Evaluation of System Reliability of Guru Nanak Dev Thermal Plant, Bhatinda

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CERTIFICATE

Certified that the thesis entitled "EVALUATION OF SYSTEM RELIABILITY OF GURU NANAKDEV THERMAL PLANT, BHATINDA" which is being submitted by Er. Satish. kumar, in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING-MECHANICAL (HEAT POWER ENGINEERING) of Punjabi University, Patiala is a record of student's own work carried out under my supervision and guidance. The matter embodied in this thesis has not been submitted to any University or Institution for the award of any degree or diploma.

The thesis has reached the standard fulfilling the requirements of the regulations for the award of the said work.

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ABSTRACT

In this work, system reliability of unit I of the existing 4x110 M.W. Units of G.N.D.Thermal Plant, Bhatinda has been evaluated. The working of the unit for the period from 1.1.77, 00 Hrs to 17.10.78, 16.40 Hrs was considered for the said purpose. The data so obtained was used in the evaluation of system reliability.

The work is based on the criterion that the unit is performing adquately well or satisfactorly so long as it is delivering power, may be at the rated or derated levels.

Various types of failures resulting in system breakdown have been studied and accordingly various components/Sub-systems and their break down times have been sorted out. The Sub-system-System relationship on functional basis is studied and a " Reliability Block Diagram" of the system is developed. The reliability of various components/Sub-systems have been worked out and commented upon. Based on the values of individual component/Sub-system reliability, system reliability of the unit has been worked out.

From the computed values of individual component reliability, the main boiler is established to be the weakest link in the thermal power plant system.

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NOMENCLATURE

Symbol	Explanation
$R_{F.O}$	Reliability of Fuel-Oil System
$R_{B.A}$	Reliability of Boiler Auxillaries
$R_{M.B}$	Reliability of Main Boiler
$R_{T.A}$	Reliability of Turbine Auxillaries
R_{T}	Reliability of Turbine
$R_{G/E}$	Reliability of Generator/Exciter
$R_{E.E}$	Reliability of Electrical Equipment
$R_{I/C}$	Reliability of Instruments/Controls
R_{s}	Reliability of System
R_{s_1}	Reliability of Sub-system 1
R_{s_2}	Reliability of Sub-system 2
R_{s_3}	Reliability of Sub-system 3
R_{s_4}	Reliability of Sub-system 4
R_1	Reliability of Induced draft Fan 1
R_2	Reliability of Induced draft Fan 2
R_3	Reliability of Forced draft Fan 1
R_4	Reliability of Forced draft Fan 2
R_5	Reliability of other components

1. PREVIEW

1.1 INTRODUCTION

The trend in the modern technology is to intensify the use of the plant and machinery. Production rates have increased and at the same time, due to extended operation, the opportunities for maintenance are reduced. In continous or semicontinous industrial process or flow-line production, the failure of a unit due to continous deterioration or catastropic failure is costly and sometimes dangerous. If some preventive measures are adopted, the failure can be reduced to a large extent if not completely avoided/eliminated.

In recent times, the development of complex systems has tremendously expanded man's capabilities but it has also increased the maintenance requirements. Huge amount of money is being spent on maintenance of complex systems. In 1975, United States Electric Utilities spent over $ 3 billion for maintenance. This represented more than 100 percent increase in five years. Almost $ 2 billion was for the maintenance of generating plant. In addition to these direct out-of- pocket costs, hidden costs are generally incurred when the system is unavailable.

The maintenance decisions largely depend on uncertain behaviour of equipment such as it is rather difficult to predict with certainty the occurance of failure or more generally the instant of transition from good state of the equipment to its failed state. A further source of uncertainty stems out from the problems associated with determination of the state of the equipment; good, failed or in-between, unless a definite maintenance action such as inspection is taken. It is therefore, essential that the foundations of "maintainability" and " reliability" are laid at the earliest stages of design so as to avoid/or reduce the failure of the equipment.

Reliability is a relatively new field whose conception is primarily due to complexity, sophistication, & automation inherent in modern technology. The approach used in reliability work varies with the individual and the organisation. In a field as young as this, few established schools of thought or doctrines are prevalent. Thus, the mathematician faced with a reliability problem often treats it as an exercise in applied probability or statistics. A manager attempts to organise a reliability group, which often turns out to be a staff organisation. The quality-control expert views reliability as an extension of his efforts. The component engineer tries to buy the best and most reliable parts. The system engineer looks for an inherently simple scheme which will lead to a reliable design.

In actuality no single approach is satisfactory, and the problem must be approached at all levels and at each step of the industrial process. Thus, reliability is essentially a birth-to-death problem, involving such areas as raw material and parts quality, conceptual design, detailed engineering design, production, test and quality control, product shipment, warehouse storage, operator skill and technique, maintenance, and product use.

It is apparent from the above discussion that reliability technique is a tool to study the reliability analysis, reliability design & reliability improvement of complex systems in modern technology. The present study deals with the reliability determination of an existing thermal power plant that is in operation.

The basic aim of reliability engineering/study is to increase the reliability of the system. The most important methods for doing this are:

a) Reduce the complexity of the system to the minimum essential for the required operation. Nonessential components and unnecessary complex configurations only increase the probabilities of system failure.

b) Increase the reliability of the components in the system.

c) Parallel redundancy: One or more("hot") spares operate in parallel. If one fails, others still function.

d) Stand by redundancy: A("cold) spare is switched in to take over the function of a component or subsystem that has failed.

e) Repair maintence: Failed components are replaced by a technician rather than switched in as in (d). Replacement is neither automatic nor necessarily immediate.

f) Preventive maintenance: Components are replaced by new ones periodically even though they maynot have failed by the time of replacement.

Methods (a) & (b) are obviously limited by the current state of technology. The other four methods enable, in principle, to develop systems having reliabilities which approach 100-percent for all arbitrarily chosen mission times. It is not always feasible to do this in view of constraints such as limits on weight, space, cost, or maintainability & availability. Another task of reliability engineering is to maximise system reliability for a given weight, size, cost or other constraints for a given reliability.

Author's interest in the problem is motivated by drastic power cuts enforced in the recent past and continously deteriorating condition of power supply in the State of Punjab. The heavy load shedding has caused much discontent & inconvenience to the general public, farmers & industrialists alike. Besides this, the State Board and the State Govt. has lost a big chunk of its revenue on account of closure of factories. Thus, the overall impact of load shedding has proved to be a big leap backward in the progress/industrialisation of the State.

The plant under study is one of the units of 4x110MW Guru Nanak Dev Thermal Plant, Bhatinda(Punjab) owned & operated by Punjab State Electricity Board. All the four units are of M/S Bharat Heavy Electricals Limited make & are identical in design. The units are coal based with oil firing at part-load operation and/or for flame stablisation.

The break down data of unit I for the period from Ist Jan, 1977 00.00 Hrs. up to 18.10.78 16.40 Hrs. (After this-the unit was released for capital maintenance) was collected. The breakdown period for the respective elements was identified & total breakdown time for the respective elements calculated. Reliability of each element was computed thereafter.

Various elements and their grouping in the system was studied and analysed on functional basis. Reliability of the system is then computed from the system- element relationship.

The present study deals with computing the reliability of unit I only and that too under various simplifying assumptions. The assumptions have been brought out in relevent sections.

1.2 LITERATURE REVIEW

1.21 HISTORY OF RELIABILITY STUDIES

Reliability was first recognized as a pressing need during World War II. The problems of maintenance, repair, and field failures became severe for the military equipment used in World War II. The preliminary steps taken were to establish joint Army & Navy parts standards and to set up the Vaccum

Tube Development Committee in June,1943. At the close of the war, between 1945 & 1950, several studies revealed some startling results:

(i) A Navy study made during maneuvers showed that the electronic equipment was operative only 30 percent of the time.

(ii) An Army study revealed that between two-thirds and three-fourths of their equipment was out of commission or under repairs.

(iii) An Air Force study conducted over a 5-year period disclosed that repair and maintenance costs were about 10 times the original cost.

(iv) A study uncovered the fact that for every tube in use there were one on the shelf and seven in transit.

(v) Approximately one electronics technician was required for every 250 tubes.

(vi) In 1937 a destroyer had 60 tubes; in 1952 the number had risen to 3,200.

These findings served as an impetus for further investigations.

One focal point of trouble appeared to be the vaccum tube. Following the vaccum tube development committee, an & airlines group set up a study in 1946 aimed at development of better electronics tubes. This was followed by parallel studies conducted by Aeronautical Radio, Inc. and Cornell University, in which, respectively, 45,000 and 100,000 defective tubes were examined. Between 1949 & 1953 Vitro Laboratories and Bell Laboratories pursued similar studies on the failure of parts other than vaccum tubes, such as resistors, capacitors, transformers, relays, etc. In 1950 the Department of Defence established an adhoc committee on reliability, which in 1952 became a permanent group called the Advisory Group on the Reliability of Electronic Equipment(AGREE). An AGREE report was published in 1957, which was shortly followed by a specification on the reliability of military electronic equipment.

Since the mid-1950s much work has been done on reliability analysis. The titles reliability engineer and reliability group have been born. Several texts have appeared on the subject of reliability, and College and industrial courses on reliability have been initiated. Many bibliographies have been published in various sources. NASA currently publishes a monthly digest entitled Reliability Abstracts & Technical Reviews, containing about 50 one- page reviews. Research results are printed in many different journals and presented at a large number of conferences. Three research publications of particular interest are The IEEE Transactions on Reliability; The Proceedings of the Annual Symposium on Reliability, a symposium sponsored by the IEEE and the ASQC; and The Proceedings of the Annual Reliability and Maintainability Conference, sponsored by the SAE, ASME, and AIAA.

1.2.2 BACKGROUND TO RELIABILITY

Safety of a thermal power generating system depends on reliability of individual components which plays a particularily important role especially when the reserve capacity is nil. Reliability is relatively new field whose conception is primarily due to complexity, sophistication, and automation inherent in a thermal power generating system.

Smith (1) has described reliability as the probability that a given system or device will operate for a given period of time, without failure, and under given operating conditions. Smith (4) has described reliability as a measure of the capacity of a piece of equipment to operate without failure when put in to service. National Aeronautics and Space Administration (NASA) has defined reliability as the probability of a device performing adequately for the period of time intended under the operting conditions encountered. Reliability is always a probability associated with a no-failure performance of a device (up to and including a large system) after an accumulated time (can be a very short or a very long period) in a specific environment over a given period of operation with some desired level of confidence. Reliability is, therefore, the probability that a given system will perform as anticipated. In a rather real sense, anything which is reliable is, by definition, well made. Shooman (3) has described that reliability leans heavily on probability for its underlying support. He has emphasied the need of a good working knowledge of probability theory for any real appreciation of reliability. Haviland (5) has described reliability as the mathematical probility that a device will operate as required. Reliability, thus leans heavily for its underlying support on applied mathematics.

