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DEVELOPMENT OF DATA, MODELS AND TECHNIQUES TO DETERMINE OPTIMAL RELIABILITY LEVEL OF ELECTRIC POWER SUPPLY FOR THE PHILIPPINES

Francisco L. Viray, Ph.D.
Dean and Professor of Electrical Engineering
College of Engineering
and
Executive Director
National Engineering Center
University of the Philippines
Diliman, Quezon City

Rowaldo R. del Mundo
Senior Engineer

Donato S. de la Cruz
University Research Associate

Ma. Concepcion O. Ojeda
University Research Associate

Ma. Lourdes D. Pangilinan
Student Assistant
National Engineering Center

ABSTRACT

This study develops models and techniques to determine optimal reliability level of electric power supply for the Philippines using data from NPC Luzon grid. A survey of outage cost incurred by industrial firms in Metro Manila and suburbs from January to June 1990 was used to develop the outage cost model. The cost of increasing reliability and the cost of having an unreliable one, from the point of view of the national economy are combined to determine the optimal level which is the point where the total cost is minimum.

INTRODUCTION

The frequent power outages in the first half of 1990 has slowed down our economic recovery and is one of the negative factors that discouraged foreign investors to build industrial facilities in the country.

To solve this problem of shortages and high level of unreliability of the electric power supply, there is a need to construct more power plants and improve the operation and maintenance of existing ones. However, building new power plants requires capital investments and additional operating costs that would translate to higher cost of electricity. On the other hand, disruptions in economic activities brought about by power outages result to losses to electricity users and to the economy in general. The industry, in particular, incurs costs related to spoilage of materials and products and reduction or stoppage of production.

Since the costs involved when power outages occur or when new power plants are built can amount to billions of pesos, a cost-benefit analysis is an imperative.

In a cost-benefit study, all costs and benefits must be enumerated and assigned peso values. In electric utility reliability studies, the cost of increasing reliability is measured by computing the additional investment, operation, maintenance and fuel costs. The cost of unreliability is quantified by the "loss-of-benefit" resulting from outages experienced by electricity users.

This study develops a methodology to determine the optimal reliability level of the power supply. It compares the cost of increasing reliability to the cost of having an unreliable one, from the point of view of the national economy.

1.0 DEFINITION OF TERMS

1.1 Outage Cost

Outage cost refers to the economic costs suffered by electricity users or the society in general, when a power outage occurs. The type and magnitude of outage cost depends on the activities of the user. Industrial users suffer differently compared to residential or commercial consumers.

Outage cost can either be direct or indirect. Direct outage costs are losses suffered by electricity users when a power outage occurs. Indirect costs are those incurred by other companies and the society in general. An example of an indirect cost is when a raw material needed by a company was not delivered because the supplier was not able to produce it due to an outage.

Outage cost can also be classified as either short-run direct cost or long-run adaptive response cost. Short-run direct costs are losses incurred during an actual outage. Long-run adaptive response costs result from activities of electricity users to lessen the impacts of anticipated outages like putting up standby generating units or resorting to other energy sources. These costs are incurred even when there is no outage.

1.2 Supply Cost

Supply cost is the cost of generating electricity to supply a particular demand at a given reliability level. It includes investment, operating, maintenance and fuel costs.

1.3 Measure of Reliability

Reliability measures used in this study are: Loss of Load Probability (LOLP), frequency and duration (F&D) of outages and percentage generating reserve based on the total dependable capacity. LOLP is the expected number of days in a year when the demand will exceed the capacity in the "UP" (not failed) state.

2.0 METHODOLOGY

The determination of the optimal reliability level of a power supply system requires the calculation of the supply and outage cost associated with the performance of the power system in supplying a given load demand for one year. The flowchart shown in Figure 1 illustrates the major steps to do it.

Supply cost is measured using a computer-based supply cost model that outputs the Annualy Supply Cost (ASC) per kWh for a given reliability level. The model is based on an annual energy generation simulation, a generation capacity model and a load model.

Outage cost is measured using a modification of Mohan Munasinghe's outage cost model. The model outputs the Annual Outage Cost (AOC) per kWh for a given reliability level.

The optimum reliability level is determined as the point where the Annual Total Cost (ATC) per kWh, from the point of view of the national economy, is minimum. ATC is the sum of the AOC and ASC.

The computed costs (AOC, ASC and ATC) at different reliability levels (LOLP) are plotted on a semi-logarithmic scale. The level where the total cost value is lowest is the optimum reliability level.

3.0 MODELS

3.1 The Supply Cost Model

The supply cost model which takes into consideration the planning procedures and policies of the National Power Corporation (NPC) has two important components: the generation capacity model and the load model. These two models which use data from the Luzon power grid of the NPC are convolved to determine the reliability level of the system.

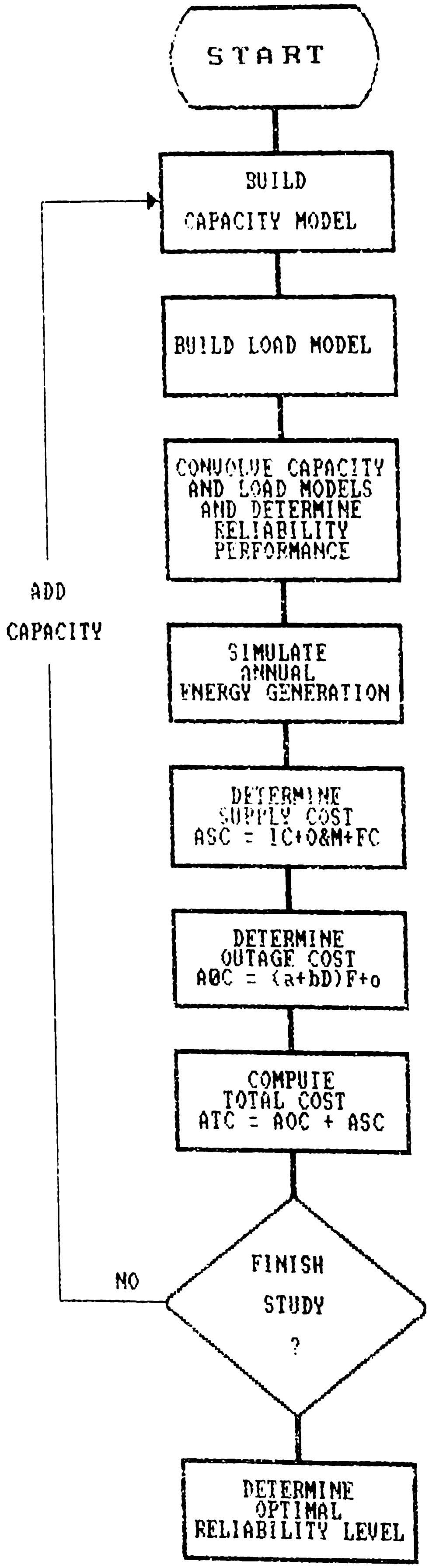

Figure 1 - PROCEDURE TO DETERMINE OPTIMAL RELIABILITY LEVEL OF THE ELECTRIC POWER SUPPLY

3.1.1 The Generation Capacity Model

The probabilistic generation capacity model of the existing power system uses recursive formulas to output a capacity outage table listing the probabilities and frequencies of capacity outages. It takes into consideration the random occurrences of failures and the stochastic nature of repairing failed generating units. Its input requirements include capacity, forced outage rate, failure rate and repair rate of each generating units.

