APPLICATION OF PROBABILITY TECHNIQUES IN THE EVALUATION OF GENERATING CAPACITY REQUIREMENTS

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PREFACE

A major capital expenditure in a modern power system is for generating facilities. These installations must be such that the load as a whole is supplied as economically as possible and with a reasonable assurance of the continuity of that service.

The determination of what is and what will be a reasonable assurance of continuity is an important problem which must be faced by engineering and management personnel. The usual approach to this problem in the past has been by relatively inflexible rule of thumb techniques such as a fixed percentage reserve. Considerable literature over the past twenty years has been published on the application of probability techniques to the evaluation of system generating capacity requirements. An unfortunate belief exists in most management and engineering circles that probability methods are the exclusive tools of statisticians and mathematicians and as such are complicated and somewhat difficult to understand without specialized training.

This thesis shows that the basic application of probability to the problem of system generating capacity requirements is not difficult to understand and should be readily acceptable to those concerned with generation planning. The added refinements which can be applied should remain as tools of the specialist but the basic concepts are relatively simple and provide a sound basis for evaluation of reliability in comparative schemes of system capacity expansion.

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ABSTRACT

An attempt is made to remove the suspicion with which most engineering and management personnel regard a supposedly highly mathematical and abstract concept known as probability. The general application of this technique to system generating capacity requirements is basically simple and should be readily acceptable to those concerned with generating capacity planning while leaving the refinements to the statistician or mathematician.

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GENERAL CONSIDERATIONS IN THE EVALUATION OF GENERATING CAPACITY REQUIREMENTS

INTRODUCTION

A prime requisite of a modern power system is the ability to meet the constantly changing system load at all times. An absolute guarantee of this ability is impossible and any attempt to approach this condition is impractical and uneconomical. An important function of the System Planning Engineer in a modern power system is to analytically determine the level of reliability to strive for and the attendant cost of maintaining this level.

The term "Generating Capacity Requirements" embraces all the factors which must be considered in the study and planning of generating capacity reserves in a modern power system. The system generating capacity must be sufficient so that the load as a whole will be supplied most economically and with a reasonable assurance of the continuity of this service. To measure the assurance of system continuity requires a determination of the reliability level of the system generating facilities and the risk of failure to meet and supply the system load demand.

SPINNING RESERVES

A certain reserve of capacity and energy known as the

"Spinning or Rolling Reserve" must be available at all times. This generating capacity should not be less than the sum of:

(a) the capacity required to meet load changes without impairing system frequency

(b) the capacity of the greatest single risk of outage.

In interconnected systems with adequate tie-line facilities, condition (b) can be modified somewhat. A spinning reserve less than the capacity of the largest working unit in the system can be used if assistance from neighboring systems is available. In an isolated or interconnected system, condition (b) can be further modified by provision for shedding certain portions of the system load at times of generating capacity deficiencies. This provision can be accomplished by under-frequency relaying of large blocks of load. Though not particularly desirable, this ability to shed load under sudden outage conditions can produce sizable economic advantages if the spinning reserve is provided by thermal generating units.

The generating capacity requirements of condition (a) can also be reduced by accurate daily and hourly forecasting of the system load, accompanied by constant and adequate generation dispatching. Human abilities are augmented in most large systems especially those possessing considerable thermal generation by analog or digital techniques.

A method which can be used to reduce the system load at times of generating capacity deficiencies is to lower the system voltage level slightly. Filament lamps will glow less brightly and some motor drives may experience outages due to increased current flow. This method should not be regarded as a means of reducing the required reserve margin but as a last resort in keeping the system together.

Assuming adequate transmission facilities, the "Spinning Reserve" held by one or a group of systems should be able to replace immediately the loss of capacity caused by the greatest single risk of outage.

STATIC RESERVES

In addition to the "Spinning Reserve" maintained by a system there must also exist a further reserve known as a "Static Reserve". This additional reserve must be sufficient to provide for:

(a) the overhaul of generating equipment
(b) outages which are not planned or scheduled
(c) load growth requirements in excess of the estimates.

A generally standard practice that has developed over many years is to consider or measure the adequacy of both the planned and installed generating capacity in terms of a percentage reserve. This figure is computed by dividing the amount that the effective rating or capability of the installed capacity exceeds the expected or forecast annual peak load by that load. The capability of the installed capacity component does not include reductions due to scheduled and routine maintenance or miscellaneous and seasonal capacity reductions.

Load forecasts made several years in advance or in the case of extremely advanced planning, five to fifteen years in advance, are subject to considerable uncertainty. An important factor in the consideration of an adequate allowance for installed generating capacity requirements is a probable load forecasting error. If some percentage of installed generating capacity is used for planning purposes and a large positive load forecasting error occurs, the actual available reserve will be considerably reduced from the design requirement. The occurrence of such a situation could be interpreted as an indication that inadequate generation planning had resulted in a deficiency of generating capacity.

An important objection to the use of the percentage reserve requirement criterion is the resultant tendency to compare the relative adequacy of generating capacity requirements provided for totally different systems on the basis of peak loads experienced throughout the year. Large differences in generating capacity requirements to provide the same assurance of continuity of service may be required in two different systems with system peak loads of the same magnitude. This situation could occur when the two systems to be compared have different types of installed or planned generating capacity with different forced outage rates, scheduled maintenance periods and system load characteristics.

To achieve the most economical expansion of the system the installation of relatively large blocks of generating capacity may be required. This may result in some surplus of generating capacity in the system for a short period following such an addition. This overbuilding can be partially offset by firm capacity purchases from neighboring systems thus allowing major generating capacity additions to be delayed one or more years at a considerable saving.

EFFECT OF UNIT SIZE ON GENERATING CAPACITY RESERVES

An important condition which must be realized is the effect of generator unit size upon generating capacity requirements. There are several viewpoints on this matter. A point of view which stems from the policy of planning generating capacity additions to provide reserves equal to a fixed percentage of peak load is that unit size does not affect generating capacity requirements. This concept attaches no penalty to a unit because of its size unless this quantity exceeds the total generating capacity reserve. Another criterion is that the generating capacity reserve should equal the capacity of the largest unit on the system plus a fixed percentage of the total installed generating capacity of the system. A third viewpoint is that the reserve requirements increase with the addition of larger size units to the system. This characteristic generally results when generating capacity requirements are determined by probability techniques. The application of probability to reserve capacity requirements is the approach elaborated here, as it provides an analytical basis for generating capacity planning which can be extended to cover partial or complete integration of systems, capacity of interconnections, effects of unit size and design, effects of maintenance schedules and other system parameters.

EFFECT OF INTERCONNECTIONS ON GENERATING CAPACITY RESERVES

The effect of interconnections between systems is an important factor in planning adequate reserve margins. Due to the diversity of forced outages and peak loads between two areas, integration through adequate interconnections will allow each area to operate with less reserve than would be required for isolated operation. In taking an interconnection into account in a generating capacity requirement study the level of system reliability of the neighboring system must be determined, together with that of the system under study.

APPLICATION OF PROBABILITY IN PLANNING GENERATING CAPACITY REQUIREMENTS

Unfortunately no standard criterion of adequate generating capacity requirements exists and each system must be analyzed individually on its own merits. It has been stated that:[1]

> "Reserve requirements in the past have been based upon rule of thumb criteria such as the fixed percentage of reserve or the outage of one or more of the largest generator units. The relationship between service reliability and such factors as the size of generator

> additions, the capacity of interconnections, the accuracy of load forecasts, the load duration characteristics and the maintenance schedules can be described only by mathematical methods based upon probability."

Application of probability techniques to this problem is an exceedingly laborious process which fortunately can be reduced considerably with the aid of a medium size digital computer. The basic concepts, however, are quite simple and do not require specialized statistical or mathematical training in order to be understood.

CHAPTER II

APPLICATION OF PROBABILITY TECHNIQUES

PROBABILITY

"In all probability" is a common phrase used in everyday conversation and people are constantly making predictions based upon what they believe is probable. Predictions based upon personal opinion with no statistical evidence cannot normally be lent credence. Philosophically, it is possible to consider all causal relationships in terms of probability. For a given cause it is possible to have some knowledge of the event which is most likely to occur but without absolute certainty of the result until it actually occurs. If a large amount of previous data has been accumulated action can usually be taken on the basis of a high degree of certainty. A statistician, therefore, provides himself with a graduated yardstick with end points of zero and one. The zero point represents a situation in which there is no possibility of the event occuring whilst unity indicates absolute certainty. Any position on the yardstick between these two points represents a relative measure of probability.

A PRIORI PROBABILITIES

This type of probability can be specified from the very nature of the event. If a coin is tossed over a very flat surface, because of our prior knowledge we know that the coin must lie either heads or tails. We consider the case of standing on edge to be entirely non-existent with an infinitesimal probability of occurrence. The probability of getting a head or a tail is exactly one half.

A second example of this type of probability is the result of rolling a die. If the die has six faces each with an equal probability of occurrence then in a single toss each face has a probability of one sixth of being in a designated position.

A priori probability is then, the predicted probability of an event occurring or not occurring based upon prior knowledge of the nature of the event.

STATISTICAL OR EMPIRICAL PROBABILITIES

This type of probability is based upon actual measured data concerning an event rather than the intrinsic properties of the event. In general this can be expressed as the number of occurrences of an event divided by the number of trials taken.

An example of this type of probability is the basic quantity used in the evaluation of generating capacity requirements. If over a long period of time a piece of equipment has operated a total time "I" and has been on forced outage a total time "F" then the probability of forced outage "p" can be expressed as:

$$p = \frac{F}{F + I}$$

The probability of the equipment remaining in operation "q" is given by:

$$q = \frac{I}{F + I}$$

and

$$p + q = 1$$

The term (F + I) is known as the demand time while "p" and "q" are known as the forced outage and availability rates respectively.

If the assumption is made that forced outages of generating equipment are random events, hence independent of each other, then these outages are governed by the same laws of chance as the tossing of coins, the rolling of dice and the spinning of a roulette wheel. This is not an unreasonable assumption in a modern power system as practically all outages are single individual occurrences. Probability theory is not specific in that predictions can be made of actual outage times and the order of occurrence. Its object is to forsee or predict the average performance of the condition investigated. Its application to the problem of generating capacity requirements will only provide a prediction of the average outage performance of a group of units over a long period of time.

FORCED OUTAGE RATE

The probability of having a unit available or unavailable at any time is the basic quantity upon which the application of probability to the problem of generating capacity requirements is based. This information is obtained from previous experience with existing units. Careful consideration must be given to future units which may differ considerably from those existing, in design and method of operation.

The inservice time component, previously designated as "I" is a relatively simple statistic to obtain and requires no further discussion. The forced outage component "F" is not as obvious and can be defined in many ways. An outage to be classed as forced is one which is caused by a failure of the prime mover, alternator or any of their ancillary equipment or pertinent structures. A relatively simple definition of a forced outage is that such an outage must satisfy one of the following conditions.[2]

1. It is not necessary to take the unit out of service immediately but the eventual outage cannot be delayed until a normally scheduled maintenance period.
2. It is necessary to take the unit out of service immediately during the heavy load hours of a weekday.
3. It is necessary to take the unit out of service immediately during off peak night hours, a weekend, or other light load periods whether or not the outage can be concluded and the unit restored to service before needed to carry the load.

The duration of the forced outage extends from the time the equipment is taken out of service to the time it is released again for operation. This time period can vary considerably for similar outage causes due to varying degrees of urgency applied to the restoration of service. A minor modification which can be applied is the determination of a minimum outage duration produced by overtime and accelerated work schedules.

Based upon the performance records of a single unit over a long period of time the forced outage time "F" and the inservice time "I" can be obtained, from which:

$$\text{Forced Outage Rate} \quad p = \frac{F}{F + I}$$

In a generating plant which has several identical units, individual outage and inservice times can be combined to give a single forced outage rate representative of the identical units. In a three identical unit plant the forced outage rate is determined by:

$$p = \frac{F_1+F_2+F_3}{F_1+F_2+F_3+I_1+I_2+I_3}$$

where:

F_1, F_2, F_3 are the individual unit forced outage times

I_1, I_2, I_3 are the individual unit inservice times.

The availability rate "q" is then obtained by:

$$q = 1 - p = \frac{I_1+I_2+I_3}{F_1+F_2+F_3+I_1+I_2+I_3}$$

By accumulating the forced outage and inservice times and computing successive cumulative forced outage rates and yearly forced outage rates any indication towards or away from a stable forced outage rate can be seen.[3] This can be shown graphically for a single unit or for a group of identical units by plotting the cumulative and yearly forced outage rates. A typical plot is shown in Figure 1.

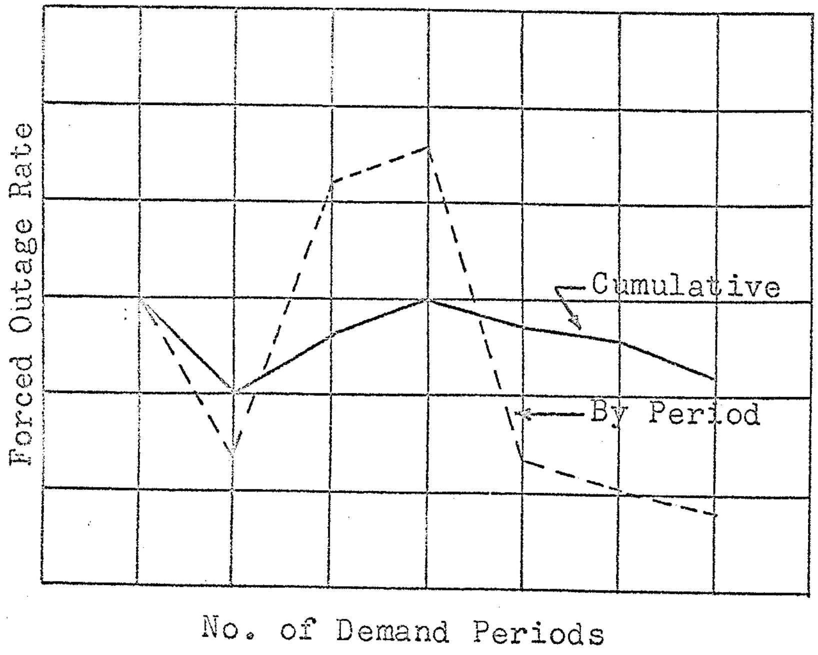


Figure 1. Typical Plot of Cumulative and Individual Forced Outage Rate.

When the cumulative forced outage rate reaches a stable value this can be looked upon as the probability of outage existing during a future time period. If aging effects are apparent, existing rates should be corrected for future application wherever possible. If the accumulated data represents a long time period this effect may be evident by graphical analysis or detected by more formal statistical methods. If the forced outage rate is representative of a group of units the investigation can be extended to examine the homogeneity of the group.

Units which possess unique design features and/or units which are possibly new to the system should be examined individually, unless their size with respect to existing units makes their effect insignificant. The forced outage rates of the largest units in the system are of major importance as these units are the most significant in any reserve generating capacity study.

It can easily be seen that in a system having a large number of identical units a stable forced outage rate will probably be achieved quite quickly. In a large system of "n" units, future operation would expect to have a number equal to "n.p" out of service on a continuous basis for as one unit goes into service another goes out on forced outage. A system which has a relatively small number of identical units would require a long time period to arrive at a stable forced outage rate.

GENERATING PLANT RELIABILITY

Probability techniques can be applied to individual generator unit or individual generating station reliability quite simply and should always be used to assess plant design criteria from the reliability viewpoint. A practical example of this would be an evaluation of the increase in station reliability by installing a header system in a thermal generating station. Assuming a two generator unit station, a header system would allow either turbine to receive steam from either boiler. A comparison of the difference in reliability with and without the header system would proceed as follows.

Individual Unit Case. Assume each unit is entirely separate and composed of a turbine-generator and boiler having forced outage rates "p_g" and "p_b" respectively. Availability rates are then:

$$q_g = 1 - p_g$$
$$q_b = 1 - p_b$$

The loss of either boiler or generator would make the unit inoperable. The unit forced outage rate is given by:

$$p_u = p_g + p_b - p_g\, p_b$$

where the product of "p_g" and "p_b" represents the probability of both boiler and turbine-generator being out of service simultaneously.

The same result can be arrived at by a slightly different approach. The inservice probability "q_u" of the two units is the product of "q_b" and "q_g" from which the forced outage probability is given by:

$$\begin{aligned} p_u &= 1 - q_u \\ &= 1 - q_b \cdot q_g \\ &= 1 - (1 - p_b)(1 - p_g) \\ &= p_b + p_g - p_b\, p_g \end{aligned}$$

This can easily be extended to any number of series elements by following the same basic method.

q_t = Total series availability rate

p_t = Total series forced outage rate

q_a, q_b, q_c, q_d = Individual availability rates

$$\therefore \quad q_t = q_a \cdot q_b \cdot q_c \cdot q_d$$

$$\therefore \quad p_t = 1 - (q_a \cdot q_b \cdot q_c \cdot q_d)$$

Having obtained the total individual unit forced outage rates the generating station outage rates can be obtained. Assuming independence of forced outages the outage probabilities of parallel conbinations of identical units are given by the Binomial Expansion.

The outage probabilities of parallel combinations of "n" dissimilar units having outage rates p_1 p_2 - - - - - p_n are obtained as follows:

$$(p_1 + q_1)(p_2 + q_2) - - - - - - - (p_n + q_n) = 1.0$$

If the "n" units are identical then this reduces to:

$$(p + q)^n = 1.0$$

In the two individual unit plant previously considered, employing the Binomial Expansion would give:

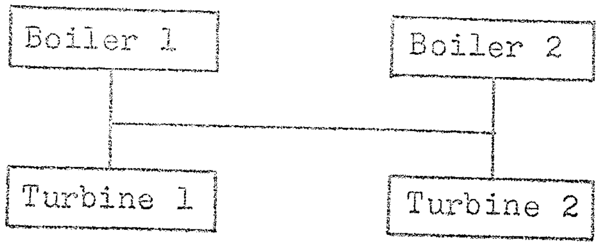
No. of Units on Outage	Probability of Outage
0	q_u^2
1	$2\ p_u\ q_u$
2	p_u^2

The same results can be obtained intuitively by saying that the probability of having both units available is the product of the individual availability probabilities. The probability of having only one unit out of service is twice the product of the probability of having one available and the probability of having the other unavailable, whilst the probability of having two units out of service is the product of the two outage probabilities. For large numbers of identical units application of the Binomial Expansion proves to be much simpler.

The previous table can be modified by using the individual boiler and turbine-generator forced outage rates.

No. of Units on Outage	Probability of Outage
0	$q_b^2 \cdot q_g^2$
1	$2\, q_b\, q_g\, (p_b + p_g - p_b\, p_g)$
2	$(p_b + p_g - p_b\, p_g)^2$

Two Unit Generating Station with Header System.



p_b = Boiler forced outage rate

p_g = Turbine-generator forced outage rate

The parallel outage combination of either boilers or turbine-generator are:

No. of Components on Outage	Probability of Boiler Outage	Probability of Turbine Outage
0	q_b^2	q_g^2
1	$2\ p_b\ q_b$	$2\ p_g\ q_g$
2	p_b^2	p_g^2

Combining the boilers and turbine-generators:

No. of Units on Outage	Probability of Outage
0	$q_b^2 \cdot q_g^2$
1	$2\ q_b\ q_g\ (p_g\ q_b + 2\ p_g\ p_b + p_b\ q_g)$
2	$p_b\ p_g\ (p_b\ p_g + 2\ q_b\ p_g + 2\ q_g\ p_b)$ $+ p_b^2\ q_g^2 + p_g^2\ q_b^2$

Typical forced outage rates for a thermal electric generating station are

$$p_g = p_b = 0.01$$

These are average figures but they serve to illustrate the difference in reliability between the two plants. Using these forced outage rates:

No. of Units on Outage	Probability of Outage. Unit Header System	Probability of Outage. Individual Unit System
0	0.96059601	0.96059601
1	0.03920400	0.03900798
2	0.00019999	0.00039601
	1.00000000	1.00000000

The increase in probability of outage of the individual unit system over that of the unit header system does not appear to be very great in the preceding table. A true evaluation of this difference requires the attendant outage probabilities to be combined with the remainder of the system generating facilities and the system load characteristics. If the generators were large compared to other units in the system this difference in reliability could be appreciable. The differences in unit outage rates for the two systems would be further increased if the number of units in the generating station were increased.

Due to the increased costs associated with header systems the present practice appears to be towards the use of individual units in most large thermal electric stations. The difference in system reliability can, however, be computed by application of probability techniques and cost comparisons can be made on an analytical basis.

This form of analysis can be used to evaluate the decrease in reliability when one large transformer is used for two generating units as opposed to each generating unit having a transformer.

An identical situation to the two unit thermal plant previously elaborated on is the case of two parallel transmission lines with an intermediate switching station. The switching station plays the same role as the boiler headers in the thermal electric plant. In the case of transmission lines, however, the forced outage rates are not quite as simple to determine as those for generating facilities. A considerable amount of statistical data on lines over similar terrain with basically identical design is required to arrive at a stable forced outage rate.

In all cases in which probability techniques are applied the forced outage rate "p" is the basic quantity on which the entire prediction of future performance depends. It is therefore essential that the forced outage rate "p" be stable and corrected for aging or other causes.

The effect of an adequate preventative maintenance program is reflected in the forced outage rates of generating facilities and though figures are extremely difficult to obtain, it should be possible to evaluate increased maintenance costs with attendant increased station and hence increased system reliability.

OUTAGE PROBABILITY VALUES FOR NON-IDENTICAL UNITS

For identical units, which have equal generating capacities and forced outages rates, the probabilities of having various combinations of units available or unavailable is relatively simple to compute using the Binomial Expansion. Tables are available for this purpose.[4]

For units which are not identical, the Binomial Expansion cannot be used. The method of approach in this case is to commence with zero outage and investigate each possible outage of a combination of units and compute the probability.

A general case for a three unit system would be as follows:

Assume units 1, 2 and 3 have outage probabilities of p_1, p_2, p_3 respectively.

Probability of units 1, 2 & 3 in service = $q_1 \cdot q_2 \cdot q_3$

Probability of units 1 & 2 in service & 3 out = $q_1\ q_2\ p_3$
Probability of units 1 & 3 in service & 2 out = $q_1\ q_3\ p_2$
Probability of units 2 & 3 in service & 1 out = $q_2\ q_3\ p_1$

Probability of units 1 & 2 out of service & 3 in = $p_1\ p_2\ q_3$
Probability of units 1 & 3 out of service & 2 in = $p_1\ p_3\ q_2$
Probability of units 2 & 3 out of service & 1 in = $p_2\ p_3\ q_1$

Probability of units 1, 2 & 3 out of service = $p_1\ p_2\ p_3$

Total probability is:

$$q_1\ q_2\ q_3 + (q_1\ q_2\ p_3 + q_1\ q_3\ p_2 + q_2\ q_3\ p_1) + (p_1\ p_2\ q_3 + p_1\ p_3\ q_2 + p_2\ p_3\ q_1) + p_1\ p_2\ p_3 = 1.0$$

For three identical units this would be:

$$q^3 + 3\ q^2\ p + 3\ q\ p^2 + p^3 = 1.0$$

In combining units with different capacities the quantity of capacity on outage rather than the number of units on outage is required.

Assume a three 10 MW generator plant with identical units is to be combined with a plant having a single 20 MW unit.

For the 3 unit plant where "p" and "q" are the outage and availability rates respectively:

Capacity Out of Service	Probability of Outage
0	q^3
10	$3 q^2 p$
20	$3 p^2 q$
30	p^3

For the single unit where "x" and "y" are the outages and availability rates respectively:

Capacity Out of Service	Probability of Outage
0	y
20	x

Combining these to give a 50 MW system:

Capacity Out of Service	Probability of Outage
0	$q^3 y$
10	$3 q^2 p y$
20	$q^3 x + 3 q p^2 y$
30	$y p^3 + 3 q^2 p x$
40	$3 q p^2 x$
50	$p^3 x$

It can clearly be seen that this can get quite complicated if large numbers of units with different capacities are to be combined. A simpler approach and one which is more suited to digital computer application is to determine the cumulative probability of an outage equal to or exceeding a certain capacity. For the same 50 MW system previously considered this would be as follows.

For the three identical 10 MW units.

Capacity Out of Service	Probability of Capacity Outage Equal to or Exceeding Amount Shown
0	$q^3 + 3\ q^2\ p + 3\ q\ p^2 + p^3 = 1.0$
10	$3\ q^2\ p + 3\ q\ p^2 + p^3$
20	$3\ q\ p^2 + p^3$
30	p^3

This is combined in two stages with the 20 MW unit. The first stage requires the probability of availability "y" of the 20 MW unit.

Capacity Out of Service	Probability of Capacity Outage Equal to or Exceeding Amount Shown
0	$q^3\ y + 3\ q^2\ p\ y + 3\ q\ p^2\ y + p^3\ y$
10	$3\ q^2\ p\ y + 3\ q\ p^2\ y + p^3\ y$
20	$3\ q\ p^2\ y + p^3\ y$
30	$p^3\ y$
40	0
50	0

The second stage uses the probability of outage "x" of the 20 MW unit.

Capacity Out of Service	Probability of Capacity Outage Equal to or Exceeding Amount Shown
0 + 20 = 20	$q^3x + 3\ q^2\ p\ x + 3\ q\ p^2\ x + p^3\ x$
10 + 20 = 30	$3\ q^2\ p\ x + 3\ q\ p^2\ x + p3\ x$
20 + 20 = 40	$3\ q\ p^2\ x + p^3\ x$
30 + 20 = 50	$p^3\ x$

Combining the two previous tables by adding the outage probabilities of corresponding amounts of capacity.

Capacity Out of Service	Probability of Capacity Outage Equal to or Exceeding Amount Shown
0	$q^3y + 3q^2py + 3qp^2y + p^3y + q^3x + 3q^2px + 3qp^2x + p^3x = 1.0$
10	$3q^2py + 3qp^2y + p^3y + q^3x + 3q^2px + 3qp^2x + p^3x$
20	$3qp^2y + p^3y + q^3x + 3q^2px + 3qp^2x + p^3x$
30	$p^3y + 3q^2px + 3qp^2x + p^3x$
40	$3qp^2x + p^3x$
50	p^3x

The individual outage probabilities for the various capacity levels can be found by subtracting the cumulative probability value from the value above it in the previous table. This procedure may look more complicated but it is one which follows a regular sequence and reduces the possibility of error.

The outage probability values associated with the installed or planned generating capacity must now be combined with the known or forecast load characteristics of the system in order to determine the level of system reliability associated with a known or predicted system load level.