Since failure and non-failure are mutually exclusive events, and there is a probability of unity that one or the other must occur, then the sum of these two probabilities also must be unity. If the reliability to time t is R (t) and the unreliability to time t is Q (t), than, from the above,

$$R(t) + Q(t) = 1 \qquad \text{-- (1)}$$

Gupta and Kapoor (2) has described statistical or emphirical probability as, if in n trials, an event E happens m times, then the probability "p" of the happening of E is given by

$$p = P(E) = \lim_{n \to \infty} \frac{n}{m} \qquad \text{-- (2)}$$

Applying this to reliability, let there be N_o articles put on test and allowed to fail without replacement so that at any time t there are N_s (t) surviving and N_f (t) failed. Then

$$N_s(t) + N_f(t) = N_o \qquad \text{-- (3)}$$

If the reliability, R (t), of these articles is the probability of nonfailure in time t , then, by the above definition of probability,

$$R(t) = N_s(t) / N_o \qquad \text{-- (4)}$$

1.2.3 RELIABILITY PARAMETERS

Reliability is essentially a study of the causes, distribution & prediction of failure. Smith (1) has defined failure as the termination of the ability of an item to perform its required function. To derive the basic reliability parameter of failure rate, $\lambda(t)$ i.e. the rate of change of the no. of failures, it is imperative to observe and measure the relationship which exists between failure and time. Occurence of failures are also defined as the mean time, between successive failures or meantime between failures (M.T.B.F). Mean time to fail (M.T.T.F) is defined as the mean operating time between successive failures.

Empirically, M.T.T.F. + Mean time to repair= M.T.B.F.

Consider a population of homogenous components from which a very large sample is taken and placed in operation at time T=0. The population initially shows a high failure rate. This decreases rather rapidly as shown in Figure 1, which is known as a bath-tub curve due to its shape. Shooman (3) has described high failure rates early in the life time of equipment due to initial weakness of defects, poor insulation, weak parts, bad assembly, poor fits etc. During the middle period of equipment operation fewer failures takes place, but it is difficult to determine their cause. In general, they seem to occur when the environmental stresses exceed the design strengths of the part or equipment. It is difficult to predict the environmental-stress amplitude or the part strengths as deterministic functions of time; thus the middle-life failures or constant failure rates are often called random failure or useful life period.

As the item reaches old age, things begin to deteriorate, and many failures occur. This failure region is called the wearout region. The bath-tub curve (Fig.1) with a period of early failures, a useful life (constant failure rate), and a wearout period, applies to most electronic components. Electromechanical & mechanical devices, on the other hand, have no period of constant failure rate since the wearout mechanism is present from the begining of the life of the device. Such variable-failures are distributed according to the Weibull function. Smith (1) has described that if a population exhibits random failures, it may be treated as having a constant failure rate for the population as a whole. Failure rates are expressed either as so many percent per 1000 h or as so many failures per hour. Constant failure rate is calculated as the number of failures divided by the number of component- hours accumulated.

Smith (1) has described componants in the range of failure rates 10^{-5} to 10^{-7} per hour exhibit current commercial reliability levels. A component with failure rate of the order of 10^{-8} per hour is considered highly reliable; one with a failure rate of 10^{-9} per hour is considered particularly reliable and would normally be encountered in special-purpose components.

1.2.4 ANALYTICAL METHODS TO DETERMINE RELIABILITY

In performing the reliability analysis of a complex system, Shooman (3) has described that the logical approach is to decompose the system into functional entities composed of units, subsystems, or components. Each entity is assumed to have two states, one good and one bad. The subdivision generates a block diagram description of system operation. Models are then formulated to fit this logical structure, and the calculus of probability is used to compute the system reliability in terms of sub-division reliabilities. Series and parallel structure often occur, and their reliability can be described very simply. In many cases the structure is of a more complicated nature, and more general techniques are needed. The formulation of a structural-reliability model can be difficult in a large, sophisticated system and requires much approximation and judgement.

Therefore, in order to predict the reliability of a system it is necessary to know the reliability of its element/component parts. To determine component reliability the failure rate (or Weibull parameters in the case of Variable failure rates) must be ascertained for each component. An attempt has been made to justify the methodology adopted for determining analytically reliability of the constituent components.

1.2.4.1 INTRODUCTION

The bath-tub curve (Figure 1) with a period of early failures, a useful life (constant failure rate), and a wearout period, applies to most electronic components (excluding relays & thermionic relays). Electro-mechanical & mechanical d-evices, on the other hand, have no period of constant failure rate since the wear out mechanism is present from the beginning of the life of the device. Smith (1) has described that variable failure rates are obtained when constant failure-rate devices are used together in redundant configuration. If variable-failure-rate components are replaced as they fail, eventually a population of homogenous components will evolve such that all the components have different "starting points". Such a population will exhibit random failures and may be treated as having a constant failure rate.

1.2.4.2 THE PROBABILITY DENSITY FUNCTION METHOD

Figure 2 represents the general case of failure probability density function f (t) plotted against time. Consider the possibility of failure in the interval from t to t+dt. The failure probability density function is such that the probability of failure in the time interval from t to t + dt is dt f (t). The area of the shaded strip is dt f (t) and is therefore the probability of failure in the time interval represented by that strip (t to t + dt). It follows that the probability of failure in the interval t_1 to t_2 is $\int_{t_1}^{t_2} f(t)\,dt$.

For the constant-failure rate case,

$$f(t) = \lambda . e^{-\ \ t} \quad \text{--(5) (SEE APPENDIX I \& II)}$$

Not constraining to the constant-failure-rate case,

$$\lambda(t) = -\frac{d\,R(t)}{R(t)\,dt} \quad \text{--(6) SEE APPENDIX II}$$

This is a general expression for failure rate in terms of reliability and is useful when failure rate cannot be derived from mean time before failure (M T B F) except when failure rate is constant.

1.2.4.3 WEIBULL FUNCTION METHOD

Electromechanical and mechanical devices have no period of constant failure rate since the wear out mechanism is present from the begining of the life of the device.

We know that $R(t) = \exp\left[-\int_0^t \lambda(t)\, dt \right]$

Since the relationship of $\lambda(t)$ to time depends on the device in question, the integral cannot be evaluated for the general case. Even if the variation of failure rate with time was known, it might well be of such a complex nature that the evaluation of the integral would prove far from simple. In practice the variation of failure rate with time is often such that the reliability function takes the form

$$R(t) = \exp\left[- \left(\frac{t - \gamma}{\eta} \right)^{\beta} \right] \quad \text{--(7)}$$ SEE APPENDIX III

Such failure's are said to be distributed according to the Weibull function.

Variable-failure-rates are obtained when constant-failure-rates devices are used together in redundant configuration. In a population of homogenous components, each individual component has a varying failure rate, and if large no's of components are replaced at the same time, then the assumption of constant-failure-rate no longer holds good.

1.2.5 SYSTEM CONFIGURATION

1.2.5.1 SERIES CONFIGURATION

The simplest and perhaps most common structure in reliability analysis is the series configuration. In the series case the functional operation of the system depends on the proper operation of all system components. A series reliability configuration will be portrayed by the block-diagram representation shown in Fig. 4 (A), or the reliability graph shown in Fig. 4 (B). In either case, a single path from cause to effect is created. Failure of any component is represented by removal of the component, which interrupts the path and thereby causes the system to fail.

The system shown in Fig. 4 is divided in to n series-connected units. The event signifying the success of the nth unit will be x_n, and $\bar{x}_n$ will represent the failure of the nth unit. The probability that unit n is successful will be $R\ (x_n)$, and the probability that unit n fails will be $Q\ (\bar{x}_n)$. The probability of system success is denoted by R_s. In keeping with the definition of reliability in section 1.2.2, the probability of system failure is

$$Q_s = 1 - R_s$$

Since the series configuration requires that all units operate successfully for system success, the event representing system sucess is the intersection of x_1, x_2,----- x_n. The probability of this event is given by

$$R_s = R\ (x_1\ x_2\ x_3 ----- x_n\ ) \quad --- (8)$$

Expansion of Equation (8) yields

$$R_s = R(x_1)\ R(x_2/x_1)\ R(x_3/x_1\ x_2) \text{------} R(x_n/x_1\ x_2 \text{----} x_{n-1}) \quad \text{---(9)}$$

The expression appearing in Equation (9) contains probabilities, which must be evaluated with care. If the units do not interact, the failures are independent, and Equation(9) simplifies to

$$R_s = R(x_1)\ R(x_2)\ R(x_3) \text{-------} R(x_n) \quad \text{---- (10)}$$

An alernative approach is to compute the probability of failure.

The reliability of a series system is always worse than the poorest component and is generally a disappointment from a reliability stand-point.

1.2.5.2 PARALLEL CONFIGURATION

In many systems several signal paths perform the same operation. If the system configuration is such that failure of one or more paths still allows the remaining path or paths to perform properly, the system can be represented by a parallel model.

A block diagram and reliability graph for a parallel system are shown in Fig.5. There are n paths connecting input to output, and all units must fail in order to interrupt all the paths. This is some times called a redundant configuration. Thus, a parallel model may occur as a result of the basic system structure or may be produced by using redundancy in a reliability design or redesign of the system.

In a parallel configuration the system is successful if any one of the parallel channels is successful. The probability of success is given by the probability of the union of the n successful events

$$R_s = R\ (x_1 + x_2 + x_3 + \text{--------} + x_n) \quad \text{----}(11)$$

System failure occurs if all the system units fail, yielding the probability of their intersection.

$$Q_s = Q\ (\bar{x}_1\ \bar{x}_2\ \bar{x}_3 \text{-----} \bar{x}_n\ ) \text{ ----- } (12)$$

Where $R_s = 1 - Q_s$

Substitution of Equation (11) into Equation (12) and expansion yields

$$R_s = 1 - R\ (\bar{x}_1)\ R\ (\bar{x}_2 / \bar{x}_1)\ R\ (\bar{x}_3 / \bar{x}_1\ \bar{x}_2\ ) \text{-----------} \text{----} R\ (\bar{x}_n / \bar{x}_1\ \bar{x}_2 \text{----} \bar{x}_{n-1}) \text{ --- } (13)$$

If the unit failures are independent, Equation (13) simplifies to

$$R_s = 1 - R\ (\bar{x}_1)\ R\ (\bar{x}_2\ ) \text{------} R\ (\bar{x}_n) \text{ --- } (14)$$

1.2.5.3 COMBINED SERIES - PARALLEL CONFIGURATION

Any complete system generally consists of a large number of components or units in series. If any one component or unit fails, the system fails. In many cases, the less reliable components in a system are backed by parallel components to increase system reliability by parallel rendundancy. Sometimes a whole group of components is backed by an equal or similar group operating in parallel with the first group. These parallel arrangements of two or more groups can be considered as single units in series within the system. If such a unit fails as a whole, the system fails.

