ELECTRICITY GENERATION EXPANSION PLANNING USING EXERGY ANALYSIS

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1.0 Introduction

Although the current planning procedures consider technical aspects of different candidate plants, it is limited to its capacity, whether it can be used for peaking or not and type of fuel used. Thus the cost minimization approach does not consider the actual exergy utilization of different technologies.

Exergy gives an absolute usefulness of some energy. So it is a better unit to assess a technology (exergy efficiency). The main objective of the project is to get the generation expansion plan based on exergeoconomic analysis to check whether the plan obtained reduces the emissions to the environment and whether a cost increment is coupled with it.

2.0 Exergy

Exergy is defined as the maximum work potential of a material or of a form of energy in relation to its environment.

On the process component level exergy indicates clearly what losses appear. Imagine a heat exchanger in which a process stream is heated from 25°C to 100°C by a process stream of 200°C which is cooled down to 120°C. In effect heat is transported from 200°C to 100°C. The latter has a much lower exergy content than the stream at 200°C. Hence a considerable amount of exergy is lost. No energy might be lost, but due to the exergy loss, elsewhere in the process an extra amount of fuel might be needed in order to provide heat at, let's say 160°C.

3.0 Electricity Generation Expansion Planning

Electric generating system planning encompasses a broad collection of activities spanning several time horizons and can be divided in to categories of analysis such as demand, generation, transmission & distribution. Each category of analysis may be carried out for short, medium & long term. The different problems to be faced & the different analytical techniques to be used depend, in general, on the timeframe and the category of electric system planning.

The primary objective of a public utility company is to, adequately (with acceptable reliability), meet the demand for electrical power at the minimum cost. Also, the utility must conform to existing constraints, such as financial limits, domestic resource availability & government policies.

WASP is a generation planning software utilized by a lot of countries. It can search for an optimal extension scheme which forecasts as far as 30 years ahead and meets given constraints. The model uses a minimum cost method for economical assessment. WASP takes into account outage costs, investment costs, fuel cost and operation & maintenance cost. In order to compare projects with different lifetimes, it uses the cost present value.

The two major functions of the model are,

1. Electricity production simulation
2. Capacity expansion optimization

The program permits the economically optimal expansion plan to be found over a 30 year period. Calculation of the expected generation of each power plant is performed by means of probabilistic simulation. The optimum is evaluated in terms of minimum discounted costs. The cost function used is ,

$$B_j = \sum_{t=1}^{T} \bar{I}_{j,t} - \bar{S}_{j,t} + \bar{F}_{j,t} + \bar{L}_{j,t} + \bar{M}_{j,t} + \bar{O}_{j,t}$$

The objective is to minimize B , where:

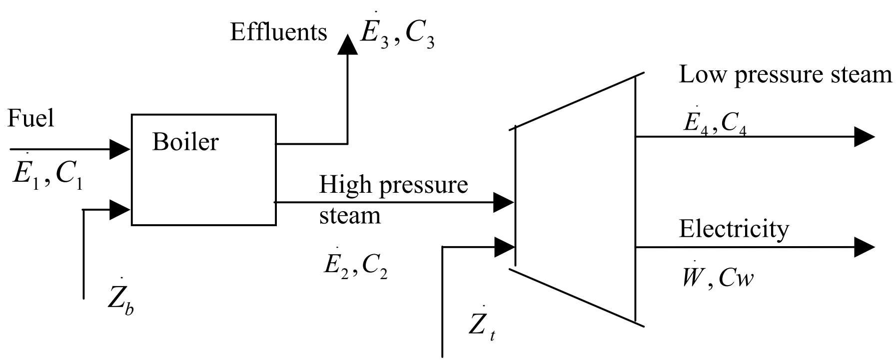
I - capital investment costs
S – salvage value of investment costs
F – fuel costs
L – fuel inventory costs
M – non-fuel operation & maintenance costs
O – cost of energy not served
j – plant number
t – period number

LDC, Demand forecasts & existing plants were taken from the C.E.B. year 2000 plan.