3.1.2 The Annual Load Model

The annual load model gives a list of daily peak loads for a whole year, the variation in daily demand and the exposure period of the peak demand from a given annual peak demand. It uses the annual load variation curve (LVC) and the typical 24-hour load duration curve (LDC).

The LVC shows the daily peak demand imposed on the system normalized by the highest peak that occured in the year.

The LDC is a plot, in decreasing order, of typical hourly loads on a weekday and normalized by the peak demand of the day. An approximation of the LDC is used to simplify energy generation estimates.

From actual 1988 NPC data, the exposure period of the peak load, i.e., when the demand level is equal to or greater than 90 per cent of the peak, is estimated to be 12 hours (9:15 A.M. to 9:15 P.M.)

3.1.3 Annual Energy Generation

Fuel consumption and annual energy generation is determined using a computer program that simulates probabilistically the annual generation for a given load demand. This program considers the probability of failures of each generating unit and economic loading order as practiced by utility companies.

3.1.4 Annual Supply Cost

The annual supply cost (ASC) per kilowatthour for the given reliability level is obtained by dividing the sum of the annual fixed charges for the capital investments, the annual operating and maintenance costs and the fuel cost of the generating units by the annual energy generation.

The model considers only the installed gas turbines and additional new ones in computing the supply cost. The operation and maintenance costs for each generating unit is considered fixed for a given year. Direct fuel cost is estimated by multiplying the energy generation (kWh) of each generating unit by its heat rate (Btu/kWh) and corresponding cost

(P/Btu). Consistent with the methodology used by the NPC, the fuel cost of hydroelectric and geothermal units are considered zero, from the national viewpoint.

To simplify calculations in evaluating reliability, it is assumed that 350 MW of the total installed capacity is under repair or on scheduled maintenance at any time. Derating of oil-fired thermal plants due to old age is considered by assuming a 10 percent reduction of the oil-based capacity. Likewise, only 95 percent of the hydroelectric capacity is considered, to account for the months of the year when water supply is limited

The NPC Luzon Grid used in the model has an initial installed capacity of 4311 MW, a dependable capacity of 3899 MW, peak demand of 3046 MW and 12.3 days per year LOLP. The installed capacity mix is 28 percent hydroelectric, 45 percent oil, 15 percent geothermal, 7 percent coal and 5 percent gas turbine.

3.2 Outage Cost Model

The outage cost function used in the study is based on the model developed by Munasinghe for the short-run direct outage cost. However, considering that many industrial plants have standby generators, the model is modified to include the long-run adaptive response costs. The model covers only the industrial sector.

In computing for the outage cost incurred by manufacturing firms the following costs are considered:

1. Spoiled or damaged raw materials and in-process and finished products. (Note: spoilage may occur at the onset of the outage or only after a certain critical duration of the outage.)

2. Energy used in processing the damaged or wasted raw materials and finished products.

3. Wages paid to idle workers during an outage.

4. Overtime necessary to produce the output not produced because of an outage.

5. Damages in equipment which usually occur when the outage is without warning.

6. Restarting operation of the plant or a particular equipment. This usually requires special procedures like warming up of machineries and equipment and may be done in a few minutes or may last for hours.

7. Adaptive response to minimize the effects of outages such as the purchase of standby generators or shifting to other energy sources.

8. Reprocessing damaged raw materials and products or selling damaged finished products at reduced prices.

3.2.1 Annual Outage Cost

The above costs are computed and converted into a compact form called the annual outage cost function (AOC). The AOC is normalized by the kilowatthour consumption and is a function of the annual frequency and duration of outages. In equation form,

$$AOC = (a + bD)F + c[P/kW\,h] \qquad (1)$$

Where:

F	- expected frequency of outages per year
D	- mean duration of outages (hour)
a	- constant outage cost per kWh incurred regardless of the duration of outage (P/kWh/outage)
b	- outage cost per kWh per hour of outage and is dependent on bot h frequency and duration of outage (P/kWh/outage-hour)
c	- constant annual cost per kWh incurred in mitigating the effects of power outages (P/kWh)

A survey of outage costs incurred by the different manufacturing firms provided the coefficients a, b and c of the outage cost function.

4.0 DISCUSSION OF RESULTS

4.1 Survey Results

The survey covered 128 manufacturing firms randomly chosen from a list of the top 1000 electricity users in the Metro Manila area and suburbs. Forty four (44) responded but only 34 of the responses were complete and proved useful.

The 34 companies, on the average, experienced three-hour outages five times per month from January to June 1990, costing them P127.3 million in outage costs.

Twenty of the respondents used generators to continue with their production during an outage. Of these, seven were able to continue their production at 100 percent while five at more than 50 percent. Eleven firms plan to install standby generators. Majority of the firms would either install standby generators or build power plants to minimize the effects of unreliable power supply on their expansion plans.

4.2 Outage Cost Coefficients

From the outage costs data gathered in the survey, the average values of outage coefficients a, b and c of the AOC function is computed resulting to the following outage cost equation for the industrial sector:

$$AOC = (0.0086 + 0.0023D)F + 0.173\,0\ [PkWh] \qquad (2)$$

The outage cost coefficients of the different industries is given in Table 1. It should be noted that industries with high coefficient a and low coefficient b are more sensitive to outage frequency than duration. On the other hand, industries with high coefficient b and low coefficient a are more sensitive to outage duration than frequency. Coefficient c accounts for the adaptive response cost.

From the table, it can be seen that food, plastic and paper industries have high coefficient a. Chemical, machinery and equipment, petroleum and tobacco industries have zero values of coefficient a, which means that they do not incur a fixed amount of loss of every outage. For the coefficient b, the non-metals and rubber industries have the highest values.