CHAPTER III

LOAD FORECASTING

GENERAL CONSIDERATIONS

There are numerous types of load forecasts made in a modern power system. Basically, the two components required in most forecasts are a knowledge of the peak load and the total energy requirements in a future time period. This time period may be a day, week, month, year or several years for system operating personnel who are concerned with economic operation, hydraulic scheduling, maintenance requirements and other system problems. For system planning personnel, load forecasts are usually on a yearly basis and are made for many years in the future. Long range forecasting is quite a controversial subject and many people claim that forecasting beyond a relatively short time period such as five to seven years is not practical. The comparison of alternate generating facilities using present worth techniques, however, requires load forecasts to be made for future time periods considerably in excess of seven years. The standard approach to this problem appears to be the development of trend lines with attendent confidence limits making possible upper and lower load boundaries for the future periods considered. Absolute reliance upon trend line techniques can, however, result in extremely inaccurate predictions of future load levels and these predictions should be recognized as merely informed guesses of future loads. A concise description of the application of statistical methods to load forecasting problems is given by M. Z. Tarnawecky in his M.Sc. thesis presented to the University of Manitoba in 1960.[5]

The approach proposed here is that detailed load forecasting should be confined to a future time period of seven years. Trend lines are then determined by using corresponding loads for the previous seven years. Each year new trend lines are established using the values from the previous seven years. This information coupled with any further known data on known or expected system changes should provide forecasts which are reasonably accurate. The words, reasonably accurate, imply that system load levels will not create any contingency that cannot be handled by adequate generating capacity planning. Nearly all generating facilities can be planned, designed and constructed in five to seven years.

Limiting the time period of record to seven years will allow fluctuation in load due to economic cycling to be smoothed out and yet allow any effects of changing social and technical conditions in the later years to influence the trend line. For extremely advanced system planning, trend lines can be used, but upper and lower boundaries given by tight confidence limits diverge quite widely. Extremely advanced planning of system generating facilities can be co-ordinated with attainment of various system load levels coupled with the probable year or years of expectancy. This approach can also be used for advanced transmission planning. Detailed forecasting need only cover two or three years in this case as the time required to design and construct reasonably large transmission facilities is considerably shorter than that required for generation sources of similar capacity.

DETAILED LOAD FORECASTING

In preparing a detailed load forecast it should be realized that in nearly all cases the values used and forecast for energy and peak load requirements are the generated values. These then differ from the actual load values by a transmission loss component. This is extremely difficult to evaluate in the case of energy generated over a particular time period but can be determined quite simply for peak load values. This transmission loss component can vary quite remarkably with the generating schedule used to meet the peak. Any major transmission or generation outage at the time of the peak can cause the peak to be considerably higher than it may have been with all facilities available. This factor should be recognized when using peak values in trend line forecasting.

System load and energy requirements vary considerably with the weather. A mild winter in a location such as Manitoba can result in energy requirements considerably below forecast values. The system peak load in Manitoba usually occurs at a time when the wind chill temperature is lower than 50°F below zero.

Correction components for weather and transmission losses could be subtracted from actual peak and energy values and modified figures used in detailed load forecasting. These variables can then be re-assigned to the forecast load levels based upon information either statistically evaluated such as weather data or planned such as knowledge of proposed transmission facilities.

With a detailed forecast period of approximately seven years any sound forecasting approach tempered with practical application should result in forecast values which do not differ appreciably from the actual and certainly not in sufficient error to cause insufficient installed generating facilities.

LOAD CHARACTERISTICS REQUIRED IN EVALUATING RELIABILITY

A knowledge of two system load characteristics is required in the evaluation of system reliability by probability techniques. The first characteristic is known as a "Load Duration Curve", the second as a "Daily Peak Load Variation Curve".

Load Duration Curve. This characteristic is defined as "a curve showing the total time within a specified period during which the load equalled or exceeded the power value shown".[6] This is a form of cumulative frequency distribution curve in which the area under the curve represents the total load energy for the time period considered.

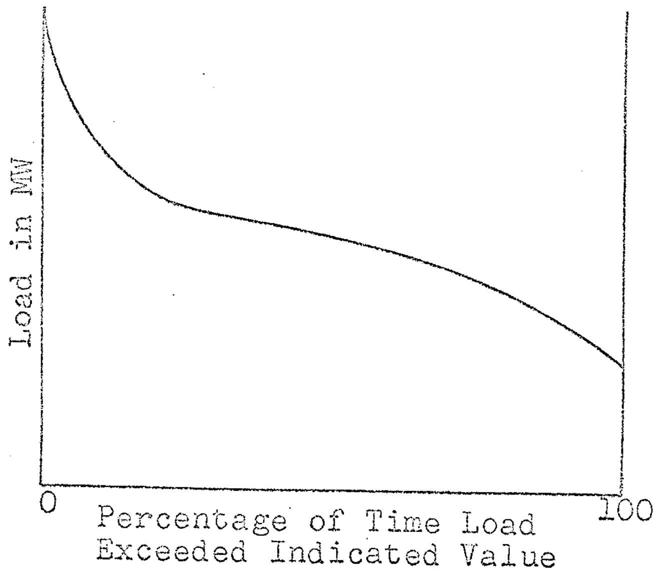


Figure 2. Typical Load Duration Curve.

These curves can be drawn for any time period, though they are usually created on a monthly and yearly basis. If the ordinate values are normalized by expressing each value as a percentage of the peak value, successive curves for the same time period can be compared. Future curves can then be forecast using a normalized curve and an energy value obtained by trend line techniques. It is interesting to note that in the Combined Southern Manitoba System, normalized Load Duration Curves for successive years are quite similar and can be used for predictions of non-hydraulic energy requirements based on forecast river flow conditions.

Daily Peak Load Variation Curve. This curve is again a form of cumulative frequency distribution curve and can be plotted for monthly, yearly or other required time periods. The ordinate values are the daily peak load values with the abscissa indicating the number of days that the peak load exceeded the indicated amount.

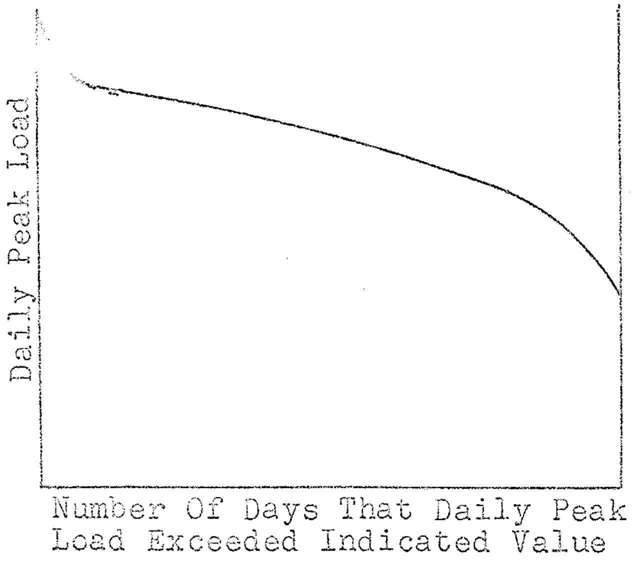


Figure 3. Typical Daily Peak Load Variation Curve.

This curve can be normalized in a similar manner to the Load Duration Curve. Although it has the same form as the Load Duration Curve, the area under the curve has no physical significance as the ordinates are the single peak load value occurring during the day.

UNCERTAINTIES IN LOAD FORECASTING

Usually departures in actual loads from forecast values are known as load forecasting errors. This is generally an erroneous conclusion as there exists considerable uncertainty in forecasting future system load levels which should not be confused with errors in computation. Attempts have been made in several papers to attach a probability value to the possible deviation in actual load from the forecast value.[1,8] In order to do this the forecast value is assumed to have an equal chance of being exceeded and of not being reached.

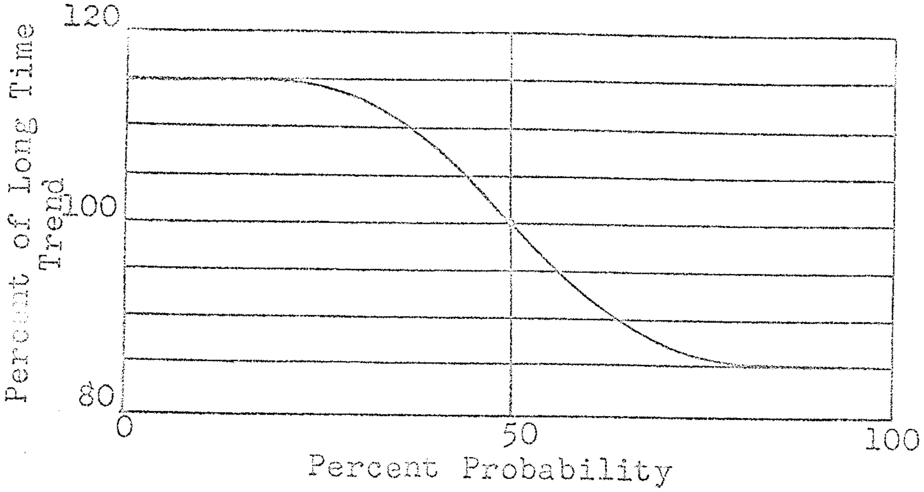


Figure 4. Typical Probable Load Forecast Accuracy Curve.

The inclusion of a probability of load forecast deviation in reserve generating capacity studies tends to produce results which indicate a larger installed reserve is required to serve a future uncertain peak load than would be required to serve the same nominal peak. The increased effort required to incorporate this concept is considerable and if knowingly omitted will not affect the value of the results. It is often used, however, in detailed simulation studies which have several random variables as it allows the forecast load values to be considered as known quantities.

COMMENTS

It is not intended to elaborate further in this thesis upon the techniques used in load forecasting. It should be realized, however, that reasonable forecasts can be produced without requiring extremely detailed studies and that attempts to improve upon these usually involve taking into account factors which require considerable effort to evaluate. The attempts at increased accuracy must be tempered with practical considerations as minor refinements can be completely overshadowed by economic or social changes occurring within the forecast period.

CHAPTER IV

EVALUATION OF GENERATING CAPACITY RELIABILITY

AVAILABLE METHODS

Having obtained the probabilities of having various combinations of generating capacity unavailable, the remaining problem is to combine these probabilities with the system load. This then gives an indication of the reliability of the particular system or a measure of its ability to meet its load requirements.

There are three established methods available for achieving this correlation between the probability of having a certain amount of generation unavailable and the system load level.[8] These methods are known as follows.

1. Loss of Load Probability
2. Loss of Energy Probability
3. Interval between Outages

LOSS OF LOAD PROBABILITY

The results of this method are given in terms of the probable number of days per year that the system load may be expected to exceed the available generating capacity. This risk is also sometimes expressed as number of years per day which is merely the reciprocal of the number of days per year. Expressing the risk as the number of days per year is a figure which has the same significance as saying the probability of throwing a two on any throw of two dice is 1/36 or 0.026 which is 2.6%. Days per year is a similar fraction, as 1 day per year is 1/365 or 1/x where "x" may represent the number of weekdays in a year. Several authors have considered the weekends as time periods in which a loss of generating capacity would not produce a curtailment in system loads. The result of this method is therefore a figure of probability of the existence of a specified condition and when considered in this light is an extremely useful result.

To obtain this probability figure, the probability of capacity outage is combined with the "Daily Peak Load Variation Curve".

Prior to combining the outage probabilities and the load characteristic it must be realised that there exists a difference between the terms "outage" and "loss of load". "Outage" indicates a loss of generation which may or may not result in a loss of load depending upon the amount of available generating capacity and the system load level. A loss of load will occur only when the capability of the generating capacity remaining in service is exceeded by the system load level.

A typical system may have the following relationship.

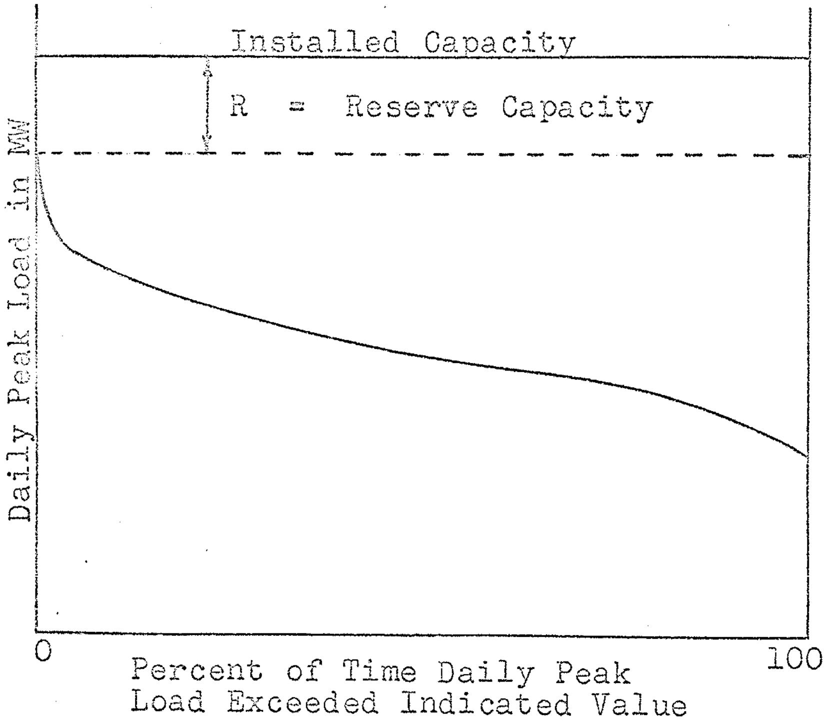


Figure 5. Relationship Between Peak Load and Installed Capacity in a Typical System.

A particular capacity outage will contribute to the system loss of load probability by an amount equal to the product of the probability of existence of the particular outage and the number of days per year that loss of load would occur if such a capacity outage were to exist. It can clearly be seen in the above figure that any capacity outage less than the quantity "R" would not contribute to the system probability of loss of load. Outages of capacity in excess of "R" would result in varying numbers of days during which loss of load could occur. This can be expressed mathematically in a very simple manner.

If: O_k = magnitude of the capacity outage

P_k = probability of an outage of capacity equal to O_k

t_k = number of days per year that an outage of magnitude O_k would cause a loss of load

the contribution to the system loss of load probability made by capacity outage O_k is P_k t_k days per year.

The total system loss of load probability is therefore

$$\sum_{k=1}^{n} P_k \, t_k \text{ days per year}$$

where "n" indicates the "n^{th}" entry in the probability table, which is the largest amount of capacity outage that can occur.

The "Daily Peak Load Variation Curve" can be obtained on a yearly, monthly or even weekly basis. The simplest application is the use of the curve on a yearly basis. If no generator maintenance were done then this approach would be correct as the number of units available to meet the load requirements would be constant throughout the year. This excludes those on forced outage of course and the probabilities of this occurrence are given in one table applicable for the year.

An allowance for the withdrawal of units from service can be made by determining a monthly component of the system loss of load probability. This would require a different table of capacity outage probabilities for each month of the year depending upon available generating capacity.

Applying the same technique as for the yearly system loss of load probability, a monthly figure is obtained.

$$\text{i.e.} \quad \sum_{1}^{n} P_k t_k \text{ days per month}$$

The yearly figure is then the sum of the monthly figures. In the case of a system in which the summer load levels are considerably below those of the winter and all scheduled maintenance is performed during these summer months the system loss of load probability contribution due to these light load periods may be negligible. In this case the yearly "Daily Peak Load Variation Curve" can be used with negligible error. If, however, the maintenance requirements of a system are scheduled at times of reasonably high system load, it is possible to have a lower system reliability or higher probability of loss of load at this load level than at the system peak period when all generating capacity is available. This approach can be used to evaluate the restrictions to place upon a maintenance program due to its effect on system reliability.

Due to the inherent uncertainties in load forecasting it is impossible to state the load level which will exist at a particular time in the future. If the probable deviations from the system forecast load level can be evaluated then these deviations can be included. This complicates the required computations to a considerable extent and it is doubtful for most studies if the resulting quantities are worth the increase in effort required.

Omitting the uncertainties in load forecasting from the computations provides a relatively simple means of obtaining a graph giving the risk of loss of load or the system loss of load probability for different load levels.

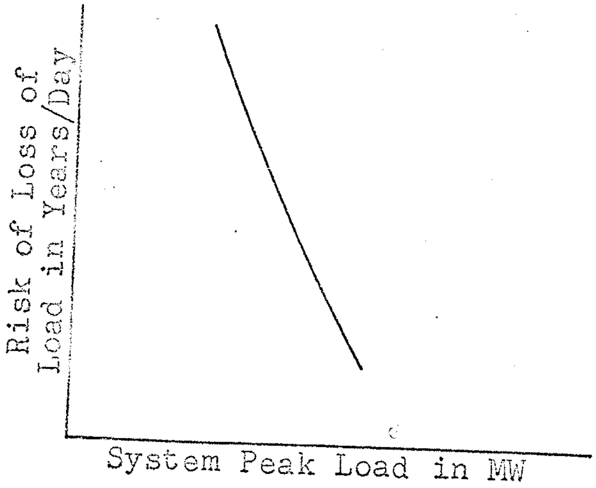


Figure 6. Typical Curve Relating Risk of Loss of Load and System Peak Load.

To this graph, maximum and minimum forecast load levels can be applied for future time periods and the risk immediately seen. This is considerably simpler and generally of more value than applying an adjustment to the compensating procedure to account for uncertainties in load forecasting.

This method as stated previously expresses system reliability as a probability of the existance of a specified condition and nothing more. Each occurrence of daily peak load in excess of available capacity is given equal weight regardless of the amount of deficiency in capacity.

LOSS OF ENERGY PROBABILITY

The results of this method are given in terms of the probable ratio of load energy curtailed due to deficiencies in the generating capacity available, to the total load energy required to serve the requirements of the system. For a given load duration curve this ratio is independent of the time period considered which is usually a month or a year. The ratio is generally an extremely small figure less than one and the usual means of expressing this energy index of reliability is to subtract this quantity from unity and thus obtain the probable ratio of load energy that will be supplied to the total load energy required by the system. This is known as the "Energy Index of Reliability".

The probabilities of having varying amounts of capacity unavailable are combined with the system load by means of the Load Duration Curve.

Any outage of generating capacity exceeding the reserve will result in a curtailment of system load energy.

O_k = magnitude of the Capacity Outage

P_k = probability of a Capacity Outage equal to O_k

A_k = energy curtailed by a Capacity Outage equal to O_k

This energy curtailment is given by the shaded area in figure 7.

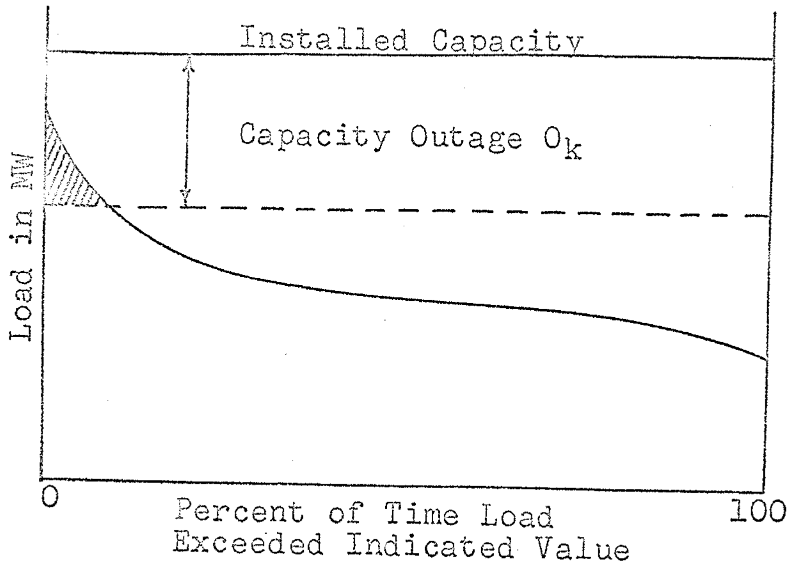


Figure 7. Typical Curve of Energy Curtailed Due to Generating Capacity Deficiency.

The probable energy curtailed is then $A_k P_k$. The sum of these products is the total probable energy curtailment "E" where

$$E = \sum A_k P_k$$

This can then be normalized by utilizing the total energy under the Load Duration Curve designated as "A"

$$E_{p.u.} = \frac{\sum A_k P_k}{A}$$

The figure "E" represents the ratio of the probable load energy curtailed due to deficiencies in available generating capacity to the total load energy required to serve the system demand. The Energy Index of Reliability EIR is then

$$EIR = 1 - E_{p.u.}$$

As in the previous method, "Loss of Load Probability", the available generating capacity is not constant over a one year period due to maintenance requirements. The probable energy curtailed can then be determined on a monthly basis, using monthly load duration curves and capacity outage probabilities for the available generation during the month. The sum of these monthly values would represent the probable yearly energy curtailed due to deficiencies in available generating capacity. The ratio of this value to the yearly system energy requirement is then the per unit value of "E".

The uncertainties of load forecasting can be taken into account in a similar manner as for the previous method. The Energy Index of Reliability can be plotted against peak load level as shown in figure 8.

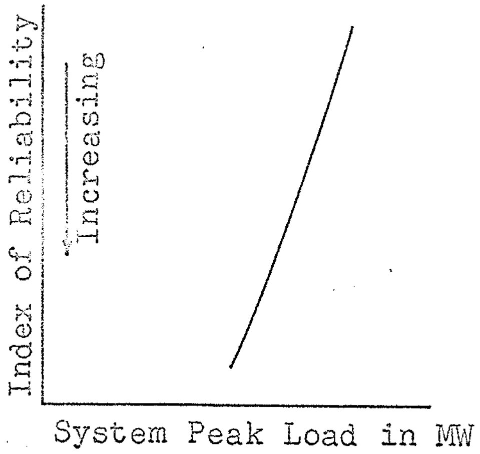


Figure 8. Typical Curve Relating Index of Reliability and System Peak Load.

The uncertainties of load forecasting can be included in both loss of load and loss of energy approaches and a curve similar to the one preceding produced.

INTERVAL BETWEEN OUTAGES

This method gauges the reliability of a system in regard to the generating capacity in terms of average intervals between outages and the corresponding average outage duration. The "interval" and "duration" are probability statistics in the same terms as the results of the Loss of Load approach, i.e. in days per year. The average duration of outage divided by the average interval between the outages is the probability of finding the specified outage condition in existence at any particular time. An example of this is the probability of an outage having an average duration of four days occurring at average intervals of four years. This corresponds to the probability that the same outage would occur at the rate of one day per year when considered in the same manner as the "Loss of Load" approach. In the "Interval Between Outages" approach the parameters "interval" and "duration" are related to the outage capacity equal to or greater than some given amount which may be more or less than the difference between the installed system capacity and the forecast system peak load.

"The concept of duration and interval of a given outage condition adds a physical significance to this approach which is lacking in the other two methods."[8] From the view of flexibility in approach and use of load conditions both previous methods are more suitable than the Interval between Outages approach. In view of this, this technique will not be discussed here further.

The application of each of these methods to a system will not of course produce identical answers when applied to the same problem as each method places its emphasis on a different system characteristic. That the applications of any of these techniques is preferable to no application at all was stated in a recent AIEE Committee Report.[8] It states that "No one answer is right and no one answer is wrong; and any of these methods should lead to system planning that is better than can be expected where decisions are made arbitrary or by rule of thumb".

INTERCONNECTION EFFECTS

Basic rule of thumb techniques when applied to the determinations of reserve capacity requirements have been in the form of percentage reserves, equivalence to largest unit in the system and equivalence to largest unit plus a percentage of the system load. A common figure used by management and unfortunately by engineering personnel as a standard criterion of adequate reserve capacity requirements is a reserve margin of 12 percent. This figure implies that the load should not exceed 89.3% of the installed capacity prior to the installation of additional capacity.* That this criterion has been adequate in the past is probably evident by the fact that adherence to it has resulted in no load curtailment due to inadequate generating capacity margins. The use of a percentage reserve margin for discussion and approximation is advantageous in that it is easily understood and applied. That this percentage reserve margin should be inflexible, especially in view of the rapidly changing technology associated with generation patterns and system interconnections is definitely not desirable. The percentage reserve margin should be computed by probability techniques and be merely a simplified yardstick for ready application. A desirable Energy Index of Reliability or Loss of Load Probability should be determined and future installations evaluated according to these criteria.

The percentage reserve method and other rule of thumb techniques are even more inadequate in evaluating the advantages of system interconnections. The problem encountered in attempting to allocate benefits, savings and costs from partial integrations of system generating facilities can only be approached by probability techniques.

$$^{*}\frac{\text{Installed Capacity} - \text{Peak Load}}{\text{Peak Load}} \times 100 = 12\%$$

It is a recognized fact that the interconnection of two or more generating systems always reduces the amount of capacity required to meet the respective load levels as compared to that amount which would be required without the interconnection. The amount of such a reduction may be large or small depending upon the inter-relation of the various characteristics of the individual systems and the level of reliability desired. The installation of the transmission facilities that are required in such an interconnection may or may not be justified. This fact can be determined only by a proper economic comparison of the alternate installations required if the interconnection were not made.

In determining the increase in load carrying capability of a group of systems upon integration, as opposed to the sum of the load carrying capabilities of the individual systems, several factors must be considered. For example, will the resulting system function as a one company system in which each fully shares the difficulties of the group or will any company assist another only as far as it is able without sharing in the difficulties? These conditions must be known in order to arrive at a true comparison of economic installations.

In applying both the "Energy Index of Reliability" and "Loss of Load Probability" approaches to this problem the diversity of loads in the individual systems can be taken into account and "Daily Peak Load Curves" and "Load Duration Curves" obtained for the combined systems. For preliminary work, however, the load characteristics can be determined without complete load integration and at a considerable reduction of the work involved. The approach is then relatively simple. The individual systems are evaluated, followed by the integrated system and the differences in reliability levels compared.

No attempt will be made here to discuss the possible basis upon which allocation of resultant capacity benefits can or should be made. One concept which appears to be quite reasonable is known as "the mutual benefits method of allocation" and is based upon benefits mutually contributed by the systems concerned.[9]

GENERAL COMMENTS

The application of any one of the three reliability evaluation methods previously discussed is definitely preferable to continued application of rule of thumb techniques to the timing of generation additions or establishing reserve capacity policies. Consistent use of any of the methods would provide basically the same schedule for capacity additions.

Unfortunately numerical analysis alone cannot establish just what is a satisfactory level of system generating capacity reliability or establish a fixed value for the index of system reliability. To determine these factors requires a measure of informed judgement. Following this, however, application of probability techniques will assist in maintaining this reliability level at minimum cost under widely changing system conditions.

CHAPTER V

A CONCEPT OF TRANSMISSION RELIABILITY

GENERAL CONSIDERATIONS

The general acceptance of probability techniques to power system problems has been quite slow. Only in the field of generating capacity requirements has their application been considerable and unfortunately this is far from universal. In other fields, progress has been slow or entirely non-existant, an exception being the subject of secondary networks where several interesting papers have been published.[7, 47]

The following concept of transmission reliability stems from the basic reliability principles used in generation planning and to the author's knowledge has not been proposed by anyone else.

QUALITY OF SERVICE

In order to put a figure of reliability on a particular terminal or sub-transmission station there must exist a definition of just what constitutes a breach of continuity at that station. If due to line outages a low voltage condition exists at the station this is not an actual breach of continuity even though the voltage level may be considerably below a desired minimum.

