Determination of Firm Generating Capacity

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Synopsis

In the early stages of the development of the WAPDA Northern Grid Zone the firm generating capacity was computed after subtracting the largest unit from the available generating capacity. With the subsequent addition of many large generators, the firm generating capacity has now been evaluated on a probability basis keeping in view the past performance of generating units in the Grid System. The results have shown that 10% of the total available capacity should be considered as Spinning Reserve and subtracted from the total generating capacity to arrive at the system firm capacity.

The establishment of the West Pakistan Water and Power Development Authority (WAPDA) in 1958 ushered in a new era in respect of power generation in the Province. The Government decided that all power stations in the Northern Grid Zone either in operation or under construction would now be under the unified management of WAPDA. The Northern Grid Zone of WAPDA covers an area of approximately 91,000 sq. miles and includes the Civil Divisions of Peshawar, D. I. Khan, Rawalpindi, Sargodha, Lahore, Multan and Bahawalpur. Included in this zone is the Main WAPDA integrated Grid System which accounts for about 90 per cent of all transmission and distribution facilities, system load, electric consumers, investment and sales of WAPDA. With WAPDA taking over the power projects, it virtually had to start from scratch regarding the assembly and compilation of statistics. In formulating a Master Plan it was necessary to prepare power load estimates up to the year 1985 and in the absence of any reliable statistics this presented a formidable task. Since 1959 WAPDA has been assembling and compiling statistics and predicting future electric load growth. In the past, the general practice of determining the firm capacity of the Northern Grid System was to subtract the name-plate rating of the largest generating unit in the system from the total available capability. In the initial stages of a growing electrical network this rule of the thumb representing the largest hazard to the system may be allowed, but as the number and size of generating units increase substantially and the system becomes larger and more complex this rule no longer applies. In the early stages of the WAPDA Northern Grid System there were basically two major generating stations; namely, Multan and Warsak. Multan had four units of 65 MW each and Warsak four units of 40 MW each. However, with the anticipated commissioning of the Lyallpur Thermal Station in December 1966, having 2 units of 65 MW each and the completion of the Mangla Power Station which up to 1970 will have 6 units of a nominal rating of 115 MW each, it is essential that the firm capacity of the total grid system should be evaluated on some probability basis.

The following factors will be considered in calculating the WAPDA Northern Grid System firm generating capacity: Firm generating capacity is defined as the generating capacity available to the system at all times during the year after allowing for the following:

(*a*) *Seasonal Variations* in river and canal flows which affect hydro-electric availability. This capability deviates from the name-plate installed capacity.

(*b*) *Co-incidental Derating.*—Since all the generating units connected to the Northern Grid System are not capable of producing their name-plate rating due to various factors including modifications, obsolescence, major repairs, damages etc., it is, therefore, necessary to derate the units and calculate the actual available capacity of each generator to meet system peak demand. This is mainly applicable to thermal stations.

(*c*) *Cold Reserve* is that portion of the system generating capacity which is deactivated for reasons of operating economy and which cannot be made available for operating purposes for many days or even weeks.

(*d*) *Scheduled Maintenance of Generating Units.*—This is programmed in such a manner that the excess of available capacity over the estimated monthly peak load is as uniform as possible. The basic premise adopted in scheduled maintenance in the Northern Grid System is as follows:

(*i*) Thermal generating units are ordinarily to be maintained during the summer months when there is excess of water in the rivers or hydel generation is at its maximum.

(*ii*) Hydel generating units to be maintained during winter months when river flows are minimum and generally do not permit all the generators to be in operation simultaneously. In the case of canal hydel stations, scheduled maintenance can also be done during periods of canals closures whenever these may occur.

(*iii*) On the above basis thermal generating units would be preferably taken out of service for scheduled maintenance during the summer months and hydel generating units would be preferably taken out of service during the winter months.

(*e*) *Forced Outages.*—Forced outages represent that portion of the generating capacity which is not available to the Grid System due to emergency breakdowns and shutdowns. The amount of generating capacity taken out of service is based on probability and past experience of the system.

Forced outage results from the failure of the turbine, generator, transformer or any of the auxiliaries that require a unit to be taken out of service. An outage to be considered forced must satisfy one of the following conditions:

(*i*) The unit must be taken out of service immediately during the peak load hours.

(*ii*) The unit must be taken out of service immediately during off peak night hours or light load period.

