MATHEMATICAL MODELING FOR OPTIMUM GENERATION MIX OF THE POWER SECTOR OF BANGLADESH

By

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The thesis titled "Mathematical Modeling for Optimum Generation Mix of the Power Sector of Bangladesh" submitted by Selina Begum to the Department of Industrial and Production Engineering of Bangladesh University of Engineering and Technology (BUET) has been accepted as satisfactory for the partial fulfillment of the requirements for the award of the degree of MASTER OF ENGINEERING (Industrial and Production).

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DECLARATION

I do hereby declare that this work has been done by me and neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or publication.

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ABSTRACT

In an age of scientific advancement and industrial revolution, electricity is now considered the prime mover of all development. There is till to date no alternative to electricity to accelerate as well as to ensure any type of development. The growth of almost all the sectors of economy of a country depends on uninterrupted power supply. In such a situation Bangladesh is suffering from generating necessary electricity and this not the only problem, there should be enough electricity to bring success in the development of all sphere of social, economic, industrial, cultural, educational and domestic uses of life.

In Bangladesh Power Development Board (BPDB) is responsible for generation, transmission and distribution of electricity in the whole country. BPDB has the over all authority and control in this sector. BPDB is responsible for distribution of electricity in most areas of the country except Dhaka Metropolitan city and its adjoining areas and some of the rural areas. Responsibility of distribution in and around Dhaka Metropolitan area lies with Dhaka Electric Supply Authority (DESA) and Dhaka Electric Supply Company (DESCO) and the country side to Rural Electrification Board (REB). According to BPDB the per capita generation of electricity in Bangladesh is as low as 136 Kilo watt-hour (kwh) and only 30% of the population is served with electricity. Quite a number of plants are going to retire in the present five year plan which makes the scenario even bleaker.

To cope with the increased demand of electricity in terms of per capita consumption and retirement of old power plants after their economic life cycle, a large amount of new capacity is to be built.

As part of reform in the power sector, private power policy was approved by the Government in the month of October, 1996. Incentive packages in terms of exemption of tax and vat on imported capital machinery and equipment, spare parts etc. is being offered to the Independent power producer (IPP).

In this thesis linear Programming model is applied to developing an expansion program for power sector of Bangladesh.

The result of the linear Programming model represents optimum operating schedules. It also shows the generation mix of various power plants at various loads through out the year in the future planning period.

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CHAPTER- I

INTRODUCTION

1.0 INTRODUCTION

Electricity is the life blood of all development activity of the modern civilization. As a matter of fact development of all sectors, from agriculture to aeronautics virtually everything is heavily dependent on electricity to verse specifically uninterrupted supply of electricity. Economic development of a country is determined on the basis of per capita energy consumption that includes use of electricity. It is one of the most important tools to increase the standard of living and development of social infrastructure. In this technology driven society the development of technology itself is dependent on uninterrupted electricity supply. One can not even think of a day without electricity providing its utility service in all sphere of life.

Bangladesh is among one of the lowest electricity consuming country. Bangladesh is facing shortage of power generation mainly due to inadequate generation capacity and increased demand of electricity. In Bangladesh the present per capita electricity consumption is 136 Kilo watt-hour (kwh) per annum which is very low in comparison with the developing countries let alone the developed countries. Demand of electricity is expected to increase further in the coming future. The electricity situation in Bangladesh can be improved if the generation capacity is increased manifolds. To meet the demand and supply gap, the Government has taken several steps some which are already implemented, some in process and some under planning. The present Government is committed to supply electricity to all by the end of the year 2020.

1.1 POWER GENERATION IN BANGLADESH

This section briefly describes the history of power generation in Bangladesh, development of the power sector, sources of energy, demand of energy in various sectors, power generating plants of Bangladesh and fuels used for the generation of power in the country and most importantly the current and future scenario of the power sector of the country.

1.1.1 Back Ground of Electricity Generation in Bangladesh

In Bangladesh, at the beginning, some private company started electricity utility business in isolated and small way. In 1947 former East Pakistan had only 21 MW of electricity supply capability by the private farms. After partition in 1948 the then Government established the Electricity Directorate under the ministry of Industry. The Directorate took over the private electric companies and started establishing newer power plants to cater to the need of increasing demand of electricity. Creation of Water and Power Development Authority (WAPDA), a statutory body in public sector was a mile stone in the history of power generation in Bangladesh. The Directorate of Electricity then merged with WAPDA. WAPDA implemented Karnafuli Hydro Power Project at Kaptai in the South-eastern part of the country and constructed 132 kV high voltage transmission line from Kaptai to Dhaka to bring 80 MW of Hydro power, which was the first high voltage network operation in Bangladesh. During 60's the generation capacity rose to 419 MW and transmission line from a scratch to 827 kW. The demand of electricity which was initially 42 MW in 1960 rose to a whopping 224 MW.

This is the consolidated history of electricity in Bangladesh in the pre liberation period. After the liberation war in 1971 Bangladesh emerged as an independent country. WAPDA was bifurcated in two bodies namely, Water Development Board (WDB) and Power Development Board (PDB). With an installed capacity of 550 MW, in 1972 Bangladesh Power Development Board (BPDB) was created as an integrated state organization. During the liberation war important installation such as power plants, bridges were demolished and the power sector suffered extensive damage. As a result, at the worst case, peak demand of electricity dropped to 30 MW from the pre-liberation level of 220 MW (1970). The rehabilitation of power sector was an immediate concern after the liberation. In the first five year plan extensive rehabilitation program was undertaken to revive the power industry. By 1974 the installed capacity raised to 667 MW and the generation capacity to 490 MW; the highest demand at that time was only 266 MW leaving a reserve margin of 46 percent. In the next two plan period the projects initiated before liberation commissioned and several other new projects were undertaken. In early 70's the installed generation capacity was 822 MW and the peak demand was 462 MW with a reserve margin of 15 percent. During this decade in the second five year plan (1980-1985) period the most important achievement in the electricity sector was the establishment of east-west inter-connector over the mighty river Jamuna. This inter-connector enabled the transfer of gas based low cost power from the east to the west. Five power generation plants having a total installed capacity of 330 MW was commissioned during this second plan period. To meet the increasing demand of electricity and to cover the whole of Bangladesh an autonomous corporation named Rural Electrification Board (REB) was formed in 1977. REB purchases electricity from BPDB and sells the utility to the consumers in the rural areas through Palli Bidyut Samities (PBS). Though generation capacity was increased by a substantial amount the demand for electricity was so high that generation capacity still lagged behind. By this time the power sector of the country was down with another disease namely "system loss". The main constraint to the expansion of power supply was the short fall of resources coupled with a huge system loss and slow response to tariff adjustments against rising fuel cost. By 1987 the system loss was a huge 37.5 percent. High system loss along with other factors like high load shedding, low account receivables, poor management and inability to improve the performance inhibited the concession loans from the donor agency to construct new power plants. There fore against a peak demand of 3970 MW in 1994-95, the installed capacity was only 2908 MW only. This meager capacity was again interrupted due to power outages owing to fluctuations in gas pressure, transmission and distribution faults. To make it even more frustrating some power plant rehabilitation program could not be materialized which further hampered the generation capacity by 271 MW and some power plants retired after the completion of their economic life time. During this plan period the net capacity increase was only 299 MW against a demand of at least 1000 MW as per growth rate. This led to a shortfall of generation of about 700 MW and was the major reason of chronic load-shedding in the fiscal year 1996-97. The government by then allowed the private power companies to operate in the country and as a result of this in October 1998 the first private company with an installed capacity of 100 MW was commissioned. At present about 18% of the total power generated to different customer is supplied by the independent power producing companies.

1.2 ENERGY SCENARIO IN NEIGHBORING COUNTRIES

The present world is in the age of scientific and technological advancement. This growth has been made possible by proper utilization of electricity. Perhaps our dependence on electricity will best be explained if we recall the recent power failure in New York, USA. The whole of New York just came to a dead halt for almost 24 hours when electricity supply could not be made. Developed countries are more dependent on electricity as compared to developing countries. Table shows the comparison of electricity consumption in Bangladesh and neighboring countries:

Country	**Population with electricity access**	**Per capita consumption (Kwh/year)**
Bangladesh	31	136
Cambodia	10	30
Nepal	15	47
Pakistan	55	337
Sri Lanka	55	244
India	70	384

Table 1-1 Comparison of electricity access with the neighboring countries
[Source: World Development Indicators, 2001]

1.3 GENERATION

Different types of power plants generate electricity and synchronize it with the national grid. There are some isolated diesel power stations at remote places and islands which are not connected with the National Grid. Terminal voltage of different generators is 11 KV, 11.5 KV and 15.75 KV.

In the Eastern Zone (eastern side of river Jamuna), electricity is generated from indigenous gas and a small percentage through hydro power. In the Western Zone, only imported liquid fuel is used for generation of electricity. The fuel cost per unit generation in the Western Zone is much higher than that of the Eastern Zone. Therefore, as a policy, low cost electricity generated in the Eastern Zone is transferred to the Western Zone through the 230 kV East-West Inter connector transmission line.

As on February, 2004 the total consumer using electricity in Bangladesh is 1754886. So it is evident that Bangladesh is one of the lowest electricity consumption rates. The key statistics for BPDB are as follows:

INSTALLED CAPACITY	4680MW
PRESENT GENERATION CAPABILITY	4368MW
PEAK DEMAND SERVED SO FAR	3592.1 MW
TRANSMISSION LINES (230 & 132 KV)	4611 KM
GRID SUB-STATION CAPACITY (230 & 132 KV)	5127MVA
DISTRIBUTION LINES (33 KV & BELOW)	43,059 KM
CONSUMER NUMBER (2003-2004) February 2004	17,45,886

Table 1-2: Key statistics of BPDB [Source PDB]

Of the total installed capacity more than 85% of the electricity generated by

BPDB is gas based, and rest of the electricity is generated by different other sources like hydro, liquid fuel etc. This scenario can, as a matter of fact, be treated as a warning sign too. According to Bangladesh Geological Society the gas deposition in Bangladesh is 11.86 TCF to sustain up to year 2019. So it is high time to start planning accordingly so as to grow and generate electricity after the indigenous gas supply is exhausted. Figure 1-1 shows the types of power plants in operation in Bangladesh.

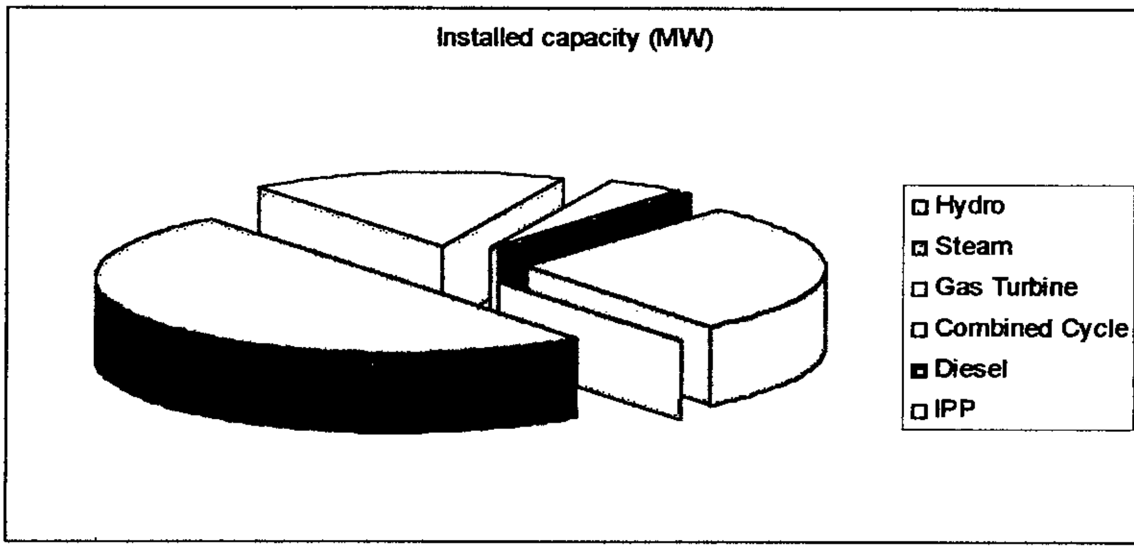


Figure 1-1: Contribution of different types of power plants

1.3.1 Alternative Fuel to Generate Electricity

As mentioned earlier most of the power plants in Bangladesh are gas based. Natural gas account for seventy percent of commercial use and consumption of gas is increasing at a very high rate of nine percent annually. It is highly likely that this supply of natural gas will be exhausted sooner or later. So the policy makers of the country have to prepare accordingly and arrange for alternative means of generating electricity. Among other sources of electricity solar energy, wind energy, coal, oil, bio-mass, nuclear energy is worth mentioning. But in Bangladesh wind energy and nuclear energy is not feasible due shortage of open space and densely populated area. Nuclear energy generation plants are very risky as well as require huge investment and poses real threat to the environment, so in Bangladesh it is not possible due to obvious reasons to establish nuclear power plants. Recently a few coals mine have been discovered in Bangladesh and very good quality coal is found. Based on coal production in Barapukuria coal mine a coal fired thermal power pant has been commissioned. The Government is encouraging people to use alternative means of electricity generation. Solar energy is being used in Bangladesh to generate electricity in some houses and in remote areas. Till now no commercial step has been taken to generate electricity from solar energy. In Bangladesh Bio-mass is used only for household activities. In fact, Bio mass is the major source of energy, electricity coverage being 15% of the population and natural gas accessible by only 3% of the households.