From the foregoing, it follows that combinations of series and parallel raliability are common, and system reliability is computed using rules of sections1.2.5.1 & 1.2.5.2

Series parallel and parallel-series reliability configurations are illustrated by the block-diagram representations shown in Figs. 6 (A) and 6 (B) respectively. The reliability of a system of n series units with m parallel elements, the reliability of a single element being R, is

$$R_s = \left[1 - (1 - R)^m \right]^n \quad \text{-------- (15)}$$

The reliability of a system with m parallel paths of n elements each, the reliability of a single element being R , is

$$R_s = \left[1 - (1 - R^n)^m \right] \quad \text{------- (16)}$$

Series-parallel configurations result in higher reliability than equivalent parallel-series configurations. Smith (4) has described that as the reliability of unit increases, the difference between series-parallel & parallel-series reliabilities decrease.

2. FORMULATION OF THE PROBLEM

2.1. PERFORMANCE CRITERION

The system is considered to be performing adequately well or satisfactorily so long as it is delivering power, may be at the rated or derated levels. In the present case, the system consists of unit I of Guru Nanak Dev Thermal Plant at Bhatinda.

2.2. PROBLEM

Unit I of the existing 4x110 M.W. units of Guru Nanak Dev Thermal Plant, Bhatinda (Punjab) owned & operated by Punjab State Electricity Board has been taken up for the present study. The problem deals with the analytical determination of reliability of unit I of the G.N.D. Thermal Plant. The working of the unit for the period from 1.1.77, 00 Hrs to 17.10.77, 16.40 Hrs. was considered for the said purpose. The data so obtained was used in the evaluation of system reliability. The unit consists of the following sub-systems/elements.

1. Water Treatment Plant.
2. Fuel Oil System.
3. Coal Plant.
4. Boiler Auxillaries.

5. Main Boiler.

6. Turbine Ausillaries.

7. Turbine.

8. Generator/Exciter.

9. Electrical Equipment.

10. Instruments/Controls.

11. System Outer Grid.

12. Shortages.

13. Ash Handling System.

2.3 DATA

The break down time of the unit I is included in Table I.

This data has been critically examined and the various types of failures leading to system break down have been studied. Accordingly various subsystems/components and their breakdown times have been sorted out. Tables II to IX include data pertaining to breakdown times of Fuel Oil System, Boiler Auxillaries, Main Boiler, Turbine Auxillaries, Turbine, Generator/Exciter, Electrical Equipment and Instruments/controls respectively.

2.4 SOLUTION TECHNIQUE.

2.4.1 DETERMINATION OF COMPONENT AND SYSTEM RELIABILITY

Following steps indicate the outline of methodology adopted for the determination of component & system reliability.

i) Collection of Data i.e. breakdown time of the Unit I.

ii) Sorting out various sub-systems and their break down times based on the failure mechanism of the system.

iii) Study of Sub-system-System relationship on functional basis.

iv) Development of Functional Block Diagram.

v) Development of Reliability Block Diagram.

From the Data given in Tables II to IX, following information is obtained:

(a) Total operating time of the system.

(b) Failure time of the sub-systems/Constituent Components at random.

On account of the limitations of the "Probability Density Function Method" and " Weibull Function Method", the technique stated in section (1.2.2) is made use of for the determination of the constituent components/ Subsystems reliability Accordingly,

$$\text{Reliability of the Constituent Component} = 1 - \frac{\text{Cummulated failure time of each Component}}{\text{Total operating time of the system.}}$$

Further, various components and their grouping has been studied and analysed on functional basis (i.e.Required for Power Generation). The system-component relationship on functional basis, whether the system is operating at full rated load or part load is shown in Fig (7). In the "Reliability Block Diagram", Fig (10), following components/Subsystems have been omitted for the reasons mentioned against each.

(i) Outergrid (For transmission of Power): Sub-system falling outside the purview of power generation.

(ii) Shortages (Coal) : Sub-system falling outside the purview of power generation.

(iii) Ash Handling System: Sub-system having no failure time during the period under study.

(iv) Water Treatment Plant: Sub-system having no failure time during the period under study.

Further, the reliability block-diagrams on functional basis for individual sub-systems are shown in Fig.(8). Also the reliability block-diagram for Boiler Auxiliaries, on function basis, is shown in Fig.(9).

From the reliability block-diagram of the system shown in Fig.(10), it is clear that the system has a series configuration.

TABLE I

BREAKDOWN TIME OF THE UNIT

S.No.	Date, Month & Year	Period From	To	Duration Hrs.	Min.	Reasons
1.	1.1.77	1415	2400	09	45	Unit tripped due to low fuel oil pressure.
	2.1.77	0000	0200	02	00	
2.	5.1.77	1625	1912	02	47	Unit tripped due to system fault.
3.	6.1.77	1600	1630	00	30	Unit tripped on axial shift.
4.	6.1.77	1710	2400	06	50	Unit stopped to check up axial shift.
	7.1.77	0000	2400	24	00	
	8.1.77	0000	2400	24	00	
	9.1.77	0000	2028	20	28	
5.	14.1.77	0925	1110	01	45	Unit tripped due to distribution oil pressure low.
6.	19.1.77	1145	1306	01	21	Unit tripped due to mal-operation of TTX relay.
7.	22.1.77	1757	1808	00	11	Unit tripped due to high axial shift.
8.	25.1.77	1115	1207	00	52	Unit tripped on rotor earth fault.

9.	30.1.77	1233	1439	02	06	Unit tripped on system fault.
10.	4.2.77	1258	2400	11	02	Unit tripped on rotor
	5.2.77	0000	2337	23	37	earth fault.
11.	6.2.77	0012	0044	00	32	Unit tripped on reverse power.
12.	6.2.77	1120	2400	12	40	Unit tripped to attend
	7.2.77	0000	0902	09	02	heavy leakage in H.P. injection line.
13.	16.2.77	1817	1838	00	21	Unit tripped on axial shift high & due to load throw off.
14.	23.2.77	1220	1230	00	10	Unit tripped on axial shift high.
15.	25.2.77	0905	0955	00	50	Unit tripped on axial shift high.
16.	26.2.77	2005	2400	03	55	Unit stopped to attend
	27.2.77	0000	2400	24	00	leakage on boiler &
	28.2.77	0000	2400	24	00	turbine side.
	1.3.77	0000	2400	24	00	
	2.3.77	0000	0104	01	04	
17.	2.3.77	1055	2400	13	05	Unit tripped without
	3.3.77	0000	1614	16	14	any initiating cause.
18.	6.3.77	1004	1023	00	19	Unit tripped manually to clean slip rings of exciter.

19.	10.3.77	1942	2400	04	18	Unit tripped due to
	11.3.77	0000	0723	07	23	burning of furnace draft cables.
20.	15.3.77	2107	2145	00	38	Unit tripped as the generator breaker opened.
21.	21.3.77	1243	1328	00	45	Unit tripped manually to clean exciter brushes.
22.	21.3.77	1337	1730	03	53	Unit tripped on rotor earth fault.
23.	22.3.77	0840	2400	15	20	Unit tripped manually
	23.3.77	0000	0145	01	45	due to critical position of pulversied coal & P.C. feeders.
24.	23.3.77	1100	2153	10	53	Unit tripped manually due to non-availability of coal mills & P.C. feeders.
25.	26.3.77	0012	0310	02	58	Unit tripped on negative sequence.
26.	29.3.77	1731	1957	02	26	Unit tripped manually due to trouble with both I.D.Fans.
27.	30.3.77	1555	1637	00	42	Unit tripped manually due to excessive knocking found in the only running F.D.Fan.

28.	31.3.77 TO 24.4.77	0442	2400 0147	19 553	18 47	Unit tripped beeause of high bearing temp. of I.D. Fan.Planned shut down.
29.	25.4.77	0534	0605	00	31	Unit tripped due to thrust bearing failure hydro-mechanical trip.
30.	26.4.77	2335	2400	00	25	Unit tripped to attend leakage of inching by pass valve & B.D. valve & to rectify P.C. Burner nozzles.
	27.4.77	0000	2400	24	00	
	28.4.77	0000	2400	24	00	
	29.4.77	0000	2400	24	00	
	30.4.77	0000	2400	24	00	
	1.5.77 TO 9.5.77	0000 0000	2400 2155	213	55	
31.	9.5.77	2205	2400	01	55	Unit tripped due to sudden variation in furnace draft.
	10.5.77	0000	0350	03	50	
32.	10.5.77	0353	1432	10	39	Unit tripped due to sudden variation in furnace draft.
33.	10.5.77	1540	2400	08	20	Unit tripped manually due to H.P. eccentricity being high.
	11.5.77	0000	1002	10	02	
34.	11.5.77	1022	1045	00	23	Unit tripped manually as both inter-cepter valves closed.
35.	15.5.77	0120	0527	04	07	Unit tripped on rotor earth fault.

36.	15.5.77	0540	0650	01	10	Unit tripped on furnace draft high. I.D.Fan interconnecting damper closed of its own.
37.	16.5.77	0635	1055	04	20	Unit tripped due to low frequency.
38.	17.5.77	1453	2053	06	00	Unit tripped due to low frequency.
39.	20.5.77	1012	1220	02	08	Unit desynchronised.
40.	22.5.77	0210	0225	00	15	Unit tripped as M.F.T. tripped due to low furnace oil pressure.
41.	23.5.77	1832	2400	05	28	Unit tripped due to operation of VAT Buck-holz's relay.
	24.5.77	0000	2400	24	00	
	25.5.77	0000	2400	24	00	
	26.5.77	0000	1426	14	26	
42.	31.5.77	1742	2400	06	18	Unit tripped due to suspected leakage in economiser.
	To 3.6.77		1620	64	20	
43.	3.6.77	1630	1945	03	15	Unit tripped on thrust bearing hydromechanical trip.
44.	5.6.77	1355	1852	04	57	Unit tripped due to low system frequency.
45.	9.6.77	0738	0845	01	07	Unit tripped due to M.F.T. trip.