(*iii*) It is not necessary to take the unit out of service immediately but the eventual outage cannot be delayed until a normal scheduled maintenance period.

The duration of a forced outage extends from the time the unit was desynchronized until the time the unit is again synchronized to the grid system.

(*f*) *Spinning Reserve* is the minimum amount of additional generation needed on the units actually in operation to provide adequately for forced outages, system regulation, instantaneous load variation and short-term errors in load forecasting.

When WAPDA took over the operation of the Northern Grid System it was observed that the system annual peak generally occurred in the month of December of each year. In 1961-62 with the commissioning of the SCARP I—Salinity Control Project and the build-up of a large private tubewell load it was observed that the system peak was shifting from the month of December to the months of August/September/October. According to the present load forecasts the annual system peak after 1966 will generally occur in the month of October each year due to the very heavy public and private tubewell load. Attached table 'A' shows the name-plate rating and actual December capability of all generating stations in the WAPDA Northern Grid System in 1970. The month of December has been selected for demonstration purposes since in the past generating statistics have related to this month. In computing the December generating capability of the grid system the following factors discussed above have been taken into account:

(*a*) Seasonal variations in rivers and canals flows;

(*b*) Co-incidental derating;

(*c*) Cold reserve;

(*d*) Spinning reserve including forced outages.

A scheduled maintenance programme from 1966-77 has also been prepared and is based on the following assumptions:

(*a*) Maintenance of generating units have been programmed mainly during periods when the system has surplus energy and capability. However, there are many months in each year showing deficits where the system cannot meet the loads and even though scheduled maintenance should normally be done, it has been deferred.

(*b*) After commissioning of each major hydel unit, 15 days for inspection have been provided in the subsequent year and one month for scheduled maintenance every two years.

(*c*) After commissioning of every major thermal unit, one month is allowed for inspection in the subsequent year and two months for scheduled maintenance every second year. However, Government Boiler Regulations require that every year the boiler should be certified and on this account 10 days each year are also allowed for boiler inspection and certification.

Spinning Reserve including Forced Outages

Calculations for forced outages as shown in Appendix I are based on past experience, and the probability of forced outage of generating units has been calculated which show that 8% of the available generating capacity or the largest unit out whichever is greater should be considered as forced outage for the WAPDA Grid System.

In order to provide for system regulation, instantaneous load variations and short term errors in load forecasting at least 2% of the total available capacity should be in reserve. This means that the total Spinning Reserve including forced outages should be 10% of the available generating capacity.

Keeping the above factors in view and referring to the attached report the total system firm capacity from December 1966 to October 1970 will be as follows:

Month & Year		Available Capacity (MW)	Spinning Reserve (MW)	Firm* Capacity (MW)
December 1966	..	599	65	534
October 1967	..	919	115	804
October 1968	..	1034	115	919
October 1969	..	1034	115	919
October 1970	..	1265	127	1138

*Excludes Scheduled Maintenance.

APPENDIX I

FORCED OUTAGE REQUIREMENTS

With the steady growth of the WAPDA Northern Grid System and the installation of more and more large hydel and thermal generating units it is very necessary that some analysis is made of the forced outage of generating units. The general method adopted by foreign utilities is based on the probability theory in figuring the probable system outages.

> Let P1, P2, P3.........Pn be the forced outage rates of unit Nos. 1, 2, 3........n expressed as the ratio of number of days outage to the number of days in the year.
> Similarly let Q1, Q2, Q3........Qn be the operating rates of unit Nos. 1, 2, 3........n expressed as the ratio of number of days running to the number of days in the year.
> Then P+Q=1 for any unit by definition.

From the probability theory the product P_1Q_2 is the probability of unit No. 2 being in service and unit No. 1 being out of service simultaneously over any given period, the product P1, P2 and P3 is the probability of units No. 1, 2 and 3 being out of service simultaneously for any given period. The product Q1, Q2, Q3 is the probability of units 1, 2, 3 being in operation simultaneously. To find the probability of different combinations of units out of service and in service use—

$$(P_1+Q_1)\,(P_2+Q_2)\,(P_3+Q_3)\ldots\ldots..(P_n-Q_n)=1$$

If all the units have the same service and outage probability P & Q, this equation reduces to $(P+Q)^n=1$

The term $P_1\,Q_2+P_2Q_1$ is the probability of having unit No. 1 out of service and unit No. 2 in service simultaneously and having unit No. 1 in service and unit No. 2 out of service.