The petroleum industry has the highest coefficient c. This is because of the fact that the capacity of its power plants supply more than double its power requirement. The paper industry, on the other hand, has a zero c value because it is not using any standby generator. The metal industry has also very low value of coefficient c compared to the other industries.

4.3 Annual Supply Cost Curve

ASC at various levels of LOLP are computed using the supply cost model. A plot of these values vesus LOLP is shown in Figure 2. It can be seen from the figure that the ASC curve increases with increasing reliability levels, i.e., decreasing LOLP. When the plot is changed into semi-logarithmic scale, the ASC curve becomes linear as shown in Figure 3.

It can also be seen that at higher LOLP values, at about more than 10 days per year, the incremental cost of increasing the reliability level is smaller compared to that at lower LOLP. For example, to decrease the LOLP by 6 days per year, from 12.3 days per year to 6.3 days per year, the reserve has to increase by 4 percentage points from 22 percent to 26 percent. At the lower LOLP, say, 0.08 days per year, an increase of 3.3 percentage point in reserve capacity will cause a very small 0.04 day per year improvement in LOLP.

4.4 Annual Outage Cost Curve

Using the F and D values correponding to a given LOLP, the values of AOC are computed. These values are plotted against LOLP on a semi-logarithmic scale shown in Figure 4. It can be seen from the graph that outage cost is inversely related to reliability level, i.e., as the reliability level of the power supply increases, outage cost decreases.

The exponentially decreasing outage cost curve shows that at higher reliability levels, there is a region where any increase in reliability will have minimal or no effect on outage cost. The outage cost at this region represents the long-run adaptive response cost. In the graph this is at an outage cost of about P0.185 per kWh.

TABLE 1

VALUES OF OUTAGE COST COEFFICIENTS a, b and c PER SUBSECTOR

INDUSTRY SUBSECTOR	a	b	c
Chemical	0	0.000489	0.157627
Food and Beverage	0.040103	0.000453	0.030995
Mach. and Equip't.	0	0.001804	0.144086
Metals	0.002375	0.002980	0.001733
Non-metals	0.007681	0.007965	0.203364
Paper	0.011114	0.001213	0
Petroleum	0	0.003120	2.994417
Plastic	0.037905	0.001779	0.074186
Rubber	0.005555	0.007532	0.190018
Textile	0.000464	0.003325	0.017701
Tobacco	0	0	0.184304

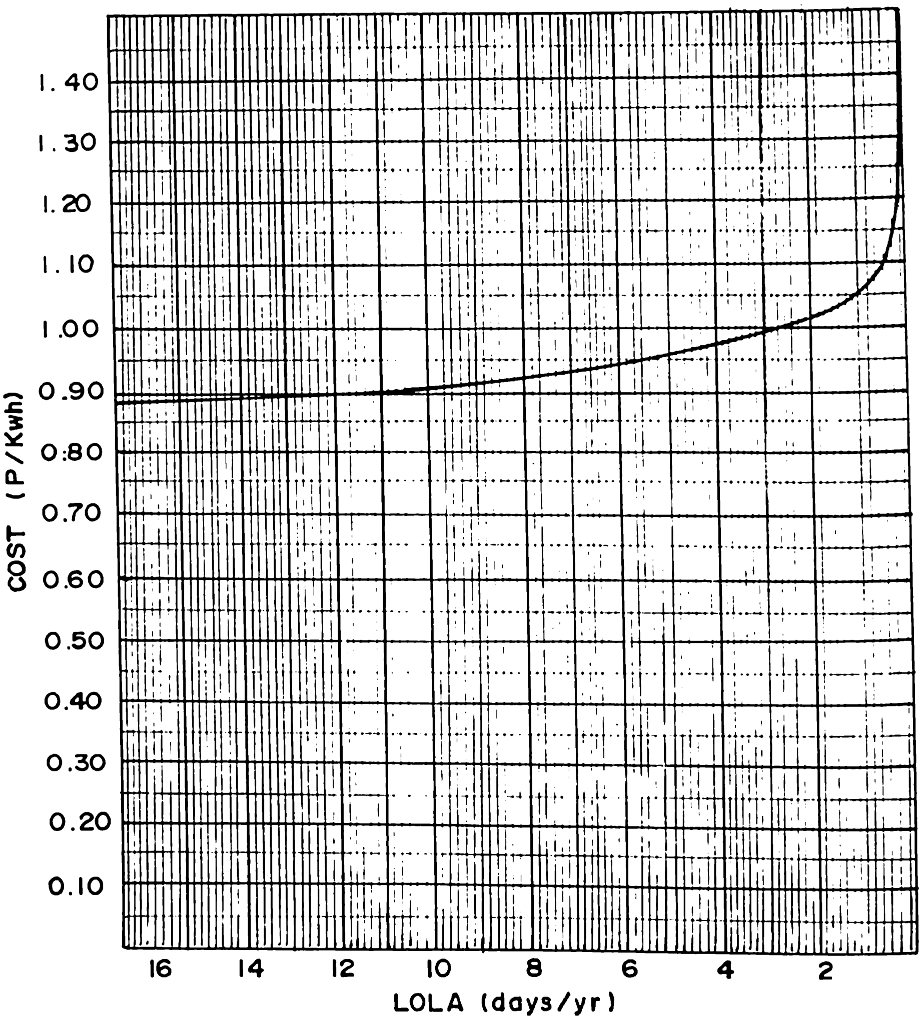

FIGURE 2 SUPPLY COST VS. GENERATION RELIABILITY[1]
(Linear LOLP scale)