1.4 CURRENT STATUS OF BPDB

The present installed generation capacity is 4710 MW, of which state run PDB controls generation of 3420 MW and the private IPPs 1290MW. However, the plants at best can generate about 3500 MW. The highest generation this year was on April 16 when the total generation was 3407 MW. Most of the power plants of the country are located in the eastern side of the country. The main reason behind this is the river Jamuna and availability of indigenous natural gas. Near about ninety percent of the power plants are located in the eastern side and the rest on the western side of the country. Table 1-3 shows the type of fuel used and capacities of various power plants of the country.

Type of plant	Fuel Used	Capacity (MW)
Steam turbine	Gas, FO, LDO, SKO	2228
Gas turbine	Gas	768
Hydro	Hydro	230
Combined cycle	Gas	180
Diesel cycle	LDO	16

Table 1-3: Present situation of BPDB [Source PDB]

At present the country has 85 power units of different capacity. Twelve of the units having total capacity of 354 MW are 31-41 years old while 14 units with generation capacity of 403 MW are 21-30 years old. There are 10 units 16-20 years old, having total capacity of 886 MW. Besides 11-15 years old 13 units have 697 MW capacity and 36 units with 2360 MW capacity are below 10 years old.

1.4.1 Power System Planning

At present only 30% of the total population has access to electricity. The latest plan of the GOB says the generation has to be taken to 16000 MW to ensure electricity for 100% people by the year 2020. The present electricity generation capacity of the country is 4710 MW. It means that the generation has to increase by 11290 MW in the next 16 years. As per the power system master plan 3510 MW electricity will be added to the national grid by the year 2007. In 2007 the electricity demand will be 5368 MW. The expansion program of the GOB is presented in table 1-4. The table shows the planning of Bangladesh Power Development Board according to Power System Master Plan up to year 2007.

Sl. No	Generating station	Type of fuel	Capacity (MW)	Expected commissioning date	Status
	Under-construction				
	Public Sector				
1	210 MW Siddhirganj Thermal Power station	Gas	210	April, 2004	Russian suppliers credit
2.	Barapukuria Coal based thermal power plant	Coal	250	June 2005	Chinese supplier credit
3.	Tongi 80 MW gas turbine P/S	Gas	105	October 2004	GOB contract signed
	Sub total		565		
	New: planned				
	Public sector				
4.	Sylhet 150 MW CCPP (100 MW CT) and associated power evaluation facilities	Gas	100	FY 2006	Awaiting ministry's approval
5.	Siddhirganj 120 MW GT P/S (including evacuation facilities)	Gas	120	FY2006	Re-Tender
6.	Saidpur 100 MW peaking power plant	HSD	100	FY 2006	Not yet funded
7.	Siddhirganj 2x120 MW peaking power plant	Gas	240	FY 2006	Tender to be floated
8.	Chandpur 150 MW CCPP	Gas	150	FY 2006	Tender to be invited
9.	Sylhet 90 MW CCPP- 2nd phase	Gas	90	FY 2006	Tender evaluation
10.	Haripur 150 MW CCPP	Gas	150	FY 2007	Finance from JBIC
11.	210 MW Khulna thermal power station	Gas	210	FY 2007	Proposal evaluation
12.	Bhola 150 MW CCPP	Gas	150	FY 2007	Not yet funded
13.	Khulna 100 MW peaking Power plant	Gas	100	FY 2008	Not yet funded
14.	210 MW Siddhirganj thermal power plant	Gas	210	FY 2008	Tender evaluation
15.	Bheramara 450 MW CCPP	Gas	450	FY 2009	Not yet funded
16.	Kaptai Siddhirganjower plant extension	Hydro	100	FY 2009	Finance from JBIC

Sl. No	Generating station	Type of fuel	Capacity (MW)	Expected commissioning date	Status
17.	Bogra 450 MW CCPS	Gas	450	FY 2010	Not yet funded
	Sub total		2620		
	Private sector				
18.	Baghabari (Westmont) CC	Gas	40	FY 2006	ST addition to existing 90 MW
19.	Baghabari (Westmont) 2nd phase	Gas	130	FY 2005	ST addition to existing 90 MW
20.	Serajganj CCPP	Gas	450	FY 2008	Approved by GOB
21.	Meghnaaghat CCPP	Gas	70	FY 2008	Tender invited
	Mixed sector				
22.	Mymensingh (RPC)	Gas	70	FY 2005	ST addition to existing 140 MW
	Sub total		1590		
	GRAND TOTAL (FY 2004-FY 2007)		2845		
	PUBLIC SECTOR		1875		
	PRIVATE SECTOR		970		

Table 1-4: Planned expansion up to year 2007 [Source: PDB]

1.5 OBJECTIVE OF THE STUDY

Generation of electricity is the most significant part of the power industry. To make electricity available for the citizen of Bangladesh by 2020 is a real challenge every Government will face. To make infrastructural development, to arrange for the huge amount of money to be generated as per the plan (table 1-5) will require extensive planning and hard work on the part of the Government.

Sl.	Item	FY 2003	FY 2007	FY 2012	FY 2020
1	Peak Demand (MW)	3407	5368	7887	14000
2	Installed capacity (MW)	4710	7746	9655	16 795
3	Transmission line (km)	3852	5454	6282	7300
4	Distribution line (Km)	196000	271 355	326 606	420 000
5	Per capita generation (Kwh)	144	200	260	426
6	Access to electricity (% of population)	32	50	65	100
7	Investment (Taka crore)	-	23428	16000	35000
Total investment from 2004-2020: Taka 74428 crore					

Table 1-5: Projected electricity data up to year 2020

An average of 700 MW of capacity addition in generation would be required per annum to ensure adequate supply of electricity to meet the growing demand. Simultaneously transmission as well as distribution facilities will have to be developed for evacuation and distribution of power. For this an appropriate generation mix has to be found out giving attention to all the variables like cost, generation capability and environmental factor etc. This work is an attempt to consider all these parameters and thus to obtain a generation mix.

1.6 ORGANIZATION OF STUDY

This work consists of five chapters' altogether. The first chapter gives a general idea of Bangladesh and its power generation perspectives showing the historical, current and future plans in the electricity of Bangladesh.

In chapter two literature reviews, different optimization techniques that can be used to optimize a generation mix are discussed in details.

Chapter three introduces the new dimension in modeling - incorporation of environment in modeling a generation mix. How environmental factors can be addressed in existing facilities as well as in future facilities. Chapter four is the mathematical formulation of the proposed model for this thesis work. Equations and the constraints have been established and their constraints set in this chapter. Chapter five presents results of the model. It also has the conclusion and recommendations for this study and scope for further research work.

CHAPTER- II

BACKGROUND STUDY

2.0 INTRODUCTION

Engineers and managers have to take many technological and managerial decisions at several stages of design, construction, operation and maintenance of any system. Optimization is the act of obtaining the best result under given circumstances. The ultimate goal of all such decision is to either minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function.

There is no single method available for solving all optimization problems efficiently. Hence quite a few models have been developed since 1940s for solving different types of optimization problems including various electricity supply industries of the world. As socio-economic conditions and related variables differ from region to region, these models are mostly country specific and modeling techniques also vary widely. Various techniques and methodologies used now are discussed in this chapter along with Bangladesh Power Development Board (BPDB)'s power system master plan and five years plan program undertaken by the Government of Peoples' Republic of Bangladesh.

The optimum seeking methods are also known as mathematical programming techniques. The mathematical programming techniques are useful in finding the minimum of a function of several variables under a prescribed set of constraints. The stochastic process techniques can be used to analyze problems that are described by a set of random variables having known probability distributions.

Every optimization problem consists of three basic components namely design variable, design constraint and objective function. Any engineering component is described by a set of quantities, which are treated as variables in the design process and are called design or decision variables. The design variables are collectively represented as a design vector.

In any problem, the design variables have to satisfy certain specified requirements. The restrictions that must be satisfied in order to produce acceptable design are collectively called design constraints. The criterion (with respect to which the design is optimized), when expressed, as a function of the design variables are known as objective function. The choice of objective function is governed by the nature of the problem. An optimization problem can be stated as follows:

Find $X = \{x_1, x_2, \dots \dots \dots, x_n\}$, which minimize $f(X)$

Subject to the constraints $g_j (X) \bullet 0, \quad j = 1, 2, \dots \dots \dots, m$

$$l_j (X) = 0, \qquad j = 1, 2, \dots \dots \dots, p$$

Where X is an n-dimensional vector called the decision vector, $f(X)$ is called the objective function and g_j and l_j are, respectively, the inequality and the equality constraints. The number of variables 'n' and the number of constraints m and/or 'p' need not be related in any way.

2.1 OPTIMIZATION TOOLS

Optimization is carried out using mathematical programming for sequencing and scheduling the different type of generating system to satisfy the power and energy demand constraint [Rao]. Following are the different types of optimization tools that are generally used in engineering problems.

2.1.1 Linear programming

Linear programming [Taha] is one of the simplest tool which typically deals with the problem of allocating limited resources among competing activities in the best possible (i.e., optimal) way. The method is applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. The constraint equations in a linear programming may be in the form of equalities or inequalities. This is the most widely used global optimization techniques in electric supply industries. These models are attractive to system planners because they have standard solution procedures.

If any of the functions among the objective and constraint functions is nonlinear, the problem is called a nonlinear problem. This is the most general programming problem and all other problems can be considered as special cases of the non-linear problem. A key assumption of linear programming is that all its functions (objective function and constraint functions) are linear. This assumption essentially holds for numerous practical problems. It is sometime possible to reformulate non-linearity into a linear programming format.

2.1.2 Dynamic programming

Dynamic programming is a mathematical technique often useful for making a sequence of interrelated decisions. It provides a systematic procedure for determining the combination of decision that maximizes overall effectiveness. In contrast to linear programming there does not exist a standard mathematical formulation of the dynamic programming problem. Rather dynamic programming is a general type of approach to problem solving, and the particular equations used must be developed to fit each individual situation. Dynamic programming can deal with discrete variables, non-convex, non-continuous and non-differentiable functions. It can also take into account the stochastic variability by a simple modification of the deterministic procedure. Then the dynamic programming technique suffers from a major drawback, known as the curse of dimensionality. However, in spite of this disadvantage, it is very suitable for the solution of a wide range of complex problems in several areas of decision-making.

2.1.3 Integer and Mixed Integer Programming

When all the variables are constrained to take only integer values in an optimization problem, it is called an integer programming problem. When some variables only are restricted to take integer values, the optimization problem is called a mixed integer programming problem.

2.1.4 Stochastic Programming

Stochastic programming is one of the most sophisticated optimization techniques developed. It deals with situations where some or all of the parameters of the optimization problems are described by stochastic (or random probabilistic) variables rather than by deterministic quantities. Depending on the nature of equations involved in the problem in terms of random variables in the problem, a stochastic optimization problem is called a stochastic linear or dynamic or nonlinear programming problem. The basic idea used in solving any stochastic programming problem is to convert the stochastic problem into an equivalent deterministic problem using the familiar techniques like linear, dynamic or nonlinear programming and then solving the resulting deterministic problem.

2.1.5 Simulation

For system optimization modeling, simulation is an easy and useful tool. The problem with simulation is that it does not reflect the real world situation accurately. These are especially useful for combinational problems and situations where mathematical formulation is very complex. Simulation provides a starting point for other more sophisticated models.

2.2 APPLICATION OF OPTIMIZATION TOOLS IN CAPACITY EXPANSION

Several methodologies have been applied to solve the problem of capacity expansion, generation mix in electric supply companies. Anderson et al [Anderson, IAEA] presented linear programming models for capacity expansion of an electricity supply system at minimum cost. In this model, the constraints are peak power conditions, limitation on the production level by the available plant capacity and power transmission capacity to carry peak power load. Luss, II [IAEA workshop, China] dealt with capacity expansion problems. The objective of the model developed by Provenzano, G [IAEA workshop, Korea]. is to minimize the sum of capital operating and transmission cost incurred in meeting future demand for electricity and gas. Matsumoto, J. et al [J Matsumoto] developed a linear programming model for the capacity expansion of a water energy system consisting of four subsystems: water system, coal system, electricity system and gas system. Ramos et al. applied standard nonlinear programming approach to solve the static optimal mix problem in generation planning.

2.3 BPDB'S POWER SYSTEM MASTER PLAN

In May 1983 Bangladesh Power Development Board has launched the master-planning cell in order to design a new plan for the development of generation and transmission system in Bangladesh. The objectives of the master plan includes finding probable load growth, types of fuel available, expansion of power plants to meet the increasing demand, setting up high voltage net work required to transfer bulk power to the main load centers etc. The power system master plan evaluates the different thermal power generation facilities throughout Bangladesh. It addresses all major aspects of thermal power plant selection. Apart from this the power system master plan also addresses the demand side of the supply - demand balance by focusing firstly on technical improvements energy reducing energy consumption through technical and efficiency improvements. Secondly, by changing the behavior pattern of the consumer; using low cost methods like turning off unused equipment, improved maintenance etc. Third and finally by managing load to reduce consumption during peak hours. Generation Planning is the most important part of the power system and the reliability of the whole power system depends largely on the reliability of power generating system. The generation in the system should be such that it can supply the demand at all times under the outage of normal maintenance and forced outage. To develop generation addition sequence Power System Master Plan of 1995 used PC-based WASP (Wein Automatic System Planning Package) [IAEA, manual]. This software determines least-cost generation addition sequences based upon the load characteristics, schedule maintenance, forced outage, and reliability level plant cost etc. The least cost generation addition sequence includes peak and base load plants of optimum unit size. Since then BPDB has been using PC-based WASP for generation planning. Annual LOLP (LOSS-OF LOAD PROBABILITY) of 1% is being used as reliability criteria, the equivalent to about 4 days/year of LOLE (LOSS-OF-LOAD-EXPECTATION).

2.4 POWER MANAGEMENT SYSTEM IN BANGLADESH

Bangladesh has a separate ministry of energy and mineral resources to control monitor and supervise the power and energy sector. This ministry has two main divisions namely power division and energy division. Bangladesh power development board produces more than 80% of the total electricity produced in the whole country and Independent and private power producers does the rest. Figure 2-1 in the following page shows the administrative and business link between different organizations of the power system.