46.	13.6.77	0140	1540	14	00	Unit tripped due to M.F.T. trip.
47.	19.6.77	1421	2400	09	39	Unit tripped manually
	20.6.77	0000	2400	24	00	to attend drum manhole
	21.6.77	0000	1121	11	21	leakage.
48.	23.6.77	2115	2158	00	43	Unit tripped due to system fault.
49.	24.6.77	1453	1730	02	37	Unit tripped due to system fault.
50.	25.6.77	0445	0834	03	49	Unit tripped due to low frequency.
51.	25.6.77	2225	2400	01	35	Unit tripped due to
	26.6.77	0000	2400	24	00	push button.
	27.6.77	0000	0534	05	34	
52.	27.6.77	1512	1540	00	28	Unit tripped on exhaust pressure high.
53.	8.7.77	1650	2400	07	10	Unit tripped due to
	9.7.77	0000	2400	24	00	the tripping of only
	10.7.77	0000	0525	05	25	available I.D. Fan.
54.	12.7.77	1600	2028	04	28	Unit tripped manually to attend damaged diaphragms of I.D. Fan.
55.	13.7.77	2200	2400	02	00	Unit tripped manually
	14.7.77	0000	0132	01	32	to attend the leakage at the flange of safety valve of B.D. valve line.

56.	27.7.77	1247	2158	09	11	Unit tripped due to the tripping of M.F.T. on I.D. Fan failure.
57.	28.7.77	0655	2400	17	05	Unit tripped due to the tripping of M.F.T. on I.D.Fan failure.
	29.7.77	0000	2400	24	00	
	30.7.77	0000	2400	24	00	
	31.7.77	0000	2400	24	00	
	1.8.77	0000	1334	13	34	
58.	9.8.77	0327	1305	09	38	Unit tripped due to trouble in coal handling plant.
59.	9.8.77	2330	2338	00	08	Unit tripped due to heavy load fluctuation on the system.
60.	16.8.77	0435	2400	19	25	Unit tripped due to trouble in only available I.D.Fan.
	17.8.77	0000	2400	24	00	
	18.8.77	0000	2022	20	22	
61.	28.8.77	1355	1538	01	43	Unit tripped on furnace draft high.
62.	31.8.77	1140	1210	00	30	Unit tripped due to tripping of only running F.D.Fan.
63.	3.9.77	2343	2400	00	17	Unit tripped due to tripping of only available I.D.Fan on thermal over load.
	4.9.77	0000	0043	00	43	
64.	4.9.77	2157	2400	02	03	Unit tripped due to tripping of only available I.D.Fan on thermal over load.
	5.9.77	0000	0005	00	05	

65.	14.9.77 To	0825	2400	15	35	Unit tripped manually for attending to various faults in boiler & turbine.
	19.9.77	0000	1824	114	24	
66.	21.9.77	0730	2400	16	30	Unit tripped manually as instruments supply failed due to tripping of station transformer II on its fire protection air pr.low.
	22.9.77	0000	0431	04	31	
67.	22.9.77	0442	0723	02	41	Unit tripped as M.F.T. tripped on abnormal furnace draft.
68.	22.9.77	0812	1030	02	18	Unit tripped manually due to tripping of B.F.P. on balancing leak off pressure high.
69.	27.9.77	1520	2017	04	57	Unit tripped due to the tripping of both C.W. pumps on condenser pr. high.
70.	27.9.77	2330	2400	00	30	Unit tripped due to the tripping of both C.W. pumps on condenser pr. high.
	28.9.77	0000	0423	04	23	
71.	30.9.77	1105	1138	00	30	Unit tripped due to failure of M.C.C. supply while changeover.

72.	6.10.77	0645	0812	01	27	Unit tripped due to mal functioning of bus-coupler.
73.	7.10.77	0155	2400	22	05	Unit tripped due to
	8.10.77	0000	2400	24	00	suspected leakage in
	9.10.77	0000	2400	24	00	super heater.
	10.10.77	0000	0210	02	10	
74.	12.10.77	1636	1812	01	36	Unit tripped due to generator field earth fault.
75.	13.10.77	0927	2400	14	33	Unit tripped due to
	14.10.77	0000	1015	10	15	system disturbance & rotor earth fault.
76.	14.10.77	1103	1518	04	15	Unit tripped due to mal-functioning of axial shift relay.
77.	17.10.77	1023	1332	03	09	Unit tripped manually through M.F.T. as both C.W. pumps had tripped.
78.	11.11.77 TO	1628	2400	07	32	Unit tripped manually to
	16.11.77	0000	2137	125	09	attend various faults on boiler & turbine side.
79.	17.11.77	0105	2400	22	55	Unit tripped manually to
	18.11.77	0000	0908	09	08	attend leakage on auxi-llary injection line right side.

80.	18.11.77	2353	2400	00	07	Unit tripped manually
	19.11.77	0000	2400	24	00	to attend the H P radial
	20.11.77	0000	0403	04	03	bearing front of turbine.
81.	26.11.77	1130	1229	00	59	Unit tripped on exhaust pressure high.
82.	26.11.77	1254	1433	01	39	Unit tripped on exhaust pressure high.
83.	7.12.77	2108	2205	00	57	Unit desynchronised for cleaning exciter brushes.
84.	8.12.77	1700	2000	03	00	Unit tripped due to exhaust pressure high.
85.	8.12.77	2312	2400	00	48	Unit tripped due to
	9.12.77	0000	1638	16	38	attend speeder gear.
86.	15.12.77	2055	2242	01	47	Unit tripped manually to attend sparking on slip rings of generators.
87.	15.12.77	2300	2400	01	00	Unit tripped due to the
	16.12.77	0000	0305	03	05	tripping of all auxllaries on under voltage.
88.	19.12.77	0837	1037	02	00	Unit tripped on rotor earth fault.
89.	21.12.77	0935	2110	11	35	Unit tripped manually to attend leakage in the deaeration line of discharge line of M.O.P.
90.	29.12.77	1613	2400	07	47	Unit tripped manually to
	TO 2.1.78	0000	1750	89	50	attend leakage in economiser section.

91.	12.1.78	1040	2400	13	20	Unit tripped manually
	13.1.78	0000	2400	24	00	to attend leakage at
	14.1.78	0000	2400	24	00	B.D. valve.
	15.1.78	0000	0238	023	38	
92.	15.1.78	0310	0332	00	22	Unit tripped on hydro-
						mechanical trip.
93.	2.2.78	1501	2400	08	59	Unit tripped manually
	TO 24.2.78	0000	0858	512	58	due to suspected leakage
						in economiser zone &
						wall super heater.
94.	24.2.78	0917	1010	00	53	Unit tripped on exhaust
						pressure high.
95.	24.2.78	1025	2400	13	35	Unit tripped manually
	25.2.78	0000	2400	24	00	due to high differential
	26.2.78	0000	1634	16	34	expansion.
96.	26.2.78	1734	2400	06	26	Unit tripped by tripping
	27.2.77	0000	0034	00	34	turbine.
97.	1.3.77	1302	1325	00	23	Unit tripped due to low
						vaccum.
98.	4.3.78	2300	2400	01	00	Unit tripped manually
	5.3.78	0000	0946	09	46	to clean the B.F.P.
						suction strainer.
99.	6.3.78	1140	1205	00	25	Unit tripped on rotor
						earth fault.
100.	6.3.78	1905	2400	04	55	Unit tripped due to total
	7.3.78	0000	0303	03	03	supply failure.

101.	9.3.78	1304	1755	04	51	Unit tripped on rotor earth fault.
102.	9.3.78	1820	2400	05	40	Unit tripped due to
	10.3.78	0000	1632	16	32	brusting of injection line of B.P.-2.
103.	11.3.78 To	0248	2400	21	12	Unit tripped due to
	24.3.78	0000	1436	302	36	leakage in boiler because of chocking of reheater tube.
104.	24.3.78	1737	2400	06	23	Unit tripped due to
	25.3.78	0000	0550	05	50	tripping of M.F.T.
105.	25.3.78	0605	1728	11	23	Unit tripped due to L.P. rotor differential expension high.
106.	30.3.78 TO	1757	2400	06	03	Unit tripped manually
	5.4.78	0000	2150	141	50	due to suspected leakage in reheater.
107.	6.4.78	1100	1243	01	41	Unit tripped due to rotor earth fault.
108.	8.4.78	1515	1632	01	17	Unit tripped manually due to tripping of B.F.P.
109.	10.4.78	0427	0610	01	43	Unit tripped due to the tripping of auto transformer on over load.
110.	10.4.78	0900	1255	03	55	Unit tripped on rotor earth fault.

111.	11.4.78	1622	1732	01	10	Unit tripped on rotor earth fault.
112.	11.4.78	2040	2400	03	20	Unit tripped to attend leakage on the impulse line indicating pressure in B.P.E.1.
	12.4.78	0000	1542	15	42	
113.	12.4.78	1616	1715	00	59	Unit tripped on hydro-machanical trip.
114.	19.4.78	0935	1045	01	10	Unit tripped due to system disturbance.
115.	25.4.78	2000	2400	04	00	Unit tripped due to excessive leakage in the generator seal oil system.
	26.4.78	0000	2400	24	00	
	27.4.78	0000	1521	15	21	
116.	28.4.78	2303	2400	00	57	Unit tripped manually to attend fault on T-G side.
	29.4.78	0000	0327	03	27	
117.	29.4.78	0543	0905	03	22	Unit tripped on rotor earth fault.
118.	2.5.78	1620	1628	00	08	Unit desynchronised due to system fault.
119.	3.5.78	1602	2305	07	03	Unit tripped due to system disturbance.
120.	6.5.78	2345	2400	00	15	Unit tripped on fuel oil pressure low.
	7.5.78	0000	0220	02	20	
121.	8.5.78	0850	1026	013636		Unit tripped on B.F.P.1A tripped on over current in Y - phase.