It is proposed, that voltage limits be defined at the substations throughout the system and that any departures outside these limits constitute a breach of continuity. This may seem somewhat harsh in that customers can be served at reduced voltage without creating undue hardship. This is true, but as in the case of generating facilities previously elaborated, low voltage operation is not a satisfactory design criterion but a last resort.

Transients caused by switching, loss of load or other system disturbances which cause departures from the acceptable voltage levels should not be classed as disruptions in continuity.

A clear difference must exist between quality of service and continuity of service and any departure from the requirements for quality of service constitutes a breach of continuity of that service.

DESIGN CRITERIA

In constructing an additional infeed to an area the reason often given is increased transmission reliability. This in most cases is not the true reason. It is obvious that the addition of a transmission line to supply a station will increase the reliability of that station. Any duplication of facilities will do this to some extent. To build a line on the basis of reliability alone implies extremely high outage rates for the remaining lines supplying the station.

The criterion used should be as follows.

(a) If with all lines in service, voltage levels fall outside the defined limits then new transmission facilities are required to meet quality of service standards, this also applies to reactive or synchronous compensation facilities at that station.

(b) With the various possible combinations of lines out of service, establish an index of reliability for the station. If this is below the design figure then additional transmission is required to meet reliability standards.

A station could still meet quality of service standards for several years of load growth but not meet reliability standards for the present if a minimum number of transmission lines were installed having high outage rates.

ESTABLISHING AN INDEX OF RELIABILITY

This requires the creation of a Load Duration Curve for the particular station and a knowledge of the load level at that station for which any outage or combination of outages of transmission facilities would cause the load voltage to lie outside the specified zone. Determination of these load levels could be done on an A.C. Network Calculator or digital computer by performing a regular load flow study of an area or the entire system at various load levels and for various line outages. The problem of backfeeding along lower voltage networks can be eliminated if it is assumed that load points having adequate voltages would not allow their voltages to drop to unacceptable levels in an attempt to maintain an unacceptable level at the station under study.

This assumes that loads are fed radially from the stations under study with extenuating circumstances in the case of stations with large low voltage transmission ties.

The forced outage rates of the transmission lines can be determined in a similar manner to the rates for generating facilities. Using these and the Load Duration Curve the probable amount of energy which might be curtailed can be determined and the index of reliability evaluated.

The forced outage rates of transmission facilities vary considerably with the time of year. The index of reliability could be at its lowest on a monthly basis during the sleet season when the load may or may not be at its highest. This would depend on the power system considered. For this condition a monthly or similar time period index of reliability would be more suitable.

COMMENTS

As most transmission lines have very low forced outage rates, lines are seldom built for reliability alone. They are built in nearly all cases to maintain the quality of service in that area for the actual load level and forecast load levels of some specified period. Addition or duplication of transmission facilities increases the station reliability but reliability is seldom the reason for addition of these facilities. The approach postulated here will allow a figure of reliability to be determined for transmission facilities which was previously not possible.

The principle postulate is that a breach of service quality constitutes a breach of service continuity and is the basis of this concept. This idea can be modified slightly by selecting various voltage zones, such as favourable, tolerable and extreme with attendent increases in the effort required to arrive at the indexes of reliability.[10]

Regardless of the voltage definition used, this method provides an analytical basis for evaluating the reliability of terminal and sub-transmission stations which was not previously available.

CHAPTER VI

A THEORETICAL PROBLEM

THE PROBLEM

The system reliability levels of four hydro-electric systems are to be evaluated. Each system has the same load characteristics and total installed capacity of 200 MW. The number of units and their capacity in each system is different. To each system is added one, two and finally three 50 megawatt units. These units are added individually and with forced outage rates of both hydraulic and thermal-electric generating units. The reliability levels of each initial system with a firm capacity purchase of 25 MW is also to be considered. Two of the original systems are interconnected and the effect on system reliability considered.

THEORETICAL SYSTEMS

The basic systems considered are as follows.

TABLE I

THEORETICAL SYSTEMS

System	No. of Units	Unit Capacity (MW)	Forced Outage Rate
A	20	10	0.01
B	10	20	0.01
C	5	40	0.01
D	4	50	0.01

A forced outage rate of 0.01 is representative of a hydraulic generating unit.

To these systems are to be added 150 MW of generating capacity, either hydraulic or thermal-electric units in three stages of 50 MW per stage. A forced outage rate of 0.02 is assumed for the thermal-electric units.

TABLE II

THEORETICAL SYSTEM DATA

System Number	Total Generating Capacity (MW)	Forced Outage Rates of the 50 MW Units Added
1A-1	200	Original System
2A-1	250	0.01
3A-1	300	0.01
4A-1	350	0.01
2A-2	250	0.02
3A-2	300	0.02
4A-2	350	0.02
1B-1	200	Original System
2B-1	250	0.01
3B-1	300	0.01
4B-1	350	0.01
2B-2	250	0.02
3B-2	300	0.02
4B-2	350	0.02
1C-1	200	Original System
2C-1	250	0.01
3C-1	300	0.01
4C-1	350	0.01
2C-2	250	0.02
3C-2	300	0.02
4C-2	350	0.02
1D-1	200	Original System
2D-1	250	0.01
3D-1	300	0.01
4D-1	350	0.01
2D-2	250	0.02
3D-2	300	0.02
4D-2	350	0.02

System "A" and "D" are to be interconnected and to each are added three 50 MW hydraulic generating units.

TABLE III

THEORETICAL INTERCONNECTED SYSTEM DATA

System Number	Total Generating Capacity (MW)	Forced Outage Rates of the 50 MW Units
1AD	400	Original Systems
2AD	450	0.01
3AD	500	0.01
4AD	550	0.01
5AD	600	0.01
6AD	650	0.01
7AD	700	0.01

System "A" is expanded to an installed capacity of 700 MW by adding ten 50 MW hydraulic generating units with forced outage rates of 0.01. This is identical to having one system with the installed capacity shown in Table III.

SYSTEM LOAD CHARACTERISTICS

All of the systems studied are assumed to have identical load characteristics. Both "Load Duration Curves" and "Daily Peak Load Variation Curves" are assumed to be represented by a straight line from the 100% to the 40% load level. In both cases the time period is considered to be one year consisting of three hundred and sixty-five days.

This assumes that there are no capacity reductions due to maintenance requirements.

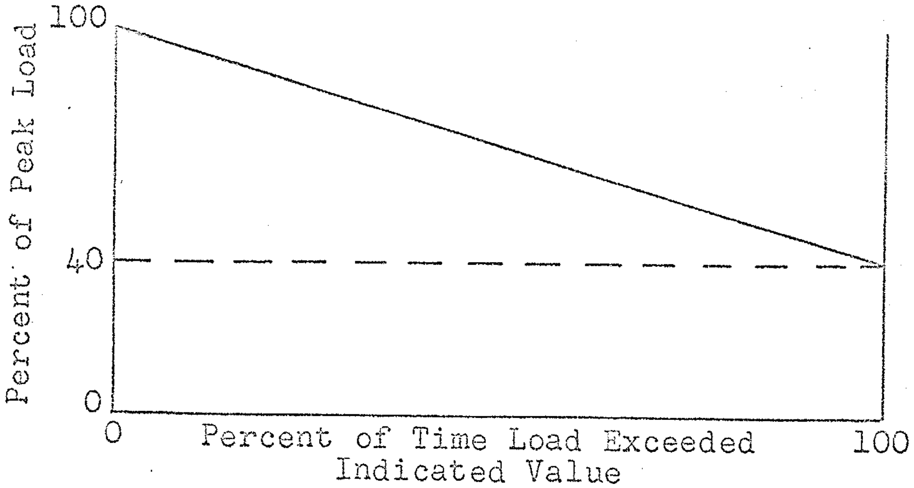


Figure 9. Load Duration and Daily Peak Load Variation Curve Used For Theoretical Systems.

"RULE OF THUMB" APPROACH TO ADEQUATE RELIABILITY

The criterion of adequate reliability used by many utilities is that a reserve margin of 12% be maintained. This criterion is also used in the Combined Southern Manitoba System. Based upon this, the largest load which could be supplied by each system is as follows.

TABLE IV

THEORETICAL SYSTEM PEAK LOADS BY PERCENTAGE RESERVE CRITERION

System	Installed Generating Capacity (MW)	Peak Load (MW)
A,B,C,D	200	178.5
A,B,C,D	250	223
A,B,C,D	300	268
A,B,C,D	350	312

"PROBABILITY METHODS" APPROACH TO ADEQUATE RELIABILITY

For each of the 28 systems shown in Table II on page 54 the probability of Loss of Load in years per day and the Index of Reliability for various load levels are shown in Appendix A. The risk corresponding to the various load levels is plotted on semi-logerithmic paper and also shown in Appendix A. These values were obtained using two relatively simple digital computer programs on the IBM 1620 digital computer.

The relative adequacy of a 12% reserve capacity margin for each of the original systems is as follows.

TABLE V

RELIABILITY OF INDIVIDUAL THEORETICAL SYSTEMS

System	Peak Load (MW)	Risk of Loss of Load (Years/Day)	Index of Reliability
A	178.5	44	0.9999983
B	178.5	3.6	0.9999977
C	178.5	0.33	0.999242
D	178.5	0.26	0.998676

It can clearly be seen that in the systems considered as the unit size increases the system reliability correspondingly decreases. Systems C and D are not practical systems but they do serve to illustrate the inadequacy of an inflexible reserve capacity criterion such as that of a fixed percentage reserve.

EFFECT OF UNIT SIZE

If a constant risk level is selected, the effect on a system of adding units can be clearly seen. The actual increase in load carrying capability can be evaluated and the capacity penalty of a large unit determined.

Using a "Risk of Loss of Load" of 10 Years/Day the effects of adding 50 MW units to systems A, B, C, and D are as follows:

TABLE VI

ALLOWABLE PEAK LOAD VALUES UNDER ASSIGNED RISK OF LOSS OF LOAD FOR THE THEORETICAL SYSTEMS

	System Peak Load in MW			
Generation Pattern	System A	System B	System C	System D
O.S. (Original System)	184	168	144	138
O.S.+ 50 MW Hydro	202	205	186	179
O.S.+ 100 MW Hydro	250	248	232	224
O.S.+ 150 MW Hydro	298	291	279	271
O.S.+ 50 MW Thermal	199	194	180	170
O.S.+ 100 MW Thermal	246	238	222	213
O.S.+ 150 MW Thermal	284	281	268	260

The penalty attached to a large unit can be seen by expressing the increase in load carrying capability of the system as a percentage of the total capacity of the units added.

TABLE VII

PERCENTAGE OF UNITS ADDED AVAILABLE TO THE SYSTEM

Generation Pattern	Percent Increase System A	System B	System C	System D
O.S. + 50 MW Hydro	36	74	84	82
O.S. + 100 MW Hydro	66	80	88	86
O.S. + 150 MW Hydro	76	82	90	89
O.S. + 50 MW Thermal	30	52	72	64
O.S. + 100 MW Thermal	62	70	78	75
O.S. + 150 MW Thermal	67	75	83	81

Similar statistics can be obtained using the "Index of Reliability" approach.

Assuming an Index of Reliability of 0.99999

TABLE VIII

ALLOWABLE PEAK LOAD VALUES UNDER ASSIGNED INDEX OF RELIABILITY FOR THE THEORETICAL SYSTEMS

Generation Pattern	System Peak Load in MW System A	System B	System C	System D
O.S. (Original System)	183	169	131	113
O.S. + 50 MW Hydro	201	197	177	164
O.S. + 100 MW Hydro	246	242	224	214
O.S. + 150 MW Hydro	292	286	274	265
O.S. + 50 MW Thermal	196	191	173	161
O.S. + 100 MW Thermal	230	228	217	210
O.S. + 150 MW Thermal	269	268	263	258

The results of the two methods are not identical as each utilizes a different load characteristic. The "Loss of Load" approach gives equal weight to each occurrence of daily peak load in excess of available capacity, whilst the "Index of Reliability" method weights each occurrence of available capacity less than the load by the percentage of load energy that is interrupted. The results, however, are quite similar and both methods produce the same basic trends when applied to systems with large numbers of machines such as most modern power systems.

FIRM CAPACITY PURCHASES

Using the "Loss of Load" approach the purchase of 25 MW of firm capacity for the original systems is examined. A firm capacity purchase is one which has an infinitesimal probability of being unavailable. Assume a Risk of Loss of Load of 10 years/day.

TABLE IX

INCREASE IN LOAD CARRYING ABILITY WITH A FIRM CAPACITY PURCHASE

	System Peak Load in MW			
Generation Pattern	System A	System B	System C	System D
O.S. (Original System)	184	168	144	138
O.S. + 25 MW Firm	209	196	173	174

It can be seen that a firm capacity purchase can increase the load carrying capability of the system by more than the firm capacity purchased. This, however, is only in systems having a small number of machines of relatively large capacity. In a normal system having a relatively large number of units a firm capacity purchase increases the load carrying capacity of the system by the amount of the firm purchase.

CONTINUOUS ADDITION OF LARGE UNITS TO A SYSTEM

The addition of large units to a system creates increases in reserve capacity requirements which when expressed as a percentage reserve decrease with the addition of more large units. This is shown by adding 50 MW hydraulic units to system "A" which has twenty 10 MW hydraulic units.

TABLE X

VARIATION IN PERCENTAGE RESERVE CRITERION FOR A FIXED RISK OF LOSS OF LOAD WITH THE ADDITION OF LARGE UNITS

Criterion A - Risk of Loss of Load of 10 years/day

Criterion B - Index of Reliability of 0.99999

Installed Capacity (MW)	Peak Load by Criterion A (MW)	Percentage Reserve for Criterion A	Peak Load by Criterion B (MW)	Percentage Reserve for Criterion B
200	184	8.7	183	9.3
250	202	23.8	201	24.4
300	250	20.0	246	22.0
350	298	17.4	292	19.9
400	345	15.9	337	18.7
450	393	14.5	382	17.8
500	439	13.9	428	16.8
550	485	13.4	477	15.3
600	529	13.2	526	14.1
650	575	13.0	573	13.4
700	621	12.8	622	12.5

It can be seen that the percentage reserve required to maintain a constant risk changes with the addition of more large units. The percentage reserve does not, however, continue to decrease as more units are added but approaches a new figure somewhat higher than that required for the original system. The difference between the original and modified percentage values depends upon the relative capacity of the unit additions to the system and the forced outage rates of the new units.

INTERCONNECTION OF SYSTEMS

The effect on capacity requirements of interconnection between two systems can be seen by selecting a constant risk level and comparing the increase in load carrying capacity of the integrated systems to the sum of the load carrying capacities of the individual systems. Systems "A" and "D" are to be integrated and individual 50 MW hydraulic units added.

Assume a Risk of Loss of Load of 10 years/day.

TABLE XI

LOAD CARRYING ABILITY OF INDIVIDUAL AND INTERCONNECTED SYSTEMS

Installed Capacity (MW)	System A Peak Load (MW)	System D Peak Load (MW)
200	184	138
250	202	179
300	250	224
350	298	271

Installed Capacity (MW)	Total Peak Load Individual Systems (MW)	Total Peak Load Interconnected Systems (MW)
400	322	345
450	340 or 363	393
500	381	439
550	429 or 426	485
600	474	529
650	521 or 522	575
700	561	621

Interconnection between systems is also enhanced by the usual diversity which exists between system loads. Although this has not been taken into account in this case, it can be seen from the above values that the integrated system can meet a greater peak load than the sum of the individual peaks with one less 50 MW unit installed than the sum of the individual installed capacities. This in itself represents a considerable advantage to integration.

Interconnection of two or more systems by adequate transmission facilities allows larger units to be added to the pool than could be absorbed by the individual systems. This is partially due to the diversity of outages and loads. The combined load growth of the integrated system may also justify the large increase in installed capacity caused by the addition of large units. The trend to large thermal units with higher efficiencies has been accelerated in

North America by the integration of extremely large systems by high voltage transmission ties.

CONCLUSIONS

The ability of different systems to carry the same peak load magnitude cannot be measured by rule of thumb techniques such as a percentage reserve. Only by the application of probability techniques can comparative reliability levels be determined.

The two approaches used, "Loss of Load" and "Index of Reliability" do not produce exactly similar results and comparison of numerical reliability levels is meaningless. Each method utilizes a different system load characteristic. Consistent application of either method is considerably better than using rule of thumb techniques.

The penalty attached to a single large generating unit addition and the attendant increase in percentage reserve required to maintain the design risk can only be determined by probability techniques. Further addition of relatively large units will reduce the percentage reserve requirement to a stable value slightly higher than that required for the original system. The difference depends on the relative capacity and forced outage rates of the unit additions.

The selection of a risk level cannot be determined by mathematical methods. Human judgement must be used to decide what is and what is not adequate reliability. Probability techniques do, however, provide a sound basis for the comparison of alternate schemes of expansion and the optimum time to implement these schemes once the risk level has been selected. Different risk levels will indicate different peak loads which can be served. In systems having a large number of units the penalty attached to a relatively large unit or units is constant over a wide risk zone.

The value to a system of an adequate transmission link with a second system can not be measured entirely in terms of the economic energy interchange available. Each system gains in reliability by an adequate interconnection. This gain can only be realized by probability techniques.

The systems investigated here have forced outage rates of 0.01 and 0.02, these values being representative of hydraulic and thermal generating units. When investigating the reliability of a particular system, probable variations in future forced outage rates should be studied and the consequences determined.

The load characteristics used were straight line approximations for simplicity of application. The degree of refinement justified for a particular system must be determined on its own merits.

CHAPTER VII

COMBINED SOUTHERN MANITOBA SYSTEM

GENERATING FACILITIES

The generation facilities of the Combined Southern Manitoba System are comprised of sixty generating units having generating capacities as shown in the following table.

TABLE XII

GENERATING FACILITIES IN THE COMBINED SOUTHERN MANITOBA SYSTEM

Present Installed Capacity

Generating Station	Generation Type	No. of Units	Machine Rating (MW) *	Station Total (MW)
Seven Sisters	Hydraulic	6	25	150
Pine Falls	Hydraulic	6	13.5	81
McArthur Falls	Hydraulic	8	7	56
Great Falls	Hydraulic	6	22	132
Slave Falls	Hydraulic	8	8.5	68
Pointe du Bois	Hydraulic	5	3.2)	
		3	4.0)	
		8	5.5)	72
Brandon	Thermal	4	30	120
Selkirk	Thermal	2	60	120
Amy Street	Thermal	2	5)	
		1	15)	
		1	25)	50
			Total Installed Capacity	849

* Available To The System

Future Installed Capacity

Grand Rapids	Hydraulic	3	110	330

ASSUMPTIONS

1. Forced Outage Rates of all hydraulic generating units is 0.008.

2. Forced Outage Rates of all thermal-electric generating units is 0.015.

3. The transmission is adequate and all generation is tied directly to the belt line which has infinitesmal probability of causing deficiencies in capacity.

4. Both "Load Duration Curves" and "Daily Peak Load Variation Curves" are represented on a yearly basis by a straight line from the 100% to 40% load points.

5. The interconnections with Saskatchewan and Ontario are neglected except in the case of the firm capacity purchase of 50 MW from Saskatchewan.

6. The flow conditions at the hydraulic generating stations are sufficiently adequate to cause no capacity or energy restrictions.

PRESENT RELIABILITY CRITERIA

The criterion presently employed by the Combined Southern Manitoba System is a fixed capacity reserve of 12%. Based on this the load carrying ability of the system with and without Grand Rapids is as follows.

TABLE XIII

MAXIMUM PEAK LOADS BY PERCENTAGE RESERVE CRITERION FOR THE COMBINED SOUTHERN MANITOBA SYSTEM

C.S.M.S. - Combined Southern Manitoba System

G.R. - Grand Rapids

F. S.P.C.- Firm Purchase From Saskatchewan Power Corp.

System	Installed Capacity (MW)	Peak Load (MW)
C.S.M.S.	849	758
C.S.M.S. - 1 Unit G.R.	959	856
C.S.M.S. - 2 Units G.R.	1069	954
C.S.M.S. - 3 Units G.R.	1179	1053
C.S.M.S. - 50 MW F. S.P.C.	899	803

RELIABILITY USING PROBABILITY TECHNIQUES

Assuming that a reserve of 12% is adequate for the Combined Southern Manitoba System the corresponding risk levels are as follows.

TABLE XIV

RISK LEVELS FOR A CAPACITY RESERVE OF 12%

Maximum Load Level (MW)	Risk of Loss of Load Years/Day	Index of Reliability
758	46.0	0.9999982

Using these risk levels the load carrying ability of the system with Grand Rapids is as follows.

TABLE XV

MAXIMUM PEAK LOAD AFTER ADDITION OF GRAND RAPIDS UNITS

Criterion A - Risk of Loss of Load

Criterion B - Index of Reliability

System	Installed Capacity (MW)	Peak Load Criterion A (MW)	Peak Load Criterion B (MW)
C.S.M.S.	849	758	758
C.S.M.S. - 1 Unit G.R.	959	832	827
C.S.M.S. - 2 Units G.R.	1069	929	923
C.S.M.S. - 3 Units G.R.	1179	1027	1020
C.S.M.S. - 50 MW F. S.P.C.	899	808	808

Using the peak load values determined at a risk of loss of load of 46.0 years/day.

TABLE XVI

VARIATION IN PERCENTAGE RESERVE WITH ADDITION OF UNITS AT GRAND RAPIDS

Installed Capacity (MW)	Percent Reserve Margin
849	12.0
899	11.2
959	15.3
1069	15.1
1179	14.8

The increase in load carrying capacity of the system with each Grand Rapids unit is as follows.

TABLE XVII

INCREASE IN LOAD CARRYING CAPACITY OF THE SYSTEM WITH UNITS AT GRAND RAPIDS

S.L.C.C. - System Load Carrying Capacity

Addition to C.S.M.S.	Increase in S.L.C.C. (MW)	Percentage L.C.C. Increase is of G.R. Capacity
1 G.R. Unit	74	67.2
2 G.R. Units	171	77.7
3 G.R. Units	269	81.5

To maintain a 12% reserve would be an increase in system load carrying capability of 89.3% of the generating unit capacity added.

CONCLUSIONS

If the risk of generating capacity deficiencies associated with a present capacity reserve of 12% is justified for the Combined Southern Manitoba System, then this risk level can be used to determine the increase in load carrying capability of the system after the development at Grand Rapids.

Due to the large units at Grand Rapids the capacity reserve required will no longer be 12%. Based upon the assumptions used this figure will be 14.8% to maintain the desired risk level.

The addition of further units of the same capacity as those at Grand Rapids will not reduce the percentage reserve required to the present figure of 12%.

The approach used here has utilized some major assumptions as to load characteristics and forced outage rates. The refinements that can be applied to this problem are numerous and do not always justify their application. Future system load characteristics can be determined reasonably accurately and Load Duration and Daily Peak Load Curves represented for digital computation. Future studies in this field performed by Manitoba Hydro should incorporate actual and forecast load characteristics on a monthly basis thus allowing maintenance schedules to be incorporated.

Unfortunately, insufficient statistics have been accumulated for the Manitoba System to deduce a stable forced outage rate for either hydraulic or thermal generating units. In view of this, studies should be done to ascertain the effect on capacity requirements of variations in the forced outage rates of generating facilities particularly those at Grand Rapids.

The actual increase in system reliability due to the interconnections with Saskatchewan and Ontario should be evaluated. This would require a three system reliability study. Such a study even on a preliminary basis using similar assumptions to those made here would illustrate the value of adequate transmission links to system reliability.

If Manitoba is to develop its northern hydraulic resources without large export contracts, considerable generation overbuild and capital expenditures on generating and transmission facilities are required. It may be possible to justify this development by capacity sharing with our neighboring provinces with Manitoba carrying the installed reserve for all three systems. This could be a cycling arrangement thus allowing each individual system to develop its possible major generating schemes which cannot be justified on a single system basis. This would not have to be complete system integration as each system could supply its own energy and capacity requirements under normal conditions with energy purchases made wherever economical. The application of probability techniques will provide a sound analytical basis from which the relative merits of different schemes of expansion can be judged from the reliability standpoint. These techniques should go hand in hand with economic evaluations of any proposed generating scheme.

In order to be able to take into account the load diversity existing between the three systems, individual and pool load characteristic curves are required. This can be done quite simply by having hourly and peak load values tabulated and forwarded to one of the three utilities where the information is punched on cards ready for digital computation. The pool load characteristics can also be used to evaluate spinning reliability of the interconnected systems.

The approach presented here is relatively simple and has utilized several simplifying assumptions. It is, however, an analytical basis upon which refinements can be made if desired. These added refinements should remain as tools of the specialist but the general concepts associated with the application of probability should be understood by those concerned with generating capacity planning.

CHAPTER VIII

CONCLUSION

Conclusions have already been stated for both the theoretical systems and actual system used in this thesis and therefore are not repeated here. It should be readily apparent, however, that reserve generating requirements vary with each power system and they can only be compared by means of analytical methods involving probability.

The factors affecting capacity requirements are:

1. the load characteristics of the system
2. the number and size of generating units in the system
3. the probability of forced outage of each unit in the system
4. the assistance available from other systems through adequate interconnections
5. the risk of a capacity deficiency acceptable to the system.

These factors cannot be correctly evaluated using rule of thumb techniques such as a percentage reserve margin. The basic concepts involved in the application of probability mathematics to this problem are quite straightforward. The refinements which can be applied are numerous and can involve detailed statistical analysis, whether or not these refinements are made will depend upon the particular problem studied.

The selection of the acceptable risk of capacity deficiency can not be made by mathematical methods. Human judgement must be used to decide what is and what is not adequate reliability. Once this has been decided, the application of mathematical techniques involving probability, provide a sound basis for economic evaluation of maintaining this criterion under widely changing system conditions.