Understanding the importance of energy sector a separate Ministry - Ministry of energy and Mineral Resources has been established. Under MEMR there are two separate divisions for power and energy. The power division deals with the generation, transmission and distribution of electricity in Bangladesh. Only the Power division and its links are shown in the figure below:

2.5 DEMAND OF ENERGY IN BANGLADESH

In energy projection future is predicted as the reflection of the past. The factors, which affect the projection of energy most significantly, are economic growth rate, population growth rate, growth rate of fertilizer industry and power generation efficiency and transmission and distribution losses. Power input from private power producers and commissioning of new power plants by BPDB complemented by the improvement in power management efficiency, transmission and distribution losses- system loss [Rahmatullah, B D] as a whole are expected to reduce over time. The projected electricity generation efficiency and transmission and distribution losses are summarized in the table 2-1

Year	1990	2000	2010	2020
Electricity generation efficiency	26%	30%	35%	37.5%
T & D Losses	40%	30%	27.5%	25%

Table 2-1: Efficiency and losses in electricity sector of Bangladesh

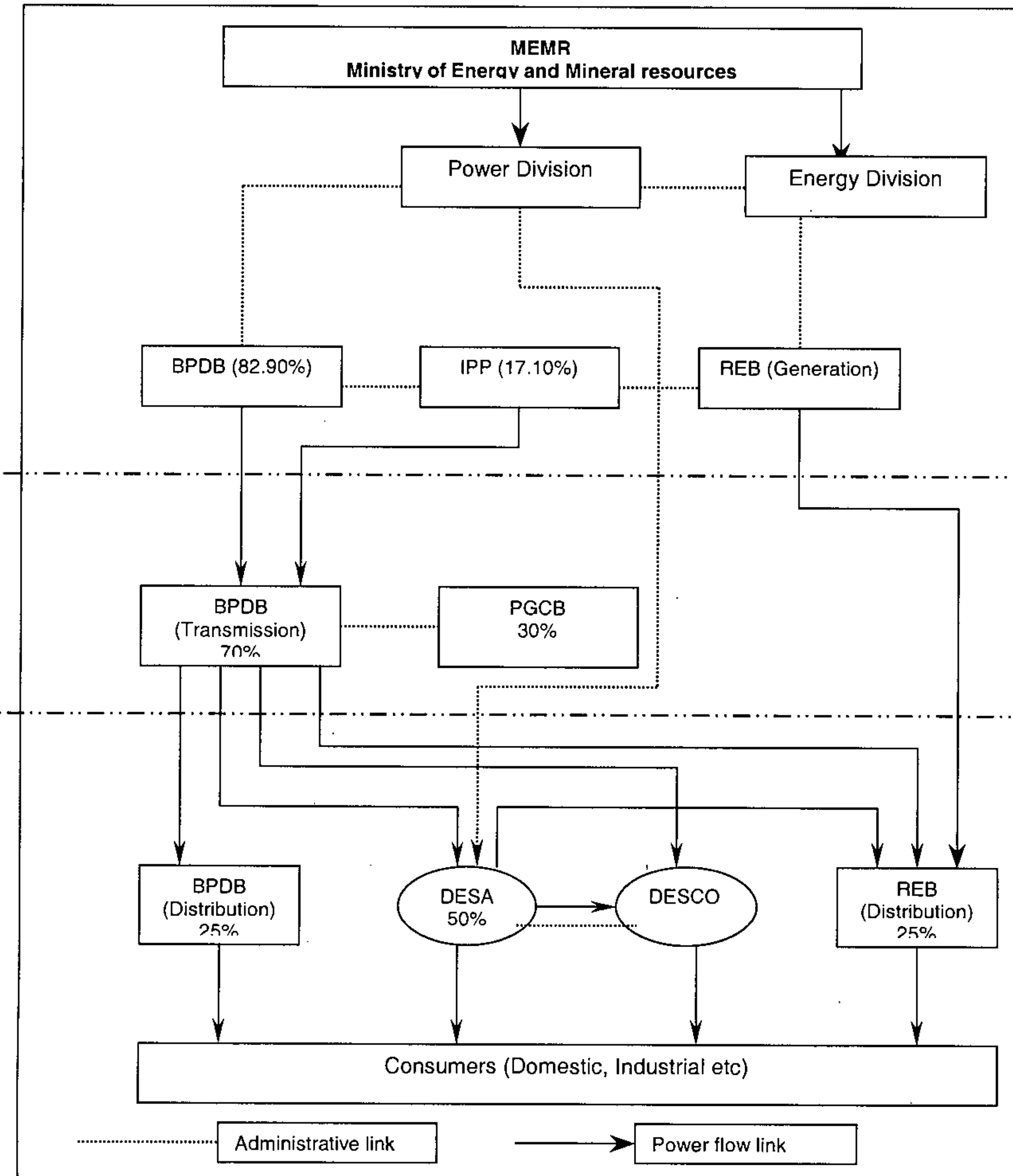


Figure 2-1: Power management system of Bangladesh [M M akan]

In the Power System Master Plan (PSMP) of 1995-benchmark load forecast was based on about 8% growth rate. However, due to shortage in generation capacity, the actual demand could not be supplied for the last few years. The maximum demand served so far is 3592.1 MW on 17.08.2003 [Energy and

Power]. The electricity development is required to be accelerated to increase access and attain economic development. The desirable economic growth rate would be about 6-7% p.a. Electricity generation grew at about 7% p.a. during the last ten years, compared with average annual GDP growth rate about 5.5%, Considering these aspects and anticipated economic growth it would be logical to use the reference forecast of demand as given in the PSMP-95. Based upon the Reference Forecast the anticipated peak demand would be about 5368 MW in FY2007 and 9906MW in FY2015. Year-wise demand forecast is given below in table 2-2.

Fiscal Year	Demand Forecast			
	MW	% Increase	GWh	%Increase
2004	4259	7.90	22.384	7.90
2005	4597	7.94	24.161	7.94
2006	4967	8.05	26.108	8.06
2007	5368	8.07	28.214	8.07
2008	5802	8.08	30.493	8.08
2009	6271	8.08	32.959	8.09
2010	6779	8.10	35.628	8.10
2011	7311	7.85	38.428	7.86
2012	7887	7.88	41.453	7.87
2013	8508	7.87	44.720	7.88
2014	9180	7.90	48.250	7.89
2015	9907	7.92	52.064	7.90

Table 2-2 Demand forecast of electricity in Bangladesh [PDB]

2.6 CHALLENGES OF POWER SECTOR IN BANGLADESH

The policy makers of Bangladesh are now aware of the implications of the adequate generation of electricity in order to achieve sustained economic emancipation. Reduction of transmission and distribution losses, root out system loss, electricity pilferage, collection of bills from the consumers and over all the management system of BPDB has to be changed for the better. These are some challenges BPDB is already facing and trying to solve the issues. In order to get the whole of the country under electricity net work the Government will require huge funding and infrastructure as well. Depleting natural gas reserve in the country is also going to pose a bigger challenge in the near future as approximately 85% of electricity generated in the country uses natural gas as fuel [Mayed, S A].

CHAPTER- III

ESTABLISHMENT OF ENVIRONMENT MANAGEMENT SYSTEM

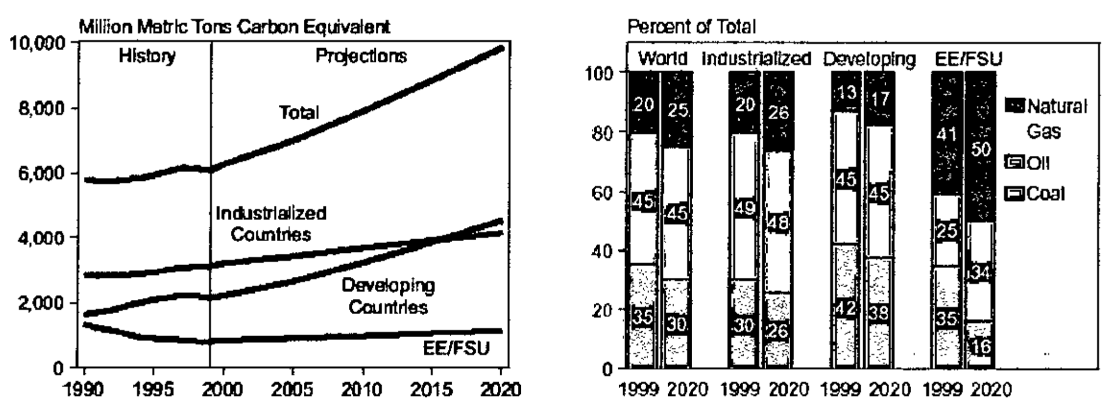
3.0 INTRODUCTION

Energy utilization in any form has been related to the development of a country as it controls the socioeconomic change. In recent years, with the improvement in the standard of living a number of different types of power plants have been installed in order to meet the rising demands of energy. The commissioning of newer power plants has no doubt brought about a positive change in overall economic development but has in turn led to a number of health and environmental hazards by interfering with the quality of air, soil and water.

Country	1990	2005	2010	2020	Percentage increase
United States	168	159	146	124	-1.4
Mexico	230	234	218	185	-1.0
Canada	214	194	178	155	-1.5
United Kingdom	109	104	96	81	-1.4
Germany	105	98	90	78	-1.4
France	72	68	62	56	-1.2
Australasia	223	203	187	159	-1.6
Eastern Europe	558	482	411	305	-2.8
China	645	555	493	392	-2.3
India	511	457	403	315	-2.3
Brazil	108	100	100	94	-0.6
South Korea	218	201	177	142	-2.0
Turkey	268	253	229	191	-1.6

Table 3-1 Carbon Intensity in Different Countries [EIA]

Toxic elements like Hg, As, Pb etc., along with oxides of sulphur and hydrocarbon have been found to diminish the quality of surrounding structures, besides interfering with the normal healthy functioning of not only human being but animals and plants as well. Fly ash from coal based thermal power plants resulted in the conversion of many prime lands into wasteland. Wastewater from different power plants is responsible for bringing change in the physiochemical characteristics of receiving water. Carbon and its different compounds are one of the major threats posed by power plants. Green house effect, rise of sea level and its consequences are all adverse affects of carbon emission. The major portion of carbon emission is from different power plants. Table 3-1 shows carbon intensity in different countries of the world at different time periods.



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, February 2001). **Projections:** EIA, World Energy Projection System (2002).

Sources: **1999:** Energy Information Administration (EIA), *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, February 2001). **2020:** EIA, World Energy Projection System (2002).

Figure 3-1: Carbon Intensity in Different Countries [EIA]

In recent year there has been a remarkable growth of interest in environmental issue – in sustainability and the better management of development in harmony with the environment. Now we feel committed to environmental protection rather than that being skeptical as how to achieve it.

The chapter of environmental negligence is left back, awareness chapter is thoroughly read and policy, planning and technology chapters are before us to address. But the situation in Bangladesh has hardly changed. Though we are now aware of environmental degradation and aware of the harmful affects of it, still we are skeptical about how to achieve it. Though new regulation has been imposed on and Bangladesh is one of the pioneering countries to sign the Kyoto protocol, there have been minimal improvements. An analysis of the current state of the power industries of Bangladesh reveals that the actually used technologies were transferred in a period where industrial waste generation, treatment and disposal represented a significant part of total production costs. A not too strict legislation at that time allowed inconsideration of externalities and poor environmental concern. Environmental management was restricted to monitoring the cost and volume of effluents transferred to waste disposal plants and landfills in the observance of sanitary inspection rules, without any regard to inadequate process performance. On the micro environmental scale, action was limited to programs of accident prevention and use of individual protection equipment, without adequate monitoring occupational health and programs for minimizing inherent process risk.

Rising concern with the environmental impact of processes has led to stricter rules and monitoring parameters with regard to working conditions and waste disposal. In response, Industries started to rethink their production processes with an eye to eliminate or minimize industrial process failures. As such, new and easily established parameters were needed to subsidize the decision maker's choice of the best way to allocate resources for improving the environmental performance of the process.

3.1 EVOLUTION OF ENVIRONMENT MONITORING

People are now extremely aware of environmental degradation and protection of environment. But this development did not occur from very early age. Earlier people used to notice different degradation of environment in terms of bad odor; killing of flora and fauna, deterioration of health condition etc., but no action was taken to stop the degradation. David J Rapport [Rapport] presents the following resumed evolution of environmental monitoring in historical terms:

Phase	Period	Observations	Indicators
First wave	17/18 centuries	Pollution of navigable rivers, fish kill and odor	Evident and easily identifiable
Second wave	1950 / 70	Toxic effects and deformation in sensitive species, environmental integrity	Pre-clinical signals or symptoms of ecosystem unbalance
Third wave	Present	Integrated measures of ecological transformations within the context of cultural and socio-economic changes	Extinction of biologic species

Table: 3-2: Evolution of environmental monitoring

3.2 ENVIRONMENTAL MANAGEMENT

Environmental management is an integrated activity that aims to conform to performance with established norms in environmental and labor law. As such, environment management principles can be of two types – internal to the process and external to the process. The internal management activities refer to experience and training of the personnel, safe working condition and healthy environment. This can be achieved by training the personnel, ensuring safe working conditions etc. The external management components refer to avoiding environmental damage, effluent treatment, minimizing environmental impacts by taking actions to eliminate or minimize industrial wastes and by keeping the community well informed of the activity risk level.