122	10.5.78	0000	0036	00	36	Unit tripped on fuel oil pressure low.
123.	16.5.78	2310	2400	00	50	Unit tripped due to abnormal furnace draft.
	17.5.78	0000	0000			
124.	23.5.78	2005	2050	00	45	Unit tripped manually as vaccum was falling due to low reheat pr.
125.	23.5.78	2235	2400	01	25	Unit tripped manually as vaccum was falling due to low reheat pr.
126.	27.5.78	0803	0829	00	26	Unit tripped on thrust bearing failure hydreu-lic trip.
127.	27.5.78	1440	2400	09	20	Unit tripped as both the R-C.chain feeders became chocked & drum pressure was reduced & subsecquently unit tripped on low vaccum pressure.
	28.5.78	0000	0345	03	45	
128.	31.5.78	1745	2400	06	15	Unit tripped on fuel oil pressure low.
129.	1.6.78	0000	0440	04	40	
129.	3.6.78 to	0512	2400	18	48	Unit tripped manually due to suspected leakage in boiler pent house.
	23.6.78	0000	2032	476	32	

130.	23.6.78	2139	2400	02	21	Unit tripped manually due to M.P. rotor differential expansion high.
	24.6.78	0000	1308	13	08	
131	25.6.78	0925	1043	01	18	Unit tripped on low fuel oil pressure.
132	25.6.78	1080	1550	05	00	Unit tripped due to tripping of only available I.D.Fan due to abnormal sound in impeller.
133	25.6.78	1957	2005	00	08	Unit tripped due to system disturbance at over speed.
134	26.6.78	0126	0304	01	38	Unit/turbine tripped manually due to excessive knocking noise in the reduction gear box.
135	26.6.78	1440	2400	09	20	Unit tripped manually due to leakage in economiser.
	27.6.78	0000	2400	24	00	
	28.6.78	0000	2400	24	00	
	29.6.78	0000	2400	24	00	
	30.6.78	0000	2400	24	00	
	1.7.78	0000	2400	24	00	
	2.7.78	0000	2400	24	00	
	3.7.78	0000	2100	21	00	
136	4.7.78	0015	2400	23	45	Unit tripped manually due to non-availability of coal mills.
	5.7.78	0000	0110	01	10	

137.	9.7.78	1202	2400	11	58	Unit tripped manually due
	10.7.78	0000	2400	24	00	to stopping of only avail-
	11.7.78	0000	0313	03	13	able I.D.Fan due to abnormal sound.
138.	16.7.78	0627	2400	17	33	Unit tripped due to leakage
	17.7.78	0000	2400	24	00	in the economiser.
	18.7.78	0000	2400	24	00	
	19.7.78	0000	1205	12	05	
139.	22.7.78	0340	0530	01	50	Unit tripped due to tripping of F.O.pump & pressure went low.
140.	27.7.78	0738	2400	16	22	Unit tripped by tripping
	TO 31.7.78	0000	2145	93	45	TTX relay.
141.	31.7.78	2155	2400	02	05	Unit tripped due to exhaust
	1.8.78	0000	1223	12	23	pressure high.
142.	3.8.78	1423	1540	01	17	Unit tripped on fuel oil pressure low.
143	5.8.78	0359	1020	06	21	Unit tripped due to loss of excitation.
144.	5.8.78	1605	1659	00	54	Unit tripped due to loss of excitation.
145.	11.8.78	0040	0440	04	02	Unit tripped due to trouble in generator seal oil system.
146.	18.8.78	0800	0907	01	07	Unit tripped due to furnace draft abnormal.

147.	18.8.78	0909	0925	00	16	Unit tripped on distribution oil pressure low.
148.	20.8.78	1812	1953	01	41	Unit tripped due to exhaust pressure high.
149.	20.8.78	2005	2045	00	40	Unit tripped due to distribution oil pressure low.
150.	29.8.78	0115	1335	12	20	Unit tripped due to leakage in the discharge line of B.F.P.
151.	7.9.78	1535	1829	02	54	Unit tripped on no coal.
152.	12.9.78	0901	2400	14	59	Unit tripped due to flash on B.F.P. motor.
	13.9.78	0000	2400	24	00	
	14.9.78	0000	0440	04	40	
153.	14.9.78	0500	0523	00	23	Unit tripped on hydromechenical trip.
154.	14.9.78	0546	0602	00	16	Unit tripped on distribution oil pressure low.
155.	15.9.78	1905	2245	03	40	Unit tripped due to leakage of oil from generator.
156.	18.9.78	1317	1403	00	46	Unit tripped due to fuel oil pressure low.
157.	18.9.78	1413	1430	00	17	Unit tripped on distribution oil pressure low.
158.	19.9.78	1700	2400	07	00	Unit tripped due to fire on turbine.
	TO					
	4.10.78	0000	0958	345.	58	

159.	4.10.78	1005	1125	01	20	Unit tripped on hydro-mechanical trip.
160.	11.10.78	1508	2145	06	37	Unit tripped due to system fault.
161.	11.10.78 TO	2307	2400	00	51	Unit tripped due to mal-
	18.10.78	0000	1640	161	33	functioning of A.V.R.

The unit was released for capital maintenance w.e.f. 18.10.78, 1640 Hrs. The unit was synchronised with the system on 27.1.79 at 1110 Hrs. after capital maintenance.

TABLE II

BREAK DOWN TIME OF THE FUEL OIL SYSTEM

Sr.No.	Date, Month & Year	Period From	To	Duration Hrs.	Min.	Reasons
1.	1.1.77	1415	2400	09	45	Unit tripped due to low
	2.1.77	0000	0200	02	00	fuel oil pressure.
2.	22.5.77	0210	0225	00	15	Unit tripped as M.F.T. tripped due to low furnace oil pressure.
3.	6.5.78	2345	2400	00	15	Unit tripped on fuel oil
	7.5.78	0000	0220	02	20	pressure low.
4.	10.5.78	0000	0036	00	36	Unit tripped on fuel oil pressure low.
5.	31.5.78	1745	2400	06	15	Unit tripped on fuel oil
	1.6.78	0000	0440	04	40	pressure low.
6.	25.6.78	0925	1043	0118	18	Unit tripped on fuel oil pressure low.
7.	22.7.78	0940	1130	01	50	F.O. pumps tripped & pressure went low.
8.9	3.8.78	1423	1540	01	17	Unit tripped on fuel oil pressure low.
9.	18.9.78	1317	1403	00	46	Unit tripped on fuel oil pressure low.

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TABLE III

BREAK DOWN TIME OF THE MAIN BOILER

S. No.	Date, Month & Year	Period From	Period To	Duration Hrs.	Duration Min.	Reasons
1.	26.2.77	2005	2400	03	55	Unit stopped to attend
	27.2.77	0000	2400	24	00	leakage on boiler & tur-
	28.2.77	0000	2400	24	00	bine side.
2.	26.4.77 TO	2335	2400	00	25	Unit tripped to attend
	9.5.77	0000	2155	213	55	leakage of by pass valve & B.D. Valve & to recti-fy P.C. burner nozzles.
3.	9.5.77	2205	2400	01	55	Unit tripped due to
	10.5.77	0000	0350	03	50	sudden variation in the furnace draft.
4.	10.5.77	0353	1432	10	39	Unit tripped due to sudden variation in the furnace draft.
5.	31.5.77 TO	1742	2400	06	18	Unit tripped due to
	3.6.77	0000	1620	64	20	suspected leakage in the economiser.
6.	13.6.77	0140	1540	14	00	Unit tripped due to M.F.T. trip.
7.	19.6.77	1421	2400	09	39	Unit tripped manually
	20.6.77	0000	2400	24	00	to attend drum man hole
	21.6.77	0000	1121	11	21	leakage.
8.	25.6.77	2225	2400	01	35	Unit tripped through
	26.6.77	0000	2400	24	00	push button.
	27.6.77	0000	0534	05	34	

9.	28.8.77	1355	1538	01	43	Unit tripped on furnace draft high.
10.	14.9.77	0825	2400	15	35	Unit tripped manually for attending to various faults in boiler & turbine.
	TO					
	19.9.77	0000	1824	114	24	
11.	22.9.77	0442	0723	02	41	Unit tripped as M.F.T. tripped on abnormal furnace draft.
12.	7.10.77	0155	2400	22	05	Unit tripped due to suspected leakage in superheater.
	8.10.77	0000	2400	24	00	
	9.10.77	0000	2400	24	00	
	10.10.77	0000	0210	02	10	
13.	11.11.77	1628	2400	07	32	Unit tripped manually to attend various faults on boiler & turbine side.
	To					
	1 .11.77	0000	2137	117	37	
14.	17.11.77	0105	2400	22	55	Unit tripped manually to attend leakage on auxillary injection line right side.
	18.11.77	0000	0908	09	08	
15.	29.12.77	1613	2400	07	47	Unit tripped manually to attend leakage in economiser section.
	To					
	2.1.78	0000	1750	89	50	
16.	2.2.78	1501	2400	08	59	Unit tripped manually due to suspected leakage in economiser zone and super heater wall.
	To					
	24.2.78	0000	0858	512	58	

17.	11.3.78 To 24.3.78	0248 / 0000	2400 / 1436	21 / 302	12 / 36	Unit tripped due to leakage in boiler because of choking of reheater tubes.
18.	24.3.78 / 25.3.78	1737 / 0000	2400 / 0550	06 / 05	23 / 50	Unit tripped due to the the tripping of M.F.T.
19.	30.3.78 To 3.4.78	1757 / 0000	2400 / 2150	06 / 141	03 / 50	Unit tripped manually due to suspected leakage in reheater.
20.	16.5.78	2310	2400	00	50	Unit tripped due to abnormal furnace draft.
21.	3.6.78 To 23.6.78	0512 / 0000	2400 / 2032	18 / 476	48 / 32	Unit tripped manually due to suspected leakage in boiler pent house.
22.	26.6.78 To 3.7.78	1440 / 0000	2400 / 2100	09 / 165	20 / 00	Unit tripped manually due to leakage in economiser.
23.	16.7.78 To 19.7.78	0627 / 0000	2400 / 1205	17 / 60	33 / 05	Unit tripped due to leakage in the economiser
24.	18.8.78	0800	0907	01	07	Unit tripped due to furnace draft abnormal.

TABLE IV

BREAK DOWN TIME OF THE BOILER AUXILLARIES

S. No.	Date, Month & Year	Period From	Period To	Duration Hrs.	Duration Min.	Reasons
1.	23.3.77	1100	2153	10	53	Unit tripped manually due to non-availability of coal mills & P.C. feeders.
2.	29.3.77	1731	1957	02	26	Unit tripped manually due to trouble with both the I.D.Fans.
3.	30.3.77	1555	1637	00	42	Unit tripped manually due to excessive knocking sound in the only running F.D.Fans.
4.	31.3.77	0442	2400	19	18	Unit tripped because of high bearing temp. of I.D.Fans.
5.	26.4.77 TO	2335	2400	00	25	Unit tripped to attend leakage of inching by pass valve & B.D.Valve & to rectify P.C. burner nozzles.
	30.4.77	0000	2400	96	00	
6.	15.5.77	0540	0650	01	10	Unit tripped on furnace draft high. I.D.Fan inter-connecting damper closed of its own.