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APPENDIX A

APPENDIX A

The abbreviations used in the following tables are as follows:

CAP OUT MW	Capacity Out of Service in MW
CUM PROB	Cumulative Probability
IND PROB	Individual Probability
DOUT	Risk in Days per Year
YOUT	Risk in Years per Day
RIND	Index of Reliability

```
SYSTEM  1A-1

INSTALLED CAPACITY  200.0000 MW
DAYS 365.0
NO OF LEVELS   5

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .817907
   10.0000  .182093   .165234
   20.0000  .016859   .015856
   30.0000  .001003   .000963
   40.0000  .000040   .000040

    DOUT        YOUT       RIND     LOAD MW
  6.083180        .16    .999291  200.0000
   .573178       1.74    .999933  190.0000
   .035249      28.37    .999995  180.0000
   .001431     698.63    .999999  170.0000
```

SYSTEM DATA

20 - 10 MW Hydraulic Units. Forced Outage Rate 0.01.

```
SYSTEM  2A-1

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   9


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .809728
   10.0000  .190272   .163582
   20.0000  .026690   .015697
   30.0000  .010993   .000953
   40.0000  .010040   .000040
   50.0000  .010000   .008180
   60.0000  .001820   .001652
   70.0000  .000168   .000158
   80.0000  .000010   .000010


    DOUT          YOUT      RIND    LOAD MW
  6.083162         .16   .999032  250.0000
  1.513761         .66   .999590  240.0000
   .873646        1.14   .999762  230.0000
   .609384        1.64   .999876  220.0000
   .347561        2.88   .999955  210.0000
   .060772       16.45   .999993  200.0000
   .005699      175.47   .999999  190.0000
   .000337     2958.90  1.000000  180.0000
```

SYSTEM DATA

20 - 10 MW Units. Forced Outage Rate 0.01

1 - 50 MW Unit. Forced Outage Rate 0.01

```
SYSTEM  3A-1

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS  13

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .801631
   10.0000   .198369    .161946
   20.0000   .036423    .015540
   30.0000   .020883    .000944
   40.0000   .019939    .000039
   50.0000   .019900    .016195
   60.0000   .003705    .003272
   70.0000   .000433    .000314
   80.0000   .000119    .000019
   90.0000   .000100    .000000
  100.0000   .000100    .000082
  110.0000   .000018    .000017
  120.0000   .000001    .000001

   DOUT          YOUT        RIND      LOAD MW
  6.083136        .16      .998964   300.0000
  2.131705        .47      .999460   290.0000
  1.416504        .71      .999674   280.0000
   .998455       1.00      .999828   270.0000
   .570336       1.75      .999936   260.0000
   .108915       9.18      .999985   250.0000
   .019542      51.17      .999995   240.0000
   .008939     111.86      .999997   230.0000
   .006055     165.13      .999998   220.0000
   .003447     290.09      .999999   210.0000
   .000577    1730.35     1.000000   200.0000
   .000032   31232.86     1.000000   190.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
2 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  4A-1

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  16


CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .793615
   10.0000   .206385    .160326
   20.0000   .046059    .015385
   30.0000   .030674    .000934
   40.0000   .029740    .000039
   50.0000   .029701    .024049
   60.0000   .005652    .004859
   70.0000   .000793    .000466
   80.0000   .000327    .000029
   90.0000   .000298    .000000
  100.0000   .000298    .000243
  110.0000   .000055    .000049
  120.0000   .000006    .000005
  130.0000   .000001    .000000
  140.0000   .000001    .000000
  150.0000   .000001    .000001


    DOUT         YOUT      RIND     LOAD MW
  6.083183        .16    .998967   350.0000
  2.561422        .39    .999413   340.0000
  1.798215        .56    .999641   330.0000
  1.271283        .79    .999809   320.0000
   .728685       1.37    .999926   310.0000
   .150704       6.64    .999980   300.0000
   .037339      26.78    .999991   290.0000
   .021443      46.63    .999995   280.0000
   .014870      67.25    .999997   270.0000
   .008469     118.07    .999999   260.0000
   .001557     642.12    .999999   250.0000
   .000228    4383.56   1.000000   240.0000
   .000079   12602.74   1.000000   230.0000
   .000055   18082.19   1.000000   220.0000
   .000028   34520.51   1.000000   210.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
3 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  2A-2

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS    9

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .801549
   10.0000   .198451    .161929
   20.0000   .036522    .015539
   30.0000   .020983    .000944
   40.0000   .020039    .000039
   50.0000   .020000    .016359
   60.0000   .003641    .003304
   70.0000   .000337    .000317
   80.0000   .000020    .000020

    DOUT          YOUT       RIND      LOAD MW
 7.299828          .14    .998518    250.0000
 2.573808          .39    .999222    240.0000
 1.719732          .58    .999527    230.0000
 1.217689          .82    .999752    220.0000
  .695180         1.44    .999911    210.0000
  .121605         8.22    .999985    200.0000
  .011430        87.49    .999998    190.0000
  .000675      1479.45   1.000000    180.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
1 - 50 MW Unit	Forced Outage Rate 0.02

```
SYSTEM  3A-2

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS  13

CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000   .785518
   10.0000   .214482   .158691
   20.0000   .055791   .015228
   30.0000   .040563   .000924
   40.0000   .039639   .000039
   50.0000   .039600   .032062
   60.0000   .007538   .006478
   70.0000   .001060   .000621
   80.0000   .000439   .000039
   90.0000   .000400   .000000
  100.0000   .000400   .000328
  110.0000   .000072   .000066
  120.0000   .000006   .000006


    DOUT         YOUT       RIND     LOAD MW
  8.110913        .12     .998230   300.0000
  3.891404        .26     .998935   290.0000
  2.818257        .35     .999336   280.0000
  2.008717        .50     .999643   270.0000
  1.158525        .86     .999859   260.0000
   .241264       4.14     .999961   250.0000
   .060250      16.60     .999983   240.0000
   .034833      28.71     .999990   230.0000
   .024278      41.19     .999995   220.0000
   .013846      72.22     .999998   210.0000
   .002372     421.50     .999999   200.0000
   .000192    5205.48    1.000000   190.0000
```

SYSTEM DATA

20 - 10 MW Units   Forced Outage Rate 0.01

2 - 50 MW Units   Forced Outage Rate 0.02

```
SYSTEM  4A-2

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  17

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .769808
   10.0000  .230192   .155517
   20.0000  .074675   .014923
   30.0000  .059752   .000906
   40.0000  .058846   .000038
   50.0000  .058808   .047132
   60.0000  .011676   .009521
   70.0000  .002155   .000914
   80.0000  .001241   .000056
   90.0000  .001185   .000001
  100.0000  .001184   .000962
  110.0000  .000222   .000195
  120.0000  .000027   .000019
  130.0000  .000008   .000000
  140.0000  .000008   .000000
  150.0000  .000008   .000007
  160.0000  .000001   .000001


   DOUT          YOUT        RIND     LOAD MW
 8.690274          .12     .998136   350.0000
 4.827232          .21     .998817   340.0000
 3.596928          .28     .999253   330.0000
 2.573420          .39     .999590   320.0000
 1.501662          .67     .999825   310.0000
  .359221         2.78     .999938   300.0000
  .126680         7.89     .999967   290.0000
  .084384        11.85     .999980   280.0000
  .059549        16.79     .999989   270.0000
  .034113        29.31     .999996   260.0000
  .006667       149.99     .999999   250.0000
  .001318       758.69     .999999   240.0000
  .000661      1512.33     .999999   230.0000
  .000470      2127.32    1.000000   220.0000
  .000260      3835.61    1.000000   210.0000
  .000030     32876.71    1.000000   200.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
3 - 50 MW Units	Forced Outage Rate 0.02

```
SYSTEM  1B-1

INSTALLED CAPACITY  200.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .904383
   20.0000   .095617    .091351
   40.0000   .004266    .004153
   60.0000   .000113    .000113

    DOUT         YOUT        RIND     LOAD MW
  6.083089        .16     .998702   200.0000
  3.341832        .30     .999566   190.0000
   .295988       3.38     .999932   180.0000
   .160743       6.22     .999978   170.0000
   .008592     116.38     .999997   160.0000
   .004582     218.21     .999999   150.0000
```

<u>SYSTEM DATA</u>

10 - 20 MW Units   Forced Outage Rate 0.01

```
SYSTEM  28-1

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   8

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000  .895339
   20.0000  .104661  .090438
   40.0000  .014223  .004111
   50.0000  .010112  .009044
   60.0000  .001068  .000112
 . 70.0000  .000956  .000914
   90.0000  .000042  .000041
  110.0000  .000001  .000001

    DOUT         YOUT       RIND    .LOAD MW
  6.083089        .16    .998655  250.0000
  3.683687        .27    .999358  240.0000
  1.075639        .93    .999719  230.0000
   .731244       1.37    .999858  220.0000
   .354050       2.82    .999949  210.0000
   .064179      15.58    .999986  200.0000
   .033362      29.97    .999995  190.0000
   .002906     344.06    .999999  180.0000
   .001574     635.12    .999999  170.0000
   .000076   13150.69   1.000000  160.0000
   .000040   24657.52   1.000000  150.0000
```

<u>SYSTEM DATA</u>

10 - 20 MW Units	Forced Outage Rate 0.01
1 - 50 MW Unit	Forced Outage Rate 0.01

```
SYSTEM  3B-1

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS  10

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .886385
   20.0000   .113615    .089534
   40.0000   .024081    .004070
   50.0000   .020011    .017907
   60.0000   .002104    .000111
   70.0000   .001993    .001809
   90.0000   .000184    .000082
  100.0000   .000102    .000091
  110.0000   .000011    .000002
  120.0000   .000009    .000009

   DOUT          YOUT       RIND      LOAD MW
 6.083131         .16     .998702    300.0000
 3.909592         .26     .999300    290.0000
 1.580798         .63     .999642    280.0000
 1.096780         .91     .999814    270.0000
  .575530        1.74     .999928    260.0000
  .111616        8.96     .999978    250.0000
  .062937       15.89     .999991    240.0000
  .012960       77.16     .999996    230.0000
  .008461      118.18     .999998    220.0000
  .003534      282.96     .999999    210.0000
  .000608     1643.84     .999999    200.0000
  .000288     3470.32    1.000000    190.0000
```

<u>SYSTEM DATA</u>

10 - 20 MW Units	Forced Outage Rate 0.01
2 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  4B-1

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  12

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .877522
   20.0000  .122478   .088638
   40.0000  .033840   .004029
   50.0000  .029811   .026592
   60.0000  .003219   .000110
   70.0000  .003109   .002686
   90.0000  .000423   .000122
  100.0000  .000301   .000269
  110.0000  .000032   .000003
  120.0000  .000029   .000028
  140.0000  .000001   .000000
  150.0000  .000001   .000001

    DOUT        YOUT       RIND     LOAD MW
  6.083092        .16    .998774   350.0000
  4.070610        .25    .999296   340.0000
  1.936159        .52    .999616   330.0000
  1.353351        .74    .999797   320.0000
   .732944       1.36    .999918   310.0000
   .152874       6.54    .999972   300.0000
   .090620      11.03    .999987   290.0000
   .026310      38.01    .999994   280.0000
   .017754      56.32    .999997   270.0000
   .008540     117.09    .999999   260.0000
   .001557     642.12    .999999   250.0000
   .000811    1232.88   1.000000   240.0000
   .000079   12602.74   1.000000   230.0000
   .000055   18082.19   1.000000   220.0000
   .000028   34520.51   1.000000   210.0000
```

SYSTEM DATA

10 - 20 MW Units	Forced Outage Rate 0.01
3 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  2B-2

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS    8

CAP OUT MW CUM PROB  IND PROB
      .0000 1.000000   .886295
    20.0000  .113705   .089525
    40.0000  .024180   .004069
    50.0000  .020111   .018088
    60.0000  .002023   .000111
    70.0000  .001912   .001827
    90.0000  .000085   .000083
   110.0000  .000002   .000002

    DOUT         YOUT       RIND     LOAD MW
  7.299755        .14    .998141   250.0000
  4.721808        .21    .998988   240.0000
  1.919688        .52    .999480   230.0000
  1.338333        .75    .999730   220.0000
   .701611       1.43    .999899   210.0000
   .124982       8.00    .999973   200.0000
   .066788      14.97    .999991   190.0000
   .005880     170.05    .999998   180.0000
   .003184     313.99    .999999   170.0000
   .000152    6575.34   1.000000   160.0000
   .000081   12328.76   1.000000   150.0000
```

SYSTEM DATA

10 - 20 MW Units   Forced Outage Rate 0.01

1 - 50 MW Unit   Forced Outage Rate 0.02

```
SYSTEM  3B-2

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS  11

CAP OUT MW CUM PROB  IND PROB
      .0000  1.000000   .868569
    20.0000   .131431   .087734
    40.0000   .043697   .003988
    50.0000   .039709   .035452
    60.0000   .004257   .000109
    70.0000   .004148   .003581
    90.0000   .000567   .000163
   100.0000   .000404   .000362
   110.0000   .000042   .000004
   120.0000   .000038   .000037
   140.0000   .000001   .000001

    DOUT         YOUT       RIND     LOAD MW
   8.110909        .12    .997968   300.0000
   5.633567        .18    .998772   290.0000
   2.979270        .34    .999299   280.0000
   2.105081        .48    .999622   270.0000
   1.163649        .86    .999845   260.0000
    .243941       4.10    .999946   250.0000
    .146202       6.84    .999974   240.0000
    .042847      23.34    .999988   230.0000
    .029117      34.34    .999994   220.0000
    .014078      71.03    .999998   210.0000
    .002494     400.94    .999999   200.0000
    .001280     780.82    .999999   190.0000
    .000067   14794.51   1.000000   180.0000
    .000035   27945.17   1.000000   170.0000
```

SYSTEM DATA

10 - 20 MW Units	Forced Outage Rate 0.01
2 - 50 MW Units	Forced Outage Rate 0.02

```
SYSTEM  4B-2

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  12

CAP OUT MW CUM PROB  IND PROB
      .0000 1.000000   .851198
    20.0000  .148802   .085979
    40.0000  .062823   .003908
    50.0000  .058915   .052114
    60.0000  .006801   .000108
    70.0000  .006693   .005264
    90.0000  .001429   .000239
   100.0000  .001190   .001063
   110.0000  .000127   .000007
   120.0000  .000120   .000107
   140.0000  .000013   .000005
   150.0000  .000008   .000008


     DOUT         YOUT       RIND     LOAD MW
   8.690270        .12     .997943   350.0000
   6.283476        .16     .998697   340.0000
   3.730815        .27     .999222   330.0000
   2.653112        .38     .999570   320.0000
   1.505881        .66     .999810   310.0000
    .361410       2.77     .999923   300.0000
    .231208       4.33     .999958   290.0000
    .094052      10.63     .999978   280.0000
    .065339      15.30     .999988   270.0000
    .034417      29.05     .999995   260.0000
    .006837     146.25     .999998   250.0000
    .003903     256.18     .999999   240.0000
    .000899    1112.01     .999999   230.0000
    .000580    1722.11    1.000000   220.0000
    .000231    4315.06    1.000000   210.0000
```

SYSTEM DATA

10 - 20 MW Units	Forced Outage Rate 0.01
3 - 50 MW Units	Forced Outage Rate 0.02

```
SYSTEM  1C-1

INSTALLED CAPACITY  200.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW CUM PROB   IND PROB
     .0000  1.000000   .950991
   40.0000   .049009   .048029
   80.0000   .000980   .000971
  120.0000   .000009   .000009

    DOUT          YOUT       RIND      LOAD MW
  6.083090         .16     .997524   200.0000
  4.834106         .21     .998414   190.0000
  3.446346         .29     .999162   180.0000
  1.895318         .53     .999699   170.0000
   .150410        6.65     .999925   160.0000
   .120693        8.29     .999951   150.0000
   .086730       11.53     .999974   140.0000
   .047543       21.03     .999991   130.0000
   .001825      547.95     .999998   120.0000
   .001493      669.71     .999999   110.0000
   .001095      913.24     .999999   100.0000
   .000608     1643.83     .999999    90.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

```
SYSTEM  2C-1

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   7

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .941481
   40.0000   .058519    .047549
   50.0000   .010970    .009510
   80.0000   .001460    .000961
   90.0000   .000499    .000480
  120.0000   .000019    .000010
  130.0000   .000009    .000009

    DOUT        YOUT       RIND     LOAD MW
  6.083113       .16     .997901   250.0000
  4.853282       .21     .998635   240.0000
  3.516512       .28     .999243   230.0000
  2.058214       .49     .999683   220.0000
   .461030      2.17     .999896   210.0000
   .150410      6.65     .999948   200.0000
   .111581      8.96     .999970   190.0000
   .068437     14.61     .999987   180.0000
   .020218     49.46     .999996   170.0000
   .002509    398.51     .999999   160.0000
   .001906    524.63     .999999   150.0000
   .001216    821.92     .999999   140.0000
   .000421   2374.43    1.000000   130.0000
```

SYSTEM DATA

5 - 40 MW Units	Forced Outage Rate 0.01
1 - 50 MW Unit	Forced Outage Rate 0.01

```
SYSTEM  3C-1

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS    9

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .932066
   40.0000  .067934   .047074
   50.0000  .020860   .018829
   80.0000  .002031   .000951
   90.0000  .001080   .000951
  100.0000  .000129   .000096
  120.0000  .000033   .000009
  130.0000  .000024   .000020
  140.0000  .000004   .000004

    DOUT          YOUT       RIND     LOAD MW
  6.083172         .16     .998178   300.0000
  4.867883         .21     .998804   290.0000
  3.565790         .28     .999318   280.0000
  2.167245         .46     .999692   270.0000
   .661118        1.51     .999887   260.0000
   .179969        5.56     .999946   250.0000
   .135987        7.35     .999968   240.0000
   .088181       11.34     .999984   230.0000
   .036029       27.75     .999994   220.0000
   .006459      154.80     .999998   210.0000
   .002859      349.75     .999999   200.0000
   .001953      512.01     .999999   190.0000
   .000946     1056.75     .999999   180.0000
   .000143     6986.29    1.000000   170.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

2 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  4C-1

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  10

CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000  .922745
   40.0000   .077255  .046603
   50.0000   .030652  .027962
   80.0000   .002690  .000942
   90.0000   .001748  .001412
  100.0000   .000336  .000283
  120.0000   .000053  .000009
  130.0000   .000044  .000029
  140.0000   .000015  .000014
  150.0000   .000001  .000001

    DOUT         YOUT       RIND     LOAD MW
  6.083196         .16    .998389  350.0000
  4.879852         .20    .998935  340.0000
  3.603583         .28    .999381  330.0000
  2.247544         .44    .999706  320.0000
   .804020        1.24    .999884  310.0000
   .209266        4.78    .999944  300.0000
   .160054        6.25    .999966  290.0000
   .107327        9.32    .999983  280.0000
   .050694       19.73    .999993  270.0000
   .011745       85.14    .999997  260.0000
   .004039      247.57    .999999  250.0000
   .002864      349.13    .999999  240.0000
   .001586      630.14    .999999  230.0000
   .000442     2260.27   1.000000  220.0000
   .000028    34520.51   1.000000  210.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

3 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  2C-2


INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   7


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .931971
   40.0000  .068029   .047069
   50.0000  .020960   .019020
   80.0000  .001940   .000951
   90.0000  .000989   .000960
  120.0000  .000029   .000010
  130.0000  .000019   .000019


    DOUT         YOUT        RIND     LOAD MW
  7.299780        .14     .997386   250.0000
  5.879591        .17     .998264   240.0000
  4.335910        .23     .999000   230.0000
  2.651892        .38     .999547   220.0000
   .807490       1.24     .999837   210.0000
   .210331       4.75     .999923   200.0000
   .159287       6.28     .999954   190.0000
   .102571       9.75     .999979   180.0000
   .039183      25.52     .999993   170.0000
   .004030     248.13     .999998   160.0000
   .003122     320.23     .999998   150.0000
   .002085     479.45     .999999   140.0000
   .000889    1124.73     .999999   130.0000
```

SYSTEM DATA

5 - 40 MW Units	Forced Outage Rate 0.01
1 - 50 MW Unit	Forced Outage Rate 0.02

```
SYSTEM  3C-2

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS   9

CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000   .913331
   40.0000   .086669   .046128
   50.0000   .040541   .037279
   80.0000   .003262   .000932
   90.0000   .002330   .001883
  100.0000   .000447   .000380
  120.0000   .000067   .000009
  130.0000   .000058   .000039
  140.0000   .000019   .000019

    DOUT           YOUT        RIND     LOAD MW
  8.110930          .12      .997444   300.0000
  6.572560          .15      .998275   290.0000
  4.924307          .20      .998969   280.0000
  3.153962          .32      .999490   270.0000
  1.247435          .80      .999791   260.0000
   .310833         3.22      .999900   250.0000
   .241102         4.15      .999937   240.0000
   .165306         6.05      .999967   230.0000
   .082622        12.10      .999987   220.0000
   .019061        52.46      .999995   210.0000
   .006417       155.81      .999998   200.0000
   .004610       216.89      .999998   190.0000
   .002602       384.27      .999999   180.0000
   .000679      1470.80     1.000000   170.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

2 - 50 MW Units   Forced Outage Rate 0.02

```
SYSTEM  4C-2

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS  12

CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000   .895065
   40.0000   .104935   .045205
   50.0000   .059730   .054800
   80.0000   .004930   .000913
   90.0000   .004017   .002768
  100.0000   .001249   .001118
  120.0000   .000131   .000009
  130.0000   .000122   .000056
  140.0000   .000066   .000058
  150.0000   .000008   .000007
  170.0000   .000001   .000000
  180.0000   .000001   .000001


   DOUT          YOUT        RIND      LOAD MW
  8.690252        .12      .997559    350.0000
  7.068332        .14      .998335    340.0000
  5.348116        .19      .998981    330.0000
  3.520386        .28      .999469    320.0000
  1.574740        .64      .999763    310.0000
   .416039       2.40      .999880    300.0000
   .326968       3.06      .999923    290.0000
   .231536       4.32      .999958    280.0000
   .129034       7.75      .999981    270.0000
   .040009      24.99      .999993    260.0000
   .011217      89.15      .999996    250.0000
   .008364     119.55      .999998    240.0000
   .005263     189.99      .999999    230.0000
   .002129     469.67      .999999    220.0000
   .000310    3138.23     1.000000    210.0000
   .000091   10958.90     1.000000    200.0000
   .000064   15616.43     1.000000    190.0000
   .000033   29589.02     1.000000    180.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

3 - 50 MW Units   Forced Outage Rate 0.02

```
SYSTEM  1D-1

INSTALLED CAPACITY  200.0000 MW
DAYS 365.0
NO OF LEVELS    4

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .960597
   50.0000   .039403    .038811
  100.0000   .000592    .000589
  150.0000   .000003    .000003


    DOUT          YOUT        RIND      LOAD MW
  6.082755          .16     .996935   200.0000
  5.141353          .19     .997793   190.0000
  4.095347          .24     .998576   180.0000
  2.926284          .34     .999239   170.0000
  1.611087          .62     .999719   160.0000
   .120531         8.30     .999920   150.0000
   .103468         9.66     .999941   140.0000
   .083781        11.94     .999961   130.0000
   .060782        16.45     .999979   120.0000
   .033568        29.79     .999993   110.0000
   .000912      1095.89     .999999   100.0000
   .000811      1232.88     .999999    90.0000
   .000684      1461.19     .999999    80.0000
   .000521      1917.81     .999999    70.0000
   .000304      3287.67    1.000000    60.0000
```

SYSTEM DATA

4 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  2D-1

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .950991
   50.0000   .049009    .048029
  100.0000   .000980    .000971
  150.0000   .000009    .000009


   DOUT          YOUT        RIND      LOAD MW
6.083090          .16      .997524   250.0000
5.094310          .20      .998245   240.0000
4.019549          .25      .998884   230.0000
2.847083          .35      .999407   220.0000
1.562954          .64      .999773   210.0000
 .150410         6.65      .999925   200.0000
 .126949         7.88      .999946   190.0000
 .100881         9.91      .999965   180.0000
 .071747        13.94      .999982   170.0000
 .038971        25.66      .999994   160.0000
 .001825       547.95      .999998   150.0000
 .001564       639.27      .999999   140.0000
 .001263       791.48      .999999   130.0000
 .000912      1095.89      .999999   120.0000
 .000497      2009.13     1.000000   110.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

```
SYSTEM  3D-1

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .941481
   50.0000  .058519   .057059
  100.0000  .001460   .001441
  150.0000  .000019   .000019

   DOUT          YOUT         RIND     LOAD MW
 6.083131          .16      .997916   300.0000
 5.065341          .20      .998537   290.0000
 3.974851          .25      .999075   280.0000
 2.803583          .36      .999507   270.0000
 1.542220          .65      .999804   260.0000
  .179945         5.56      .999927   250.0000
  .150435         6.65      .999949   240.0000
  .118360         8.45      .999968   230.0000
  .083369        11.99      .999983   220.0000
  .045045        22.20      .999994   210.0000
  .002889       346.07      .999998   200.0000
  .002433       410.96      .999999   190.0000
  .001926       519.11      .999999   180.0000
  .001359       735.40      .999999   170.0000
  .000722      1384.28     1.000000   160.0000
```

SYSTEM DATA

6 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  4D-1

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .932066
   50.0000  .067934   .065903
  100.0000  .002031   .001998
  150.0000  .000033   .000033

   DOUT         YOUT       RIND    LOAD MW
  6.083161       .16    .998197   350.0000
  5.046591       .20    .998740   340.0000
  3.947198       .25    .999205   330.0000
  2.779094       .36    .999574   320.0000
  1.535631       .65    .999824   310.0000
   .209266      4.78    .999929   300.0000
   .173878      5.75    .999951   290.0000
   .135962      7.35    .999969   280.0000
   .095237     10.50    .999984   270.0000
   .051380     19.46    .999994   260.0000
   .004015    249.07    .999998   250.0000
   .003345    298.88    .999999   240.0000
   .002618    381.90    .999999   230.0000
   .001825    547.95    .999999   220.0000
   .000955   1046.08   1.000000   210.0000
```

SYSTEM DATA

7 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  2D-2

INSTALLED CAPACITY  250.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .941385
   50.0000  .058615   .057247
  100.0000  .001368   .001353
  150.0000  .000015   .000015


    DOUT          YOUT       RIND     LOAD MW
  7.299756         .14     .997009  250.0000
  6.118186         .16     .997874  240.0000
  4.833869         .21     .998640  230.0000
  3.432797         .29     .999268  220.0000
  1.898291         .53     .999709  210.0000
   .210331        4.75     .999894  200.0000
   .177601        5.63     .999924  190.0000
   .141234        7.08     .999951  180.0000
   .100589        9.94     .999974  170.0000
   .054864       18.23     .999991  160.0000
   .003041      328.77     .999998  150.0000
   .002607      383.56     .999998  140.0000
   .002105      474.89     .999999  130.0000
   .001520      657.53     .999999  120.0000
   .000829     1205.48     .999999  110.0000
```

SYSTEM DATA

4 - 50 MW Units   Forced Outage Rate 0.01

1 - 50 MW Unit   Forced Outage Rate 0.02

```
SYSTEM  3D-2

INSTALLED CAPACITY  300.0000 MW
DAYS 365.0
NO OF LEVELS    4

CAP OUT MW CUM PROB  IND PROB
      .0000 1.000000   .922557
   50.0000   .077443   .074930
  100.0000   .002513   .002471
  150.0000   .000042   .000042


    DOUT          YOUT        RIND     LOAD MW
  8.110909         .12     .997182   300.0000
  6.766074         .15     .998008   290.0000
  5.325177         .19     .998725   280.0000
  3.777548         .26     .999303   270.0000
  2.110872         .47     .999702   260.0000
   .310858        3.22     .999874   250.0000
   .260113        3.84     .999911   240.0000
   .204955        4.88     .999944   230.0000
   .144783        6.91     .999970   220.0000
   .078880       12.68     .999989   210.0000
   .006387      156.56     .999996   200.0000
   .005378      185.91     .999997   190.0000
   .004258      234.83     .999998   180.0000
   .003005      332.68     .999999   170.0000
   .001596      626.22     .999999   160.0000
```

SYSTEM DATA

4 - 50 MW Units   Forced Outage Rate 0.01

2 - 50 MW Units   Forced Outage Rate 0.02