Five stages can be identified in environment management system [M Gaya]

Stage (0):	without management
Stage (1):	observance of legislations
Stage (2):	system development and implementation
Stage (3):	integration with other management areas
Stage (4):	integration with total quality

3.3 ENVIRONMENT MANAGEMENT IN BANGLADESH

The Government of Bangladesh has carried out several studies in association with research institutes ranging from vulnerability and adaptation assessment to potential of Green House Gas (GHG) abatement of different sectors in order to fulfill the commitment under the United Nations Frameworks Convention on Climate Change (UNFCCC). The Government of Bangladesh is a signatory to UNFCCC, which was signed in 1992 as well as the Kyoto protocol. Several initiatives have been undertaken as obligations to UNFCC by different organizations to assess the vulnerability, adaptation and mitigation measures for Bangladesh against the threat of climate change. Some of the studies are – 'Climate change country study: Bangladesh under US climate change study program', 'Asia Least-cost green house gas abatement strategy', 'South –South-North (SSN) project, Clean Development Mechanism project: Opportunities in Bangladesh' etc. Besides Government has also initiated some policy actions, which support activities under the climate convention, reduction of green house gases and considerations on adaptation. Many of the key policies and actions are focused towards the sustainable development goals. Energy sector policy has emphasized the role of renewable energy particularly solar PV. The Government in cooperation with NGOs ha already established a solar village with over 800 households electrified by solar PV. Many other NGOs and private sectors are increasingly promoting the renewable energy technologies in the country. In Bangladesh tree plantation has become a major annual event and festival involving Government, NGOs and local communities. This is adding significantly to Carbon sequestration potential as well as supply of nutrition for the rural poor by providing fruits.

3.4 QUANTITATIVE MONITORING

Environmental monitoring earlier was in qualitative form. There was no method to measure the degree of environmental pollution or degradation. Recently environmentalists, scientists began thinking about quantifying it. Inception of international environment management system (ISO 14000 series) [BS 7750] really enhanced the development of quantification of environmental factors.

With respect to compliance with the present international standardization proposal on environmental norms, the environmental performance indicators are addressed in the following manner on environment performance assessment as shown in table 3-3.

Environmental performance assessment	
1Chapter 3 With respect to utilization	Guarantee a comprehensive assessment of all environmental aspects
	Identify critical and relevant aspects of environmental performance
With respect to the assessment areas of environmental performance	Management system identify weak and strong points in an organization
	Operational systems process load on the environment
	State of the environment and environmental condition on the moment of assessment

Table: 3-3: Environmental performance assessment

3.4.1 Indicators of the State of Environment

ISO 14000 standard identifies the conditions of environment at the moment of assessment. It concerns not only the waste load but also it identifies its influence in eventual environmental changes, independent of the actions of the adjacent organizations. The purpose of this standard is to identify environmental problems and help the decision making process in taking improvement measures.

3.4.2 Operational System Indicators

Operational system is defined as the set of activities related with the design and operation of physical installations, equipment and mass and energy flow, for the deliverance of products and service. The following categories [Haines] can be specified for the study of these indicators:

- Program oriented measures
- Activity based measures
- Mass based measures
- Standardized efficiency measures

3.4.3 Management Indicators

Management of an organization involve all proceedings and activities related to organization, planning, resource allocation, operational control of processes, feedback and checking of performance results, identification of the cause of deficiencies and illustration of the progress made toward the established goal of environmental improvement.

3.5 INDICATOR COMPOSITION

The following indicators could be used following [Haines]

(i) Legal compliance Indicator

As the percentage of compliance in a plant on a monthly and annual basis, to which extent the organization is complying to Government regulations

$$\%C = (\mathbf{T}_s - E_s/T_s) \times 100$$

Where,

$\%C$ = Percentage of compliance
T_s = Total number of samples taken
E_s = Number of samples outside the norms

(ii) Cost of compliance indicator, presented in one of the two possible forms

(a) as a percentage of sales (COC)

COC = (environmental expenditure / total sales) x 100

(b) as cost per production unit

COC = (environmental expenditure / total product)

3.6 ENVIRONMENTAL COSTING

In today's world, environmental remediation, compliance and management are gradually becoming critical aspects of enlightened business practice [Atkinson, 1995]. Perhaps the best way to control and reduce environmental costs is to use the activity based costing method; first the activity that cause environmental costs have to be identified, secondly the costs associated with the activities have to be determined and thirdly these costs must assigned to the most appropriate products, distribution channel and customers. The basic understanding here is to become aware about how different activities generate environmental costs.

Environmental costs fall in two categories, explicit and implicit. Explicit costs include the direct cost of modifying technology and processes, costs of cleanup and disposal, costs of permit to operate a facility, fines levied by the government agencies and litigation fees. Implicit costs are often more closely tied to the infrastructure required to monitor environmental issues.

3.7 POLLUTION BY DIFFERENT POWER PLANTS

In Bangladesh different power plants use different types of fuel. Burning of different fuels generate different polluting agents which contaminate the environment. Not only the suspended materials but power plant operation also affects the nearby human habitat, ecosystem of the surrounding area simply by its size and operation. Steam turbine, Gas turbine, Combined cycle power cycle all affects the environment by burning different types of fuel and generates considerable amount of CO_2, SO_2, NO_x, fly ash, Hg,. Coal fired power plants generate large amount of burned coal in the form of ash which is toxic in nature and also used for land fills. Moreover, this hot ash increases the temperature of surrounding environment. At least one coal fired plant is planned to be in operation soon and more might be added in the future. Though apparently it seems that as hydro power plants do not use any conventional fuel like other power plants and consequently its contribution in terms of pollution should be little but this is not the case. As hydro power plant requires constant water flow for its operation, dams are built to maintain required flow of water by controlling the flow of the original river which directly affects the ecosystem of the concerned area. While one area becomes draught prone the other side of the river remains susceptible of overflow of water.

In the coming future most of the electricity generated in Bangladesh will be using natural gas, different liquid fuel and coal to generate electricity. As CO_2 emission from natural gas is relatively low compared to other fossil fuels and natural gas is virtually free of SO_2 and Hg, electricity generators can help meet their emission requirements by switching to natural gas. Due to different controversies with hydro power plants no further addition of hydro power plants is planned. So planning should be made in such a way that the emissions from the power plants are kept strictly under control through installation of equipment to check and control emissions like precipitators, catalytic reduction equipment, SO_2 scrubber [EIA], implementation of rules and regulation, using advanced technology. Incorporation of these measures into all existing and new system will no doubt translate into monetary cost. Though initially it will increase the cost of power generation but in the long run it ensures sustainable and economic production and generation of electricity.

If such measures are not incorporated, the indirect cost in terms of degraded ecosystem will have to be counted

3.8 CONCLUSION

This evaluation to conformance to environment management could very efficiently and effectively implement in Bangladesh. Implementation of this type of monitoring activity will definitely increase the credibility of electricity companies to the donor agencies and/or countries. To the companies as a matter of fact, this type of activity will be having an effect similar to the Baldridge effect, by improving the performances of power plants towards sustainable development. From the discussion it appears that the mix of power generating units have different scales of environmental impact and thereby cost. With respect to environmental cost it seems gas based combined cycle plants would be the least cost followed by gas fired single cycle steam plants, gas fired gas turbine plants, oil fired steam plants, oil fired gas turbine plants, hydro plants, diesel plants and coal fired plants.

CHAPTER- IV

POWER GENERATION MODEL

4.0 INTRODUCTION

As mentioned earlier Bangladesh is a country where per capita electricity generation is one of lowest and only about 30% of the total population has access to electricity. The present Government has undertaken project to ensure electricity for all by the year 2020. In order to make this true a substantial amount of new generation capacity has to be built within the next few years. It is expected that the demand of electricity will grow at the rate of 7.5% to 8% per annum. This will also require huge amount of investment. Keeping these things in view, it is high time that a strategy is worked out so as to how the expansion program should go and what should be the generation mix in the power sector. In Bangladesh, at present five types of power plants are in operation. This categorization is made on the basis of type of power plant technology. The categories are steam turbine, gas turbine, hydro, combined cycle power plants and some diesel power plants. Among these power plants most of the plants are of steam turbine followed by gas turbine and combined cycle. Though hydro power plants have very low operations and maintenance cost, still the Government can not install newer hydro power plants due to other reasons like availability of required water head through out the year to generate hydro power. In the next few years the trend is to install more combined cycle power plants. Fast installation of combined cycle plants and less fuel, operation and maintenance cost is the main reason behind this.

4.1 MATHEMATICAL MODEL

The mathematical model for this project consists of several variables such as plant capacity of existing and new power plants and costs associated with installation and running the plants. Compete mathematical model is explained step by step in the following sections.

4.2 ASSUMPTIONS

The model has several assumptions in order to simplify the formulation of the problem. The assumptions are listed below.

4.2.1 Types of Plants

In Bangladesh power plants of different technologies are in operation. These are steam turbine, gas turbine, hydro, combined cycle and diesel cycle. In order to identify these different types of power plants in the model subscripts used are shown in table 4-1

Plant type *i*	**Technology**
1	Steam Turbine
2	Gas Turbine
3	Hydro
4	Combined Cycle
5	Diesel Cycle

Table 4-1: Plant type subscripts (Number of unit types $i = 5$)

4.2.2 Planning Horizon

The planning horizon in this model has been restricted to 6 years. The base year here is the year 2004 and the year 2005 is the first planning period. So in total from 2005 to 2010, there are 6 planning years. This is shown in table 4-2

Time Period *t*	Year of Operation
1	2005
2	2006
3	2007
4	2008
5	2009
6	2010

Table 4-2: planning horizon (Number of time period, T = 6)

4.2.3 Load duration curve

The load duration curve has been constructed based on the load for the year. The load duration curve is monotonically decreasing function of time. The area under the curve is the annual total demand of electricity. Using discrete approximation, the load duration curve can be represented by discrete number of demand blocks of width TD_p as shown in figure 4-1 and in table 4-3

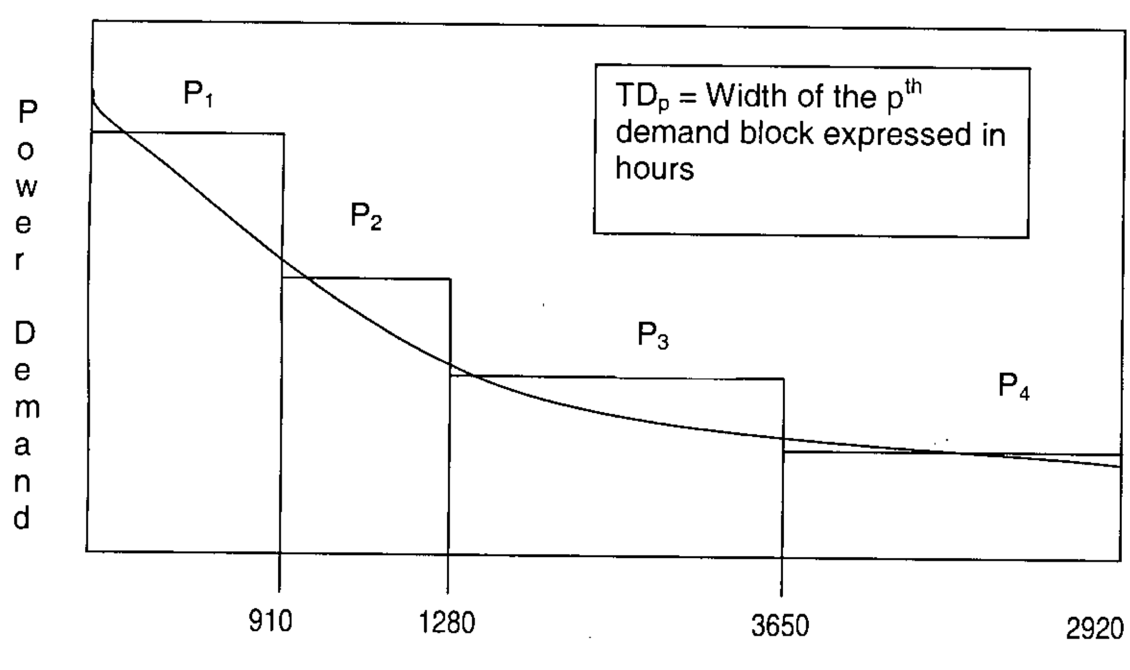


Figure 4-1: A typical daily load duration curve

Demand Block p	Time block in hours of any year, t	Duration in hours (TD_p)	Status
1	0-910	910	Peak demand
2	910-2190	1280	Off-peak (day) demand
3	2190-5840	3650	Off-peak demand
4	5840-8760	2920	Base load demand

Table 4-3: Load duration curve demand blocks

4.2.4 Existing plant capacities (CE_{it})

The existing plant capacity and the planning and the cumulative capacity in different time periods in MW are shown in table 4-4. As it is clear from the planning of the Government, the Government is interested to ensure electricity for all by the year 2020. For this a growth rate of approximately eight percent per annum has been set. Installation of electric power plants requires huge investment and long time to complete an installation. This is evident from the table 4-4. Management's preference for some technology over other is also clear in this table. In the coming years substantial amount of combined cycle power plant capacity is going to be added to the national grid of Bangladesh. Because diesel power plants require excessive investment there will be no more diesel power plants installations.

Plant type i	Technology	Time periods	1 2005	2 2006	3 2007	4 2008	5 2009	6 2010
1	Steam Turbine	Existing + planned	2438	340	210	210	-	-
		Cumulative		2778	2988	3198	3198	3198
2	Gas Turbine	Existing + planned	869	120	-	100	-	-
		Cumulative		989	989	1089	1089	1089
3	Hydro	Existing + planned	230	-	-	-	100	-
		Cumulative		230	230	230	330	330
4	Combined Cycle	Existing + planned	180	340	310	-	450	450
		Cumulative		520	830	830	1280	1730
5	Diesel Cycle	Existing + planned	16.2	-	-	-	-	-
		Cumulative		16.2	16.2	16.2	16.2	16.2

Table 4-4: Power plant capacity in MW

4.3 INDEX

i = plant type as discussed above, $i = 1, I$.

t = time period, $t = 1, T$.

p = load duration block, $p = 1, P$.