3.0 Methodology &Calculations

To obtain the maximum energy potential from scarce resources of fuel, the electricity generation plan should be based on exergy costing. The objective of the plan being the minimum investment and operational cost throughout the period, all different technologies of electricity generation are analysed to obtain the cost per unit input of exergy.

For example;
Steam Turbine



$\dot{E}_1$ - Exergy rate of fuel

$\dot{E}_2$ - Exergy rate of steam

$\dot{E}_3$ - Exergy rate of effluents

$\dot{E}_4$ - Exergy rate of steam

$\dot{W}$ - Electricity output

C_1 - Fuel cost per unit of exergy

C_2 - steam(H.P.) cost/exergy

C_3 - Cost of effluents/exergy

C_4 - steam(L.P) cost /exergy

C_w - Benefit per unit of electricity

$\dot{Z}_T$ - Capital cost of turbine/sec

$\dot{Z}_B$ - Capital cost of boiler/sec

Considering the cost balance for boiler

$$\dot{E}_1 C_1 + \dot{Z}_b = \dot{E}_2 C_2 + \dot{E}_3 C_3$$

Considering the cost balance for the turbine

$$\dot{E}_2 C_2 + \dot{Z}_t = \dot{E}_4 C_4 + \dot{W} C_w$$

Cost of 'high pressure steam' and 'low pressure steam' are considered to be same.

$$C_2 = C_4$$

$$C_1 = \frac{\dot{E}_3 C_3 - \dot{Z}_b + \dot{E}_2 \left[\dfrac{\dot{W} C_w - \dot{Z}_t}{\dot{E}_2 - \dot{E}_4} \right]}{\dot{E}_1} \quad \text{-----(1)}$$

Element	***Value***
$\dot{E}_1$	***0.754GW***
$\dot{E}_2$	***0.428GW***
$\dot{E}_3$	***0.029GW***
$\dot{E}_4$	***0.157GW***
$\dot{W}$	***0.300GW***
C_3	***0.000***
C_w	***20.46 $/GJ***

Then, C_1 = 10.56 $/GJ

Similarly, the costs were calculated for all the candidate plants;

Plant	*C_1 ($/GJ)*	*Index*
Diesel – residual oil (10MW)	4.61	A
Diesel - furnance oil (10MW)	4.61	B
Steam – furnance oil (300MW)	10.63	C
Steam–coal-Trinco(300MW)	10.38	D
Steam – coal – West coast(300MW)	10.32	E
Gas Turbine(35MW)	4.53	F
Gas Turbine(105MW)	6.53	G
Combined cycle(150MW)	9.93	H
Combined cycle(300MW)	12.17	J

Fuel Type	Emission Factors			
	Particulate (mg/MJ)	CO_2 g/MJ	SO_2 g/MJ	NO_X g/MJ
Fuel oil	13.0	75.5	1.7087	1.20
Resudual oil	13.0	76.6	1.7078	1.20
Coal	40.0	92.7	0.3791	0.30
Auto diesel	5.0	73.3	0.2383	0.28
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Naphtha	0.0	72.6	0.0000	0.28

4.0 Results

Optimum expansion plant additions obtained from the WASP are;

year	Base case	C_w=20.46$/GJ	C_w= 58.46$/GJ	C_w= 146.14 $/GJ
2004	-	-	H	H
2005	J	H	-	-
2006	E	F,G	E	F
2007	-	G	-	E
2008	E	E	E	E
2009	-	E	F	D
2010	G	-	E	-
2011	D	C	D	H
2012	D	E	H	G
2013	G	D	E	F-2
2014	D	G	H-2	H
2015	B	J	E	J
2016	G-3	D,G	H-4	E
2017	D,F	F,G,H	E	H-2
2018	D,G	A,B,D,F	E-1	D
2019	F,G-3	D,G	H-4	E