```
SYSTEM  4D-2

INSTALLED CAPACITY  350.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .904106
   50.0000   .095894    .091883
  100.0000   .004011    .003919
  150.0000   .000092    .000092

   DOUT          YOUT        RIND     LOAD MW
  8.690218        .12      .997366   350.0000
  7.230061        .14      .998140   340.0000
  5.681409        .18      .998804   330.0000
  4.035968        .25      .999334   320.0000
  2.284372        .44      .999697   310.0000
   .415998       2.40      .999858   300.0000
   .346204       2.89      .999900   290.0000
   .271425       3.68      .999937   280.0000
   .191106       5.23      .999967   270.0000
   .104610       9.56      .999987   260.0000
   .011193      89.34      .999995   250.0000
   .009327     107.21      .999997   240.0000
   .007300     136.99      .999998   230.0000
   .005087     196.55      .999999   220.0000
   .002665     375.22      .999999   210.0000
```

SYSTEM DATA

4 - 50 MW Units	Forced Outage Rate 0.01
3 - 50 MW Units	Forced Outage Rate 0.02

```
SYSTEM 1A-1 & 25 MW FIRM PURCHASE

INSTALLED CAPACITY  225.0000 MW
DAYS 365.0
NO OF LEVELS    5

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .817907
   10.0000   .182093    .165234
   20.0000   .016859    .015856
   30.0000   .001003    .000963
   40.0000   .000040    .000040


     DOUT          YOUT        RIND      LOAD MW
  5.407277          .18      .999440   225.0000
   .506530         1.97      .999948   215.0000
   .030950        32.31      .999996   205.0000
   .001247       801.37      .999999   195.0000
```

SYSTEM DATA

20 - 10 MW Units   Forced Outage Rate 0.01

1 - 25 MW Firm Capacity Purchase

```
SYSTEM 1B-1 & 25 MW FIRM PURCHASE

INSTALLED CAPACITY  225.0000 MW
DAYS 365.0
NO OF LEVELS   4

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000  .904383
   20.0000  .095617  .091351
   40.0000  .004266  .004153
   60.0000  .000113  .000113

    DOUT          YOUT       RIND     LOAD MW
  5.407191         .18     .998975  225.0000
  2.953250         .34     .999661  215.0000
   .259891        3.85     .999947  205.0000
   .140135        7.14     .999983  195.0000
   .007431      134.56     .999998  185.0000
   .003928      254.58     .999999  175.0000
```

SYSTEM DATA

10 - 20 MW Units   Forced Outage Rate 0.01

1 - 25 MW Firm Capacity Purchase

```
SYSTEM 1C-1 & 25 MW FIRM PURCHASE

INSTALLED CAPACITY  225.0000 MW
DAYS 365.0
NO OF LEVELS   4


CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .950991
   40.0000   .049009    .048029
   80.0000   .000980    .000971
  120.0000   .000009    .000009


    DOUT          YOUT        RIND      LOAD MW
  5.407191         .18      .998043   225.0000
  4.271999         .23      .998761   215.0000
  3.026058         .33      .999354   205.0000
  1.652328         .61      .999771   195.0000
   .130084        7.69      .999944   185.0000
   .103451        9.67      .999964   175.0000
   .073589       13.59      .999981   165.0000
   .039875       25.08      .999994   155.0000
   .001510      662.10      .999999   145.0000
   .001216      821.92      .999999   135.0000
   .000875     1141.55      .999999   125.0000
   .000476     2100.45     1.000000   115.0000
```

SYSTEM DATA

5 - 40 MW Units   Forced Outage Rate 0.01

1 - 25 MW Firm Capacity Purchase

```
SYSTEM 1D-1 & 25 MW FIRM PURCHASE

INSTALLED CAPACITY  225.0000 MW
DAYS 365.0
NO OF LEVELS   4


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .960597
   50.0000  .039403   .038811
  100.0000  .000592   .000589
  150.0000  .000003   .000003


   DOUT        YOUT       RIND     LOAD MW
  5.407016       .18    .997578  225.0000
  4.543649       .22    .998276  215.0000
  3.596049       .28    .998902  205.0000
  2.551261       .39    .999422  195.0000
  1.393511       .72    .999790  185.0000
   .103416      9.67    .999941  175.0000
   .087858     11.38    .999957  165.0000
   .070291     14.23    .999972  155.0000
   .050302     19.88    .999985  145.0000
   .027352     36.56    .999995  135.0000
   .000730   1369.86    .999999  125.0000
   .000634   1575.34    .999999  115.0000
   .000521   1917.81    .999999  105.0000
   .000384   2602.74    .999999   95.0000
   .000214   4657.53   1.000000   85.0000
```

SYSTEM DATA

4 - 50 MW Units   Forced Outage Rate 0.01

1 - 25 MW Firm Capacity Purchase

```
SYSTEM  1AD

INSTALLED CAPACITY  400.0000 MW
DAYS 365.0
NO OF LEVELS  16

CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000    .785679
   10.0000   .214321    .158722
   20.0000   .055599    .015231
   30.0000   .040368    .000925
   40.0000   .039443    .000040
   50.0000   .039403    .031744
   60.0000   .007659    .006413
   70.0000   .001246    .000616
   80.0000   .000630    .000037
   90.0000   .000593    .000001
  100.0000   .000592    .000481
  110.0000   .000111    .000098
  120.0000   .000013    .000009
  130.0000   .000004    .000001
  140.0000   .000003    .000000
  150.0000   .000003    .000003

    DOUT          YOUT       RIND     LOAD MW
  6.083149         .16    .998997   400.0000
  2.896090         .35    .999403   390.0000
  2.082229         .48    .999632   380.0000
  1.474798         .68    .999803   370.0000
   .849250        1.18    .999920   360.0000
   .188653        5.30    .999975   350.0000
   .057165       17.49    .999988   340.0000
   .035928       27.83    .999993   330.0000
   .025074       39.88    .999996   320.0000
   .014246       70.19    .999998   310.0000
   .002717      368.02    .999999   300.0000
   .000482     2072.66   1.000000   290.0000
   .000217     4602.74   1.000000   280.0000
   .000135     7397.26   1.000000   270.0000
   .000070    14246.55   1.000000   260.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
4 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  2AD

INSTALLED CAPACITY  450.0000 MW
DAYS 365.0
NO OF LEVELS  17


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .777822
   10.0000  .222178   .157135
   20.0000  .065043   .015079
   30.0000  .049964   .000916
   40.0000  .049048   .000039
   50.0000  .049009   .039283
   60.0000  .009726   .007937
   70.0000  .001789   .000761
   80.0000  .001028   .000047
   90.0000  .000981   .000001
  100.0000  .000980   .000794
  110.0000  .000186   .000160
  120.0000  .000026   .000016
  130.0000  .000010   .000001
  140.0000  .000009   .000000
  150.0000  .000009   .000008
  160.0000  .000001   .000001


    DOUT          YOUT       RIND     LOAD MW
  6.083166         .16    .999037   450.0000
  3.149632         .32    .999409   440.0000
  2.302698         .43    .999633   430.0000
  1.633839         .61    .999801   420.0000
   .945944        1.06    .999917   410.0000
   .224246        4.46    .999971   400.0000
   .078287       12.77    .999985   390.0000
   .051708       19.34    .999991   380.0000
   .036204       27.62    .999995   370.0000
   .020632       48.47    .999998   360.0000
   .004188      238.73    .999999   350.0000
   .000984     1016.19    .999999   340.0000
   .000534     1870.57   1.000000   330.0000
   .000361     2768.57   1.000000   320.0000
   .000196     5095.88   1.000000   310.0000
   .000020    49314.97   1.000000   300.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
5 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM  3AD

INSTALLED CAPACITY  500.0000 MW
DAYS 365.0
NO OF LEVELS  17


CAP OUT MW  CUM PROB   IND PROB
     .0000  1.000000   .770044
   10.0000   .229956   .155564
   20.0000   .074392   .014928
   30.0000   .059464   .000906
   40.0000   .058558   .000039
   50.0000   .058519   .046669
   60.0000   .011850   .009428
   70.0000   .002422   .000905
   80.0000   .001517   .000055
   90.0000   .001462   .000002
  100.0000   .001460   .001179
  110.0000   .000281   .000238
  120.0000   .000043   .000023
  130.0000   .000020   .000001
  140.0000   .000019   .000000
  150.0000   .000019   .000017
  160.0000   .000002   .000002


    DOUT         YOUT        RIND     LOAD MW
  6.083137        .16     .999079   500.0000
  3.352390        .30     .999423   490.0000
  2.479414        .40     .999639   480.0000
  1.762510        .57     .999803   470.0000
  1.026419        .97     .999914   460.0000
   .258136       3.87     .999967   450.0000
   .100167       9.98     .999982   440.0000
   .068232      14.66     .999989   430.0000
   .047884      20.88     .999994   420.0000
   .027360      36.55     .999997   410.0000
   .005839     171.23     .999999   400.0000
   .001606     622.42     .999999   390.0000
   .000960    1041.10     .999999   380.0000
   .000657    1520.55    1.000000   370.0000
   .000354    2818.00    1.000000   360.0000
   .000034   28767.05    1.000000   350.0000
```

<u>SYSTEM DATA</u>

20 - 10 MW Units   Forced Outage Rate 0.01

6 - 50 MW Units   Forced Outage Rate 0.01

```
SYSTEM  4AD

INSTALLED CAPACITY  550.0000 MW
DAYS 365.0
NO OF LEVELS  17


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000  .762343
   10.0000  .237657  .154009
   20.0000  .083648  .014778
   30.0000  .068870  .000898
   40.0000  .067972  .000038
   50.0000  .067934  .053903
   60.0000  .014031  .010889
   70.0000  .003142  .001045
   80.0000  .002097  .000064
   90.0000  .002033  .000002
  100.0000  .002031  .001634
  110.0000  .000397  .000330
  120.0000  .000067  .000032
  130.0000  .000035  .000001
  140.0000  .000034  .000001
  150.0000  .000033  .000028
  160.0000  .000005  .000005


   DOUT          YOUT        RIND     LOAD MW
  6.083185        .16      .999121   550.0000
  3.518522        .28      .999440   540.0000
  2.624798        .38      .999648   530.0000
  1.869586        .53      .999805   520.0000
  1.095467        .91      .999913   510.0000
   .290844       3.44      .999965   500.0000
   .122585       8.16      .999980   490.0000
   .085318      11.72      .999988   480.0000
   .059992      16.67      .999993   470.0000
   .034410      29.06      .999997   460.0000
   .007719     129.55      .999999   450.0000
   .002405     415.68      .999999   440.0000
   .001513     660.61      .999999   430.0000
   .001042     958.90      .999999   420.0000
   .000563    1773.61     1.000000   410.0000
   .000076   13150.69     1.000000   400.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
7 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM 5AD

INSTALLED CAPACITY  600.0000 MW
DAYS 365.0
NO OF LEVELS  17


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .754720
   10.0000  .245280   .152468
   20.0000  .092812   .014631
   30.0000  .078181   .000889
   40.0000  .077292   .000037
   50.0000  .077255   .060988
   60.0000  .016267   .012320
   70.0000  .003947   .001183
   80.0000  .002764   .000072
   90.0000  .002692   .000002
  100.0000  .002690   .002157
  110.0000  .000533   .000435
  120.0000  .000098   .000042
  130.0000  .000056   .000002
  140.0000  .000054   .000001
  150.0000  .000053   .000044
  160.0000  .000009   .000009


    DOUT          YOUT        RIND     LOAD MW
  6.083165         .16     .999160    600.0000
  3.657252         .27     .999458    590.0000
  2.746848         .36     .999658    580.0000
  1.960650         .51     .999809    570.0000
  1.156031         .87     .999912    560.0000
   .322561        3.10     .999962    550.0000
   .145279        6.08     .999978    540.0000
   .102716        9.74     .999986    530.0000
   .072356       13.82     .999993    520.0000
   .041664       24.00     .999997    510.0000
   .009769      102.36     .999999    500.0000
   .003352      298.33     .999999    490.0000
   .002179      458.74     .999999    480.0000
   .001501      666.04     .999999    470.0000
   .000619     1219.62    1.000000    460.0000
   .000121     8219.15    1.000000    450.0000
```

SYSTEM DATA

20 - 10 MW Units	Forced Outage Rate 0.01
8 - 50 MW Units	Forced Outage Rate 0.01

```
SYSTEM 6AD

INSTALLED CAPACITY  650.0000 MW
DAYS 365.0
NO OF LEVELS  17

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .747173
   10.0000   .252827  .150943
   20.0000   .101884  .014485
   30.0000   .087399  .000879
   40.0000   .086520  .000038
   50.0000   .086482  .067924
   60.0000   .018558  .013723
   70.0000   .004835  .001316
   80.0000   .003519  .000081
   90.0000   .003438  .000003
  100.0000   .003435  .002744
  110.0000   .000691  .000555
  120.0000   .000136  .000053
  130.0000   .000083  .000003
  140.0000   .000080  .000000
  150.0000   .000080  .000066
  160.0000   .000014  .000014

    DOUT        YOUT      RIND     LOAD MW
  6.083162        .16   .999197  650.0000
  3.775030        .26   .999476  640.0000
  2.851154        .35   .999667  630.0000
  2.039596        .49   .999812  620.0000
  1.210196        .83   .999911  610.0000
   .353533       2.83   .999960  600.0000
   .168178       5.95   .999976  590.0000
   .110366       8.31   .999985  580.0000
   .054921      11.78   .999992  570.0000
   .019090      20.37   .999996  560.0000
   .011989      83.40   .999998  550.0000
   .004427     225.87   .999999  540.0000
   .002949     339.00   .999999  530.0000
   .002035     491.26   .999999  520.0000
   .001121     891.87  1.000000  510.0000
   .000170    5870.84  1.000000  500.0000
```

SYSTEM DATA

20 - 10 MW Units — Forced Outage Rate 0.01

9 - 50 MW Units — Forced Outage Rate 0.01

```
SYSTEM  7AD

INSTALLED CAPACITY  700.0000 MW
DAYS 365.0
NO OF LEVELS  18

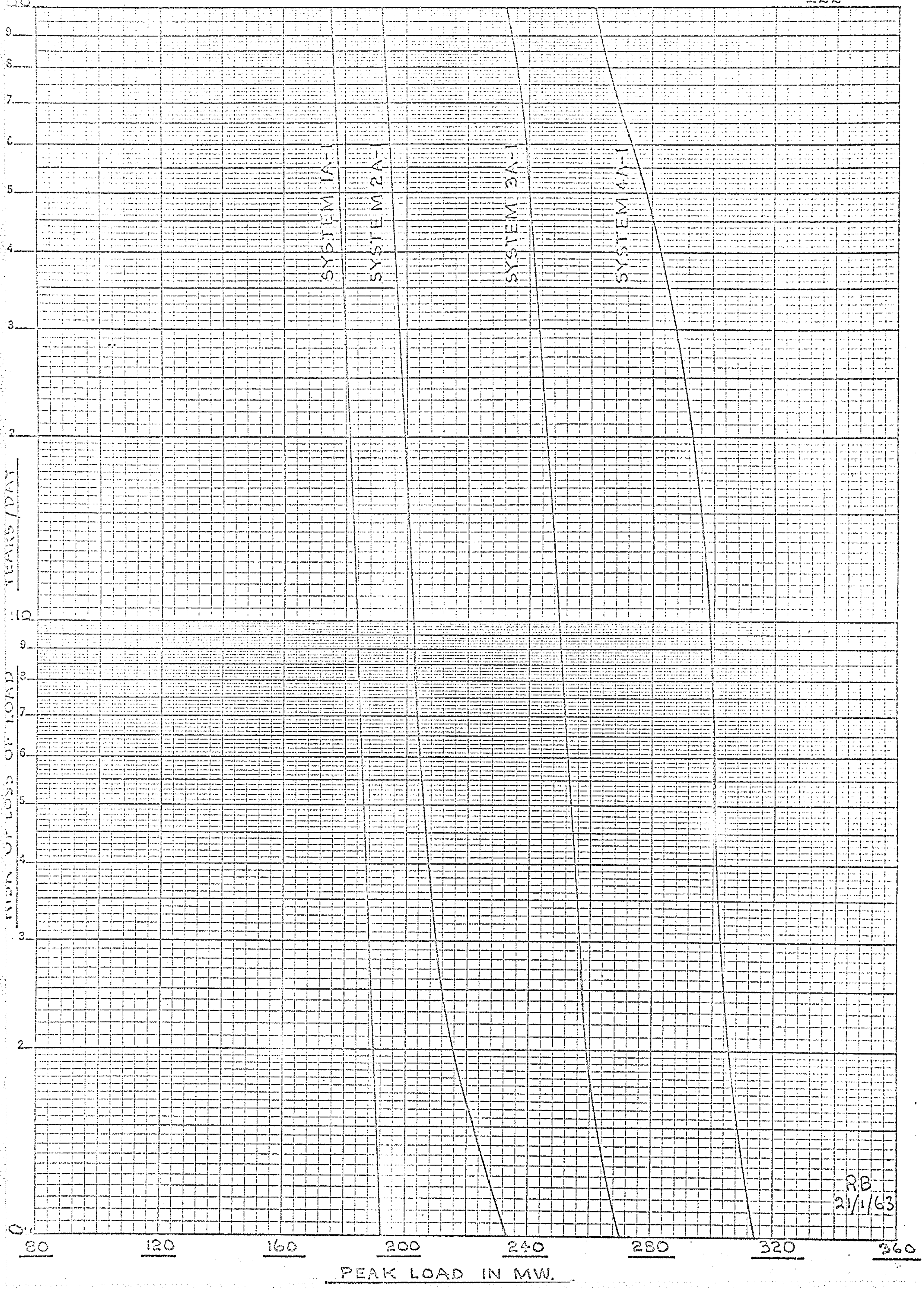

CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .739701
   10.0000   .260299   .149434
   20.0000   .110865   .014340
   30.0000   .096525   .000871
   40.0000   .095654   .000037
   50.0000   .095617   .074717
   60.0000   .020900   .015094
   70.0000   .005806   .001449
   80.0000   .004357   .000088
   90.0000   .004269   .000003
  100.0000   .004266   .003397
  110.0000   .000869   .000686
  120.0000   .000183   .000066
  130.0000   .000117   .000004
  140.0000   .000113   .000000
  150.0000   .000113   .000092
  160.0000   .000021   .000020
  170.0000   .000001   .000001