4.4 VARIABLES

X_{it} = Capacity required (MW) for new units type i in period t.

CX_i = Maximum capacity (MW) of type i required to install during the entire planning horizon.

OX_{ipt} = Output used (MW) from a new type i in load block p and time period t.

OE_{ipt} = Output used (MW) from an existing type i in load block p and time period t.

4.5 CALCULATION OF NUMBER OF VARIABLES

Total variables required = (2 x I x P x T) + (I x T) + I = I(1+T+2PT)

With i = 5, $P = 4$ and $T = 6$:

5x4x6 = 120 OX_{ipt} variables + 5x4x6 = 120 OE_{ipt} variables + 5x6 = 30 X_{it} variables + I = 5 CX_i variables = a total of 275 variables.

4.6 DATA/PARAMETERS

CE_{it} = Capacity (MW) of existing units type i in period t.

TD_p = Duration of load block p in hours.

AF_{it} = Availability factor [Krajwski] for type i in period t (reliability and other factors should be considered in setting this parameter).

PD_{pt} = Maximum power demand in MW in load block p in period t

VC_{it} = Variable cost

= Fuel costs (Tk/MWh) + Environmental cost (expenditure and penalty) for plant type i in period t (for both existing and new).

FC_{it} = Fixed cost

= Annual investment cost + annual operating and maintenance costs (Tk/MWh) for plant type i in period t (for both existing and newly proposed).

4.7 COMPLETE MODEL

4.7.1 Objective Function

$$\text{Minimize } Z = \sum_{p=1}^{P} TD_p \sum_{i=1}^{I} \sum_{t=1}^{T} VC_{it}(OX_{ipt} + OE_{ipt}) + \sum_{i=1}^{I} \sum_{t=1}^{T} FC_{it} X_{it}$$

First term: variable costs of existing plus newly proposed plants

Second term: fixed cost of new plants

The fixed cost for the existing plants is ignored since it has no influence on the optimization process.

4.7.2 Constraints

The constraints used in the model are capacity demand, demand satisfaction, new plant constraint etc. The constraints are explained in details in the following sections

4.7.2.1 Capacity constraint

The output of each type of power generation unit cannot exceed the total capacity of the existing or planned units of this type, multiplied by the corresponding availability factor in the first load block of a given year t:

$OX_{ipt} + OE_{ipt} \leq AF_{it}(X_{it} + CE_{it})$ for $p = 1$ only, and all i and t.

Putting all variables in the LHS and constant in the RHS, we can rewrite as

$OX_{ipt} + OE_{ipt} - AF_{it}X_{it} \leq AF_{it}CE_{it}$ for $p = 1$ only, and all i and t.

The values of p = 2, 3 and 4 would not effect the capacity determination constraint as they have much lower demand.

The number of constraint of this type = I x T = 5x6 = 30.

4.7.2.2 Demand Satisfaction

The power demand at each load block must be satisfied.

$\sum_{i=1}^{I} OX_{ipt} + OE_{ipt} \geq PD_{pt}$ for all p and t

The number of constraints = P x T = 4x6 = 24.

4.7.2.3 New Plant Constraint

Once a certain type of plants with a given capacity is added to the existing capacity, that plant will be retained through out the planning horizon considered. In addition, further capacity may be added in a future period. For example, suppose the model has decided to install a new plant of type 1 with 50MW capacity in period 1, it will exist in the system until period 6 since the technical life is usually longer than 6 years. To ensure this, the following constraints are necessary:

$X_{it+1} \geq X_{it}$

or $X_{it+1} - X_{it} \geq 0$ for all i and t

Number of constraints of this type = I x T = 5x6 = 30.

4.7.2.4 Preference for New Plants

Management may prefer certain type of technology over others and / or like to have all the technologies in certain ratios. The maximum capacity required from each new type *i* can be found using the following constraints:

$CX_i \geq X_{it}$ for all *i* and *t*.

or $CX_i - X_{it} \geq 0$ for all *i* and *t*.

Then the total capacity required from all new types of plants is: $\sum_{i=1}^{I} CX_i$

The number of constraints: I x T = 5x6 = 30

Total number of constraints = 30 + 24 + 30 + 30 = 114.

4.7.2.4 Nonnegative Constraints

As in all linear programming problems the non-negativity constraints must be satisfied, which gives us

$OX_{ipt}, OE_{ipt}, X_{it}, CX_i \geq 0$

4.8 COMPLETE MODEL

Minimize $Z = \sum_{p=1}^{P} TD_p \sum_{i=1}^{I} \sum_{t=1}^{T} VC_{it}(OX_{ipt} + OE_{ipt}) + \sum_{i=1}^{I} \sum_{t=1}^{T} FC_{it} X_{it}$

Subject to

$OX_{ipt} + OE_{ipt} - AF_{it} X_{it} \leq AF_{it} CE_{it}$ for $p = 1$ only, and all *i* and *t*.

$\sum_{i=1}^{I} OX_{ipt} + OE_{ipt} \geq PD_{pt}$ for all *p* and *t*

$X_{it+1} - X_{it} \geq 0$ for all *i* and *t*

$CX_i - X_{it} \geq 0$ for all *i* and *t*.

$OX_{ipt}, OE_{ipt}, X_{it}, CX_i \geq 0$

4.9 DATA INPUT TO THE MODEL

The data available for the model has been collected from various sources. Some of the sources include Bangladesh Power Development Board (BPDB), different websites, journals, reports published by various organizations etc.

4.9.1 Time Interval

Table 4-5 indicates the time periods used in the model with the corresponding values of time periods.

't' Subscript	Time Periods	Status
1	2005	First future time period
2	2006	Second future time period
3	2007	Third future time period
4	2008	Fourth future time period
5	2009	Fifth future time period
6	2010	Sixth future time period

Table 4-5 Time intervals used in the model

4.9.2 Discount Rate

In this study, since the investment is of capital nature a discount rate of 5% per annum has been used. Besides for installation in different time periods wherever required investment amount is not available the price is taken to escalate at a rate of ten percent per annum. This rate might seem high but the logic behind this is here price increase for machinery, and other variables and inflation rate of currencies have been considered.

4.9.3 Operations and Maintenance Cost

The operations and maintenance cost for various power plants does not vary much over time. So for simplification and ease of calculation this cost is taken as fixed over various time periods and the cost is taken as a component of fixed cost.

4.9.4 Fixed Cost

In this model the fixed cost considers the capital investment required to install a new power plant. This investment comes generally from two sources- from the government sources and from some foreign source in the form of loan or sometimes aid. Capital cost estimates in taka/Mwh for various power plants have been taken from different sources [PDB, Mahbubul Haque] and then transformed into taka/MW by using then exchange rate. These costs are then annualised as shown in table 4-6.

Time period	Types of Power Plants				
	Steam Turbine	Gas Turbine	Hydro	Combined Cycle	Diesel
0	2.981	3.697	4.492	5.772	6.524
1	3.507	4.067	5.681	6.350	7.249
2	3.857	4.473	6.249	6.985	8.055
3	4.243	4.921	6.874	7.683	8.950
4	4.667	5.413	7.561	8.451	9.944
5	5.134	5.954	8.318	9.297	11.049
6	5.647	6.550	9.149	10.226	12.277

Table 4-6 Annuitzed capital costs for different types of power plants in different time periods in million taka/MWH

4.9.5 Variable Cost

The variable cost has two components fuel costs and environmental expenditure for different types of power plants per annum.

4.9.5.1 Fuel cost

The fuel cost of different types of power plants have been taken from PDB sources. It is assumed that fuel prices increases one percent annually.

Plants	Time Periods					$(10^3$ taka/MWh)
	1	2	3	4	5	6
Steam Turbine	1.423	1.508	1.599	1.695	1.797	1.904
Gas Turbine	4.485	4.754	5.039	5.342	5.662	6.002
Hydro Plants	8.984	11.362	13.748	15.122	16.636	18.298
Combined Cycle	0.667	0.707	0.750	0.794	0.842	0.892
Diesel Cycle	4.177	4.428	4.693	4.975	5.273	5.590

Table 4-7 Fuel costs for different power plants

4.9.5.2 Environmental Cost

To find out environmental cost a high penalty factor of 5% of fuel cost is added to the fuel cost in each time period. For the Hydro power plants as it does not have any fuel cost incurred, but certainly results in environmental degradation in terms of ecosystem unbalance so we have kept the environmental cost as 0.2% of fixed cost.

Plants	Time Periods					$(10^3$ taka/MWh)
	1	2	3	4	5	6
Steam Turbine	0.1423	0.1508	0.1599	0.1695	0.1797	0.1904
Gas Turbine	0.4485	0.4754	0.5039	0.5342	0.5662	0.6002
Hydro Plants	8.984	11.362	13.748	15.122	16.636	18.298
Combined Cycle	0.0667	0.0707	0.0750	0.0794	0.0842	0.0892
Diesel Cycle	0.4177	0.4428	0.4693	0.4975	0.5273	0.5590

Table 4-8 Environmental costs for different power plants

CHAPTER- V

RESULTS AND DISCUSSION

5.0 INTRODUCTION

Linear programming software [lp_solve] is used to run this model. The result obtained lp_solve is also verified by NEOS server. The model was sent to the NEOS server and the result was obtained. The model contains the following number of rows and variables:

Solver: FortMP 3.2e

Rows: 93

Variables: 270

Iterations: 78

5.1 OUTPUT

The output gives values of plant capacities and outputs of various types of power plants. The peak plant output during the peak demand for different planning years are given in table 5-1

Variables	Value (MW)
OX111	4237
OX112	4680.86
OX113	4756
OX114	4884
OX115	4894
OX411	153
OX412	230
OX413	612
OX414	918
OX415	1377
OX416	2065

Table 5-1: Output in different plan periods in MW

The output of the model shows that the steam turbine and combined cycle power plants to be constructed. Though hydro power plants are the cheapest in terms of operations, constraints were set restricting the installation of hydro power plants.

For the combined cycle power plants the peak demand for existing as well as new power plants in cumulative form is available. The maximum demand in the 6th year is 2065 MW for new installation. This result is at par with the future planning of Bangladesh Power Development Board.

Installations of hydro power plants have been restricted by the model in order to cope with the planning program according to the Power System Master Plan. Otherwise because of very low operations and maintenance and fuel cost most of the planning would be reflected in hydro installation.

For diesel units, they are actually small captive power generation and do not have any substantial economies of scale.

The peak period demands in different plan periods are shown in table 5-2. These are values expressed in MW and cumulative of existing and new power plants.

Time period	Demand
1	4237
2	4680
3	4756
4	4884
5	4894

Table 5-2 peak period demand

Regarding plant capacity this model suggests as in the case of steam turbine the expansion program should be 2663 MW in the first year and the same value in the following years. This can be explained as the expansion program should be taken up in the first year of planning and in the subsequent years no further addition is required.

5.2 ELECTRICITY GENERATION COST

Objective function: 0.136480421 E+12

Taking annual growth rate of eight percent, the total cost associated with electricity generation, operations and maintenance, fuel cost and new plant installation for the 6 years plan period will be 13.6 x 10^{10} Taka.

The fixed cost (FC_{it}) of existing plants which comprising of annual investment cost and annual operations and maintenance cost is ignored as in this case it does not have any influence on the optimization process. The variable cost (VC_{it}) for both existing and planned plants has been considered in the model.

5.3 CONCLUSIONS

In this research work a linear programming model is devised to find an optimum generation mix for different types of power plants. The expansion planning keeping the cost factor in account has been considered. This is a year by year expansion program; the future periods here begins from 2005 and ends in 2010.

The output includes plant capacity and output during different time periods of considerations at eight percent growth with the main objective of ensuring electricity for all by the year 2020.

Some of the major conclusions referred by this model are described below:

- It is high time that the electricity industry of Bangladesh start implementing environment friendly operations and maintenance system. The procedure could be started from elementary things like establishing different indices as stated in the chapter three of the thesis work
- The model indicates that combined cycle, steam turbine and gas turbine power plants should be installed. There is scope for very little expansion of hydro power plant to exploit the existing capacity more.
- Small diesel power units are used for captive power generation. As compare to larger scale power developments as per PSMP, these are very small and do not odder much economies of scale.
- In all the projection periods steam turbine, gas turbine and combined cycle power plants are used in all the periods of demand blocks.

This type of mathematical model calls for availability of necessary data and information. In Bangladesh no updated database is available; moreover the data available from various sources differs considerably to be trust worthy. A lot of assumptions are required to make the model mathematically operable, which might lead to results that might seem made up.

5.4 RECOMMENDATIONS

This model takes into account the different costs terms associated with power plants operations, load duration curve, plant availability etc. Present day scenario is changing with adoption of private power producers. When private power plants generates electricity, BPDB just buys the generated electricity and distributes it in the national grid, which means the investment required by BPDB or on the part of Government then simply becomes very small. But this call for other parameters like how much electricity to buy, the rate per unit of generated electricity. As electricity is consumed as it is generated, there has to be plan to make sure enough electricity is bought from the power plant producers at the minimum possible cost.

Again BPDB sells electricity at different prices to different consumers; different private producers also sell electricity at different price - these factors could be considered in the future research work.