[1] Peak Demand = 3046 MW

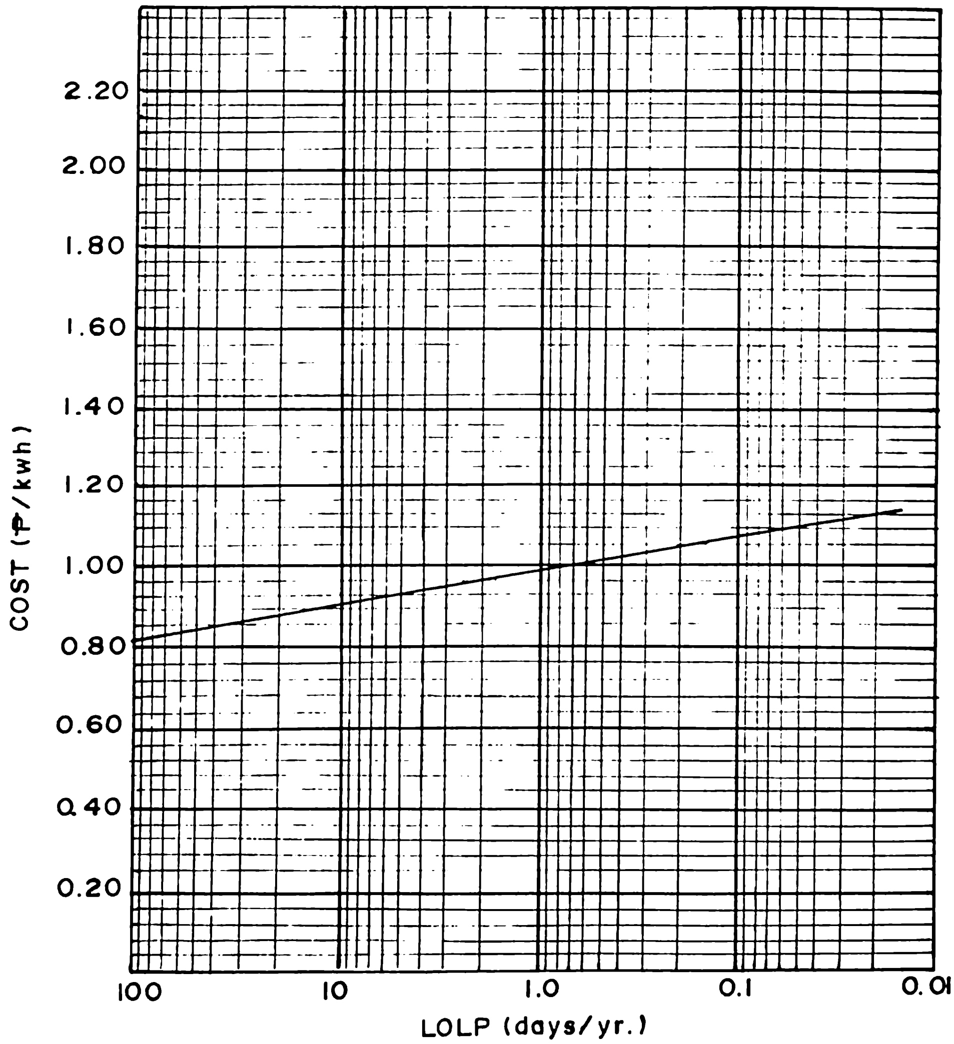

FIGURE 3 - SUPPLY COST VS. GENERATION RELIABILITY[1]

[1] Peak Demand = 3046 MW

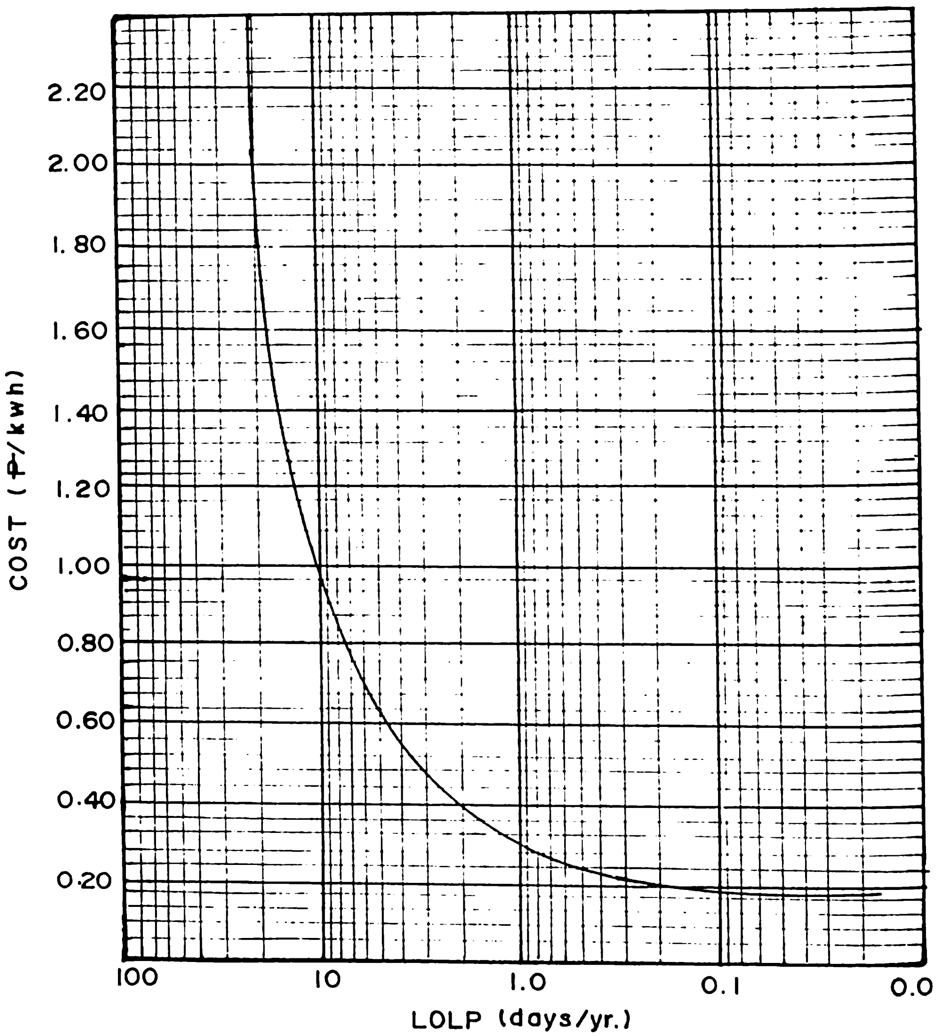

Figure 4: OUTAGE COST VS. GENERATION RELIABILITY

Peak Demand = 3046 MW

a = 0.008558

b = 0.002349

c = 0.173047

A plot of outage cost against percent reserve is shown in Figure 5. It is also an exponentially decaying curve with the lowest value corresponding to the fixed adaptive response cost.

4.5 Annual Total Cost Curve

The plot of ATC versus LOLP as shown in Figure 6 is asymptotic to the increasing outage cost curve at low reliability levels and to the increasing supply cost curve at high reliability levels. Thus, there is indeed a point in the curve where the total cost is at a minimum corresponding to optimal reliability level.