   DOUT         YOUT      RIND     LOAD MW
 6.083123         .16   .999231   700.0000
 3.876374         .26   .999494   690.0000
 2.141572         .34   .999677   680.0000
 2.109067         .47   .999816   670.0000
 1.259364         .79   .999911   660.0000
  .333859        2.61   .999958   650.0000
  .191197        5.23   .999975   640.0000
  .138169        7.24   .999984   630.0000
  .097647       10.24   .999991   620.0000
  .056674       17.64   .999996   610.0000
  .014366       69.60   .999998   600.0000
  .005650      176.98   .999999   590.0000
  .003828      261.21   .999999   580.0000
  .002646      377.82   .999999   570.0000
  .001466      681.89  1.000000   560.0000
  .000243     4109.57  1.000000   550.0000
  .000011    88766.73  1.000000   540.0000
```

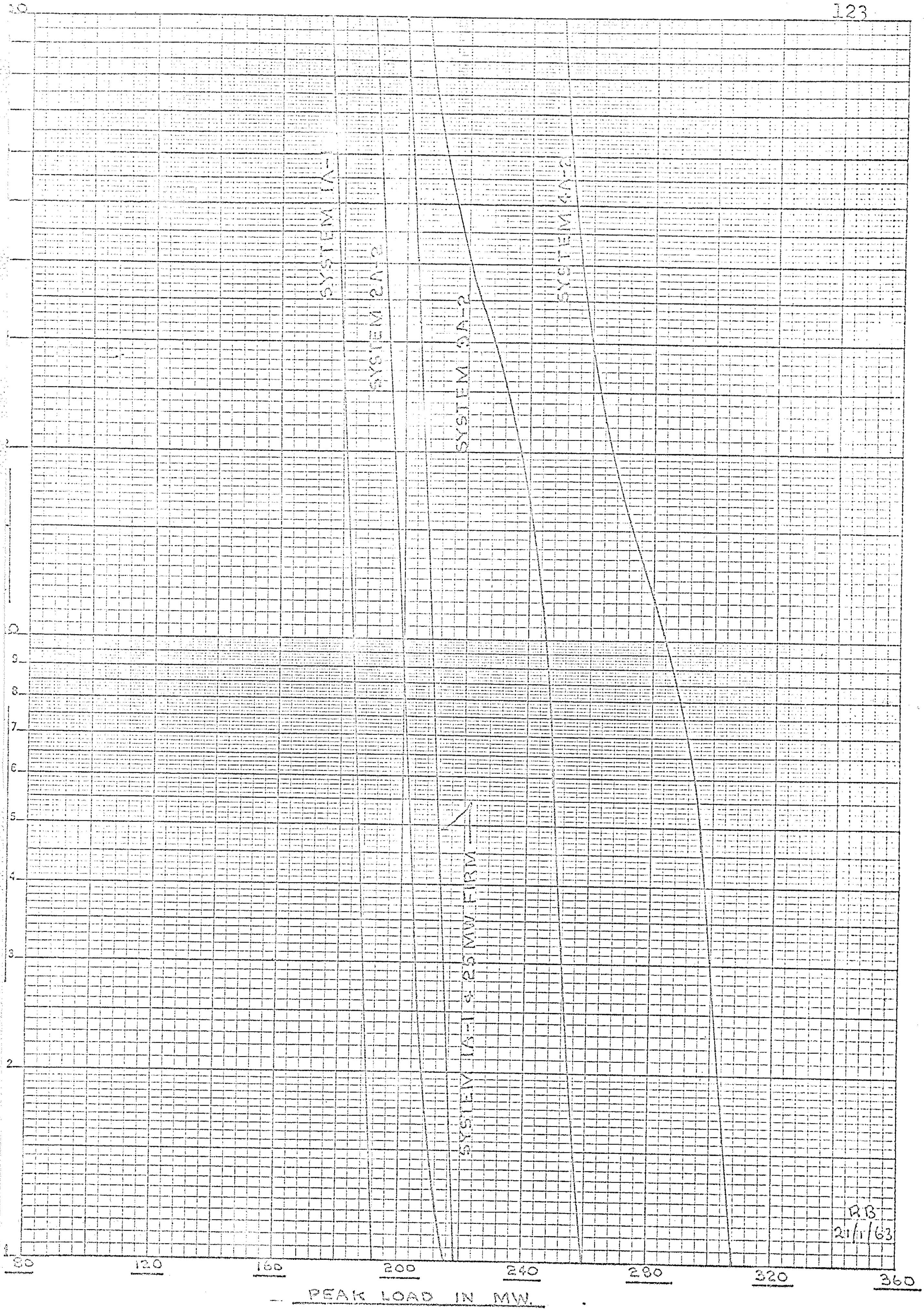
SYSTEM DATA

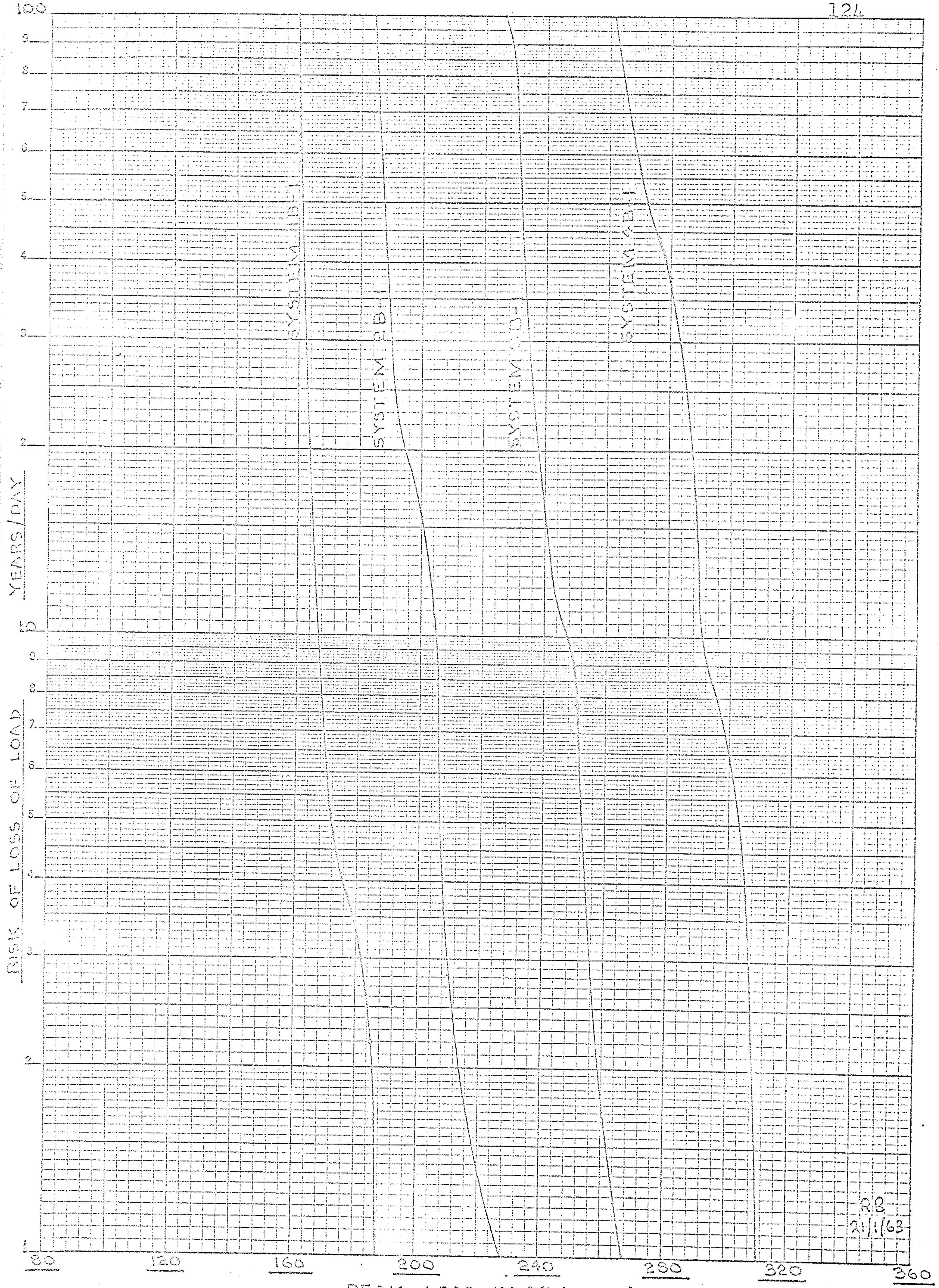
20 - 10 MW Units   Forced Outage Rate 0.01

10 - 50 MW Units   Forced Outage Rate 0.01

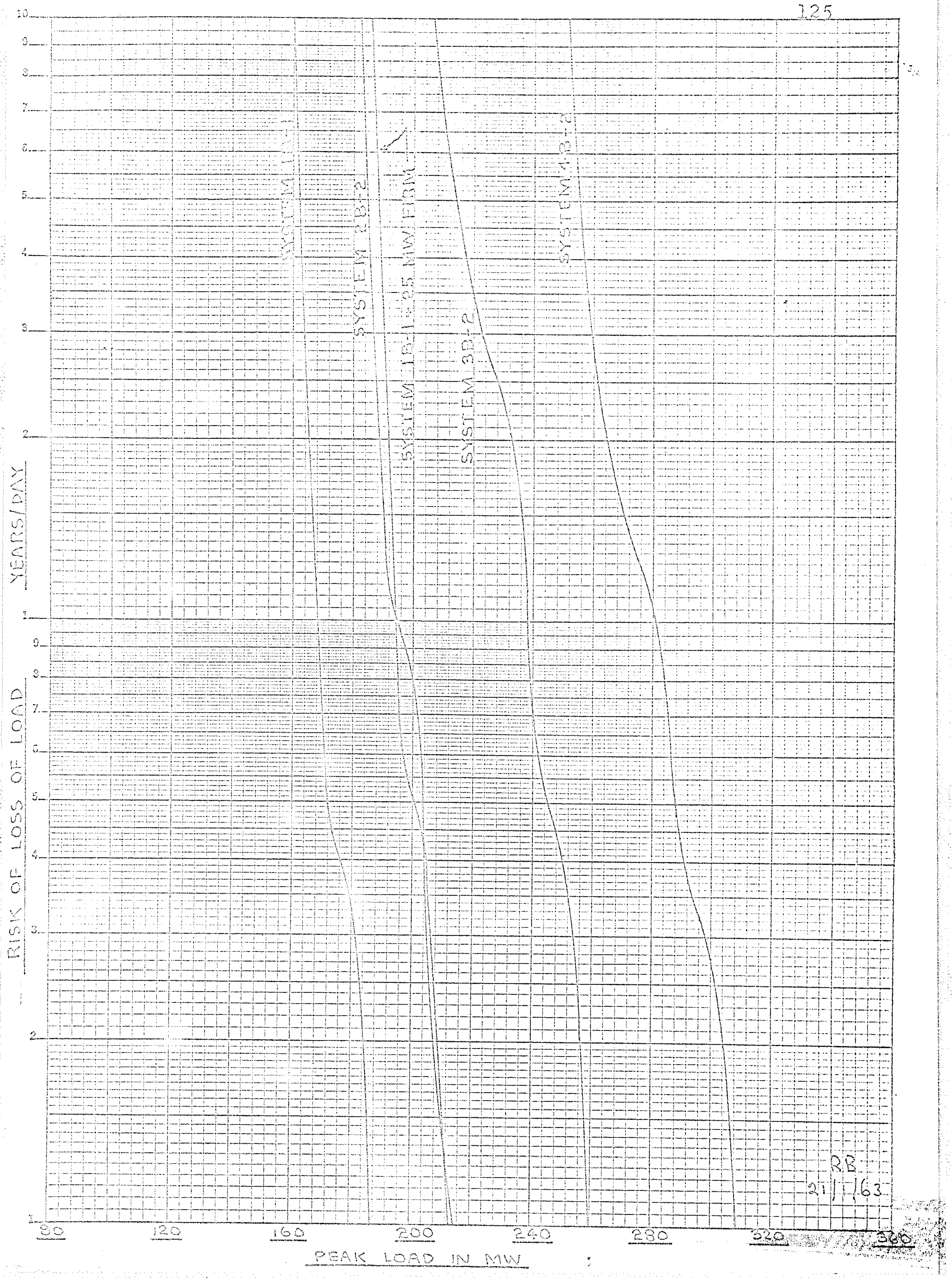

SYSTEM 1A-1
SYSTEM 2A-1
SYSTEM 3A-1
SYSTEM 4A-1
INDEX OF LOSS OF LOAD YEARS/DAY
10
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
0
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.

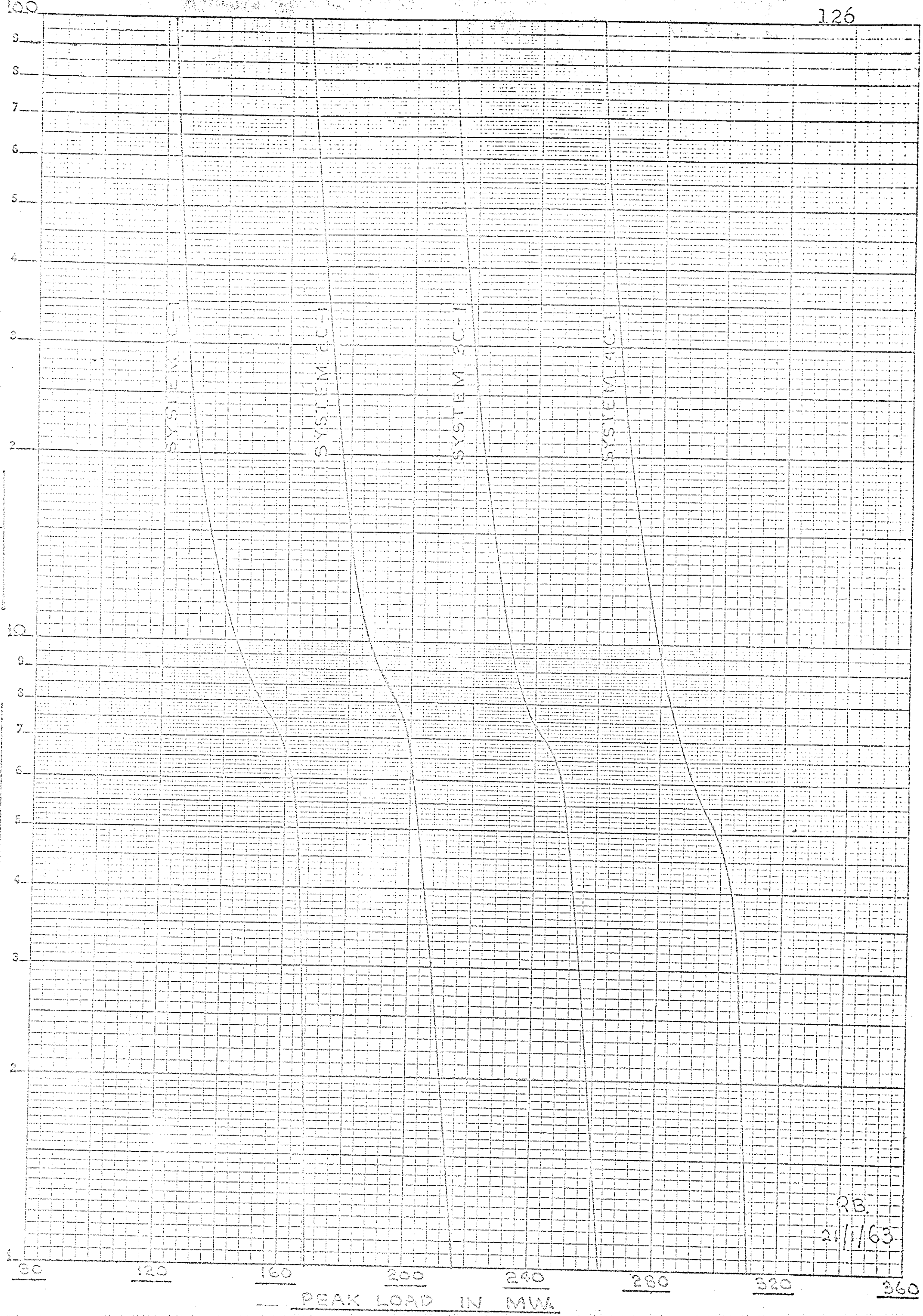
RB
21/1/63

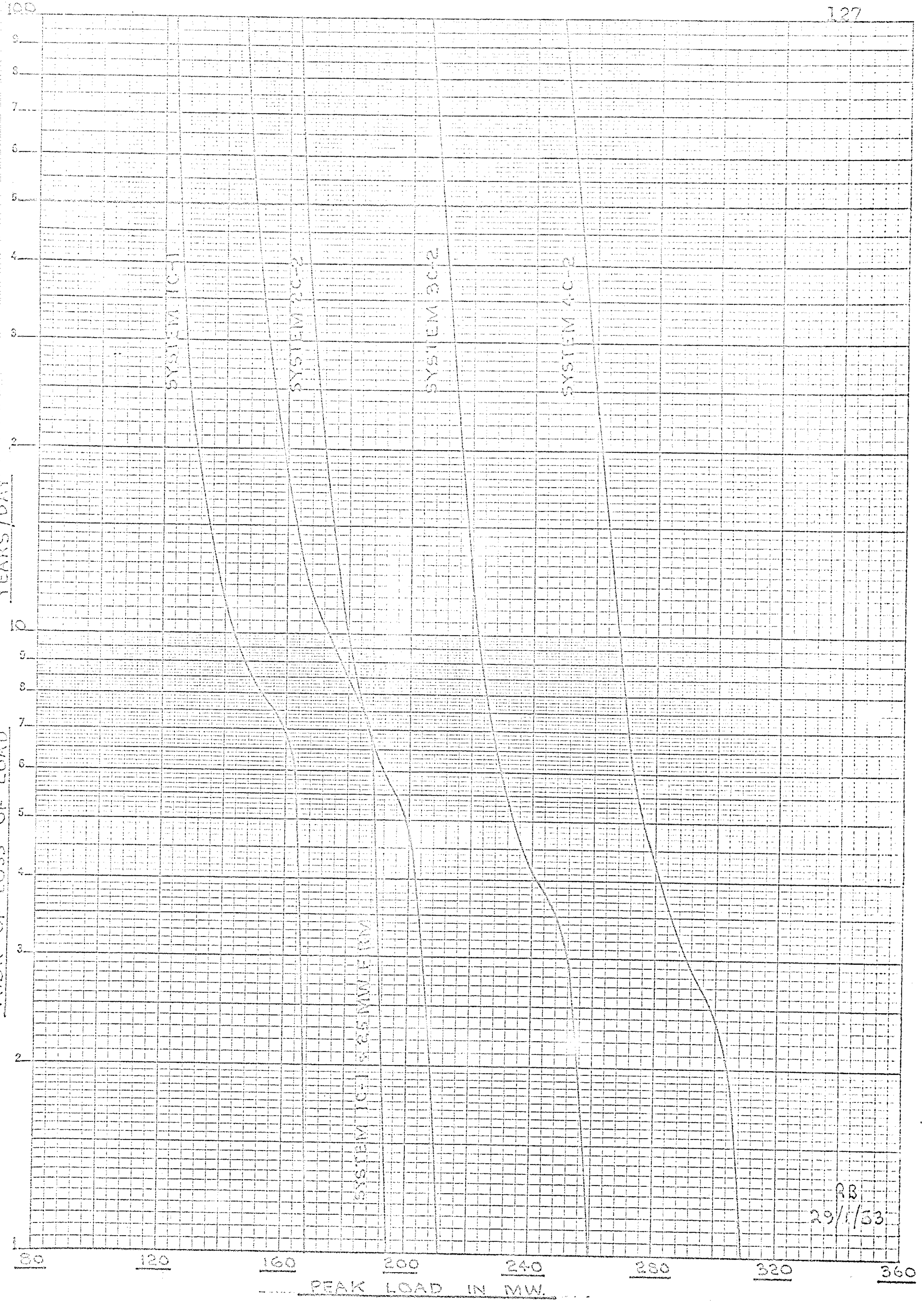

10
10
9
8
7
6
5
4
3
2
1
SYSTEM 1A-1
SYSTEM 2A-2
SYSTEM 3A-2
SYSTEM 4A-2
SYSTEM 1A-1 + 25 MW FIRM
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.
RB
21/1/63


100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD
YEARS/DAY
SYSTEM 1B-1
SYSTEM 2B-1
SYSTEM 3B-
SYSTEM 4B-1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.

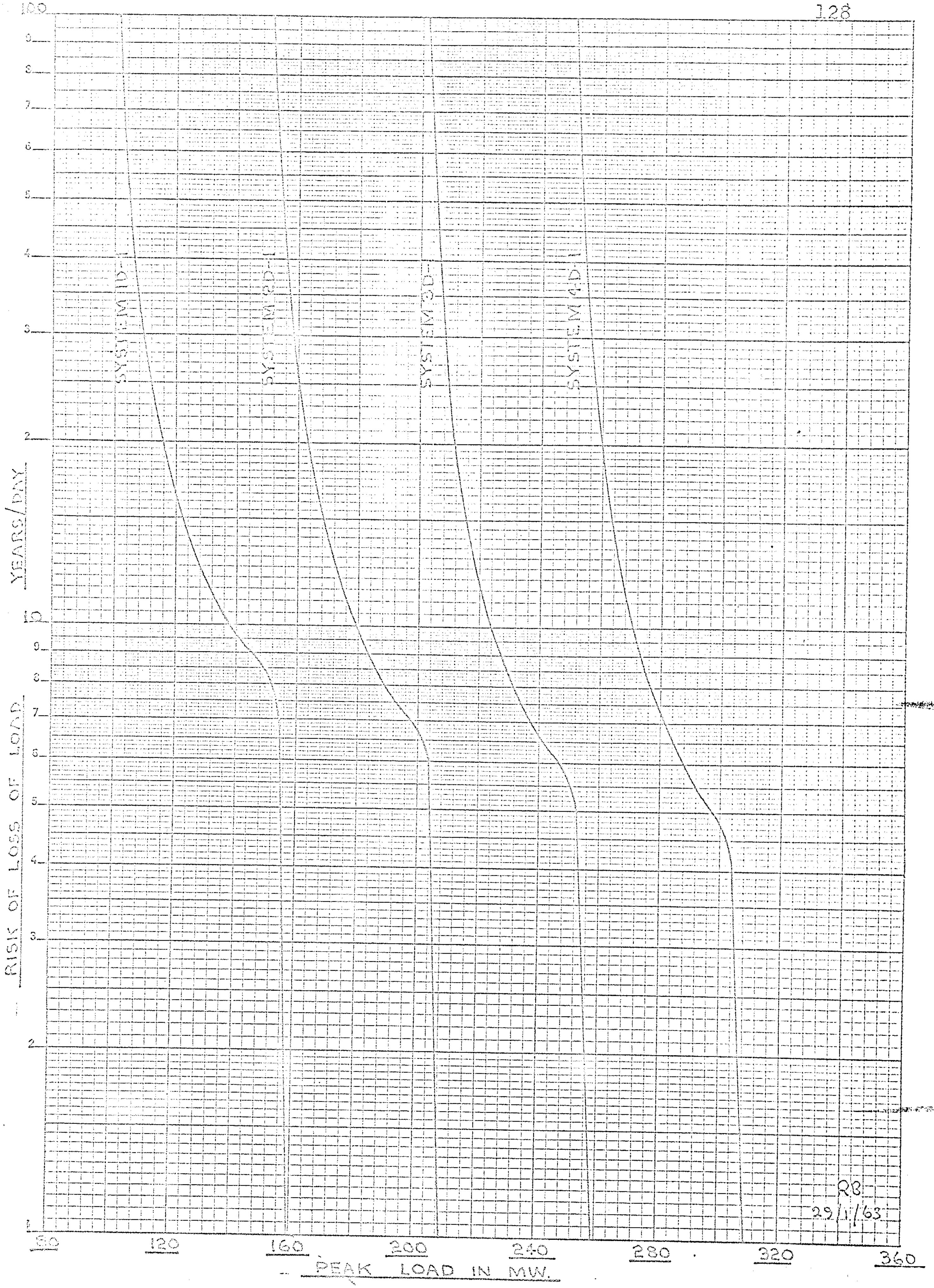
RB
21/1/63


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD YEARS/DAY
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
SYSTEM 1B-1
SYSTEM 2B-2
SYSTEM 1B-1 + 25 MW FIRM
SYSTEM 3B-2
SYSTEM 4B-2
RB
21/1/63

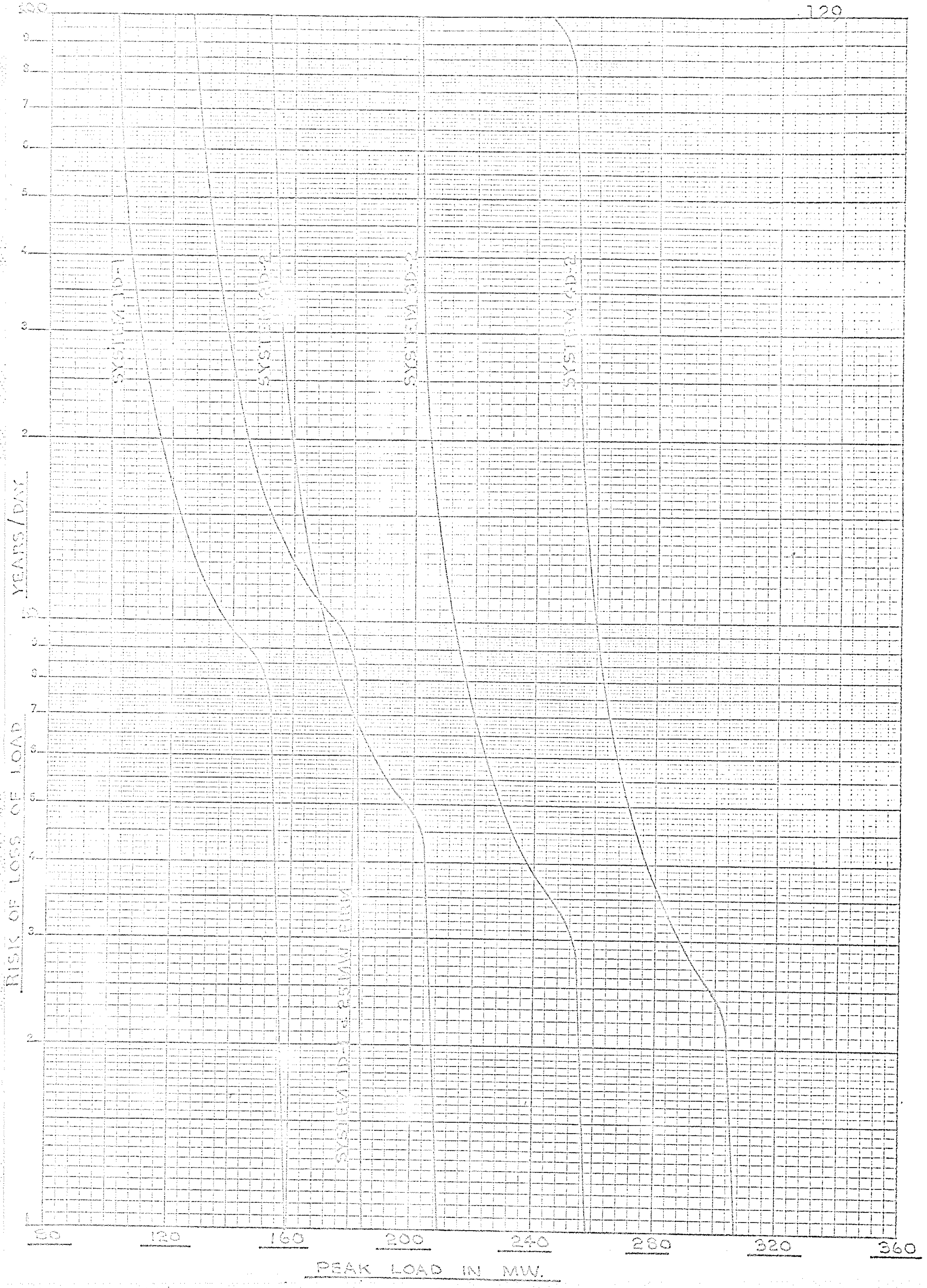

100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
SYSTEM 1C-1
SYSTEM 2C-1
SYSTEM 3C-1
SYSTEM 4C-1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.
R.B.
21/1/63.

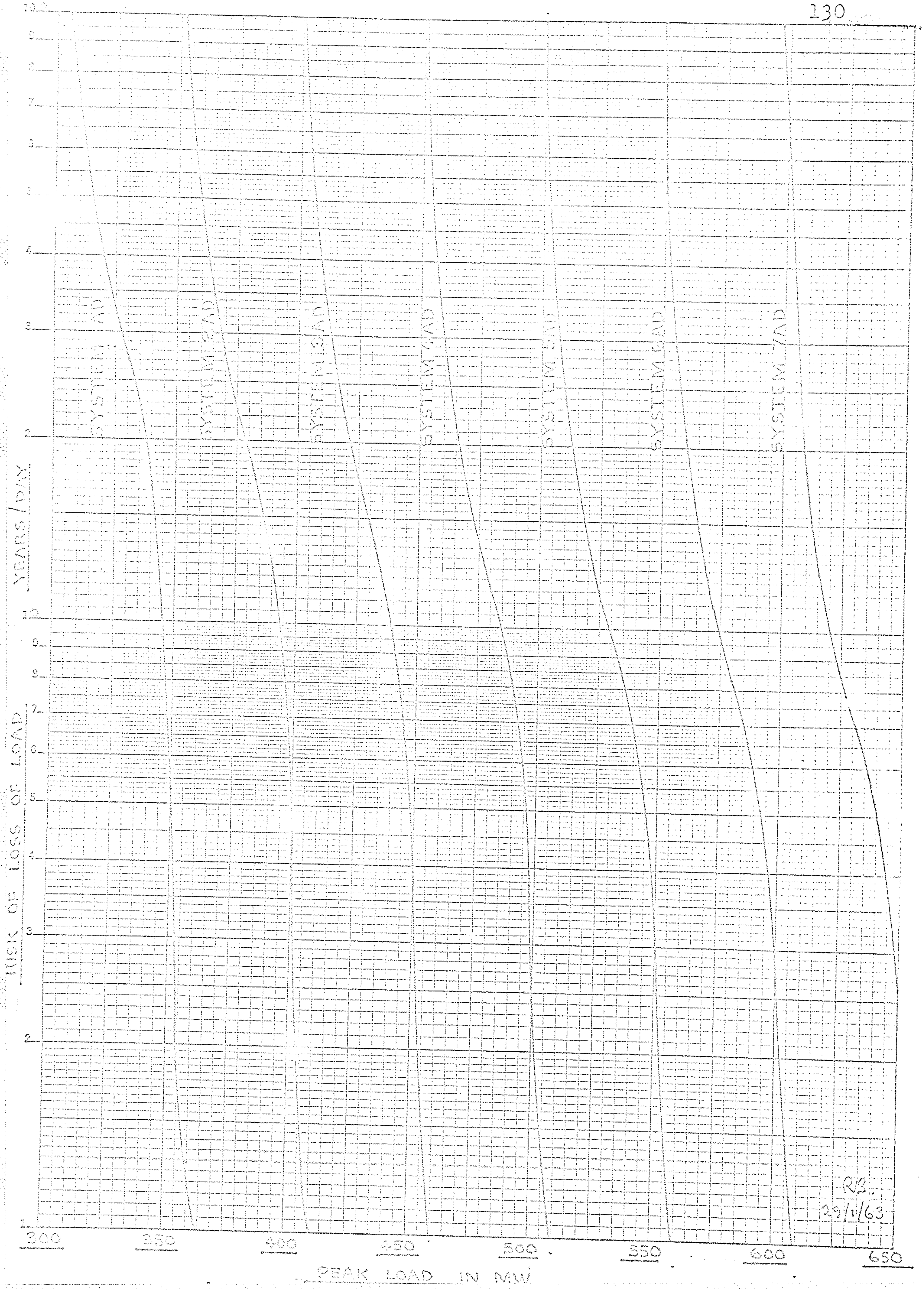

100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD YEARS/DAY
SYSTEM 1C-1
SYSTEM 2C-2
SYSTEM 3C-2
SYSTEM 4-C-2
SYSTEM 1C-1 + 25 MW F RM
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.

RB
29/1/53

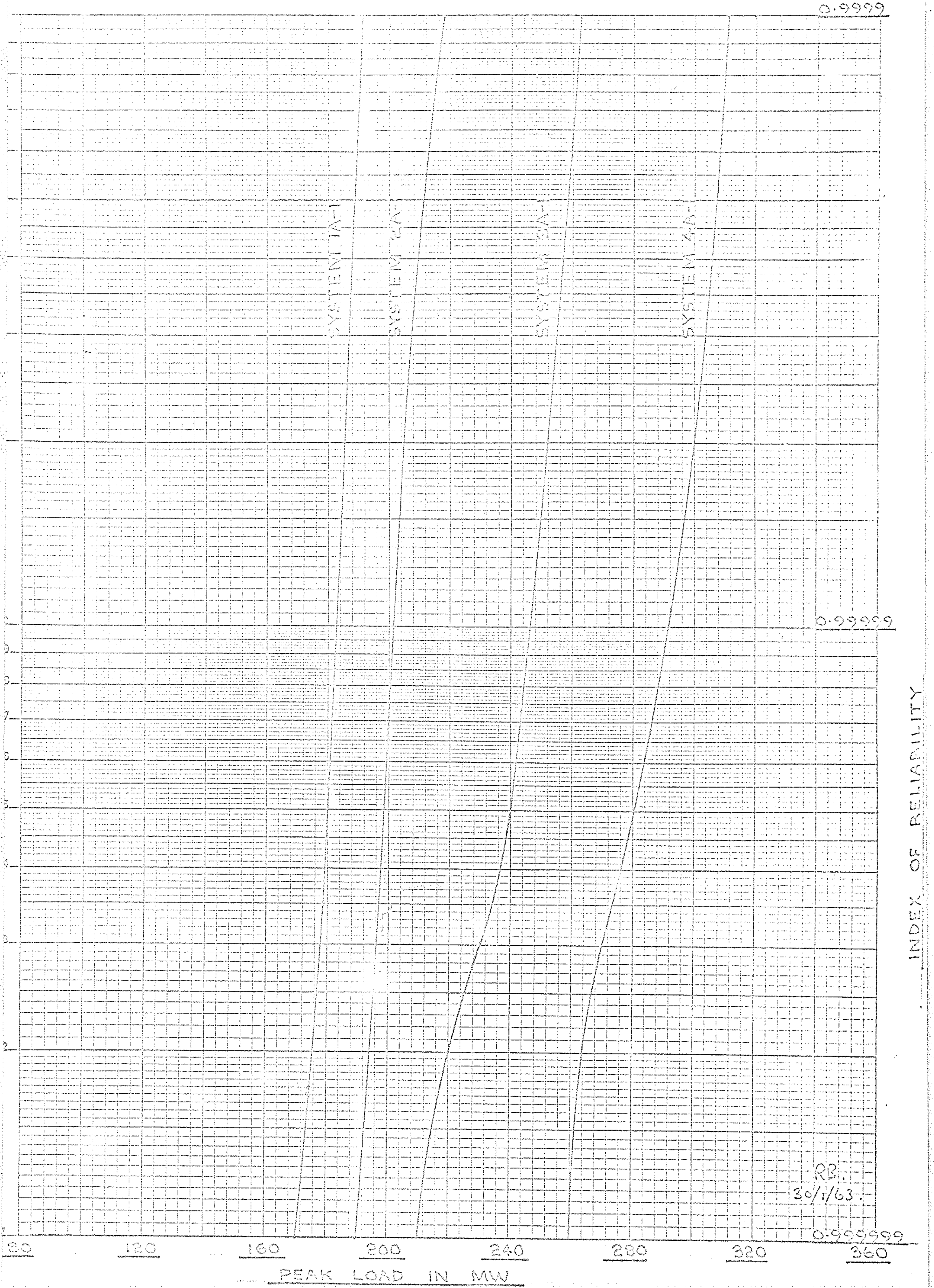

100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD YEARS/DAY
SYSTEM 1D-1
SYSTEM 2D-1
SYSTEM 3D-1
SYSTEM 4D-1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.

RB
29/1/63

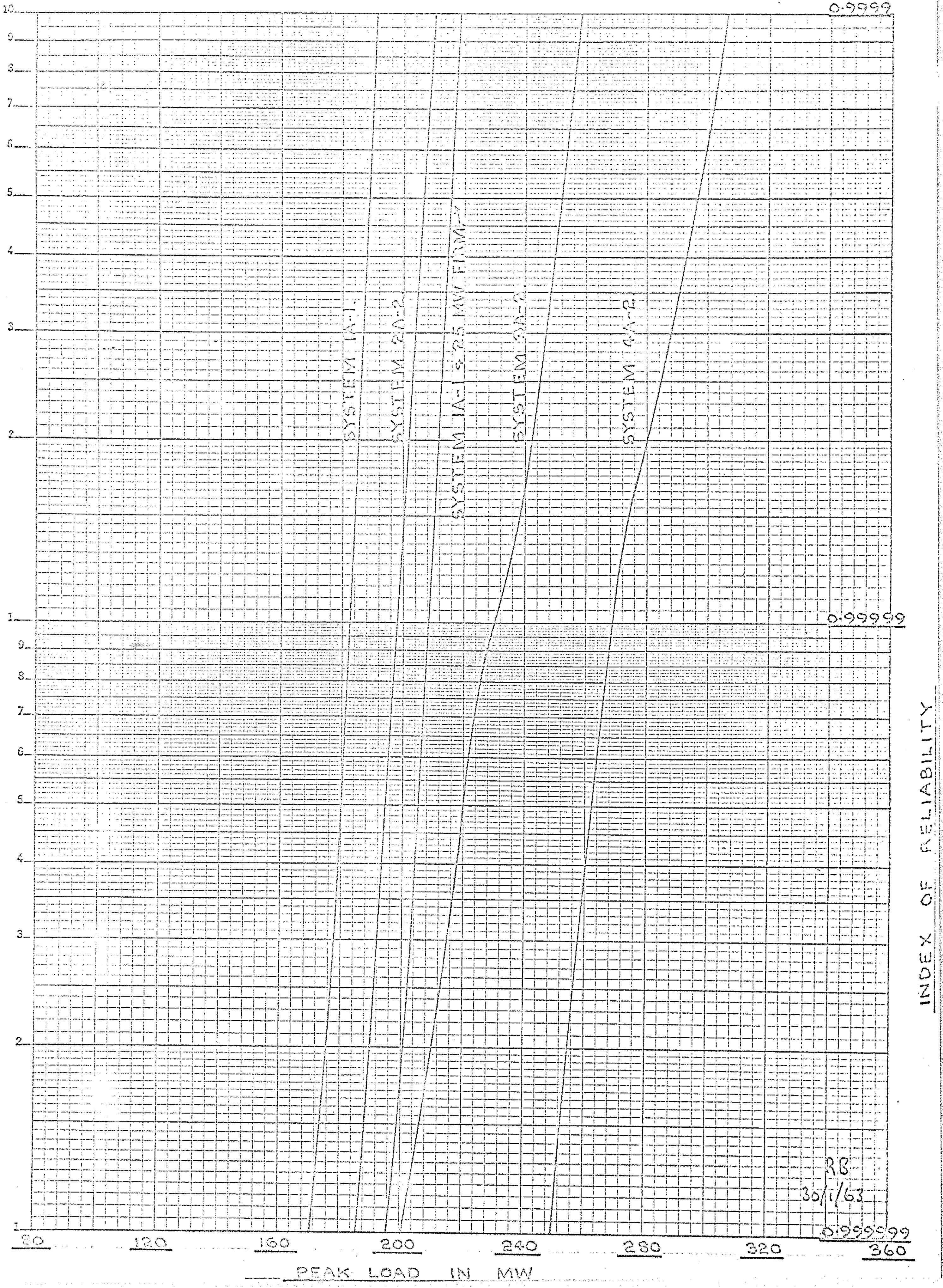

100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD YEARS/DAY
80
120
160
200
240
280
320
360
PEAK LOAD IN MW.
SYSTEM 1D-1
SYSTEM 2D-2
SYSTEM 3D-2
SYSTEM 4D-2
SYSTEM 1D-1 & 25MW FIRM