The use of probability methods makes it possible to compute the overall source reliability from the known forced outage rate of each of the generators which comprise the WAPDA Northern Grid System. The procedure outlined above can obviously be extended so that by means of adding one generator at a time to the existing system whose characteristics are known, it is possible to obtain for any number of generators a listing showing every possible outage that could occur and the corresponding probability of its existence. Forced outage capability and duration is important when the grid system has insufficient capacity to meet the system load.

In determining the forced outage probability of the WAPDA Northern Grid System up to 1970 the following data has been used:

Name of Station	No. of Units	Size of Units	Total capacity
Multan ..	4	65 MW	260 MW
Lyallpur ..	2	65 MW	130 MW
Warsak ..	6	40 MW	240 MW
Mangla ..	6	115 MW	690 MW
Lahore ..	6	14 MW	84 MW
Old Hydel ..	20	5 MW	100MW
Old Thermal ..		(in cold reserve).	

The forced outages of the Multan and Warsak Generating Units have been based on actual outages for the 3-year period 1963-65. Both these stations were actually commissioned in 1960 and during the period 1960-63 the forced outages rates were considerably higher due to commissioning problems and initial operation. It was therefore decided to take the subsequent three-year period so that the statistics indicate a truer picture. The forced outages of the Old Hydel stations are based on past performances as reported by the station staff. The forced outage probability of the proposed two units at Lyallpur has been taken as 2.5 per cent each. The forced outage probability of the gas turbines at Lahore has been taken as 2 per cent each. The forced outage probability of the 6 units at Mangla has been taken as 1 per cent each. The following figures have been used as the basis of the calculations :

Station		Probable Outage (percent)
Multan Thermal		
Unit No. 1	..	(0.954+0.046)
Unit No. 2	..	(0.915+0.085)
Unit No. 3	..	(0.920+0.080)
Unit No. 4	..	(0.975+0.025)
Lyallpur Thermal		
Unit No. 1	..	(0.975+0.025)
Unit No. 2	..	(0.975+0.025)

Station		Probable Outage (Percent)
Warsak Hydel		
Unit No. 1	..	(0.997+0.003)
Unit No. 2	..	(0.995+0.005)
Unit No. 3	..	(0.999+0.001)
Unit No. 4	..	(0.998+0.002)
Unit No. 5	..	(0.998+0.002)
Unit No. 6	..	(0.998+0.002)
Lahore Gas		
Unit No. 1	..	(0.980+0.020)
Unit No. 2	..	(0.980+0.020)
Unit No. 3	..	(0.980+0.020)
Unit No. 4	..	(0.980+0.020)
Unit No. 5	..	(0.980+0.020)
Unit No. 6	..	(0.980+0.020)
Mangla Hydel		
Unit No. 1	..	(0.990+010)
Unit No. 2	..	(0.990+010)
Unit No. 3	..	(0.990+010)
Unit No. 4	..	(0.990+010)
Unit No. 5	..	(0.990+010)
Unit No. 6	..	(0.990+010)
Old Hydel		
Malakand	..	(0.997+0.003)
Dargai	..	(0.997+0.003)
Rasul	..	(0.950+0.050)
Chichoki	..	(0.910+0.090)
Nandipur	..	(0.900+0.100)
Shadiwal	..	(0.999+0.001)

The following figures indicate the frequency and forced outage duration times of the Multan Thermal and Warsak Hydel stations for the period 1963-1965 :—

Multan Thermal Station

(1963)

Unit No. 1		*Unit No.* 2	
Frequency (Nos.)	Duration (Hours)	Frequency (Nos.)	Duration (Hours)
1	33.00	1	4.50
2	62.50	2	94.00
3	93.00	3	130.00
4	8.00	4	190.00
5	42.00	5	89.00
6	7.50	6	101.00
7	9.00		
8	1.50		
9	7.00		
10	62.00		
11	4.50		
12	5.50		

(1964)

Unit No. 1		*Unit No.* 2		*Unit No.* 3		*Unit No.* 4	
Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)
1	57.00	1	68.00	1	102.00	1	14.50
2	10.50	2	81.00	2	102.00	2	4.00
3	8.00	3	97.00	3	105.00	3	25.50
4	10.00	4	77.00	4	160.00	4	17.50
5	124.00	5	96.00	5	11.50	5	5.50
6	18.00	6	59.00	6	24.00		
7	56.00	7	123.00				
8	111.00	8	8.00				
9	5.00	9	113.00				
10	14.00	10	109.00				