4.6 Estimate of Optimal Reliability Level

For the given peak demand of 3046 MW, the optimum reliability level (see Figure 6) is between 0.55 to 0.65 day per year LOLP and the annual total cost to the economy is P1.27/kWh, broken down into P1.04/kWh supply cost and P0.23/kWh outage cost. This level of reliability requires 36 percent reserve capacity or a total dependable installed capacity of 4143 MW.

Considering the limitations of this study, the estimated optimal reliability level of 0.55 to 0.65 day per year LOLP should not be taken yet as the absolute optimum reliability level for the Philippines.

In order to establish the confidence level for the values, the upper bound curves at 95 percent and 85 percent confidence levels of the outage cost are derived. The optimal reliability level for the two upper bound curves is 0.08 day per year LOLP. The corresponding annual total cost to the economy is P1.65/kWh (P1.11/kWh supply cost and P0.54/kWh outage cost) and P1.45/kWh (P1.11/kWh supply cost and P0.34/kWh outage cost) for the 95 percent and 85 percent confidence levels, respectively. (See Figure 7)

5.0 SENSITIVITY ANALYSIS

Two cases were examined to determine the behavior of the optimal reliability level as electric power demand increases. In both cases it was assumed that electricity demand increases with GDP. The first considered the case when the relation between demand and GDP is linear, that is, electric energy intensity (kWh/GDP) is constant. The second case is when the relationship is nonlinear, that is, energy intensity varies.

CASE 1 - Constant Energy Intensity

If the electric energy intensity is constant, the coefficients a and b of the outage cost model do not change when electricity demand increases. In this case, if peak demand is increased by 8.5 percent from 3046 MW to 3305, the resulting cost curves (ASC, AOC and

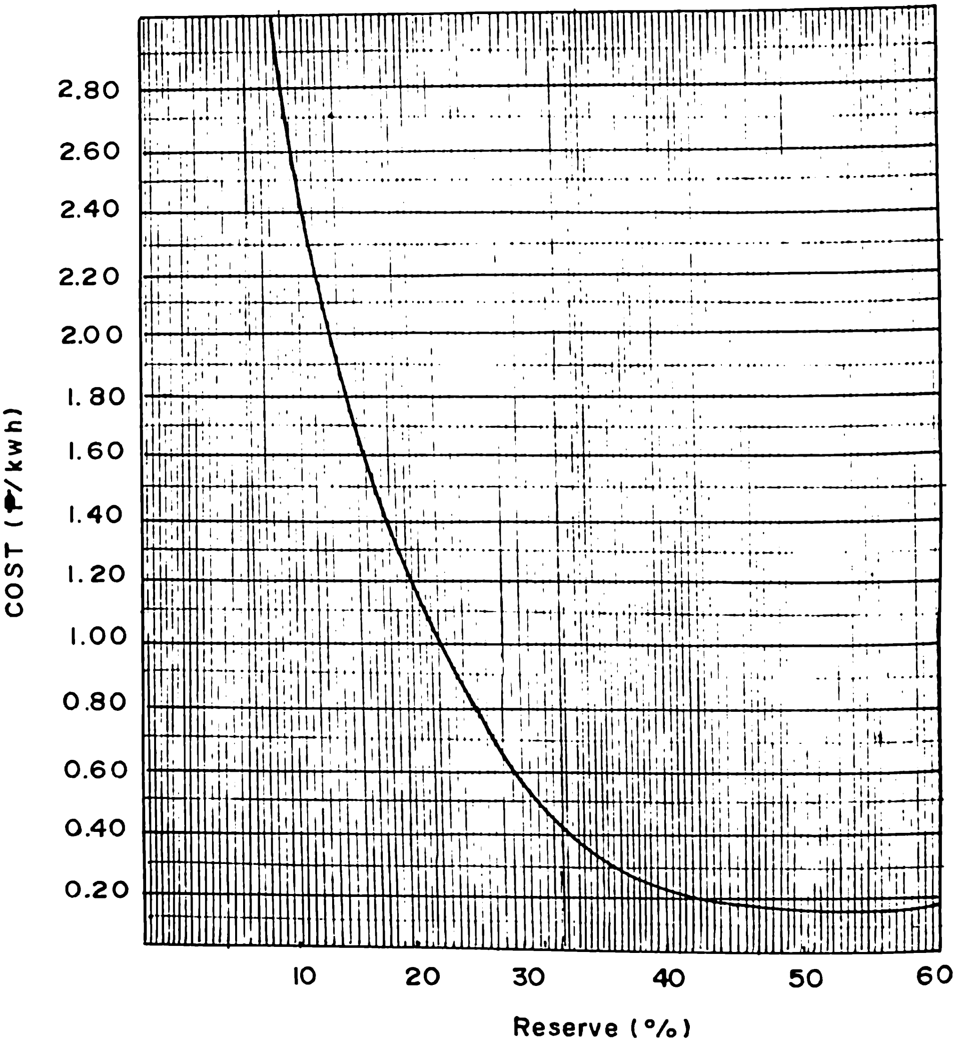

Figure 5: OUTAGE COST VS. GENERATING RESERVE[1]