100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD YEARS / DAY
SYSTEM AD
SYSTEM 2AD
SYSTEM 3AD
SYSTEM 4AD
SYSTEM 5AD
SYSTEM 6AD
SYSTEM 7AD
300
350
400
450
500
550
600
650
PEAK LOAD IN MW

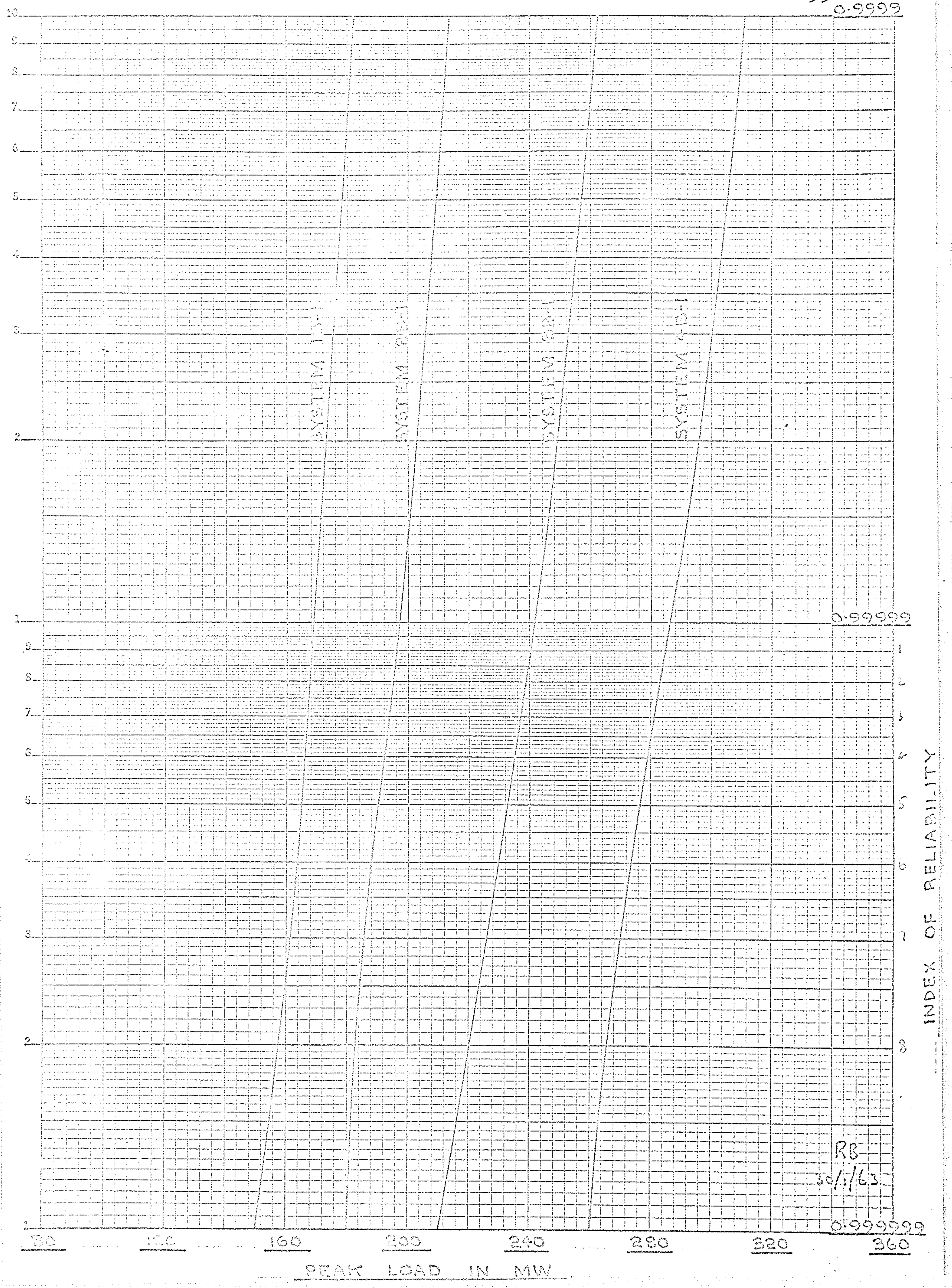
RB.
29/1/63

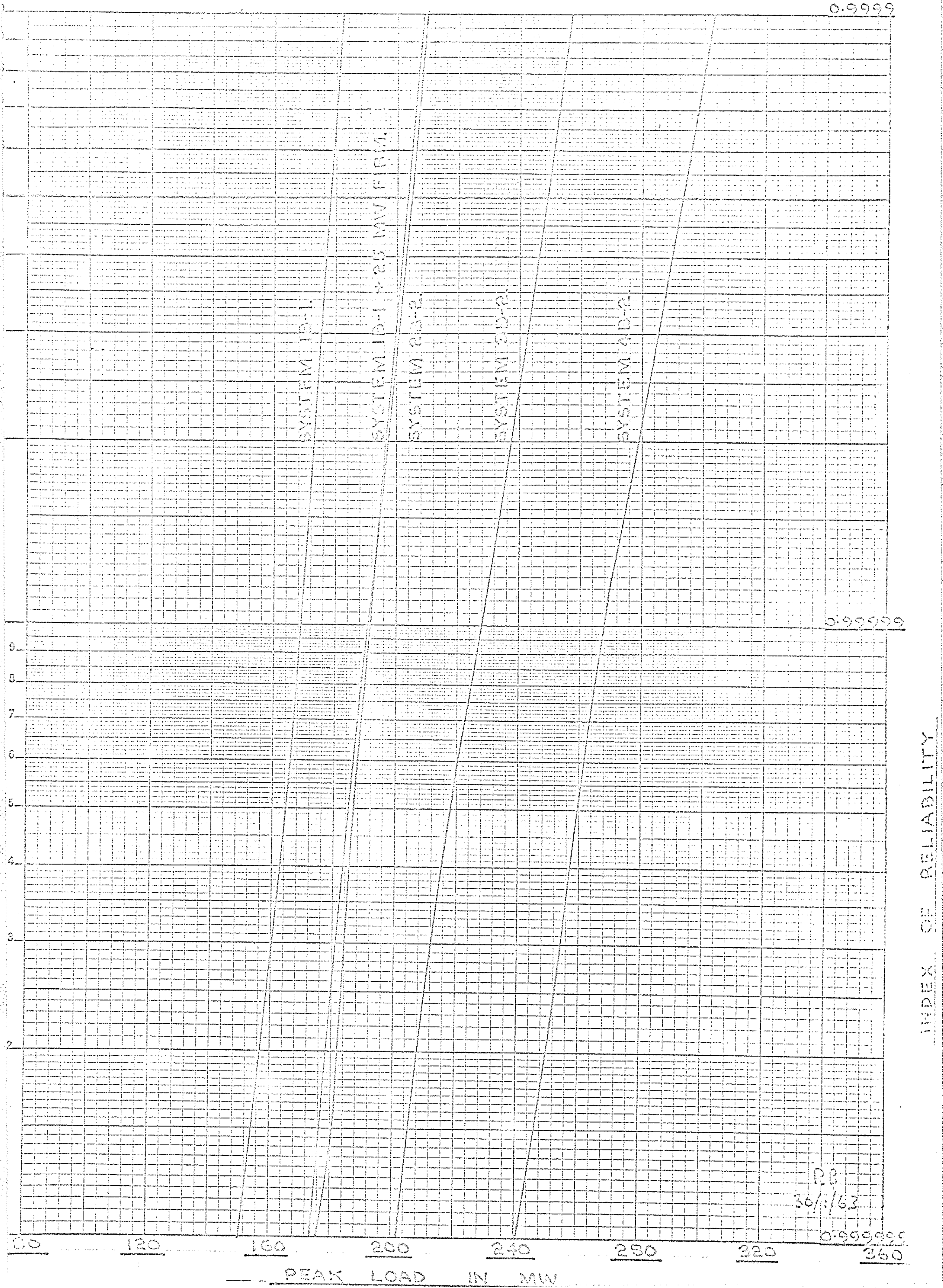

0.9999
0.99999
0.999999
9
8
7
6
5
4
3
2
SYSTEM 1A-1
SYSTEM 2A-1
SYSTEM 3A-1
SYSTEM 4A-1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
INDEX OF RELIABILITY

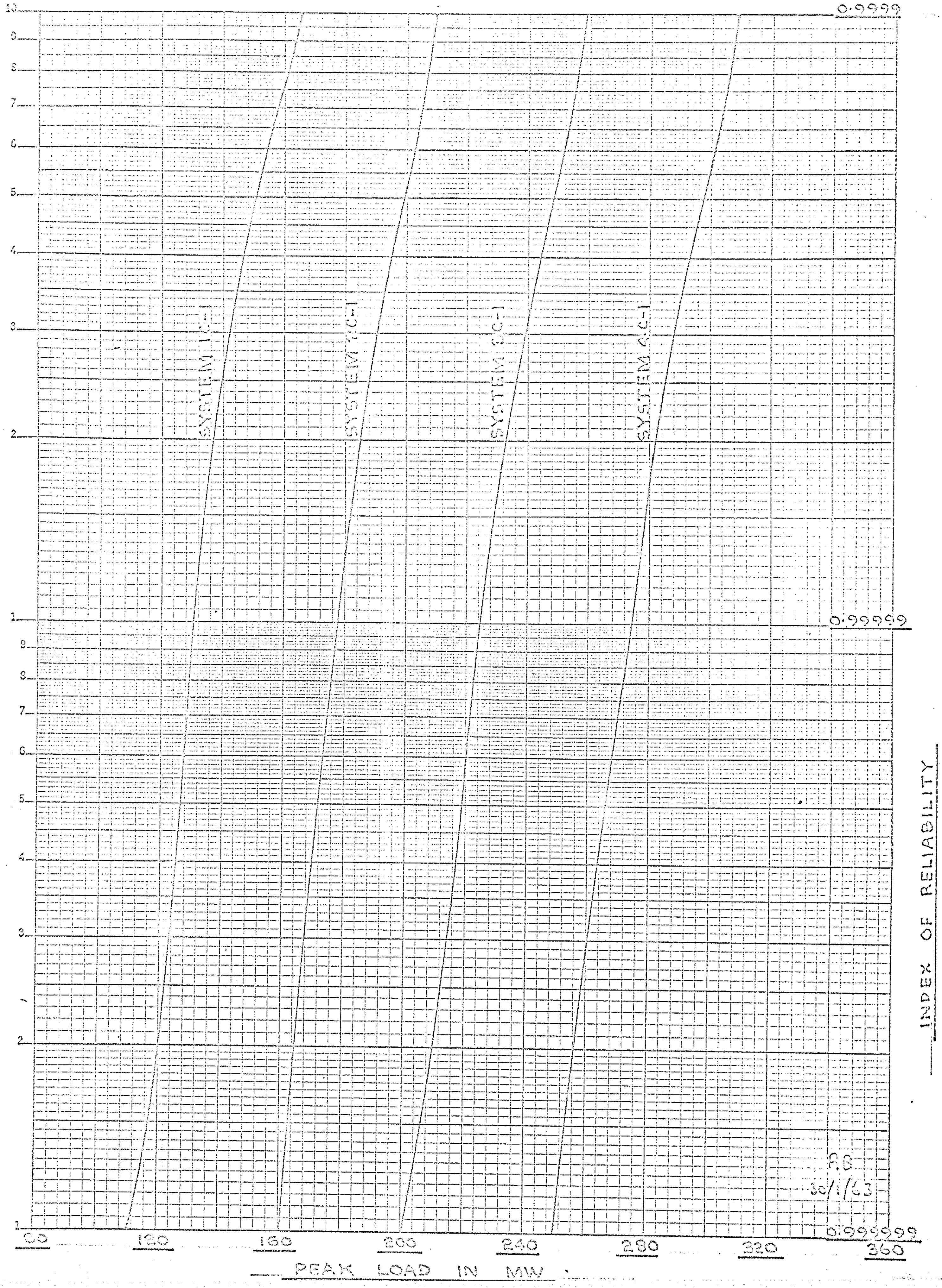
RB.
30/1/63


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
0.9999
0.99999
0.999999
INDEX OF RELIABILITY
SYSTEM IA-1
SYSTEM 2A-2
SYSTEM IA-1 + 25 MW FIRM
SYSTEM 3A-2
SYSTEM 4A-2
80
120
160
200
240
280
320
360
PEAK LOAD IN MW

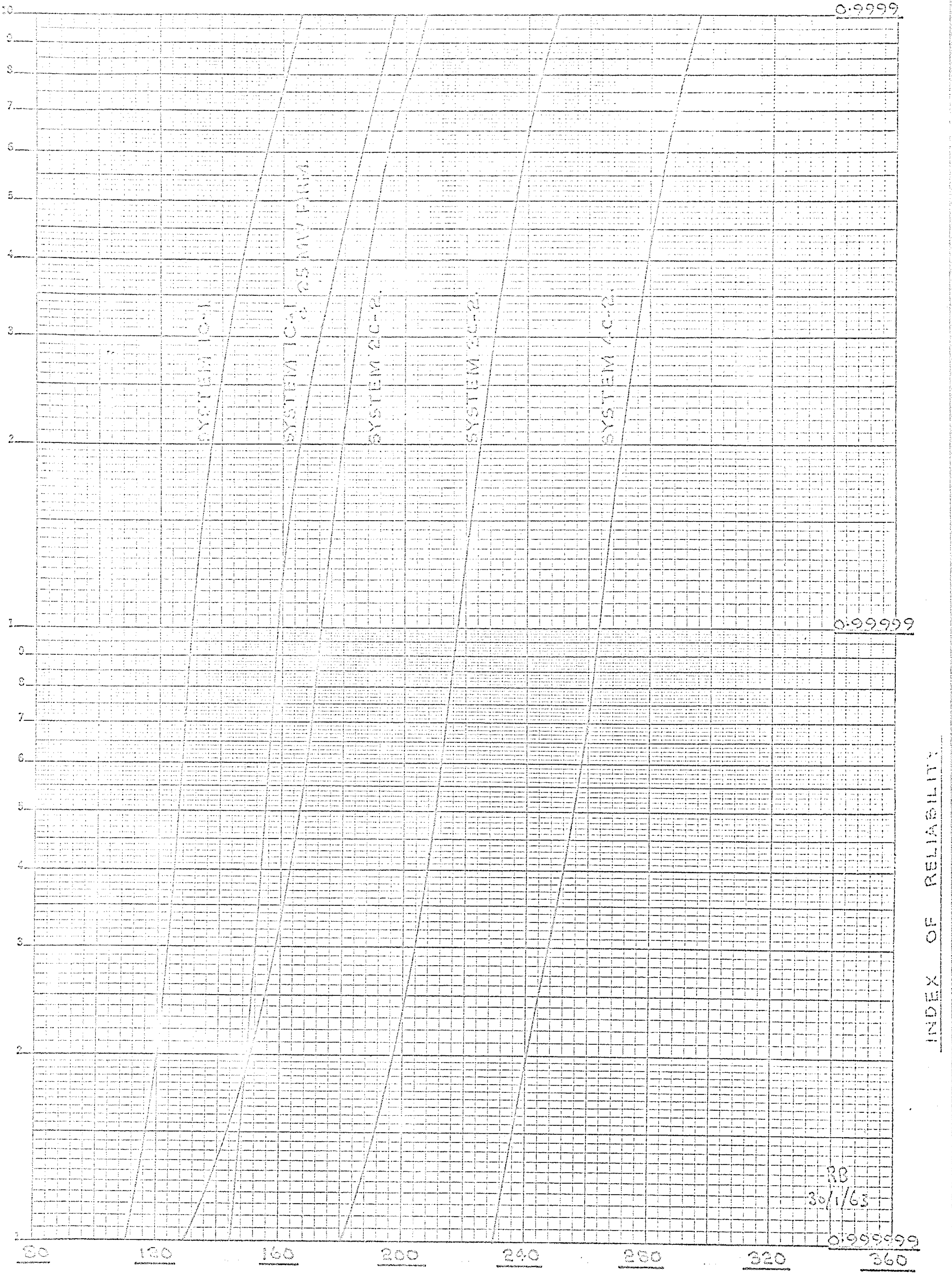
RB
30/1/63

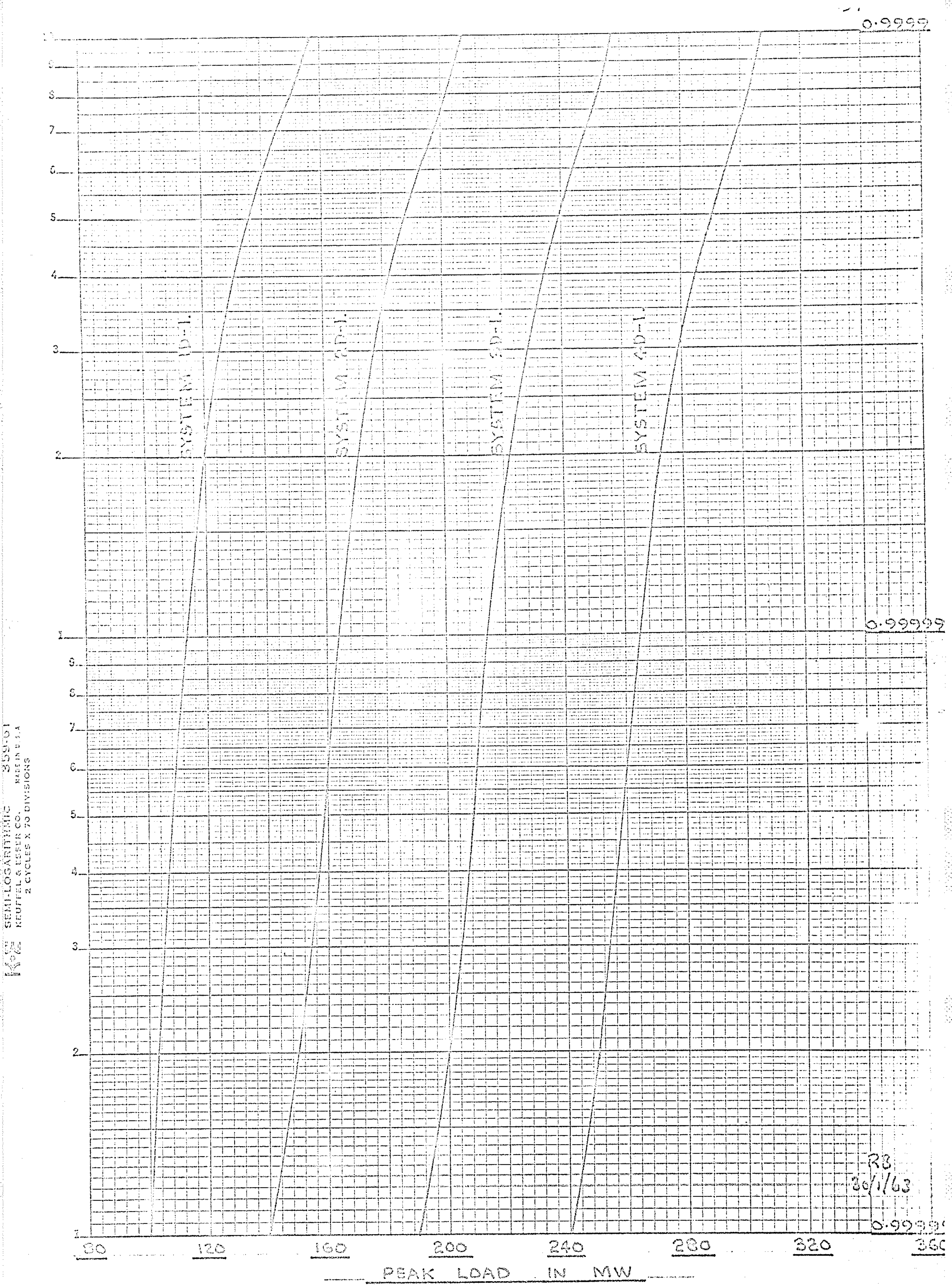

0.9999
0.99999
0.999999
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
SYSTEM 1B-1
SYSTEM 2B-1
SYSTEM 3B-1
SYSTEM 4B-1
INDEX OF RELIABILITY
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
RB
30/1/63


0.9999
SYSTEM 1B-1.
SYSTEM 1B-1 + 25 MW FIRM.
SYSTEM 2B-2.
SYSTEM 3D-2.
SYSTEM 4B-2.
0.99999
9
8
7
6
5
4
3
2
INDEX OF RELIABILITY
R.B.
30/1/63
0.999999
80
120
160
200
240
280
320
360
PEAK LOAD IN MW

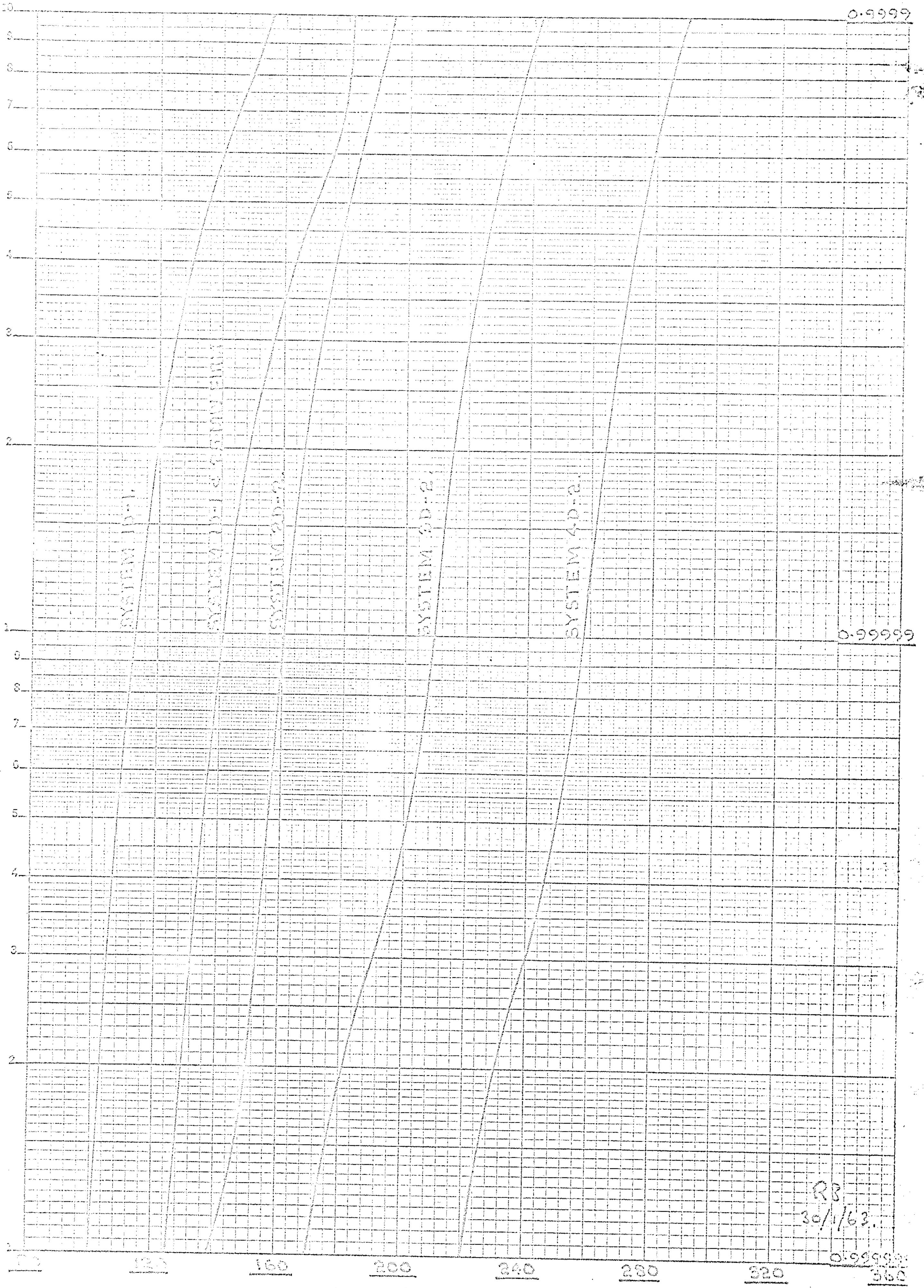

0·9999
0·99999
0·999999
SYSTEM 1 C-1
SYSTEM 2 C-1
SYSTEM 3 C-1
SYSTEM 4 C-1
10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
INDEX OF RELIABILITY

A.B
30/1/63

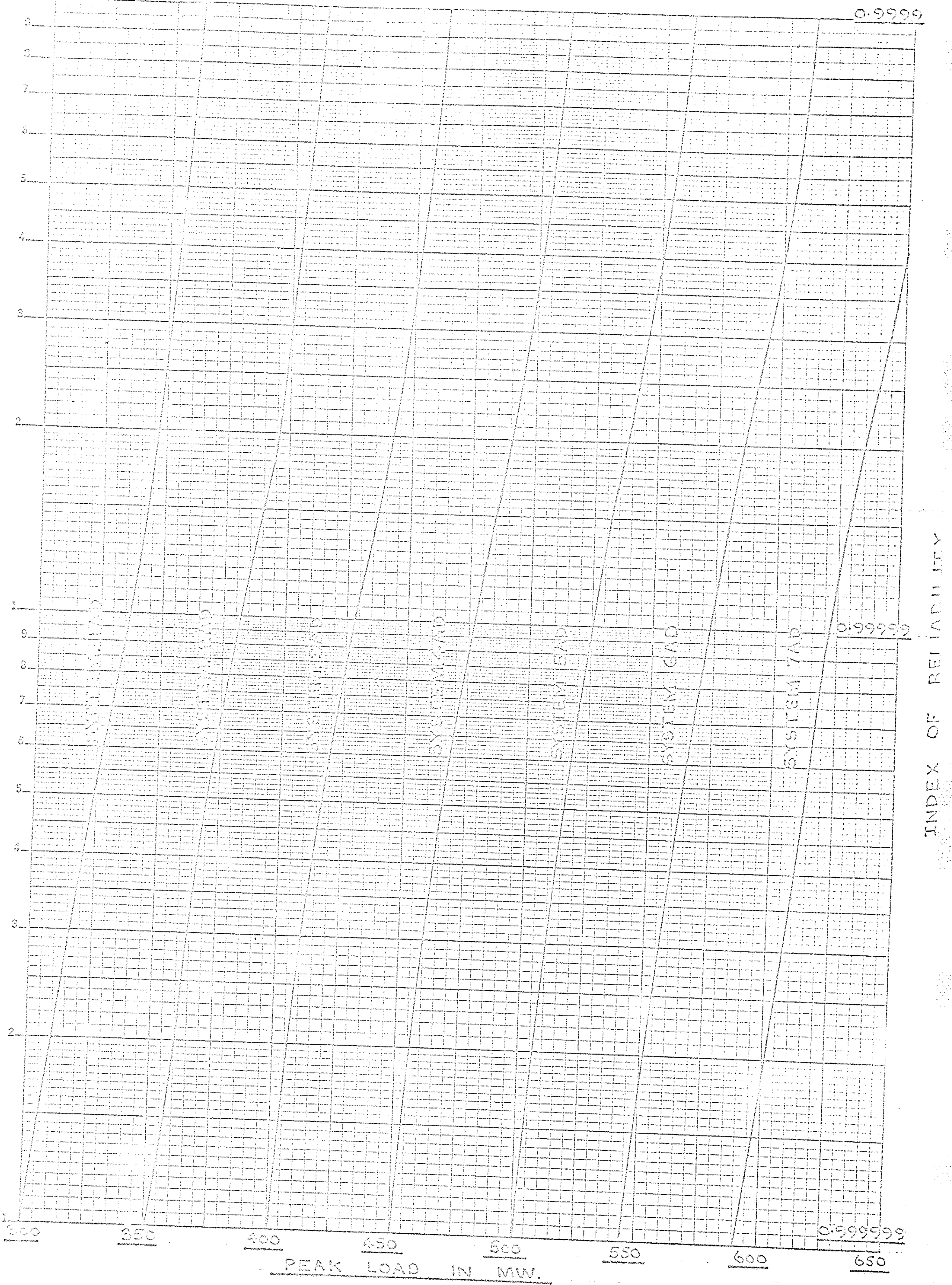

0·9999
0·99999
0·999999
10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
SYSTEM 1C-1
SYSTEM 1C-1 + 25 MW FARM
SYSTEM 2C-2
SYSTEM 3C-2
SYSTEM 4C-2
INDEX OF RELIABILITY
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
RB
30/1/63


0.9999
SYSTEM 1D-1.
SYSTEM 2D-1.
SYSTEM 3D-1.
SYSTEM 4D-1.
0.99999
0.9999
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
SEMI-LOGARITHMIC 359-61
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

R3
30/1/63


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
0·9999
0·99999
0·999999
SYSTEM 1D-1.
SYSTEM 1D-1 & [illegible]
SYSTEM 2D-2.
SYSTEM 3D-2.
SYSTEM 4D-2.
80
120
160
200
240
280
320
360
PEAK LOAD IN MW
INDEX OF RELIABILITY.

RB
30/1/63.


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
0.9999
0.99999
0.999999
SYSTEM 1AD
SYSTEM 2AD
SYSTEM 3AD
SYSTEM 4AD
SYSTEM 5AD
SYSTEM 6AD
SYSTEM 7AD
INDEX OF RELIABILITY
300
350
400
450
500
550
600
650
PEAK LOAD IN MW.

APPENDIX B

APPENDIX B

The abbreviations used in the following tables are as follows:

C.S.M. SYSTEM	Combined Southern Manitoba System
G.R.	Grand Rapids
CAP OUT MW	Capacity Out of Service in MW
CUM PROB	Cumulative Probability
IND PROB	Individual Probability
DOUT	Risk in Days per Year
YOUT	Risk in Years per Day
RIND	Index of Reliability

Generating Unit Data for the Combined Southern Manitoba System is given on page 67.