(1965)

Unit No. 1		Unit No. 2		Unit No. 3		Unit No. 4	
Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)	Freq. (Nos.)	Duration (Hours)
1	14.00	1	1.00	1	2.50	1	16.00
2	62.00	2	10.00	2	37.50	2	197.50
3	10.50	3	389.00	3	61.00	3	3.50
4	33.50	4	4.50	4	21.00	4	20.50
5	16.50	5	196.00	5	218.00	5	95.00
6	19.50	6	4.50	6	420.00		
7	21.50	7	20.00				
8	15.50	8	51.00				
9	60.50						
10	81.00						
11	12.00						

ANNUAL AVERAGE

Unit No. 1 11 outages of average duration 33 hrs.
Unit No. 2 .. 8 outages of average duration 88 hrs.
Unit No. 3 .. 6 outages of average duration 105 hrs.
Unit No. 4 .. 5 outages of average duration 40 hrs.
Overall average .. 7 outages of 70 hours each (approx. 3 days).

Warsak Hydel Station

Unit No. 1		Unit No. 2		Unit No. 3		Unit No. 4	
Freq. (Nos.)	Duration (Hrs. minutes)	Freq. (Nos.)	Duration (Hrs. minutes)	Freq. (Nos.)	Duration (Hrs. minutes)	Freq. (Nos.)	Duration (Hrs. minutes)
			1963				
1	00.58	1	32.00	1	02.48	1	04.25
2	04.28	2	00.47	2	01.55	2	02.48
3	15.26	3	04.17	3	09.37		
4	02.13	4	00.05	4	01.18		
		5	02.48				
			1964				
1	00.25	1	02.27	1	02.08	1	06.19
2	00.23	2	02.02	2	03.11	2	02.45
3	02.41	3	08.38				

Unit No. 1		Unit No. 2		Unit No. 3		Unit No. 4	
Freq. (Nos.)	Duration (Hrs. mlnutes)	Freq. (Nos.)	Duration (Hrs. minutes)	Freq. (Nos.)	Duration (Hrs. minutes)	Freq. (Nos.)	Duration (Hrs. minutes)
			1965				
1	04.15	1	15.10	1	07.30	1	24.15
2	06.55	2	09.20	2	06.35	2	02.55
3	03.16	3	06.04			3	05.39
4	02.25	4	07.43			4	02.41
5	06.39	5	09.25			5	01.17
6	00.27	6	06.25			6	01.50
7	05.25	7	02.50			7	00.38
8	01.31	8	03.41			8	07.03
9	02.55						

Forced outage probability, frequency and duration of outages

The forced outage probability of each generating unit in each power station both individually and collectively can be obtained by expansion of the series $(P+Q)^n=1$.

Frequency and duration of outages is obtained by the preparation of table 'B' (attached herewith). Construction of this table has been done by listing every major capacity outage that could occur. For this table consideration has been given only to the large units at Mangla, Multan, Lyallpur and Warsak. After listing each capacity outage, the various ways in which this event could occur are shown, and the probability of existence of each of the capacity outage combinations is computed in a manner similar to the procedure for each individual station. The probability of losing Ok megawatts in exactly the manner specified is denoted as Pr, where r represents the total number of units on forced outage for this condition. In addition, to losing Ok megawatts exactly in the manner specified, it is also possible to lose Ok megawatts in some other way. The sum of various Pr's gives Pk. Having obtained the forced outage probability of various combinations of generating units comprising the entire grid system calculation of Dr is made for each value of Pr which is listed. By definition Dr is a measure of the frequency of an r-fold outage given by the formula :—

$$Dr=Pr\left[\frac{r}{t}-\frac{(n-r)}{(1-p)T}\right]^*$$

The values of T, t and p are average values for the system and have been based on the forced outage rate of 20 days in a year. For each capacity outage Ok a value of Dr is computed for every possible way in which this capacity outage could be brought about. These values are then summed to produce one value Dk which can be associated with the outage magnitude Ok. By definition the value of Fk+ that applies for the condition to zero capacity outages is zero. This fact permits the evaluation of Fk+ for all other values of K as Dk is known and the recurrence relationship applies as shown in table 'B' Knowing Fk+, the average time duration of outage of Ok megawatts or more denoted by the symbol *tk* is obtained by dividing Pk by Fk+so that—

$$tk=\frac{Pk}{Fk+}$$

As interval between outages is the reciprocal of frequency, the interval between occurrences of outages of Ok megawatts or more and represented by the symbol $Tk=\frac{1}{Fk+}$. Calculations of the forced outage probability, frequency and duration of outages is shown in table 'B'.