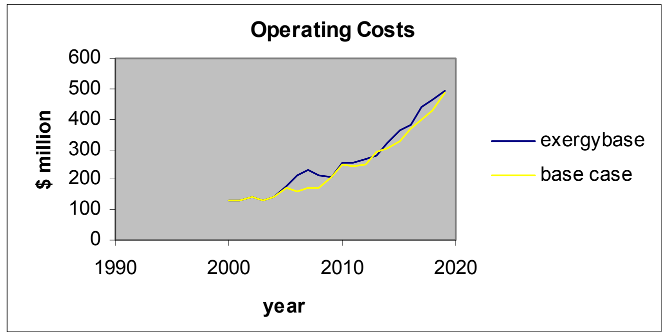
The detailed study results done between the base case & C_1=20.46$/GJ case. These are shown in the following section.

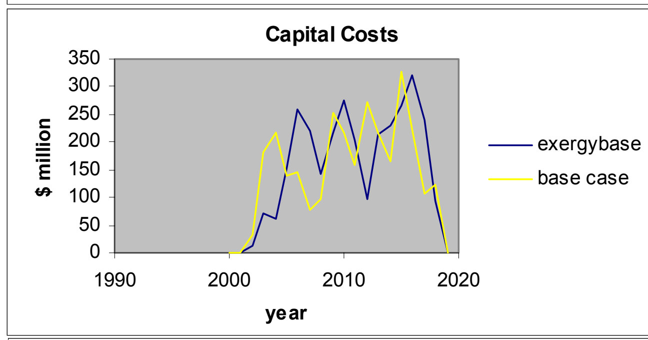
For the total 20 year planning period considered the change in costs & emissions from the base case are;

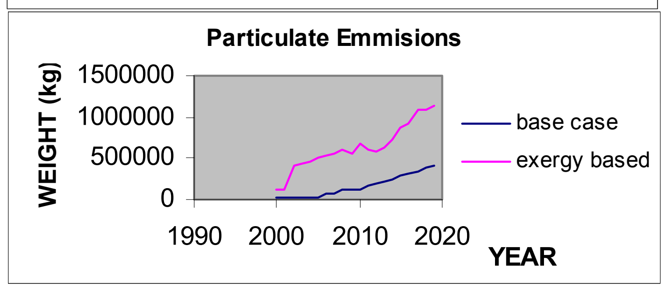
Operating cost = +6.83%
Capital cost = +6.84%
Particulate emissions = - 16%
Co_2 = +3.2%
So_2 = +24.5%
Nox = + 15.5%

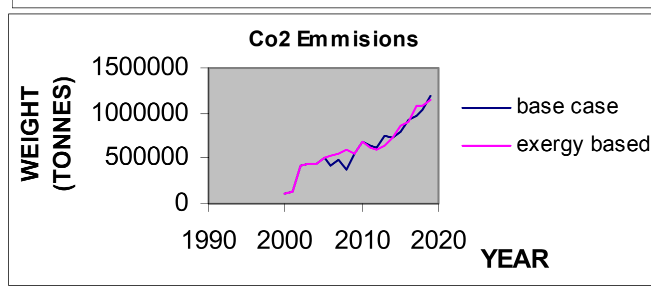
5.0 Conclusion

There is a significant reduction in particulate emissions while the other emissions & costs escalate. The cause for this can be seen from the WASP o/p and the emission factors used.









The exergy based plan rejects steam plants which result in a reduction in particulate emissions due to lower coal consumption. This compensated by a higher usage of fuel oil & diesel, since, diesel & fuel oil has higher So2 & Nox emissions than coal, it has resulted in higher total emissions. Obviously, as the exergy based plan is sub-optimal in an economic context the operating & capital cost have increased.

6.0 References

6.1 Expansion planning for electrical Generating systems : IAEA technical publications 241
6.2 C.E.B. Year 2000 plan
6.3 www.exergyonline.com
6.4 Thermodynamics for Engineers : Moran & Shaft