[1] Peak Demand = 3046 MW

a = 0.008558

b = 0.002349

c = 0.173047

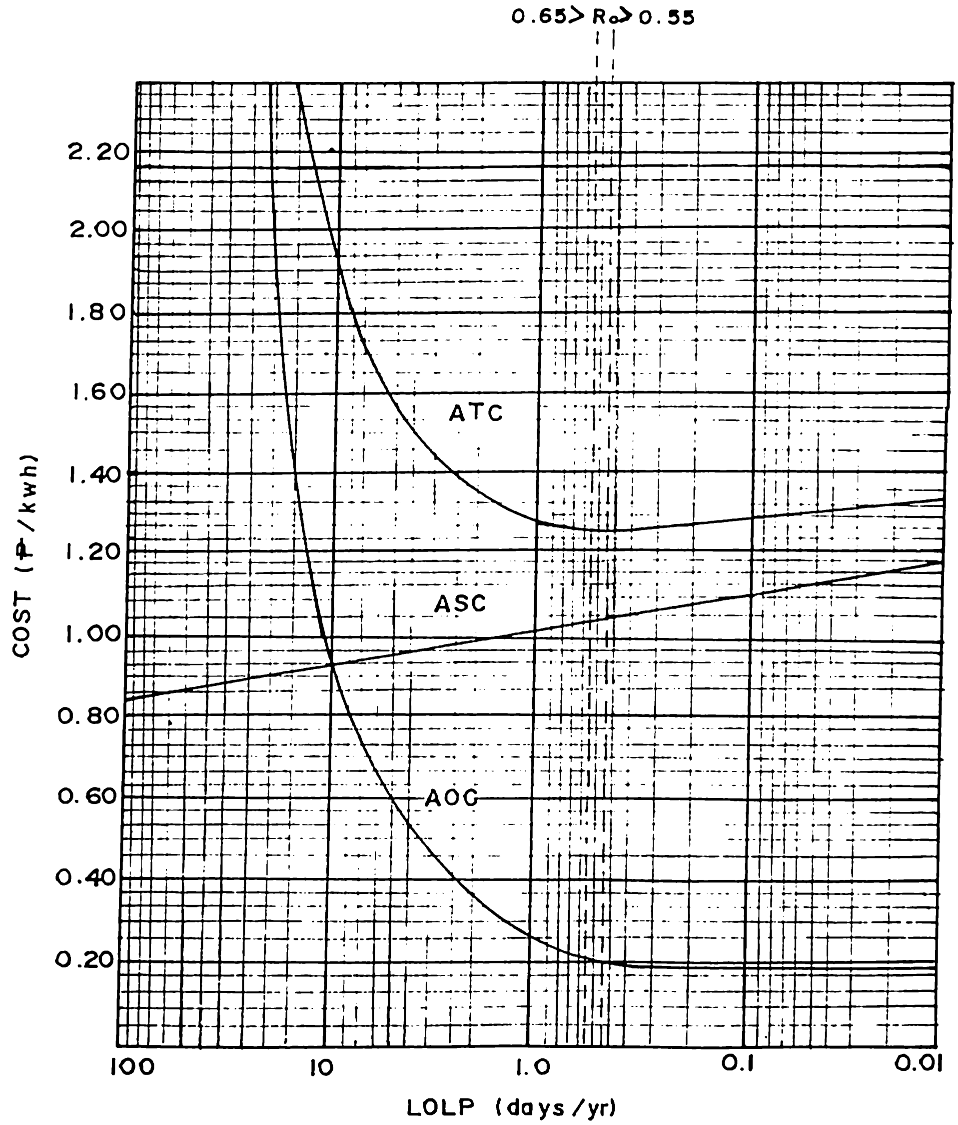

FIGURE 6 : TOTAL COST VS. GENERATION REALIABILITY

Peak Demand = 3046 MW

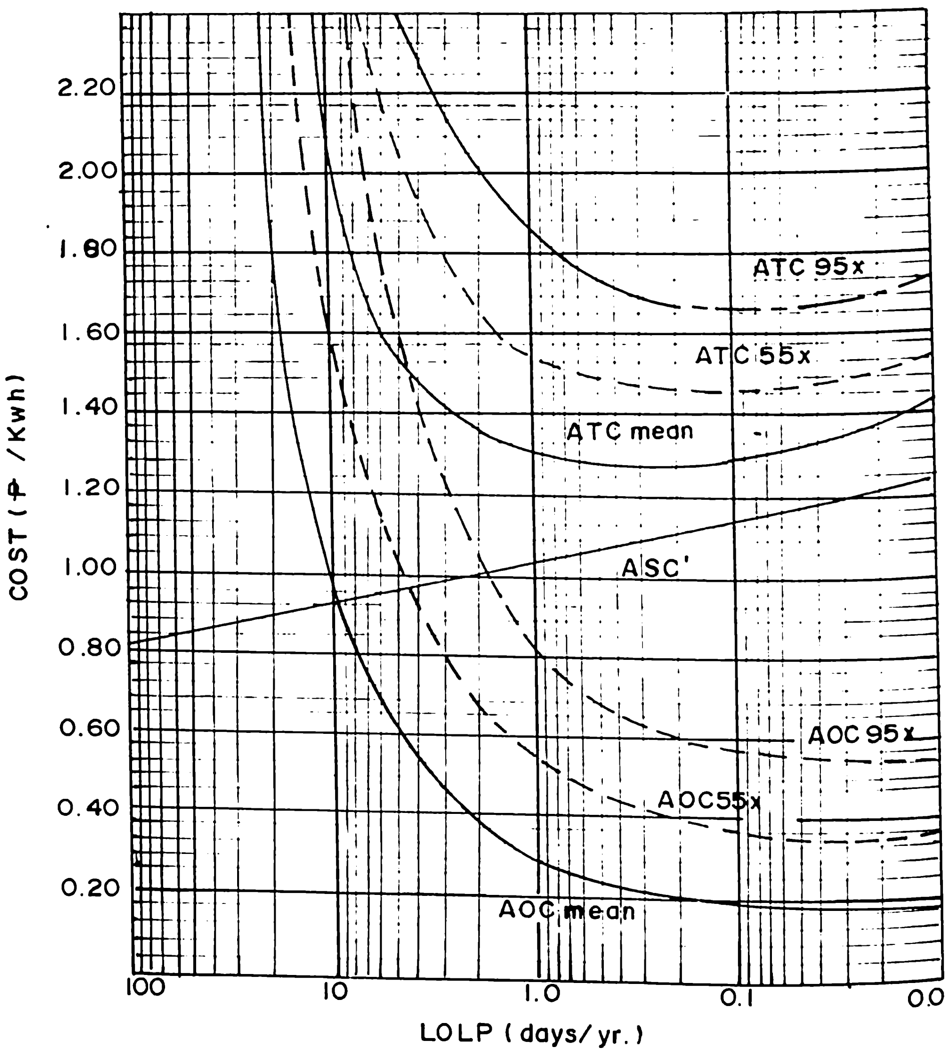

Figure 7 - UPPER BUND COST ESTIMATES @ 85% AND 95% CONFIDENCE LEVEL.

[1]Peak Demand = 3046 MW

ATC) for the two given demands are the same. This is to be expected since the cost curves are normalized with respect to total kilowatthour consumption.

The very slight deviation between the cost curves, as shown in Figure 8, arises from the difference in generation mix for the two demands. Nevertheless, considering the total cost curve, the optimal reliability level is still within the 0.55 to 0.65 range. *This implies that if energy intensity is constant, the optimal reliability level remains practically the same at different demand levels.*

CASE 2 - Varying Energy Intensity

To simulate the nonlinear relationship between electricity demand and GDP, the values of coefficients a and b are increased when the peak demand is increased. This means that coefficients a and b are functions of GDP and that the industry will incur bigger losses per kilowatthour of curtailed energy as the economy grows or as the Philippines industrializes.