**See* reference No. 2.

Definition of Symbols—

P =Forced outage rate

Q =Availability rate

t $=\frac{\text{days on forced outage}}{\text{number of forced outage}}$

T $=\frac{\text{days on forced outage}+\text{days operated}}{\text{number of forced outages}}$

F =Average frequency of outage per unit.

n =Total number of machines on system.

r =Number of machines simultaneously on forced outage.

Pr =Probability of existence of exactly r units on forced outage.

Ok =MW on forced outage,

Pk =Probability of existence of actually Ok MW on forced outage.

Dr $=\Pr\left[\frac{r}{t}-\frac{(n-r)}{(1-p)T}\right]$ =frequency of an r-fold outage

Dk =frequency of an outage magnitude Ok

--where average t for the system has been taken as 0.01 (3 days)

—where average P for the system has been taken as 0.02 (2% outages)

—where average T for the system has been taken as $0.5\left(\frac{330}{7\times100}\right)$

} Based on 20 days average outage per year

For each capacity outage entry Ok, a value of Dr is computed. The values are summed to produce Dk.

Fk+ = frequency of occurrence of outages of exactly Ok MW

tk = $\frac{Pk}{Fk+}$ average time duration of an outage of Ok MW or more.

Tk = $\frac{1}{Fk+}$ average interval between occurrence of outages of Ok MW or more.

The following table shows the calculated outage probability of each station :—

Station	Capacity Out (MW)	Probability Outage
Multan & Lyallpur ..	0	0.723925000
	65	0.228130000
	130	0.047530000
	195	0.000413250
	260	0.000001030
	325	0.000000720
	390	0.000000000
Warsak ..	0	0.985014000
	40	0.014798000
	80	0.000088020
	120	0.000000266
	160	0.000000000
	200	0.000000000
	240	0.000000000
Mangla ..	0	0.940500000
	115	0.058039400
	230	0.001440900
	345	0.000019453
	460	0.000000247
	575	0.000000000
	690	0.000000000
Lahore ..	0	0.885843000
	14	0.108470000
	28	0.005534090
	42	0.000150590
	56	0.000002302
	70	0.000000018
	84	0.000000000
Old Hydel -	0	0,7726153013

Station		Capacity Outage (MW)	Probability Outage
Old Hydel	..	20	0.2083456486
		40	0.0184661883
		62	0.0005694601
		75	0.0000033950
		88	0.0000000067
		100	0.0000000000

The figures given below are summarized from the attached table 'B'.

WAPDA Grid System—Forced outage probability

Available Capacity in Dec. 1970=1400MW

Capacity Forced Outage (MW)	Probability of Forced Outage Days/Years	Duration of each Forced Outage Days/Years	Frequency of Outages Times/Years	Interval between outages Days
40	11.0	0.40	28	11.8
65	75.0	3.95	19	17.4
115	21.0	2.10	10	33.0
105	1.8	0.26	7	47.0
155	2.8	0.47	6	55.0
180	3.1	0.78	4	82.5

The results shown above are stated in terms of the probable number of days per year that a generating unit will not be available to the Grid System as a result of forced outage. This is a probability exactly similar in its significance to the statement that the probability of throwing II on any throw of the dice is 2/36 or 0.056 or 5.6 per cent. Probability is expressed as a fraction or decimal in the range of 0 to 1. Days per year is also a fraction, for 1 day per year represents a probability of 1/365 or 0.274 per cent.