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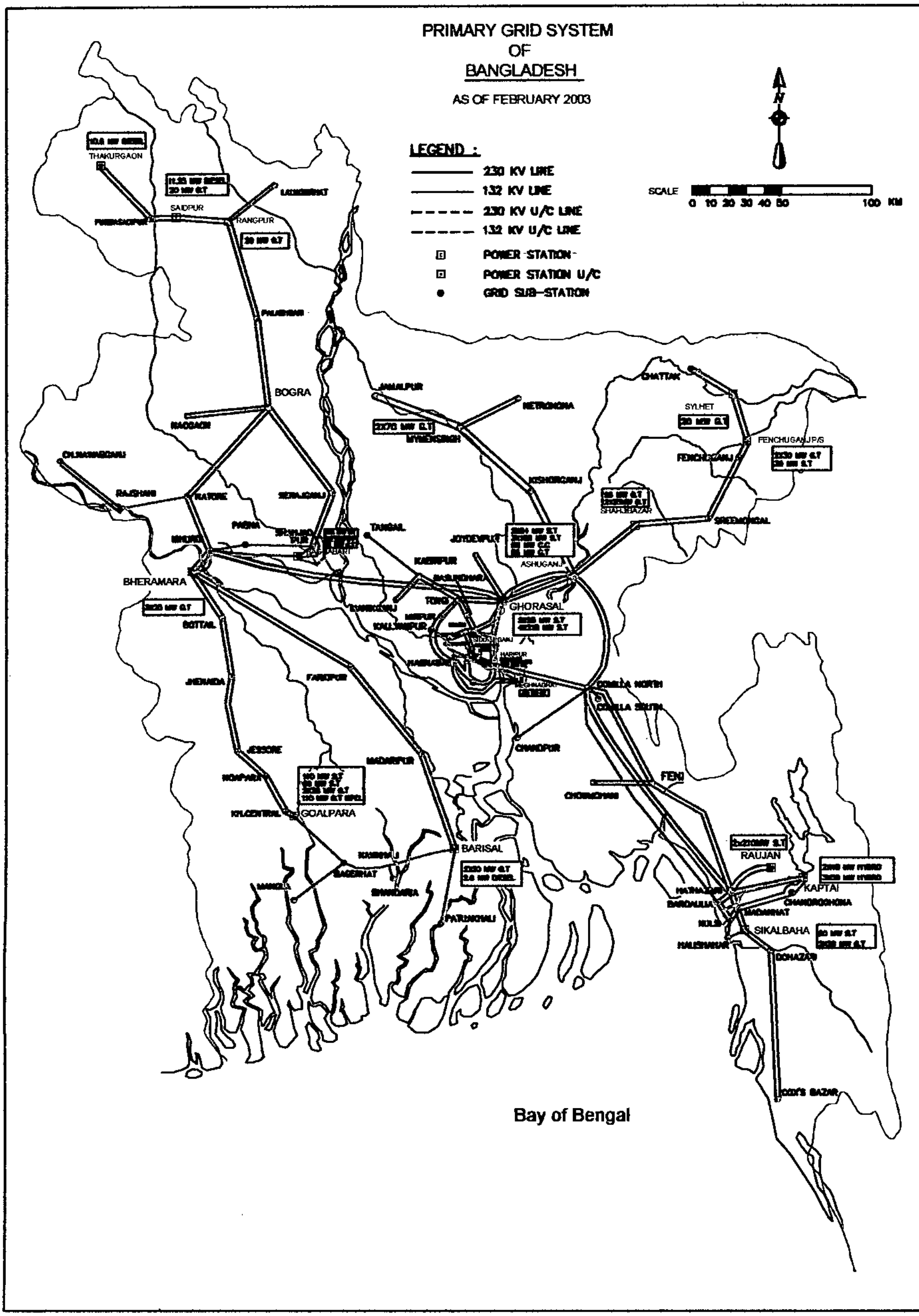
Annexure- I


PRIMARY GRID SYSTEM
OF
BANGLADESH
AS OF FEBRUARY 2003
LEGEND :
230 KV LINE
132 KV LINE
230 KV U/C LINE
132 KV U/C LINE
POWER STATION
POWER STATION U/C
GRID SUB-STATION
SCALE
0 10 20 30 40 50 100 KM
N
THAKURGAON
SAIDPUR
RANGPUR
BOGRA
RAJSHAHI
BHERAMARA
GHORASAL
ASHUGANJ
SYLHET
FENCHUGANJ P/S
SHAHJIBAZAR
JAMALPUR
MYMENSINGH
NETROKONA
KISHORGANJ
TANGAIL
JOYDEVPUR
TONGI
MIRPUR
HARIPUR
MEGHNAGHAT
COMILLA NORTH
COMILLA SOUTH
CHANDPUR
FENI
JESSORE
GOALPARA
BARISAL
RAUJAN
KAPTAI
SIKALBAHA
DOHAZARI
COX'S BAZAR
Bay of Bengal

Annexure- II

Data Input to the Model

Min: 129493 OX111 + 137228 OX112 + 145509 OX113 + 154245 OX114 + 163527 OX115 + 173264 OX116 + 1821440 OX121 + 1930240 OX122 + 2046720 OX123 + 2169600 OX124 + 2300160 OX125 + 2437120 OX126 + 5193950 OX131 + 5504200 OX132 + 5836350 OX133 + 6186750 OX134 + 6559050 OX135 + 6949600 OX136 + 4155160 OX141 + 4403360 OX142 + 4669080 OX143 + 4949400 OX144 + 5247240 OX145 + 5559680 OX146 + 408135 OX211 + 432614 OX212 + 458549 OX213 + 486122 OX214 + 515242 OX215 + 546182 OX216 + 5740800 OX221 + 6085120 OX222 + 6449920 OX223 + 6837760 OX224 + 7247360 OX225 + 7682560 OX226 + 16370250 OX231 + 17352100 OX232 + 18392350 OX233 + 19498300 OX234 + 20666300 OX235 + 21907300 OX236 + 13096200 OX241 + 13881680 OX242 + 14713880 OX243 + 15598640 OX244 + 16533040 OX245 + 17525840 OX246 + 817544 OX311 + 1033942 OX312 + 1251068 OX313 + 1376102 OX314 + 1513876 OX315 + 1665118 OX316 + 11499520 OX321 + 14543360 OX322 + 17597440 OX323 + 19356160 OX324 + 21294080 OX325 + 23421440 OX326 + 32791600 OX331 + 41471300 OX332 + 50180200 OX333 + 55195300 OX334 + 60721400 OX335 + 66787700 OX336 + 26233280 OX341 + 33177040 OX342 + 40144160 OX343 + 44156240 OX344 + 48577120 OX345 + 53430160 OX346 + 60697 OX411 + 64337 OX412 + 68250 OX413 + 72254 OX414 + 76622 OX415 + 81172 OX416 + 853760 OX421 + 904960 OX422 + 960000 OX423 + 1016320 OX424 + 1077760 OX425 + 1141760 OX426 + 2434550 OX431 + 2580550 OX432 + 2737500 OX433 + 2898100 OX434 + 3073300 OX435 + 3255800 OX436 + 1947640 OX441 + 2064440 OX442 + 2190000 OX443 + 2318480 OX444 + 2458640 OX445 + 2604640 OX446 + 380107 OX511 + 402948 OX512 + 427063 OX513 + 452725 OX514 + 479843 OX515 + 508690 OX516 + 5346560 OX521 + 5667840 OX522 + 6007040 OX523 + 6368000 OX524 + 6749440 OX525 + 7155200 OX526 + 15246050 OX531 + 16162200 OX532 + 17129450 OX533 + 18158750 OX534 + 19246450 OX535 + 20403500 OX536 + 12196840 OX541 + 12929760 OX542 + 13703560 OX543 + 14527000 OX544 + 15397160 OX545 + 16322800 OX546 + 12949.3 OE111 + 13722.8 OE112 + 14550.9 OE113 + 15424.5 OE114 + 16352.7 OE115 + 17326.4 OE116 + 182144.0 OE121 + 193024.0 OE122 + 204672.0 OE123 + 216960.0 OE124 + 230016.0 OE125 + 243712.0 OE126 + 519395.0 OE131 + 550420.0 OE132 + 583635.0 OE133 + 618675.0 OE134 + 655905.0 OE135 + 694960.0 OE136 + 415516.0 OE141 + 440336.0 OE142 + 466908.0 OE143 + 494940.0 OE144 + 524724.0 OE145 + 555968.0 OE146 + 40813.5 OE211 + 43261.4 OE212 + 45854.9 OE213 + 48612.2 OE214 + 51524.2 OE215 + 54618.2 OE216 + 574080.0 OE221 + 608512.0 OE222 + 644992.0 OE223 + 683776.0 OE224 + 724736.0 OE225 + 768256.0 OE226 + 1637025.0 OE231 + 1735210.0 OE232 + 1839235.0 OE233 + 1949830.0 OE234 + 2066630.0 OE235 + 2190730.0 OE236 + 1309620.0 OE241 + 1388168.0 OE242 + 1471388.0 OE243 + 1559864.0 OE244 + 1653304.0 OE245 + 1752584.0 OE246 + 81754.4 OE311 + 103394.2 OE312 + 125106.8 OE313 + 137610.2 OE314 + 151387.6 OE315 + 166511.8 OE316 + 1149952.0 OE321 + 1454336.0 OE322 + 1759744.0 OE323 + 1935616.0 OE324 + 2129408.0 OE325 + 2342144.0 OE326 + 3279160.0 OE331 + 4147130.0 OE332 + 5018020.0 OE333 + 5519530.0 OE334 + 6072140.0 OE335 + 6678770.0 OE336 + 2623328.0 OE341 + 3317704.0 OE342 + 4014416.0 OE343 + 4415624.0 OE344 + 4857712.0 OE345 + 5343016.0 OE346 + 6069.7 OE411 + 6433.7 OE412 + 6825.0 OE413 + 7225.4 OE414 + 7662.2 OE415 + 8117.2 OE416 + 85376.0 OE421 + 90496.0 OE422 + 96000.0 OE423 + 101632.0 OE424 + 107776.0 OE425 + 114176.0 OE426 + 243455.0 OE431 + 258055.0 OE432 + 273750.0 OE433 + 289810.0 OE434 + 307330.0 OE435 + 325580.0 OE436 + 194764.0 OE441 + 206444.0 OE442 + 219000.0 OE443 + 231848.0 OE444 + 245864.0 OE445 + 260464.0 OE446 + 38010.7 OE511 + 40294.8 OE512 + 42706.3 OE513 + 45272.5 OE514 + 47984.3 OE515 + 50869.0 OE516 + 534656.0 OE521 + 566784.0 OE522 + 600704.0 OE523 + 636800.0 OE524 + 674944.0 OE525 + 715520.0 OE526 + 1524605.0 OE531 + 1616220.0 OE532 + 1712945.0 OE533 + 1815875.0 OE534 + 1924645.0 OE535 + 2040350.0 OE536 + 1219684.0 OE541 + 1292976.0 OE542 + 1370356.0 OE543 + 1452700.0 OE544 + 1539716.0 OE545 + 1632280.0 OE546 + 2980562.596 X11 + 3506544.23 X12 + 3857198.653 X13 + 4242918.519 X14 + 4667210.371 X15 + 5133931.408 X16 + 5647324.548 X21 + 3697048.817 X22 + 4066753.698 X22 + 4473429.068 X23 + 4920771.975 X24 + 5412849.172 X25 + 5954134.09 X26 + 6549547.499 X31 + 4492162.252 X32 + 5681036.74 X33 + 6249140.414 X34 + 6874054.455 X35 + 7561459.901 X36 + 8317605.891 X41 +

```
9149366.48 X42 + 5772423.726 X43 + 6349666.098 X44 + 6984632.708 X45 + 7683095.979 X46 +
8451405.577 X51 + 9296546.134 X52 + 10226200.75 X53 + 6524344.765 X54 + 7249271.961 X56;
/*capacity demand*/
OX111 + OE111 - 0.80 X11 <= 2106.43;
OX112 + OE112 - 0.85 X12 <= 2417.13;
OX113 + OE113 - 0.85 X13 <= 2610.50;
OX114 + OE114 - 0.85 X14 <= 2819.34;
OX115 + OE115 - 0.85 X15 <= 3044.89;
OX116 + OE116 - 0.85 X16 <= 3228.48;
OX211 + OE211 - 0.70 X21 <= 608.30;
OX212 + OE212 - 0.75 X22 <= 741.75;
OX213 + OE213 - 0.75 X23 <= 801.09;
OX214 + OE214 - 0.75 X24 <= 865.18;
OX215 + OE215 - 0.75 X25 <= 934.39;
OX216 + OE216 - 0.75 X26 <= 1009.15;
OX311 + OE311 - 0.50 X31 <= 207;
OX312 + OE312 - 0.50 X32 <= 223.56;
OX313 + OE313 - 0.50 X33 <= 241.45;
OX314 + OE314 - 0.50 X34 <= 260.76;
OX315 + OE315 - 0.50 X35 <= 281.62;
OX316 + OE316 - 0.50 X36 <= 304.15;
OX411 + OE411 - 0.85 X41 <= 153;
OX412 + OE412 - 0.85 X42 <= 229.5;
OX413 + OE413 - 0.85 X43 <= 612;
OX414 + OE414 - 0.85 X44 <= 918;
OX415 + OE415 - 0.85 X45 <= 1377;
OX416 + OE416 - 0.85 X46 <= 2065.50;
OX511 + OE511 - 0.90 X51 <= 16.2;
OX512 + OE512 - 0.90 X52 <= 16.2;
OX513 + OE513 - 0.90 X53 <= 16.2;
OX514 + OE514 - 0.90 X54 <= 16.2;
OX515 + OE515 - 0.90 X55 <= 16.2;
OX516 + OE516 - 0.90 X56 <= 16.2;
/* Demand staisfaction*/
OX111 + OX211 + OX311 + OX411 + OX511 + OE111 + OE211 + OE311 + OE411 + OE511 >= 4597;
OX121 + OX221 + OX321 + OX421 + OX521 + OE121 + OE221 + OE321 + OE421 + OE521 >=
2988.05;
OX131 + OX231 + OX331 + OX431 + OX531 + OE131 + OE231 + OE331 + OE431 + OE531 >=
2528.35;
OX141 + OX241 + OX341 + OX441 + OX541 + OE141 + OE241 + OE341 + OE441 + OE541 >=
2068.65;
OX112 + OX212 + OX312 + OX412 + OX512 + OE112 + OE212 + OE312 + OE412 + OE512 >= 4967;
OX122 + OX222 + OX322 + OX422 + OX522 + OE122 + OE222 + OE322 + OE422 + OE522 >=
3228.55;
OX132 + OX232 + OX332 + OX432 + OX532 + OE132 + OE232 + OE332 + OE432 + OE532 >=
2731.85;
OX142 + OX242 + OX342 + OX442 + OX542 + OE142 + OE242 + OE342 + OE442 + OE542 >=
2235.15;
OX113 + OX213 + OX313 + OX413 + OX513 + OE113 + OE213 + OE313 + OE413 + OE513 >= 5368;
OX123 + OX223 + OX323 + OX423 + OX523 + OE123 + OE223 + OE323 + OE423 + OE523 >=
3489.20;
OX133 + OX233 + OX333 + OX433 + OX533 + OE133 + OE233 + OE333 + OE433 + OE533 >=
2952.40;
OX143 + OX243 + OX343 + OX443 + OX543 + OE143 + OE243 + OE343 + OE443 + OE543 >=
2415.60;
```

```
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3771.3;
OX134 + OX234 + OX334 + OX434 + OX534 + OE134 + OE234 + OE334 + OE434 + OE534 >=
3191.10;
OX144 + OX244 + OX344 + OX444 + OX544 + OE144 + OE244 + OE344 + OE444 + OE544 >=
2610.90;
OX115 + OX215 + OX315 + OX415 + OX515 + OE115 + OE215 + OE315 + OE415 + OE515 >= 6271;
OX125 + OX225 + OX325 + OX425 + OX525 + OE125 + OE225 + OE325 + OE425 + OE525 >=
4076.15;
OX135 + OX235 + OX335 + OX435 + OX535 + OE135 + OE235 + OE335 + OE435 + OE535 >=
3449.05;
OX145 + OX245 + OX345 + OX445 + OX545 + OE145 + OE245 + OE345 + OE445 + OE545 >=
2821.95;
OX116 + OX216 + OX316 + OX416 + OX516 + OE116 + OE216 + OE316 + OE416 + OE516 >= 6779;
OX126 + OX226 + OX326 + OX426 + OX526 + OE126 + OE226 + OE326 + OE426 + OE526 >=
4406.35;
OX136 + OX236 + OX336 + OX436 + OX536 + OE136 + OE236 + OE336 + OE436 + OE536 >=
3728.45;
OX146 + OX246 + OX346 + OX446 + OX546 + OE146 + OE246 + OE346 + OE446 + OE546 >=
3050.55;
/*New plant constraint*/
X11 >= 0;
X12 - X11 >= 0;
X13 - X12 >= 0;
X14 - X13 >= 0;
X15 - X14 >= 0;
X16 - X15 >= 0;
X21 >= 0;
X22 - X21 >= 0;
X23 - X22 >= 0;
X24 - X23 >= 0;
X25 - X24 >= 0;
X26 - X25 >= 0;
X31 >= 0;
X32 - X31 >= 0;
X33 - X32 >= 0;
X34 - X33 >= 0;
X35 - X34 >= 0;
X36 - X35 >= 0;
X41 >= 0;
X42 - X41 >= 0;
X43 - X42 >= 0;
X44 - X43 >= 0;
X45 - X44 >= 0;
X46 - X45 >= 0;
X51 >= 0;
X52 - X51 >= 0;
X53 - X52 >= 0;
X54 - X53 >= 0;
X55 - X54 >= 0;
X56 - X55 >= 0;
/*1300 - X11 >= 0;
1300 - X12 >= 0;
1300 - X13 >= 0;
```

```
1300 - X14 >= 0;
1300 - X15 >= 0;
1300 - X16 >= 0;*/
OX311 + OX312 + OX313 + OX314 + OX315 + OX316 + OE311 + OE312 + OE313 + OE314 + OE315
+ OE316 <= 330;
OX311 + OX312 + OX313 + OX314 + OX315 + OX316 <= 100;
OX321 + OX322 + OX323 + OX324 + OX325 + OX326 <= 65;
OX331 + OX332 + OX333 + OX334 + OX335 + OX336 <= 55;
OX341 + OX342 + OX343 + OX344 + OX345 + OX346 <= 45;
OE311 + OE312 + OE313 + OE314 + OE315 + OE316 <= 230;
OE321 + OE322 + OE323 + OE324 + OE325 + OE326 <= 150;
OE331 + OE332 + OE333 + OE334 + OE335 + OE336 <= 127;
OE341 + OE342 + OE343 + OE344 + OE345 + OE346 <= 104;
/*X11 + X12 + X13 + X14 + X15 + X16 <= 3500;*/
X21 + X22 + X23 + X24 + X25 + X26 <= 1500;
X31 + X32 + X33 + X34 + X35 + X36 <= 330;
X41 + X42 + X43 + X44 + X45 + X46 <= 2500;
X51 + X52 + X53 + X54 + X55 + X56 <= 16.2;
3198 - X11 >= 0;
3198 - X12 >= 0;
3198 - X13 >= 0;
3198 - X14 >= 0;
3198 - X15 >= 0;
3198 - X16 >= 0;
1089 - X21 >= 0;
1089 - X22 >= 0;
1089 - X23 >= 0;
1089 - X24 >= 0;
1089 - X25 >= 0;
1089 - X26 >= 0;
330 - X31 >= 0;
330 - X32 >= 0;
330 - X33 >= 0;
330 - X34 >= 0;
330 - X35 >= 0;
330 - X36 >= 0;
1730 - X41 >= 0;
1730 - X42 >= 0;
1730 - X43 >= 0;
1730 - X44 >= 0;
1730 - X45 >= 0;
1730 - X46 >= 0;
16.2 - X51 >= 0;
16.2 - X52 >= 0;
16.2 - X53 >= 0;
16.2 - X54 >= 0;
16.2 - X55 >= 0;
16.2 - X56 >= 0;
```