It can be seen in Figure 9 that when coefficients a and b are increased the optimal reliability level increases to between 0.1 to 0.3 day per year LOLP. This implies that if energy intensity increases with GDP, the optimal reliability level increases with electricity demand.

6.0 LIMITATIONS OF THE STUDY

The following limitations should be taken into consideration when interpreting the numerical results of this study:

1. The outage cost curve covers the industrial sector only. This made the estimated optimal reliability level higher.

2. In computing for the frequency and duration of capacity shortage, repair and failure rates are assumed to be 0.5 per day for all types of generating units since there are no available data.

3. Unit additions to increase reliability are made only of gas turbines. Optimal generation mix is not considered.

7.0 CONCLUSIONS

The outage cost equation given in Eq. (2) shows that manufacturing firms are more sensitive to outage frequency than duration. For example, a single six-hour outage would cost P0.20/kWh while six one-hour interruptions would cost P0.24/kWh.

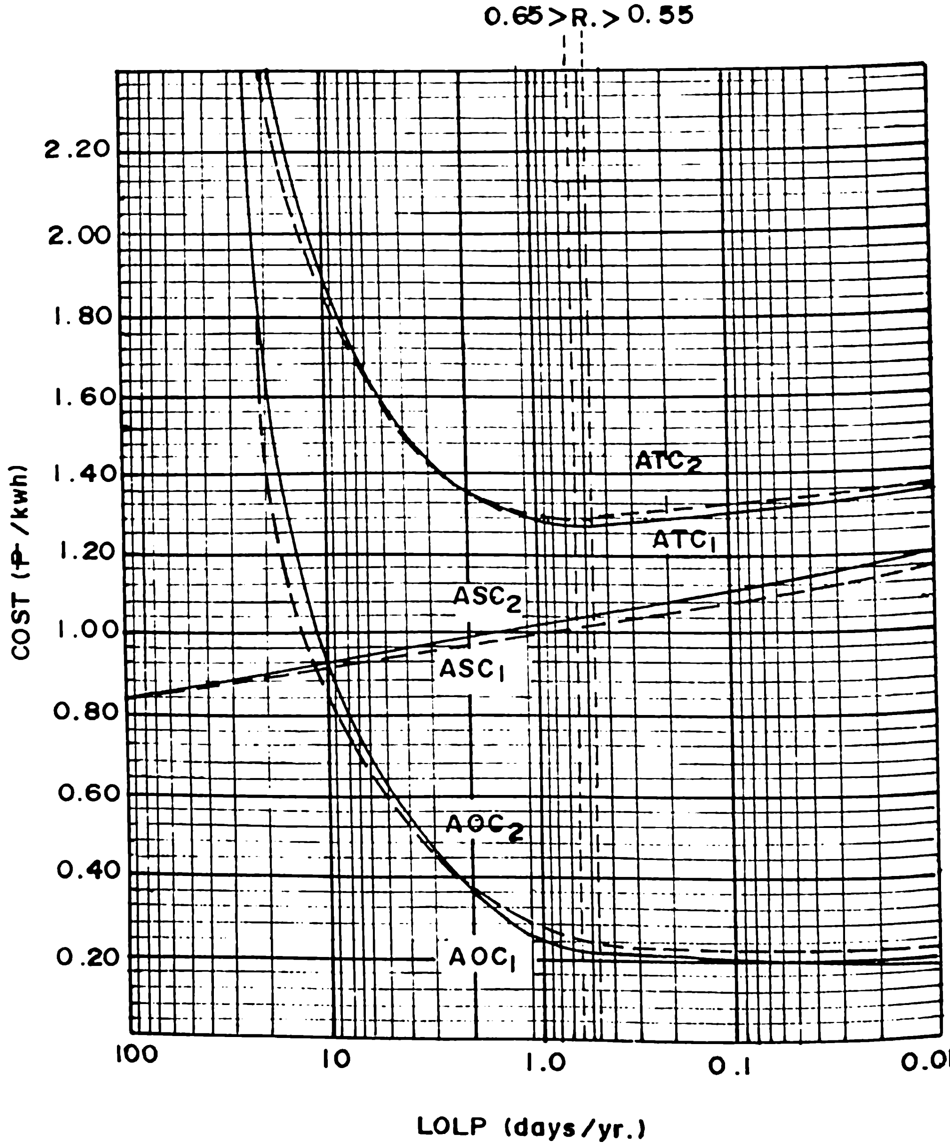

Figure 8 - SENSITIVITY ANALYSIS
CASE I - Constant Energy Intensity.