7.	8.7.77	1650	2400	07	10	Unit tripped due to
	9.7.77	0000	2400	24	00	the tripping of only
	10.7.77	0000	0525	05	25	available I.D.Fan.
	12.7.77	1600	2028	04	28	Unit tripped manually to attend damaged diaphragm of I.D.Fan.
9.	27.7.77	1247	2158	09	11	Unit tripped due to tripping of MFT on I.D.Fan failure.
10.	28.7.77 To	0655	2400	17	05	Unit tripped due to
	1.8.77	0000	1334	85	34	the tripping of MFT on I.D.Fan failure.
11.	31.8.77	1140	1210	00	30	Unit tripped due to tripping of only running F.D.Fan.
12.	11.11.77 To	1628	2400	07	32	Unit tripped manually
	16.11.77	0000	2137	117	37	to attend various faults on boiler & turbine side.
13.	27.5.78	1440	2400	09	20	Unit tripped as both
	28.5.78	0000	0345	03	45	the R.C.chain feeders became choked & drum pr. was reduced & subsecquently unit tripped on low vaccum pressure.
14.	25.6.78	1050	1550	0500	00	Unit tripped due to tripping of only available I.D.Fan due to abnormal sound in impeller.

15.	9.7.78	1202	2400	11	58	Unit tripped manually
	10.7.78	0000	2400	24	00	due to stopping of
	11.7.78	0000	0313	03	13	only available I.D.Fan due to abnormal sound.

TABLE V

BREAK DOWN TIME OF THE TURBINE

S. No.	Date, Month & Years	Period From	To	Duration Hrs.	Min.	Reasons
1.	14.1.77	0925	1110	01	45	Unit tripped due to low distribution oil pr.
2.	6.2.77	1120	2400	12	40	Unit tripped to attend heavy leakage in H.P. injection line.
	7.2.77	0000	0902	09	02	
3.	26.2.77	2005	2400	03	55	Unit stopped to attend leakage of boiler & turbine side.
	27.2.77	0000	2400	24	00	
	28.2.77	0000	2400	24	00	
4.	31.3.77	0442	2400	19	18	Unit kept under planned shut down for turbine bearing inspection.
	To 24.4.77	0000	0147	534	29	
5.	10.5.77	1540	2400	08	20	Unit tripped manually due to H.P.eccentricity being high.
	11.5.77	0000	1002	10	02	
6.	11.5.77	1022	1045	00	23	Unit tripped manually as both interceptor valve closed.
7.	27.6.77	1512	1540	00	28	Unit tripped on exhaust pressure high.
8.	13.7.77	2200	2400	02	00	Unit tripped manually to attend the leakage on the flange of safety valve of B.D.valve line.
	14.7.77	0000	0132	01	32	

9.	14.9.77 To 19.9.77	0825	2400	15	35	Unit tripped manually for attending to various faults in boiler & turbine.
	19.9.77	0000	1824	114	24	
10.	11.11.77 To	1628	2400	07	32	Unit tripped manually to attend to various faults on boiler and turbine side.
	16.11.77	0000	2137	21	37	
11.	18.11.77	2353	2400	00	07	Unit tripped manually to attend the H.P. radial bearing frunt of turbine.
	19.11.77	0000	2400	24	00	
	20.11.77	0000	0403	04	03	
12.	26.11.77	1130	1229	00	59	Unit tripped on exhaust pressure high.
13.	26.11.77	1254	1433	01	39	Unit tripped on exhaust pressure high.
14.	8.12.77	1700	2000	03	00	Unit tripped due to exhaust pressure high.
15.	8.12.77	2312	2400	00	48	Unit tripped due to attend speeder gear.
	9.12.77	0000	1638	16	38	
16.	21.12.77	0935	2112	11	35	Unit tripped manually to attend leakage in the deacration line of MOP.
17.	12.1.78	1040	2400	13	20	Unit tripped manually to attend leakage of B.D.valve.
	13.1.78	0000	2400	24	00	
	14.1.78	0000	2400	24	00	
	15.1.78	0000	0258	02	58	

18.	15.1.78	0310	0332	00	22	Unit tripped on hydro-mechanical trip.
19.	24.2.78	0917	1010	00	53	Unit tripped on exhaust pressure high.
20.	24.2.78	1025	2400	13	35	Unit tripped manually
	25.2.78	0000	2400	24	00	due to high differen-
	26.2.78	0000	1634	16	34	tial expansions.
21.	1.3.78	1302	1325	00	23	Unit tripped due to low vaccum.
22.	9.3.78	1820	2400	05	40	Unit tripped due to
	10.3.78	0000	1632	16	32	bursting of injection line of B.F.-2.
23.	25.3.78	0605	1728	11	23	Unit tripped due to L.P. rotor differential expansion high.
24.	28.4.78	2303	2400	00	57	Unit tripped manually
	29.4.78	0000	0327	03	27	to attend fault on T-G side.
25.	23.6.78	2139	2400	02	21	Unit tripped manually
	24.6.78	0000	1308	13	08	due to H.P.rotor diff-erential expansion high.
26.	27.7.78 To	0738	2400	16	22	Unit tripped by tripping TTX.
	31.7.78	0000	2145	94	45	
27.	31.7.78	2155	2400	02	05	Unit tripped due to exhaust pressure high.

28.	18.8.78	0909	0925	00	16	Unit tripped on distribution oil pr. low.
29.	20.8.78	1814	1953	01	41	Unit tripped due to exhaust pr. high.
30.	20.8.78	2005	2045	00	40	Unit tripped due to distribution oil pr. low.
31.	14.9.78	0546	0602	00	16	Unit tripped due to distribution oil pr. low.
32.	18.9.78	1413	1430	00	17	Unit tripped due to distribution oil pr. low.
33.	19.9.78	1700	2400	07	00	Unit tripped due to fire on turbine.
	To					
	4.10.78	0000	0958	345	58	
34.	4.10.78	1005	1125	01	20	Unit tripped on hydro-mechanical trip.

TABLE VI

BREAK DOWN TIME OF THE TURBINE AUXILLARIES

S. No.	Date, Month & Year	Period From	Period To	Duration Hrs.	Duration Min.	Reasons
1.	22.9.77	0812	1030	02	18	Unit tripped manually due to tripping of BFP on balancing leak off pressure high.
2.	27.9.77	1520	2017	04	57	Unit tripped due to the tripping of both CW pumps on condenser pr. high.
3.	27.9.77	2330	2400	00	30	Unit tripped due to the tripping of both C.W. pumps on condenser pr. high.
	28.9.77	0000	0423	04	23	
4.	17.10.77	1023	1332	03	09	Unit tripped manually through MFT as both C.W. pumps has tripped.
5.	11.11.77	1628	2400	07	32	Unit tripped manually to attend various faults on boiler & turbine side.
	To 16.11.77	0000	2137	117	37	
6.	4.3.78	0230	1316	10	46	Unit tripped manually to clean the BFP suction strainer.
7.	8.4.78	1515	1632	01	17	Unit tripped manually due to tripping of BFP.

8.	8.5.78	0850	1026	01	36	Unit tripped on B.F.P. tripped on over current Y- phase.
9.	23.5.78	2005	2050	00	45	Unit tripped manually as vaccum was falling due to low reheat pr.
10.	23.5.78	2235	2400	01	25	Unit tripped manually as vaccum was falling due to low reheat pr.
11.	29.8.78	0115	1335	12	20	Unit tripped due to leakage in the discharge line of B.F.P.

::::::::::::

TABLE VII

BREAK DOWN TIME OF THE GENERATOR/EXCITER

S. No.	Date, month & Year	Period From	Period To	Duration Hrs.	Duration Min.	Reasons
1.	25.1.77	1115	1207	00	52	Unit tripped on rotor earth fault.
2.	6.2.77	0012	0044	00	32	Unit tripped on reverse power.
3.	6.3.77	1004	1023	00	19	Unit tripped manually to clean slip rings of exciter.
4.	21.3.77	1243	1328	00	45	Unit tripped manually to clean exciter brushes.
5.	21.3.77	1337	1730	03	53	Unit tripped on rotor earth fault.
6.	15.5.77	0120	0527	04	07	Unit tripped on rotor earth fault.
7.	12.10.77	1636	1812	01	36	Unit tripped due to generator field earth fault.
8.	13.10.77	0927	2400	14	33	Unit tripped due to system disturbance & rotor earth fault.
9.	7.12.77	2108	2205	00	57	Unit desynchronized cleaning exciter brushes.
10.	19.12.77	0837	1037	02	00	Unit tripped on rotor earth fault.

TABLE VIII

BREAK DOWN TIME OF THE ELECTRICAL EQUIPMENT

S. No.	Date, Month & Year	Period From	Period To	Duration Hrs.	Duration Min.	Reasons
1.	16.2.77	1817	1838	00	21	Unit tripped on axial shift high due to load throw off.
2.	15.3.77	2107	2145	0038	38	Unit tripped as the generator breaker opened.
3.	20.5.77	1012	1220	02	08	Unit desynchronized.
4.	23.5.77	1832	2400	05	28	Unit tripped due to operation of VAT Buckh-olz's relay.
	24.5.77	0000	2400	24	00	
	25.5.77	0000	2400	24	00	
	26.5.77	0000	1426	14	26	
5.	21.9.77	0730	2400	16	30	Unit tripped manually as instruments supply failed due to tripping of station transformer on its fire protection air pressure low.
	22.9.77	0000	0431	04	31	
6.	15.12.77	2300	2400	01	00	Unit tripped due to tripping of all auxill-aries on under voltage.
	16.12.77	0000	0305	03	05	
7.	10.4.77	0427	0610	01	43	Unit tripped due to the tripping of auto T/F on over load.
8.	12.9.78 To	0901	2400	14	59	Unit tripped due to flash on BFP Motor.
	14.9.78	0000	0440	28	30	

TABLE IX

BREAK DOWN TIME OF THE INSTRUMENTS/CONTROLS

S. No.	Date, Month & Year	Period From	To	Duration Hrs.	Min.	Reasons
1.	6.1.77	1600	1630	00	30	Unit tripped on axial shift.
2.	6.1.77 To	1710	2400	06	50	Unit tripped to check up axial shift.
	9.1.77	0000	2028	68	28	
3.	19.1.77	1145	1306	01	21	Unit tripped due to mal operation of TTX relay.
4.	22.1.77	1757	1808	00	11	Unit tripped due to high axial shift.
5.	23.2.77	1220	1230	00	10	Unit tripped on high axial shift.
6.	25.2.77	0905	0955	00	50	Unit tripped on high axial shift.
7.	10.3.77	1942	2400	04	18	Unit tripped due to burning of furnace draft cables.
	11.3.77	0000	0724	07	24	
8.	2.3.77 To	1055	2400	13	05	Unit tripped without any initiating cause.
	3.3.77	0000	1614	16	14	
9.	25.4.77	0534	0605	00	31	Unit tripped due to thrust bearing failure hydromechanical trip.