Annexure-III

```
****************************************************************

                    NEOS Server Version 4.0

    Job#    : 465471
    Solver  : FortMP 3.2e
    Start   : 10/27/2004 0:13:43
    End     : 10/27/2004 0:13:46
    Host    : pergamon.iems.northwestern.edu

    Announcements:

    The latest version of the NEOS server can be found at:
    http://www-neos.mcs.anl.gov/
    Users can consult the NEOS Guide at:
    http://www.mcs.anl.gov/otc/Guide/
    which has extensive information on optimization.

    Disclaimer:

    This information is provided without any express or
    implied warranty. In particular, there is no warranty
    of any kind concerning the fitness of this
    information for any particular purpose.

****************************************************************
```

FORTMP SOLUTION REPORT: (TOTAL ITERATIONS= 92)
LP: OPTIMAL
IP: NONE
PROBLEM NAME =
OBJECTIVE NAME = R0
RHS NAME = RHS
BOUNDS NAME = BND
MROW = 93
NCOL = 270
LP OPTIMUM VALUE = 0.574988944E+11

COLUMNS.......STRUCTURAL VARIABLES

NO	STATE	NAME	VALUE	LOWER BND	UPPER BND	REDUCED COST
1	L	OX111	0.	0.	NONE	116543.7
2	L	OX112	0.	0.	NONE	123505.2
3	L	OX113	0.	0.	NONE	130958.1
4	L	OX114	0.	0.	NONE	138820.5
5	L	OX115	0.	0.	NONE	147174.3
6	L	OX116	0.	0.	NONE	155937.6
7	L	OX121	0.	0.	NONE	1736064.
8	L	OX122	0.	0.	NONE	1839744.
9	L	OX123	0.	0.	NONE	1950720.
10	L	OX124	0.	0.	NONE	2067968.
11	L	OX125	0.	0.	NONE	2192384.
12	L	OX126	0.	0.	NONE	2322944.
13	L	OX131	0.	0.	NONE	4950495.
14	L	OX132	0.	0.	NONE	5246145.
15	L	OX133	0.	0.	NONE	5562600.
16	L	OX134	0.	0.	NONE	5896940.
17	L	OX135	0.	0.	NONE	6251720.
18	L	OX136	0.	0.	NONE	6624020.
19	L	OX141	0.	0.	NONE	3960396.
20	L	OX142	0.	0.	NONE	4196916.
21	L	OX143	0.	0.	NONE	4450080.
22	L	OX144	0.	0.	NONE	4717552.
23	L	OX145	0.	0.	NONE	5001376.

24	L	OX146	0.	0.	NONE	5299216.
25	L	OX211	0.	0.	NONE	367321.5
26	L	OX212	0.	0.	NONE	389352.6
27	L	OX213	0.	0.	NONE	412694.1
28	L	OX214	0.	0.	NONE	437509.8
29	L	OX215	0.	0.	NONE	463717.8
30	L	OX216	0.	0.	NONE	528855.6
31	L	OX221	0.	0.	NONE	5655424.
32	L	OX222	0.	0.	NONE	5994624.
33	L	OX223	0.	0.	NONE	6353920.
34	L	OX224	0.	0.	NONE	6736128.
35	L	OX225	0.	0.	NONE	7139584.
36	L	OX226	0.	0.	NONE	7568384.
37	L	OX231	0.	0.	NONE	16126795.
38	L	OX232	0.	0.	NONE	17094045.
39	L	OX233	0.	0.	NONE	18118600.
40	L	OX234	0.	0.	NONE	19208490.
41	L	OX235	0.	0.	NONE	20358970.
42	L	OX236	0.	0.	NONE	21581720.
43	L	OX241	0.	0.	NONE	12901436.
44	L	OX242	0.	0.	NONE	13675236.
45	L	OX243	0.	0.	NONE	14494880.
46	L	OX244	0.	0.	NONE	15366792.
47	L	OX245	0.	0.	NONE	16287176.
48	L	OX246	0.	0.	NONE	17265376.
49	L	OX311	0.	0.	NONE	735789.6
50	L	OX312	0.	0.	NONE	990680.6
51	L	OX313	0.	0.	NONE	1205213.1
52	L	OX314	0.	0.	NONE	1327489.8
53	L	OX315	0.	0.	NONE	1462351.8
54	L	OX316	0.	0.	NONE	1647791.6
55	L	OX321	0.	0.	NONE	11414144.
56	L	OX322	0.	0.	NONE	14452864.
57	L	OX323	0.	0.	NONE	17501440.
58	L	OX324	0.	0.	NONE	19254528.
59	L	OX325	0.	0.	NONE	21186304.
60	L	OX326	0.	0.	NONE	23307264.
61	L	OX331	0.	0.	NONE	32548145.
62	L	OX332	0.	0.	NONE	41213245.

63	L	OX333	0.	0.	NONE	49906450.
64	L	OX334	0.	0.	NONE	54905490.
65	L	OX335	0.	0.	NONE	60414070.
66	L	OX336	0.	0.	NONE	66462120.
67	L	OX341	0.	0.	NONE	26038516.
68	L	OX342	0.	0.	NONE	32970596.
69	L	OX343	0.	0.	NONE	39925160.
70	L	OX344	0.	0.	NONE	43924392.
71	L	OX345	0.	0.	NONE	48331256.
72	L	OX346	0.	0.	NONE	53169696.
73	L	OX411	0.	0.	NONE	54627.3
74	L	OX412	0.	0.	NONE	57903.3
75	L	OX413	0.	0.	NONE	61425.
76	L	OX414	0.	0.	NONE	65028.6
77	L	OX415	0.	0.	NONE	68959.8
78	L	OX416	0.	0.	NONE	73054.8
79	L	OX421	0.	0.	NONE	768384.
80	L	OX422	0.	0.	NONE	814464.
81	L	OX423	0.	0.	NONE	864000.
82	L	OX424	0.	0.	NONE	914688.
83	L	OX425	0.	0.	NONE	969984.
84	L	OX426	0.	0.	NONE	1027584.
85	L	OX431	0.	0.	NONE	2191095.
86	L	OX432	0.	0.	NONE	2322495.
87	L	OX433	0.	0.	NONE	2463750.
88	L	OX434	0.	0.	NONE	2608290.
89	L	OX435	0.	0.	NONE	2765970.
90	L	OX436	0.	0.	NONE	2930220.
91	L	OX441	0.	0.	NONE	1752876.
92	L	OX442	0.	0.	NONE	1857996.
93	L	OX443	0.	0.	NONE	1971000.
94	L	OX444	0.	0.	NONE	2086632.
95	L	OX445	0.	0.	NONE	2212776.
96	L	OX446	0.	0.	NONE	2344176.
97	L	OX511	0.	0.	NONE	342096.3
98	L	OX512	0.	0.	NONE	362653.2
99	L	OX513	0.	0.	NONE	384356.7
100	L	OX514	0.	0.	NONE	407452.5
101	L	OX515	0.	0.	NONE	431858.7

102	L	OX516	0.	0.	NONE	491363.6
103	L	OX521	0.	0.	NONE	5261184.
104	L	OX522	0.	0.	NONE	5577344.
105	L	OX523	0.	0.	NONE	5911040.
106	L	OX524	0.	0.	NONE	6266368.
107	L	OX525	0.	0.	NONE	6641664.
108	L	OX526	0.	0.	NONE	7041024.
109	L	OX531	0.	0.	NONE	15002595.
110	L	OX532	0.	0.	NONE	15904145.
111	L	OX533	0.	0.	NONE	16855700.
112	L	OX534	0.	0.	NONE	17868940.
113	L	OX535	0.	0.	NONE	18939120.
114	L	OX536	0.	0.	NONE	20077920.
115	L	OX541	0.	0.	NONE	12002076.
116	L	OX542	0.	0.	NONE	12723316.
117	L	OX543	0.	0.	NONE	13484560.
118	L	OX544	0.	0.	NONE	14295152.
119	L	OX545	0.	0.	NONE	15151296.
120	L	OX546	0.	0.	NONE	16062336.
121	B	OE111	3612.5	0.	NONE	0.
122	B	OE112	4017.32938	0.	NONE	0.
123	B	OE113	4210.69938	0.	NONE	0.
124	B	OE114	4419.53938	0.	NONE	0.
125	B	OE115	4645.08938	0.	NONE	0.
126	B	OE116	4713.5	0.	NONE	0.
127	L	OE121	0.	0.	NONE	96768.
128	L	OE122	0.	0.	NONE	102528.
129	L	OE123	0.	0.	NONE	108672.
130	L	OE124	0.	0.	NONE	115328.
131	L	OE125	0.	0.	NONE	122240.
132	L	OE126	0.	0.	NONE	129536.
133	L	OE131	0.	0.	NONE	275940.
134	L	OE132	0.	0.	NONE	292365.
135	L	OE133	0.	0.	NONE	309885.
136	L	OE134	0.	0.	NONE	328865.
137	L	OE135	0.	0.	NONE	348575.
138	L	OE136	0.	0.	NONE	369380.
139	L	OE141	0.	0.	NONE	220752.
140	L	OE142	0.	0.	NONE	233892.