From the above table it can be seen that a 40 MW unit at Warsak is on forced outage for 11 days in a year, a 65 MW unit at Multan is on forced outage for 75 days in a year, and a 115 MW unit at Mangla is on forced outage for 21 days in a year. Simultaneous outage of a Warsak and Multan unit is for 1.8 days in a year, simultaneous outage of a Warsak and Mangla unit in for 2.8 days in a year, and simultaneous outage of a Multan and Mangla unit for 3.1 days in a year. The frequency and duration time of each outage is also shown in the above table, from which it can be seen that a 115 MW unit is on forced outage 10 times in a year with an average duration time of 2.1 days each, and this outage recurs after an interval of 35 days. On the basis of an available capacity of 1400 MW in 1970, 115 MW represents a forced outage of 8%. In the above analysis schedule maintenance has been considered on the basis of one month per year for a generating unit at Multan, Lyallpur and Mangla power stations so that there are approximately 330 operating days in a year for these units.

However, no numerical calculations can alone establish what is a satisfactory level of generating system reserve requirements and reliability or determination of a proper value of the index of system reliability. The selection of a satisfactory level of reliability or a value of forced outage requires human judgment and experience. Questions like "How much generating capacity should be installed to cater for forced outage?" or "What is an acceptable level of reliability?" can only be answered after evaluation of the economics of the overall grid system. In any case, there comes a point when judgment must be exercised to differentiate between what is and what is not adequate reliability. The level of reliability generally adopted by American Utilities is based on a certain reserve capacity to be on probable forced outage for one day in five years whereas for the WAPDA Grid System a level of reliability corresponding to a probable forced outage of approx. 20 days in one year has been assumed. This figure was assumed on the basis of the past performance of the Multan Power Station. During the initial stages of the WAPDA Grid System and even up to the period 1960-65 there were serious limitations in the availability of Foreign Exchange with the result that it was not possible to implement a large generation programme, therefore the question of providing reserve capacity for the grid system did not arise, and in case of forced outages of generating units, load shedding had to be carried out for any emergency. This situation was so acute that in the year 1965 load shedding to the extent of 50-60 MW was carried out.

After WAPDA took over the overall construction and operation of power stations, the total available generating capacity in 1960 was 307 MW. In the absence of any reliable statistics it was agreed to consider as forced outage the largest unit on the system, namely, one generator at Multan rated at 65 MW. This rule of the thumb was justified at that time since there was always the possibility that the system could lose this unit on a forced outage. It is interesting to note from the probability results that the formula of allowing the largest unit out on forced outage is justified even up to 1969 when the total available generating capacity is 1035 MW. However, with the commissioning of many large generating units in the future at Mangla, Tarbela, Gariala, etc., the formula of the largest unit out will no longer apply, but

8% of the total available generating capacity should be considered as probable forced outage.

Statistics of American utilities show that the probability of forced outage of a 66 MW thermal turbo-generator unit is approximately 1.5 to 2.0 per cent, and the probability of forced outage of a hydro-electric unit is approximately 0.7 per cent. Actually in the case of the WAPDA Grid System it has been observed that the forced outage rate of the thermal units at Multan are between 4.5 to 8.5 per cent. This naturally reflects on the quality of maintenance besides other factors. The performance of the hydro-electric units at Warsak are very good with an average outage rate of approximately 0.3 per cent. Generating capacity to be kept in reserve for forced outages can be considerably reduced by having regular maintenance programmes, availability of spare parts and experienced technical personnel. By adopting these methods it is possible to reduce the investment on the outlay of additional reserve generating capacity. The figure of 8% of the available system capacity that has been adopted as the basis of forced outage probability is on the conservative side since American utilities generally adopt a figure of 10% to 20%. Once the selection of a reserve requirement has been made, probability methods with due recognition of their nature, can maintain the desired reliability with minimum costs under widely varying conditions. A provision of 10% of the total available capacity has been used for forced outages, errors in load forecasting, voltage variations etc., so that a Spinning Reserve capacity of 10% should be available to the system.

The application of probability methods has now reached a stage where it should be accepted as a normal tool of the system planner. The system performance should be carefully studied and statistics maintained. With regular maintenance programmes it is possible that the reserve requirement decreases resulting in a considerable saving of capital investment.