10.	3.6.77	1630	1945	03	15	Unit tripped due to thrust bearing failure hydromechanical trip.
11.	14.10.77	1103	1518	04	15	Unit tripped due to the system disturbance and rotor earth fault.
12.	26.2.78	1734	2400	06	26	Unit tripped by tripping turbine.
	27.2.78	0000	0034	00	34	
13.	11.4.78	2040	2400	03	20	Unit tripped to attend leakage on the impulse line indicating pressure in B.P.E.
	12.4.78	0000	1542	15	42	
14.	27.5.78	0803	0829	00	26	Unit tripped on thrust bearing failure hydraulic trip.
15.	14.9.78	0500	0523	00	23	Unit tripped on hydromechanical shift.
16.	7.9.78	1535	1829	02	54	Unit tripped on no coal.

3. CALCULATIONS AND RESULTS

3.1 CALCULATIONS FOR COMPONENT RELIABILITY

In order to work out the reliability of various components, total cummulated failure time of various components, have been evaluated from the data included in section 2.3, Tables II to IX. As the total operating time of the system is known & the total cummulated failure time of each component within the total operating time of the system has been evaluated, reliability of each component can be worked out.

Reliability of the Component =

$$= 1 - \frac{\text{Total cummulated failure time of the Component}}{\text{Total operating time of the system}}$$

Table X & XI given below present the reliability of boiler auxilliaries and various other components respectively.

TABLE X

RELIABILITY OF BOILER AUXILLARIES

	I.D.Fan 1	I.D.Fan 2	F.D.Fan 1	F.D.Fan 2	Others
Component Unreliability.	0.00538	0.00924	0.000046	0.000033	0.01033
Component Reliability	0.99461	0.99075	0.999953	0.999966	0.98966
	R_1	R_2	R_3	R_4	R_5

Sub-system Reliability $= \left[1 - (1-R_1)(1-R_2) \right] \times \left[1 - (1-R_3)(1-R_4) \right] \times R_5$

$= 0.98961$

TABLE XI

RELIABILITY OF INDIVIDUAL COMPONENTS

S. No	Component	Total Cummulated Failure Time of Components in Hrs	Total Operating Time of The System in Hrs	Reliability
1.	Fuel Oil System	25	15,041	0.99833
2.	Boiler Aux.	37636	15,041	0.98961
3.	Main Boiler	2,666	15,041	0.82275
4.	Turbine Aux.	159	15,041	0.98942
5.	Turbine	854	15,041	0.94322
6.	Generator/ Exciter	40	15,041	0.99734
7.	Electrical Equipment	142	15,041	0.99055
8.	Instruments/ Controls	149	15,041	0.99009

3.2 CALCULATIONS FOR SYSTEM RELIABILITY

3.2.1 ASSUMPTIONS

(i) The functional entity of each component/sub-system is independent of the other i.e. failures are independent.

(ii) A system has two states only, good or bad.

3.2.2 SYSTEM RELIABILITY

Smith (5) has described that a series system is one in which all components are so interrelated that the entire system will fail if any of its components fail. It is gathered from the study of data given in Table I and the system-component relationship on functional basis that the entire system trips on account of any fault in any of the components. In line with the above definition of series system, the system-component relationship of the unit under consideration is essentially that of series type. The system reliability is therefore the product of reliabilities of the constituent components. Therefore,

$$R_s = R_{s_1} \times R_{s_2} \times R_{s_3} \times R_{s_4} \qquad \text{----} \ (17)$$

where;

$$R_{s_1} = R_{F.O} \times R_{E.E} \times R_{I/C} \ ,$$

$$R_{s_2} = R_{B.A} \times R_{E.E} \times R_{I/C} \times R_{M.B} \times R_{E.E.} \times R_{I/C},$$

$$R_{s_3} = R_{T.A} \times R_{E.E} \times R_{I/C} \times R_{T} \times R_{E.E} \times R_{I/C},$$

$$R_{s_4} = R_{G/E} \times R_{E.E} \times R_{I/C}$$

Taking values for reliability of various sub-systems from Table XI & putting these in equation (17) ,

$$R_s = 0.97909 \times 0.78311 \times 0.89761 \times 0.97812$$

$$R_s = 0.67317 \text{ i.e. } 67.317\%$$

5. SCOPE FOR FURTHER WORK

Having determined the reliability values for each sub-system as well as the system reliability it was possible to establish the weak links or less reliable Sub-systems. Thus various steps can be adopted to improve the system reliability. Some of the areas in which further work shall help in achieving our objective are enumerated below:

1. PREVENTIVE MAINTENANCE

From the failure time distribution of main boiler, turbine, boiler auxillaries & turbine auxillaries, a detailed preventive maintenance programme can be drawn up for a more efficient management of the thermal power plant.

2. DESIGN MODIFICATIONS

From the computed results for individual Sub-systems/components reliabilities, it is clear that the main boiler is the weakest link in the thermal power plant system. This warrants a more rigorous and accurate approach for its design & manufacture. A higher system reliability can be achieved by improvements/modifications in the existing designs of its various components. The extra expenditure incurred in research & development suggesting design modifications is likily to be compensated by achieving a higher system reliability & consequently less break downs.

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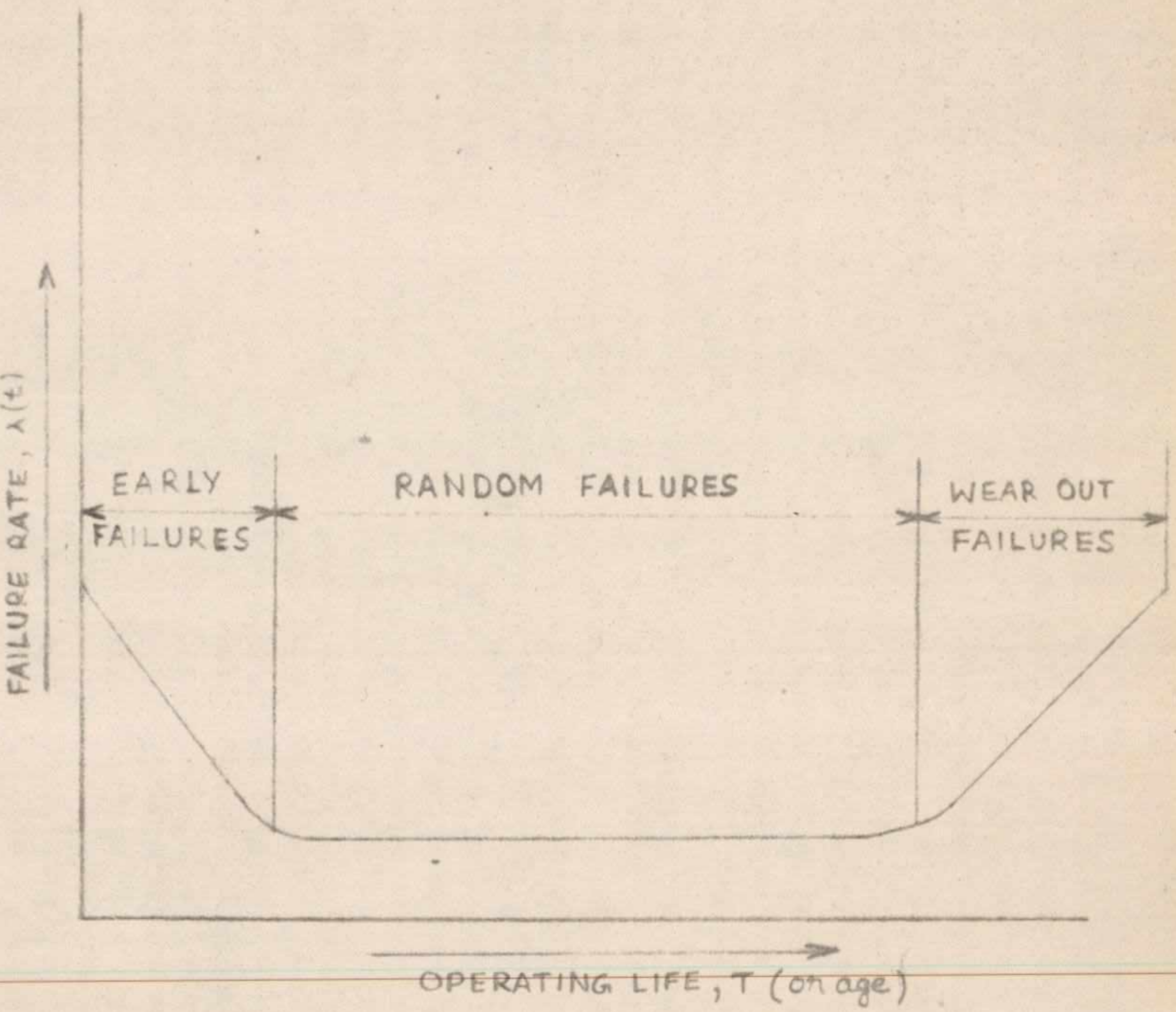