141	L	OE143	0.	0.	NONE	247908.
142	L	OE144	0.	0.	NONE	263092.
143	L	OE145	0.	0.	NONE	278860.
144	L	OE146	0.	0.	NONE	295504.
145	B	OE211	608.3	0.	NONE	0.
146	B	OE212	703.97062	0.	NONE	0.
147	B	OE213	529.10062	0.	NONE	0.
148	B	OE214	448.26062	0.	NONE	0.
149	B	OE215	232.71062	0.	NONE	0.
150	L	OE216	0.	0.	NONE	37291.8
151	L	OE221	0.	0.	NONE	488704.
152	L	OE222	0.	0.	NONE	518016.
153	L	OE223	0.	0.	NONE	548992.
154	L	OE224	0.	0.	NONE	582144.
155	L	OE225	0.	0.	NONE	616960.
156	L	OE226	0.	0.	NONE	654080.
157	L	OE231	0.	0.	NONE	1393570.
158	L	OE232	0.	0.	NONE	1477155.
159	L	OE233	0.	0.	NONE	1565485.
160	L	OE234	0.	0.	NONE	1660020.
161	L	OE235	0.	0.	NONE	1759300.
162	L	OE236	0.	0.	NONE	1865150.
163	L	OE241	0.	0.	NONE	1114856.
164	L	OE242	0.	0.	NONE	1181724.
165	L	OE243	0.	0.	NONE	1252388.
166	L	OE244	0.	0.	NONE	1328016.
167	L	OE245	0.	0.	NONE	1407440.
168	L	OE246	0.	0.	NONE	1492120.
169	B	OE311	207.	0.	NONE	0.
170	L	OE312	0.	0.	NONE	60132.8
171	L	OE313	0.	0.	NONE	79251.9
172	L	OE314	0.	0.	NONE	88998.
173	L	OE315	0.	0.	NONE	99863.4
174	L	OE316	0.	0.	NONE	149185.4
175	L	OE321	0.	0.	NONE	1064576.
176	L	OE322	0.	0.	NONE	1363840.
177	L	OE323	0.	0.	NONE	1663744.
178	L	OE324	0.	0.	NONE	1833984.
179	L	OE325	0.	0.	NONE	2021632.

180	L	OE326	0.	0.	NONE	2227968.
181	L	OE331	0.	0.	NONE	3035705.
182	L	OE332	0.	0.	NONE	3889075.
183	L	OE333	0.	0.	NONE	4744270.
184	L	OE334	0.	0.	NONE	5229720.
185	L	OE335	0.	0.	NONE	5764810.
186	L	OE336	0.	0.	NONE	6353190.
187	L	OE341	0.	0.	NONE	2428564.
188	L	OE342	0.	0.	NONE	3111260.
189	L	OE343	0.	0.	NONE	3795416.
190	L	OE344	0.	0.	NONE	4183776.
191	L	OE345	0.	0.	NONE	4611848.
192	L	OE346	0.	0.	NONE	5082552.
193	B	OE411	153.	0.	NONE	0.
194	B	OE412	229.5	0.	NONE	0.
195	B	OE413	612.	0.	NONE	0.
196	B	OE414	918.	0.	NONE	0.
197	B	OE415	1377.	0.	NONE	0.
198	B	OE416	2065.5	0.	NONE	0.
199	B	OE421	2988.05	0.	NONE	0.
200	B	OE422	3228.55	0.	NONE	0.
201	B	OE423	3489.2	0.	NONE	0.
202	B	OE424	3771.3	0.	NONE	0.
203	B	OE425	4076.15	0.	NONE	0.
204	B	OE426	4406.35	0.	NONE	0.
205	B	OE431	2528.35	0.	NONE	0.
206	B	OE432	2731.85	0.	NONE	0.
207	B	OE433	2952.4	0.	NONE	0.
208	B	OE434	3191.1	0.	NONE	0.
209	B	OE435	3449.05	0.	NONE	0.
210	B	OE436	3728.45	0.	NONE	0.
211	B	OE441	2068.65	0.	NONE	0.
212	B	OE442	2235.15	0.	NONE	0.
213	B	OE443	2415.6	0.	NONE	0.
214	B	OE444	2610.9	0.	NONE	0.
215	B	OE445	2821.95	0.	NONE	0.
216	B	OE446	3050.55	0.	NONE	0.
217	B	OE511	16.2	0.	NONE	0.
218	B	OE512	16.2	0.	NONE	0.

219	B	OE513	16.2	0.	NONE	0.
220	B	OE514	16.2	0.	NONE	0.
221	B	OE515	16.2	0.	NONE	0.
222	L	OE516	0.	0.	NONE	33542.6
223	L	OE521	0.	0.	NONE	449280.
224	L	OE522	0.	0.	NONE	476288.
225	L	OE523	0.	0.	NONE	504704.
226	L	OE524	0.	0.	NONE	535168.
227	L	OE525	0.	0.	NONE	567168.
228	L	OE526	0.	0.	NONE	601344.
229	L	OE531	0.	0.	NONE	1281150.
230	L	OE532	0.	0.	NONE	1358165.
231	L	OE533	0.	0.	NONE	1439195.
232	L	OE534	0.	0.	NONE	1526065.
233	L	OE535	0.	0.	NONE	1617315.
234	L	OE536	0.	0.	NONE	1714770.
235	L	OE541	0.	0.	NONE	1024920.
236	L	OE542	0.	0.	NONE	1086532.
237	L	OE543	0.	0.	NONE	1151356.
238	L	OE544	0.	0.	NONE	1220852.
239	L	OE545	0.	0.	NONE	1293852.
240	L	OE546	0.	0.	NONE	1371816.
241	B	X11	1882.5875	0.	3198.	0.
242	B	X12	1882.5875	0.	3198.	0.
243	B	X13	1882.5875	0.	3198.	0.
244	B	X14	1882.5875	0.	3198.	0.
245	B	X15	1882.5875	0.	3198.	0.
246	B	X16	1882.5875	0.	3198.	0.
247	B	X21	0.	0.	1089.	0.
248	L	X22	0.	0.	1089.	12948090.09187
249	B	X23	0.	0.	1089.	0.
250	B	X24	0.	0.	1089.	0.
251	B	X25	0.	0.	1089.	0.
252	B	X26	0.	0.	1089.	0.
253	L	X31	0.	0.	330.	22267713.65662
254	B	X32	0.	0.	330.	0.
255	B	X33	0.	0.	330.	0.
256	B	X34	0.	0.	330.	0.
257	B	X35	0.	0.	330.	0.

258	B	X36	0.	0.	330.	0.
259	L	X41	0.	0.	1730.	10634953.54056
260	B	X42	0.	0.	1730.	0.
261	B	X43	0.	0.	1730.	0.
262	B	X44	0.	0.	1730.	0.
263	B	X45	0.	0.	1730.	0.
264	L	X46	0.	0.	1730.	7675268.159
265	B	X51	0.	0.	16.2	0.
266	L	X52	0.	0.	16.2	7199180.79812
267	B	X53	0.	0.	16.2	0.
268	B	X54	0.	0.	16.2	0.
269	L	X56	0.	0.	16.2	7246086.051
270	B	X55	0.	0.	16.2	0.

ROWS..........LOGICAL VARIABLES

NO	STATE	NAME	VALUE	LOWER RHS	UPPER RHS	SHADOW PRICE
1	B	R0	0.574988944E+11	NONE	NONE	-1.
2	L	R1	2106.43	NONE	2106.43	-30348180.30875
3	L	R2	2417.13	NONE	2417.13	-29538.6
4	L	R3	2610.5	NONE	2610.5	-31304.
5	L	R4	2819.34	NONE	2819.34	-33187.7
6	L	R5	3044.89	NONE	3044.89	-35171.5
7	B	R6	3113.30062	NONE	3228.48	0.
8	L	R7	608.3	NONE	608.3	-30320316.10875
9	B	R8	703.97062	NONE	741.75	0.
10	B	R9	529.10062	NONE	801.09	0.
11	B	R10	448.26062	NONE	865.18	0.
12	B	R11	232.71062	NONE	934.39	0.
13	B	R12	0.	NONE	1009.15	0.
14	L	R13	207.	NONE	207.	-30279375.20875
15	B	R14	0.	NONE	223.56	0.
16	B	R15	0.	NONE	241.45	0.
17	B	R16	0.	NONE	260.76	0.
18	B	R17	0.	NONE	281.62	0.
19	B	R18	0.	NONE	304.15	0.
20	L	R19	153.	NONE	153.	-30355059.90875
21	L	R20	229.5	NONE	229.5	-36827.7
22	L	R21	612.	NONE	612.	-39029.9

23	L	R22	918.	NONE	918.	-41386.8
24	L	R23	1377.	NONE	1377.	-43862.
25	L	R24	2065.5	NONE	2065.5	-9209.2
26	L	R25	16.2	NONE	16.2	-30323118.90875
27	L	R26	16.2	NONE	16.2	-2966.6
28	L	R27	16.2	NONE	16.2	-3148.6
29	L	R28	16.2	NONE	16.2	-3339.7
30	L	R29	16.2	NONE	16.2	-3539.9
31	B	R30	0.	NONE	16.2	0.
32	L	R31	4597.	4597.	NONE	30361129.60875
33	L	R32	2988.05	2988.05	NONE	85376.
34	L	R33	2528.35	2528.35	NONE	243455.
35	L	R34	2068.65	2068.65	NONE	194764.
36	L	R35	4967.	4967.	NONE	43261.4
37	L	R36	3228.55	3228.55	NONE	90496.
38	L	R37	2731.85	2731.85	NONE	258055.
39	L	R38	2235.15	2235.15	NONE	206444.
40	L	R39	5368.	5368.	NONE	45854.9
41	L	R40	3489.2	3489.2	NONE	96000.
42	L	R41	2952.4	2952.4	NONE	273750.
43	L	R42	2415.6	2415.6	NONE	219000.
44	L	R43	5802.	5802.	NONE	48612.2
45	L	R44	3771.3	3771.3	NONE	101632.
46	L	R45	3191.1	3191.1	NONE	289810.
47	L	R46	2610.9	2610.9	NONE	231848.
48	L	R47	6271.	6271.	NONE	51524.2
49	L	R48	4076.15	4076.15	NONE	107776.
50	L	R49	3449.05	3449.05	NONE	307330.
51	L	R50	2821.95	2821.95	NONE	245864.
52	L	R51	6779.	6779.	NONE	17326.4
53	L	R52	4406.35	4406.35	NONE	114176.
54	L	R53	3728.45	3728.45	NONE	325580.
55	L	R54	3050.55	3050.55	NONE	260464.
56	L	R55	0.	.	NONE	21297981.651
57	L	R56	0.	.	NONE	17816545.231
58	L	R57	0.	.	NONE	13985954.978
59	L	R58	0.	.	NONE	9771246.004
60	L	R59	0.	.	NONE	5133931.408
61	L	R60	0.	.	NONE	15576896.72813

62	L	R61	0.	.	NONE	20761184.305
63	L	R62	0.	.	NONE	16287755.237
64	L	R63	0.	.	NONE	11366983.262
65	L	R64	0.	.	NONE	5954134.09
66	L	R65	0.	.	NONE	30857853.762
67	L	R66	0.	.	NONE	26365691.51
68	L	R67	0.	.	NONE	20684654.77
69	L	R68	0.	.	NONE	14435514.356
70	L	R69	0.	.	NONE	7561459.901
71	L	R70	0.	.	NONE	28119148.572
72	L	R71	0.	.	NONE	19001085.637
73	L	R72	0.	.	NONE	13261837.326
74	L	R73	0.	.	NONE	6947350.008
75	B	R74	0.	.	NONE	0.
76	L	R75	0.	.	NONE	18839401.44088
77	L	R76	0.	.	NONE	16744706.045
78	L	R77	0.	.	NONE	6521339.035
79	B	R78	0.	.	NONE	0.
80	L	R79	0.	.	NONE	3185.91
81	B	R80	207.	NONE	330.	0.
82	B	R81	0.	NONE	100.	0.
83	B	R82	0.	NONE	65.	0.
84	B	R83	0.	NONE	55.	0.
85	B	R84	0.	NONE	45.	0.
86	B	R85	207.	NONE	230.	0.
87	B	R86	0.	NONE	150.	0.
88	B	R87	0.	NONE	127.	0.
89	B	R88	0.	NONE	104.	0.
90	B	R89	0.	NONE	1500.	0.
91	B	R90	0.	NONE	330.	0.
92	B	R91	0.	NONE	2500.	0.
93	B	R92	0.	NONE	16.2	0.