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TABLE A.—*Generating Capability, December* 1970

Hydel Station	Name Plate Rating (KW)	Actual December Capability (KW)	Reference
Mangla ..	690,000	690,000	Note No. 1
Warsak ..	160,000	100,000	Note No. 2
Malakand ..	19,600	14,600	Note No. 3
Dargai ..	20,000	17,500	Note No. 3
Rasul ..	22,000	7,500	Note No. 3
Chichoki ..	13,200	4,500	Note No. 3
Shadiwal ..	13,500	6,000	Note No. 3
Nandipur ..	13,800	5,800	Note No. 3
Renala ..	1,100	600	Note No. 3
Kurramgarhi ..	4,000	2,800	Note No. 3
Sub-total ..	957,200	842,000	
Steam Stations			
Multan ..	260,000	262,000	Note No. 4
Lyallpur ..	132,000	132,000	
Sub-total ..	392,000	394,000	
Gas Turbine			
Multan ..	5,700	5,700	
Lahore ..	85,000	85,000	
Sub-total ..	90,700	90,700	
Total ..		1,326,700	
Old Thermal Stations in Old Reserve ..		20,000	Note No. 5
Grand Total ..		1,346,700	
Spinning Reserve at 10% inc. Forced Outages ..		134,700	
Firm Capacity ..		1,212,000	

Note No. 1.—By 1970 there will be six units installed in the Mangla Power Station rated at 125 MVA each. With an operating power factor of 0.94 each unit would be capable of generating 115 MW. However, during the low water periods in March and April the output of each unit is reduced to 76 MW.

Note No. 2.—By 1970 the Warsak Power Station will still have only 4 units of 40 MW each. In the absence of re-regulating facilities it will only be possible to generate 100 MW during winter months since higher water releases will flood the downstream irrigation bunds.

Note No. 3.—Small hydel stations, Malakand, Dargai, Rasul, Shadiwal, Chichoki and Nandipur are located on irrigation canals. The main purpose of these irrigation canals is for agriculture and power generation is a secondary consideration. Output of these stations is limited during winter months, as a result of low flows in the rivers. The actual capability of many stations is, therefore, less than 50% of the installed capacity.

Note No. 4.—The four units at Multan have a rating of 65 MW each. However, due to the removal of some blades of the steam turbine rotor of unit No. 2, the output of this machine has been reduced to 62 MW. Units No. 3 and 4 which were commissioned in 1963 are capable of generating 67.5 MW each to meet the winter peak load.

Note No. 5.—There is 20 MW available capacity in old thermal and diesel stations at Lyallpur, Montgomery and Warsak. These stations due to their dilapidated conditions have been considered as Cold Reserve. It would take some time before these stations can be started and synchronized with the grid system.

Index K	Capacity outage MW Ok	Number of units on outage from various size groups: 40 (6)	65 (6)	115 (6)	Units: Out r	In n—r	Probability that Ok will be out as shown Pr	Probability that Ok will be out in some way Pk	Times per year: Dr	Dk	Frequency of initiation of Outages of Ok times per year Fk +	Average time duration Outages Ok years tk	Interval between occurrences of Ok years Tk	Remarks
1	0	—	—	—	0	30	0.45869262	0.45869262	28.083066	28.083066	0	∞	∞	All units running.
2	40	1	—	—	1	29	0.014798	0.0332640	0.60405436	8.22229096	28.08306600	0.00121	0.0356	One unit at Warsak (40 MW) on forced outage.
					2	28	0.0184663		7.618223660					
3	65	—	1	—	1	29	0.228130	0.228699	9.31226660	9.33549318	19.86077504	0.001198	0.0505	One unit at Multan (65 MW) on forced outage.
					3	27	0.000569		0.02322658					
4	115	—	—	1	1	29	0.058039	0.061496	2.36915198	2.86301900	10.52528186	0.00636	0.0955	One unit at Mangla (115 MW) on forced outage.
					3	27	0.003457		0.49386702					
5	105	1	1	—	2	28	0.00217046		0.31000620	1.16453410	7.66220286	0.000788	0.1320	One unit at Warsak and one unit at Multan (105 MW). Simultaneously on forced outage.
					4	26	0.00024561	0.00564954	0.00852085					
					3	27	0.003454514		0.84600705					
6	155	1	—	1	2	28	0.000425308		0.06075836	2.05820500	6.49766876	0.001422	0.1540	One unit at Warsak and one unit at Mangla (155 MW). Simultaneously on forced outage.
					3	27	0.008125920	0.008603128	1.99003291					
					4	26	0.00005190019		0.00741443					
7	180	—	1	1	2	28	0.008914570		1.27353975	1.39987774	4.43946305	0.00236	0.2250	One unit at Multan and one unit at Mangla (180 MW) Simultaneously on forced outage.
					3	27	0.000449359	0.009477843	0.11006624					
					3	27	0.000113914		0.01627175					