```
G.S.M.SYSTEM


INSTALLED CAPACITY  849.0000 MW
DAYS 365.0
NO OF LEVELS  19


CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000   .643960
   10.0000   .356040   .139120
   20.0000   .216920   .074385
   30.0000   .142535   .080412
   40.0000   .062123   .018120
   50.0000   .044003   .008373
   60.0000   .035630   .023917
   70.0000   .011713   .005244
   80.0000   .006469   .002646
   90.0000   .003823   .002576
  100.0000   .001247   .000582
  110.0000   .000665   .000263
  120.0000   .000402   .000282
  130.0000   .000120   .000063
  140.0000   .000057   .000028
  150.0000   .000029   .000022
  160.0000   .000007   .000004
  170.0000   .000003   .000002
  180.0000   .000001   .000001


    DOUT          YOUT       RIND     LOAD MW
  6.318267         .16    .999453   849.0000
  3.812037         .26    .999678   839.0000
  2.266227         .44    .999815   829.0000
  1.235179         .81    .999895   819.0000
   .783306        1.28    .999941   809.0000
   .458085        2.18    .999970   799.0000
   .189177        5.29    .999986   789.0000
   .100136        9.99    .999993   779.0000
   .050264       19.89    .999996   769.0000
   .020285       49.30    .999998   759.0000
   .010428       95.89    .999999   749.0000
   .005095      196.25    .999999   739.0000
   .001810      552.24    .999999   729.0000
   .000820     1218.47   1.000000   719.0000
   .000343     2913.69   1.000000   709.0000
   .000095    10445.80   1.000000   699.0000
   .000035    28315.05   1.000000   689.0000
   .000008   111615.98   1.000000   679.0000
```

```
C.S.M.SYSTEM & 50 MW FIRM CAPACITY PURCHASE

INSTALLED CAPACITY  899.0000 MW
DAYS 365.0
NO OF LEVELS  19


CAP OUT MW CUM PROB  IND PROB
     .0000 1.000000   .643960
   10.0000   .356040   .139120
   20.0000   .216920   .074305
   30.0000   .142535   .080412
   40.0000   .062123   .018120
   50.0000   .044003   .008373
   60.0000   .035630   .023917
   70.0000   .011713   .005244
   80.0000   .006469   .002646
   90.0000   .003823   .002576
  100.0000   .001247   .000582
  110.0000   .000665   .000263
  120.0000   .000402   .000282
  130.0000   .000120   .000063
  140.0000   .000057   .000028
  150.0000   .000029   .000022
  160.0000   .000007   .000004
  170.0000   .000003   .000002
  180.0000   .000001   .000001


   DOUT         YOUT       RIND    LOAD MW
 5.966064         .17   .999512  899.0000
 3.597633         .28   .999713  889.0000
 2.137315         .47   .999835  879.0000
 1.164109         .86   .999906  869.0000
  .737712        1.36   .999948  859.0000
  .431107        2.32   .999974  849.0000
  .177903        5.62   .999987  839.0000
  .094097       10.63   .999994  829.0000
  .047196       21.19   .999997  819.0000
  .019032       52.54   .999998  809.0000
  .009775      102.29   .999999  799.0000
  .004772      209.53   .999999  789.0000
  .001694      590.11   .999999  779.0000
  .000767     1303.20  1.000000  769.0000
  .000320     3119.17  1.000000  759.0000
  .000089    11192.99  1.000000  749.0000
  .000032    30369.86  1.000000  739.0000
  .000008  119834.92  1.000000  729.0000
```

```
C.S.M.SYSTEM & 1 UNIT AT G.R.


INSTALLED CAPACITY  959.0000 MW
DAYS 365.0
NO OF LEVELS  25


CAP OUT IN CUM PROB  IND PROB
      .0000  1.000000   .638808
    10.0000   .361192   .138007
    20.0000   .223185   .073790
    30.0000   .149395   .079769
    40.0000   .069626   .017975
    50.0000   .051651   .008306
    60.0000   .043345   .023726
    70.0000   .019619   .005202
    80.0000   .014417   .002625
    90.0000   .011792   .002555
   100.0000   .009237   .000577
   110.0000   .008660   .005413
   120.0000   .003247   .001393
   130.0000   .001854   .000657
   140.0000   .001197   .000671
   150.0000   .000526   .000167
   160.0000   .000359   .000071
   170.0000   .000288   .000193
   180.0000   .000095   .000043
   190.0000   .000052   .000021
   200.0000   .000031   .000021
   210.0000   .000010   .000005
   220.0000   .000005   .000002
   230.0000   .000003   .000002
   240.0000   .000001   .000001


    DOUT          YOUT         RIND      LOAD MW
  6.151766         .16      .999426   959.0000
  3.901258         .26      .999622   949.0000
  2.496893         .40      .999748   939.0000
  1.545488         .65      .999829   929.0000
  1.101414         .91      .999882   919.0000
   .767867        1.30      .999920   909.0000
   .483100        2.07      .999945   899.0000
   .354284        2.82      .999963   889.0000
   .258538        3.87      .999975   879.0000
   .178965        5.59      .999985   869.0000
   .115633        8.65      .999991   859.0000
   .054943       18.20      .999995   849.0000
   .032055       31.20      .999997   839.0000
   .018837       53.09      .999998   829.0000
   .010176       98.27      .999999   819.0000
   .006346      157.57      .999999   809.0000
   .003692      270.81      .999999   799.0000
   .001518      658.37      .999999   789.0000
   .000796     1255.44     1.000000   779.0000
   .000395     2528.21     1.000000   769.0000
   .000152     6566.68     1.000000   759.0000
   .000073    13680.33     1.000000   749.0000
   .000032    30369.86     1.000000   739.0000
   .000008  119834.92     1.000000   729.0000
```

```
C.S.M.SYSTEM & 2 UNITS AT G.R.

INSTALLED CAPACITY 1069.0000 MW
DAYS 365.0
NO OF LEVELS  29

CAP OUT MW CUM PROB  INC PROB
     .0000  1.000000   .633698
   10.0000   .366302   .136903
   20.0000   .229399   .073200
   30.0000   .156199   .079130
   40.0000   .077069   .017831
   50.0000   .059238   .008239
   60.0000   .050999   .023536
   70.0000   .027463   .005160
   80.0000   .022303   .002604
   90.0000   .019699   .002535
  100.0000   .017164   .000573
  110.0000   .016591   .010480
  120.0000   .006111   .002486
  130.0000   .003625   .001243
  140.0000   .002382   .001304
  150.0000   .001078   .000310
  160.0000   .000768   .000137
  170.0000   .000631   .000382
  180.0000   .000249   .000084
  190.0000   .000165   .000042
  200.0000   .000123   .000041
  210.0000   .000082   .000009
  220.0000   .000073   .000045
  230.0000   .000028   .000013
  240.0000   .000015   .000006
  250.0000   .000009   .000005
  260.0000   .000004   .000001
  270.0000   .000003   .000001
  280.0000   .000002   .000002
   DOUT          YOUT       RIND     LOAD MW
 6.019453         .17    .999419 1069.0000
 3.972104         .25    .999594 1059.0000
 2.679845         .37    .999711 1049.0000
 1.790091         .56    .999790 1039.0000
 1.352671         .74    .999846 1029.0000
 1.012299         .99    .999889 1019.0000
  .714856        1.40    .999920 1009.0000
  .554777        1.80    .999944  999.0000
  .425100        2.36    .999962  989.0000
  .305118        3.20    .999976  979.0000
  .200512        4.99    .999983  969.0000
  .097358       10.27    .999991  959.0000
  .059111       16.89    .999995  949.0000
  .036357       27.50    .999996  939.0000
  .021150       47.28    .999998  929.0000
  .014245       70.20    .999998  919.0000
  .009262      107.97    .999999  909.0000
  .005095      196.26    .999999  899.0000
  .003448      289.95    .999999  889.0000
  .002346      426.23    .999999  879.0000
  .001512      661.34    .999999  869.0000
  .000940     1063.77   1.000000  859.0000
  .000437     2287.89   1.000000  849.0000
  .000239     4179.32   1.000000  839.0000
  .000132     7570.75   1.000000  829.0000
  .000066    14958.87   1.000000  819.0000
  .000037    26597.22   1.000000  809.0000
```

```
C.S.M.SYSTEM & 3 UNITS AT G.R.


INSTALLED CAPACITY 1179.0000 MW
DAYS 365.0
NO OF LEVELS  29


CAP OUT MW CUM PROB  IND PROB
     .0000  1.000000   .628631
   10.0000   .371369   .135808
   20.0000   .235561   .072614
   30.0000   .162947   .078498
   40.0000   .084449   .017689
   50.0000   .066760   .008174
   60.0000   .058586   .023348
   70.0000   .035238   .005119
   80.0000   .030119   .002583
   90.0000   .027536   .002515
  100.0000   .025021   .000568
  110.0000   .024453   .015463
  120.0000   .008990   .003561
  130.0000   .005429   .001818
  140.0000   .003611   .001926
  150.0000   .001685   .000449
  160.0000   .001236   .000202
  170.0000   .001034   .000567
  180.0000   .000467   .000125
  190.0000   .000342   .000062
  200.0000   .000280   .000061
  210.0000   .000219   .000014
  220.0000   .000205   .000128
  230.0000   .000077   .000033
  240.0000   .000044   .000015
  250.0000   .000029   .000016
  260.0000   .000013   .000004
  270.0000   .000009   .000002
  280.0000   .000007   .000007


   DOUT          YOUT        RIND     LOAD MW
  5.911601         .17    .999424 1179.0000
  4.029612         .25    .999581 1169.0000
  2.027973         .35    .999690 1159.0000
  1.989866         .50    .999767 1149.0000
  1.556298         .64    .999824 1139.0000
  1.210362         .83    .999870 1129.0000
   .902682        1.11    .999904 1119.0000
   .717520        1.39    .999931 1109.0000
   .557336        1.79    .999953 1099.0000
   .408633        2.45    .999970 1089.0000
   .271354        3.69    .999981 1079.0000
   .134738        7.42    .999988 1069.0000
   .084358       11.85    .999992 1059.0000
   .053608       18.63    .999995 1049.0000
   .033063       30.25    .999996 1039.0000
   .023411       42.69    .999997 1029.0000
   .016271       61.45    .999998 1019.0000
   .010261       98.03    .999999 1009.0000
   .007415      134.06    .999999  999.0000
```

```
.00543        184.12    .999999  989.0000
.003746       266.88    .999999  979.0000
.002410       414.81    .999999  969.0000
.001135       880.69   1.000000  959.0000
.000653      1529.41   1.000000  949.0000
.000375      2661.30   1.000000  939.0000
.000189      5265.94   1.000000  929.0000
.000105      9441.77   1.000000  919.0000
.0000[illegible]    21346.19   1.000000  909.0000
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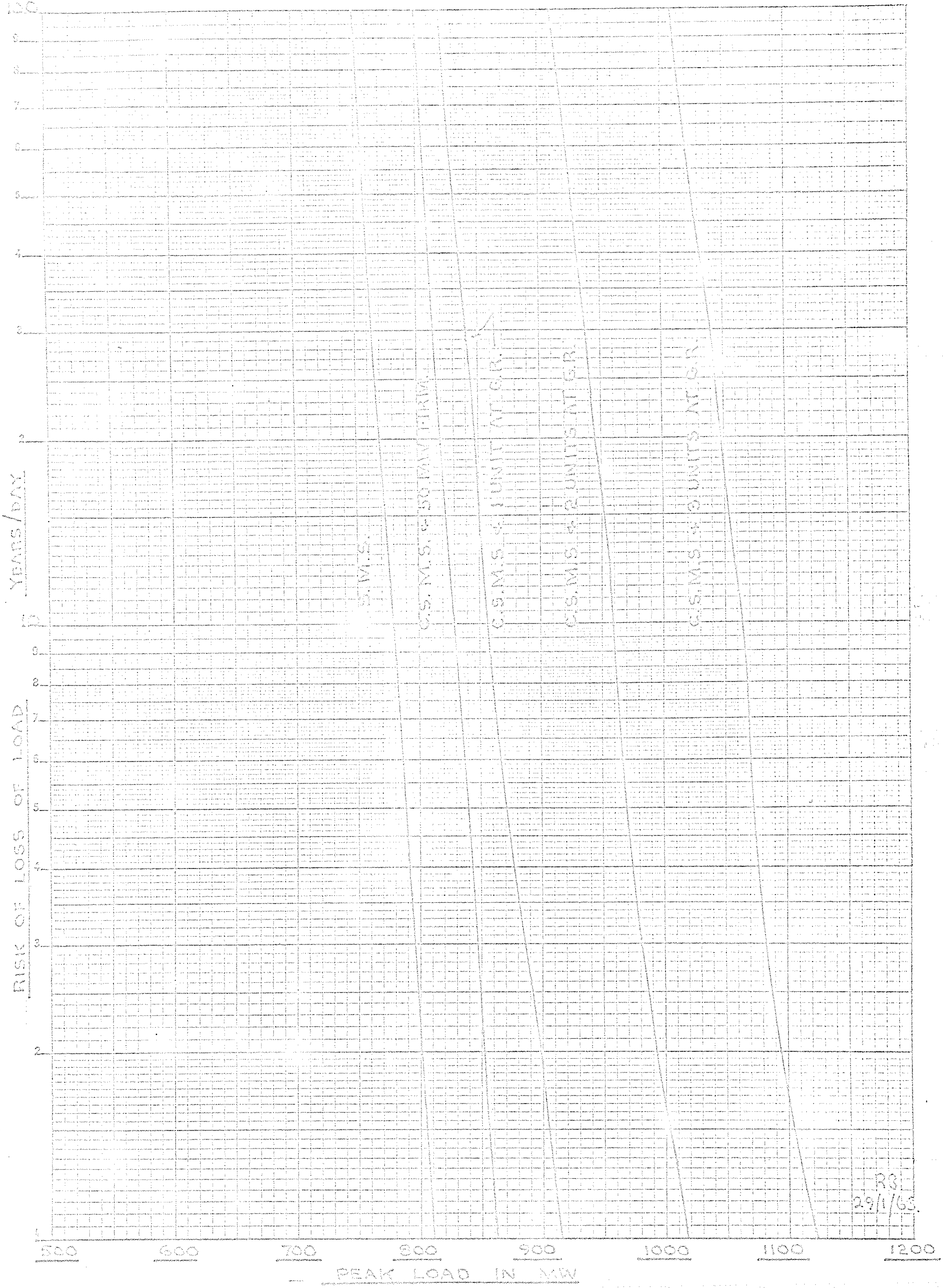
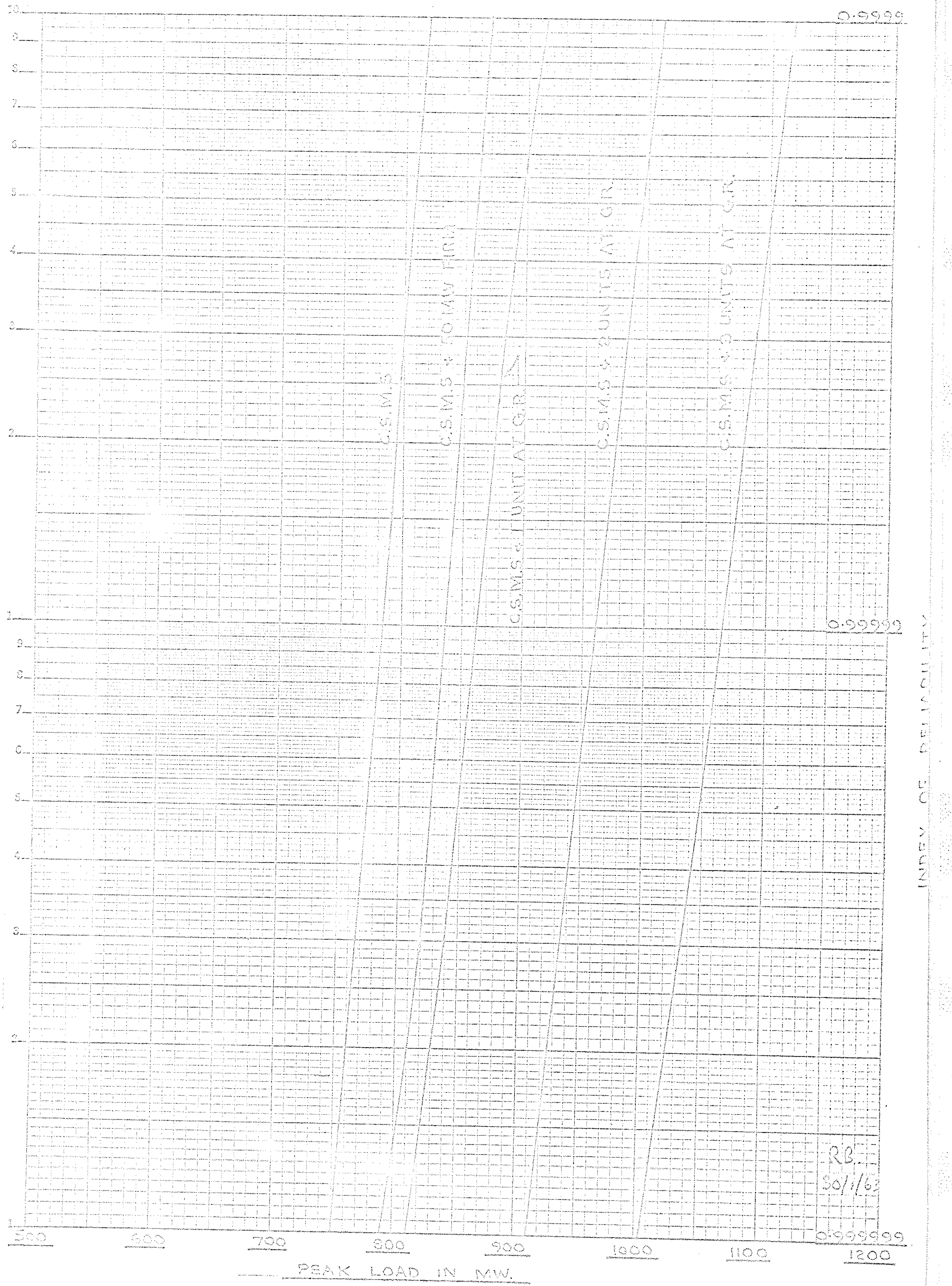

1.0
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
RISK OF LOSS OF LOAD
YEARS/DAY
S.M.S.
C.S.M.S. + 50 MW THRU.
C.S.M.S. + 1 UNIT AT G.R.
C.S.M.S. + 2 UNITS AT G.R.
C.S.M.S. + 3 UNITS AT G.R.
500
600
700
800
900
1000
1100
1200
PEAK LOAD IN MW

RB.
29/1/63.


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
0.9999
0.99999
0.999999
C.S.M.S
C.S.M.S + 70 MW FIRM
C.S.M.S + 1 UNIT AT G.R.
C.S.M.S + 2 UNITS AT G.R.
C.S.M.S + 3 UNITS AT G.R.
INDEX OF RELIABILITY
500
600
700
800
900
1000
1100
1200
PEAK LOAD IN MW.

RB.
30/1/63