8 : Number of New Power Plants by Fuel Type (x_{it})

Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Nat. Gas	0	0	2	1	3	7	0	3	4	3	7	5	0	4
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Gas turbine	0	1	1	2	0	1	0	0	0	0	0	4	2	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPP	14	14	14	14	14	14	14	14	14	14	14	14	14	14
IPP	31	32	33	35	37	39	42	44	47	50	53	56	59	62
Import	10	11	11	11	13	13	12	15	16	17	18	19	18	17

Table 9 : Production capacity of old and new power plants by time ($a_{it} \times x_{it} \times u_j$)

Type (*j*)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Nat Gas	0	0	1,260	1,881	3,758	8,133	8,072	9,892	12,313	14,116	18,415	21,419	21,256	23,597
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	495	492	983	973	966	956	949	943	936	929	923	916	910
Gas turbine	0	225	449	897	889	881	872	866	860	854	848	1,744	2,182	2,167
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPP	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567	3,567
IPP	7,899	8,154	8,408	8,918	9,428	9,937	10,702	11,211	11,976	12,740	13,504	14,269	15,033	15,798
Import	2,646	2,911	2,911	2,911	3,440	3,440	3,175	3,969	4,234	4,498	4,763	5,027	4,763	4,498
Old by EGAT	14,163	13,472	12,834	12,243	11,329	10,859	10,421	10,013	9,179	8,843	6,479	5,067	4,910	4,847
Sum	28,275	28,824	29,921	31,400	33,383	37,784	37,765	40,468	43,071	45,555	48,506	52,015	52,627	55,384

7. Conclusions

This paper presents an efficient technique to solve the problem of generation expansion planning using an expert system approach. The expert system approach has the capability to emulate the human expertise in the field of generation planning. The proposed technique is based on the decision tree concept instead of the currently-used techniques of mathematical programming. New concepts based on the natural properties of the problem are developed to minimize the computation burden by making the decision tree of minimum size. The proposed technique generates a variety of recommended solutions (strategies) under different circumstances and uncertain events.

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