Subscripts 1 & 2 refer to demands 1 & 2, 3046 MW & 3305 MW respectively

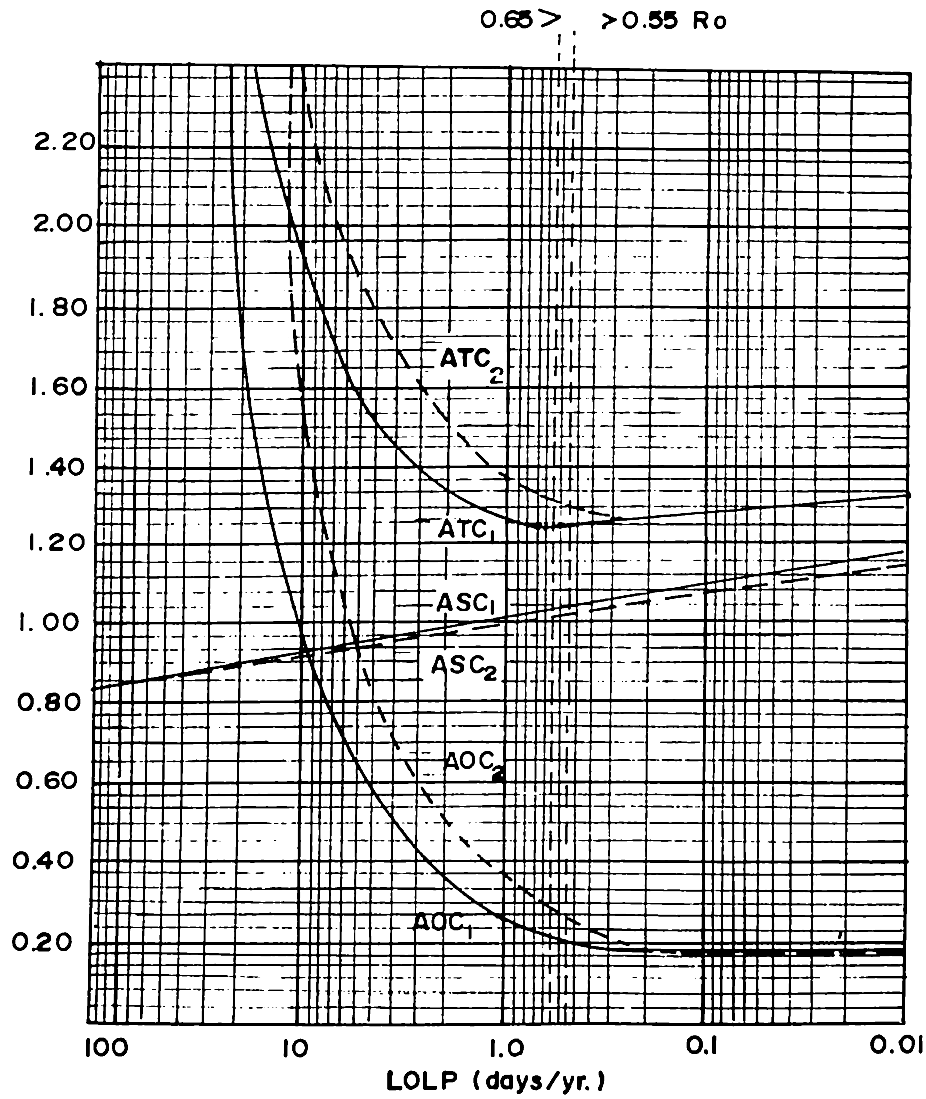

FIGURE 9 - SENSITIVITY ANALYSIS
CASE 2 - Varying Energy Intensity

Subscripts 1 & 2 refer to demands 1 & 2, 3046 MW & 3305 MW respectively

The adaptive response cost or the coefficient c in the outage cost equation will increase in the next one to two years as a result of on-going and planned investments on new standby generating systems and power plants. This will result to an increase in total cost to the economy.

With respect to the behavior of the cost curves, the following can be concluded:

1. As electricity demand increases, the normalized supply cost curve vs. reliability is practically the same, except for small deviations due to differences in generation mix. It follows that if the supply cost is given in absolute pesos, the supply cost vs. reliability moves upward, that is, supply cost at the same reliability level increases. The increase is almost uniform over the entire range of the reliability level.

2. As demand increases and coefficients a and b are independent of GDP, the normalized outage cost curve vs. reliability is practically the same, except for small deviations due to differences in generation mix. However, if a and b increase with GDP, the curve moves slightly to the right. Nevertheless, in both cases, if the outage cost is given in absolute pesos, the outage cost curve vs. reliability moves to the right, that is, the cost of outages at the same reliability level increases. Moreover, the reliability level at which outage costs rises steeply increases considerably. At the higher reliability level, outage cost increase is not as much as in the lower reliability levels.

3. Based on the foregoing statements and when the total cost is expressed in absolute pesos, the total cost curve vs. reliability moves upward, that is, the total cost to the economy at the same reliability level increases.

The behavior of the optimal reliability level as demand increases depends on whether the outage cost coefficients a and b vary with GDP or not. If the latter, the optimal reliability level is practically constant. But if the former, the optimal reliability level inches to a higher value.

With all the limitations inherent in the study, the estimate of the optimal reliability of power supply for the Philippines is 0.55 to 0.65 day per year LOLP at an annual cost to the economy of P1.27 per kWh. If the outage coefficients a and b do not vary much with economic growth of the Philippines, then this range will hold for the coming years. Otherwise, this range should be expected to inch towards a higher reliability level.

The range of the optimal reliability level found in this study is the same criterion used by industrialized countries in their power system planning and operation. This is not surprising because the entire peak demand of 3046 MW is assumed to supply only industrial loads. This leads to the conclusion that industrialization puts pressure on the utility to continually increase the reliability of its grid. This also bolsters the accepted theory that energy is a vital input to production.

A simulation of the reliability of the present generating capacity of NPC Luzon Grid to supply a peak demand of 3046 MW yielded about 12.3 days per year LOLP. Bringing this to the optimal reliability level of about 0.55 to 0.65 day per year LOLP would require about P14.6 B ($1.00 = P30.00) - a considerable amount of investment. This would translate into an increase in electricity supply cost from P0.90 per kWh to P1.04 per kWh.

8.0 RECOMMENDATIONS

On the bases of the results and conclusions, the study recommends the following plans and policies for the government:

1. Restore government subsidy to the electric power sector

The substantial investment needed in improving the present level of reliability of the power supply can be raised by NPC through foreign borrowing and/or increasing its revenues. However, the latter is only possible if the price of electricity is increased to its true cost. Unfortunately, the current economic state of the country cannot afford such an increase.

Industrialization cannot be achieved without first providing the power supply requirements of a country. On the other hand, economic growth may not come without industrialization. The subsidy will provide the impetus for industrialization until a level is achieved where the economy can afford the true cost of electricity.

2. Implement industrial zoning

Industrial zones could facilitate the control of power curtailment by establishing different levels of reliability depending on the industry's contribution to GDP. Such a policy should be extended to commercial and residential loads, especially in the Metro Manila area.

3. Encourage private investments in energy generation

The build-operate-transfer (BOT) scheme in power generation should be encouraged since the present power situation forces many manufacturing firms to build their own power plants anyway. Moreover, private power generation in export processing zones, industrial parks and the likes should also be encouraged.

4. Prioritize power development programs

Government policies should place high priority on power development program of the NPC since a high level of reliability of the power system must be maintained to sustain economic growth.

5. Use different reliability criteria in power system planning

In the planning, it is necessary to use different reliability level criteria for the different grids of NPC if only to decrease the capital investment requirements. The reliability level can be based on the degree and rate of development of a particular area. Different localities in a grid can also have different criteria. Moreover, while the commercial sector requirement for reliability level could be as high as the industrial sector (but it could be lower), that for the residential is definitely lower. Thus, the density of the types of loads in a locality can be used to determine reliability level criteria. Likewise, efforts to reduce supply cost on the part of the utility should be pursued, among which are optimal generation planning and efficient operation and maintenance.

6. Pursue vigorously the development of cheap sources of energy

All efforts towards lowering supply cost will reduce the seemingly unaffordable investment requirements of high reliability level of power supply.

7. Consider the use of non-conventional energy in rural areas

Inasmuch as rural areas do not require a high reliability level of electricity supply, systems like non-conventional energy, which are comparable to lower reliability grids can be considered. Subsidizing non-conventional energy systems can be cheaper for the government than investing in an equivalent power grid.

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