FIG.1. BATHTUB CURVE; FAILURE RATE VERSUS AGE

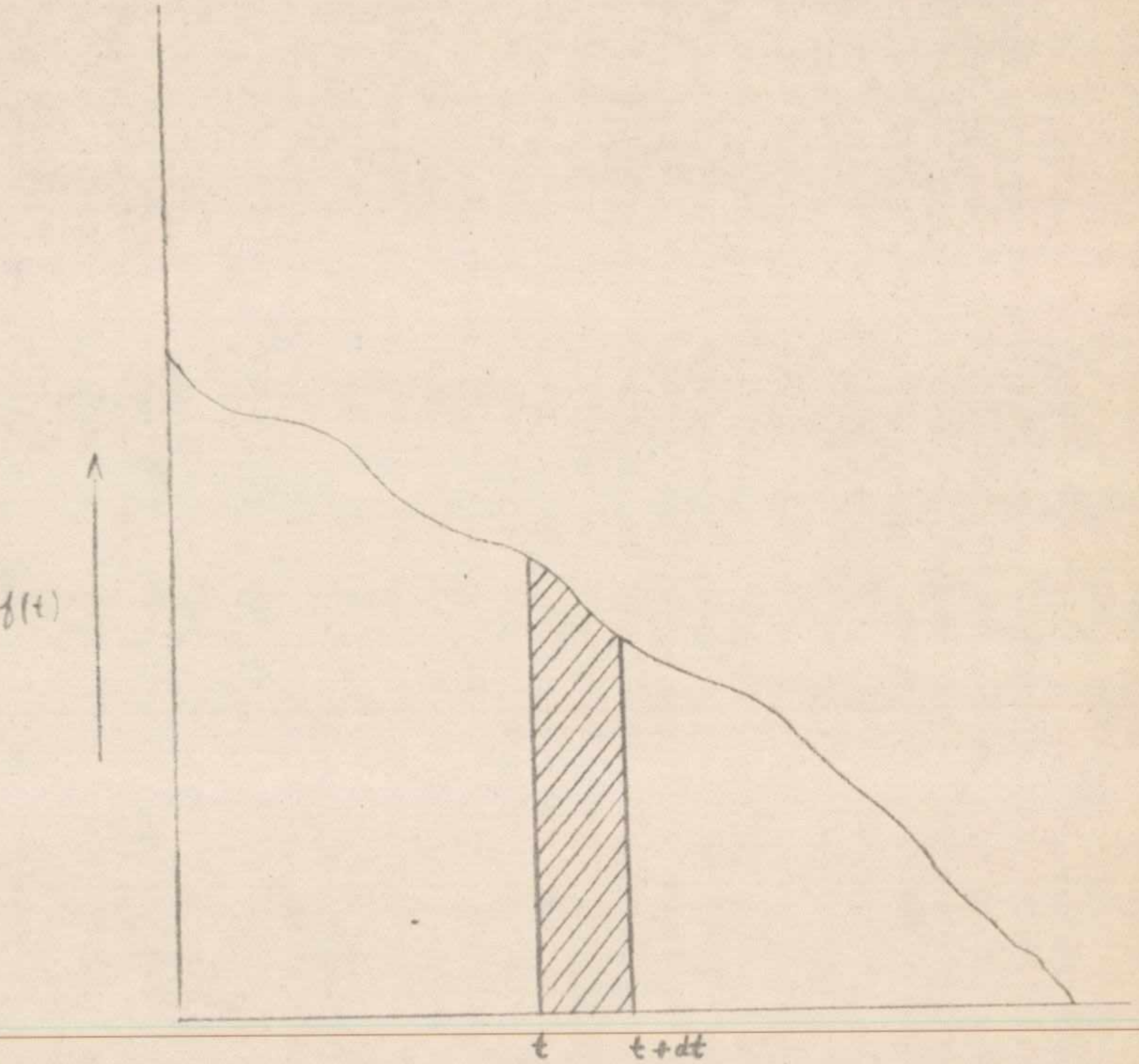


FIG.2 PROBABILITY DENSITY FUNCTION

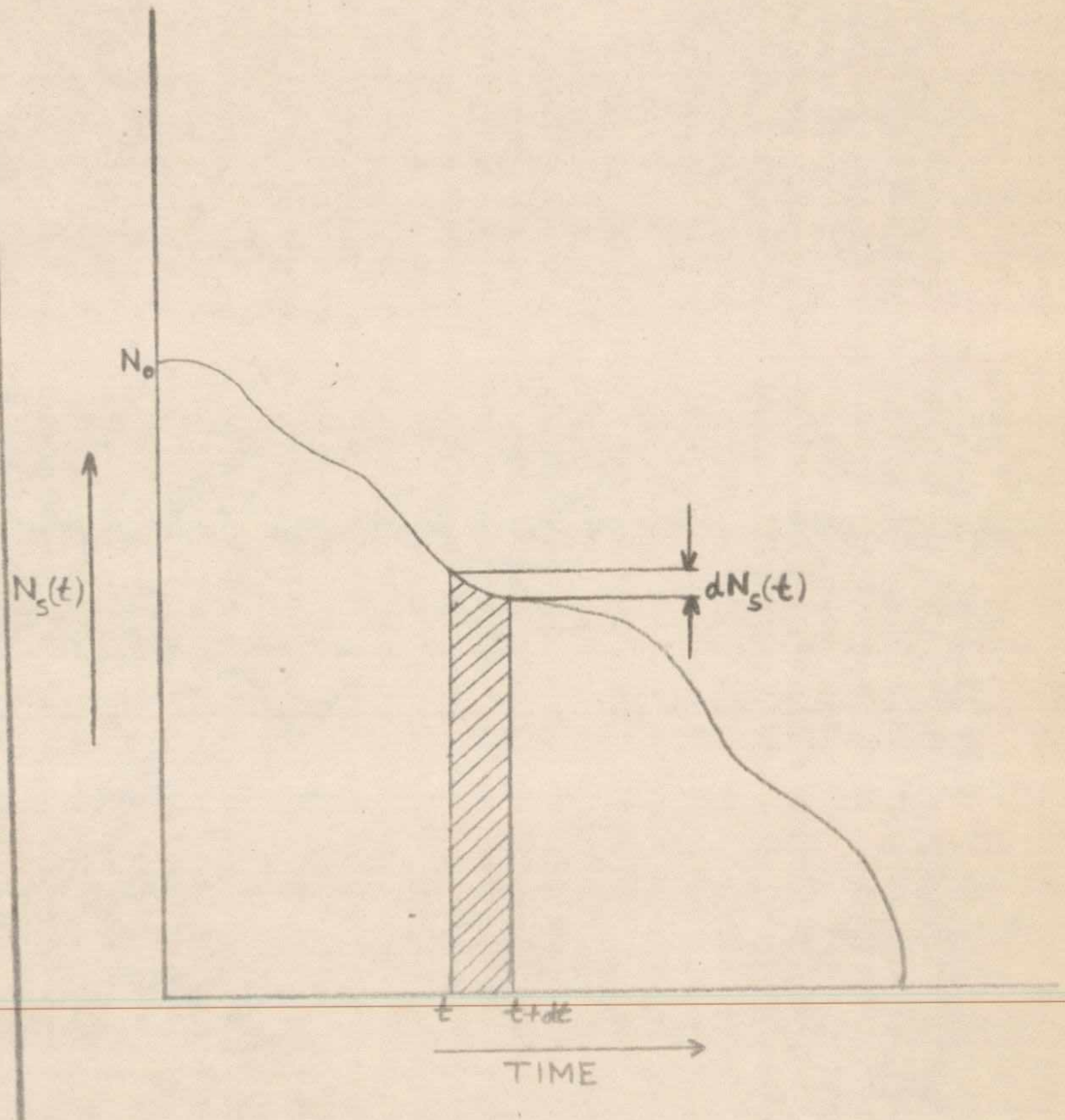


FIG.3 THEORETICAL NON-REPLACEMENT TEST

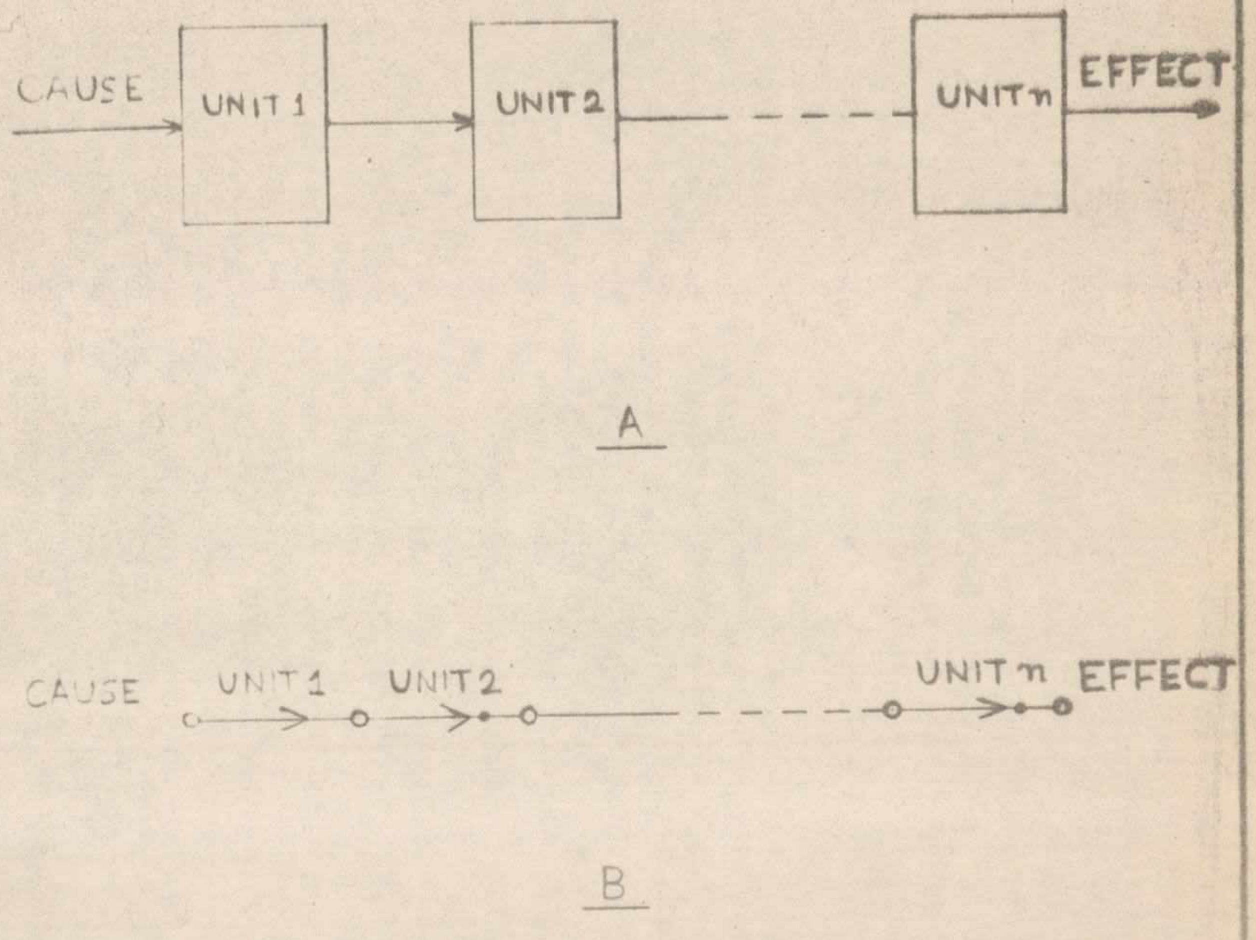


FIG. 4 SERIES RELIABILITY CONFIGURATION

A. RELIABILITY BLOCK DIAGRAM;

B. RELIABILITY GRAPH.

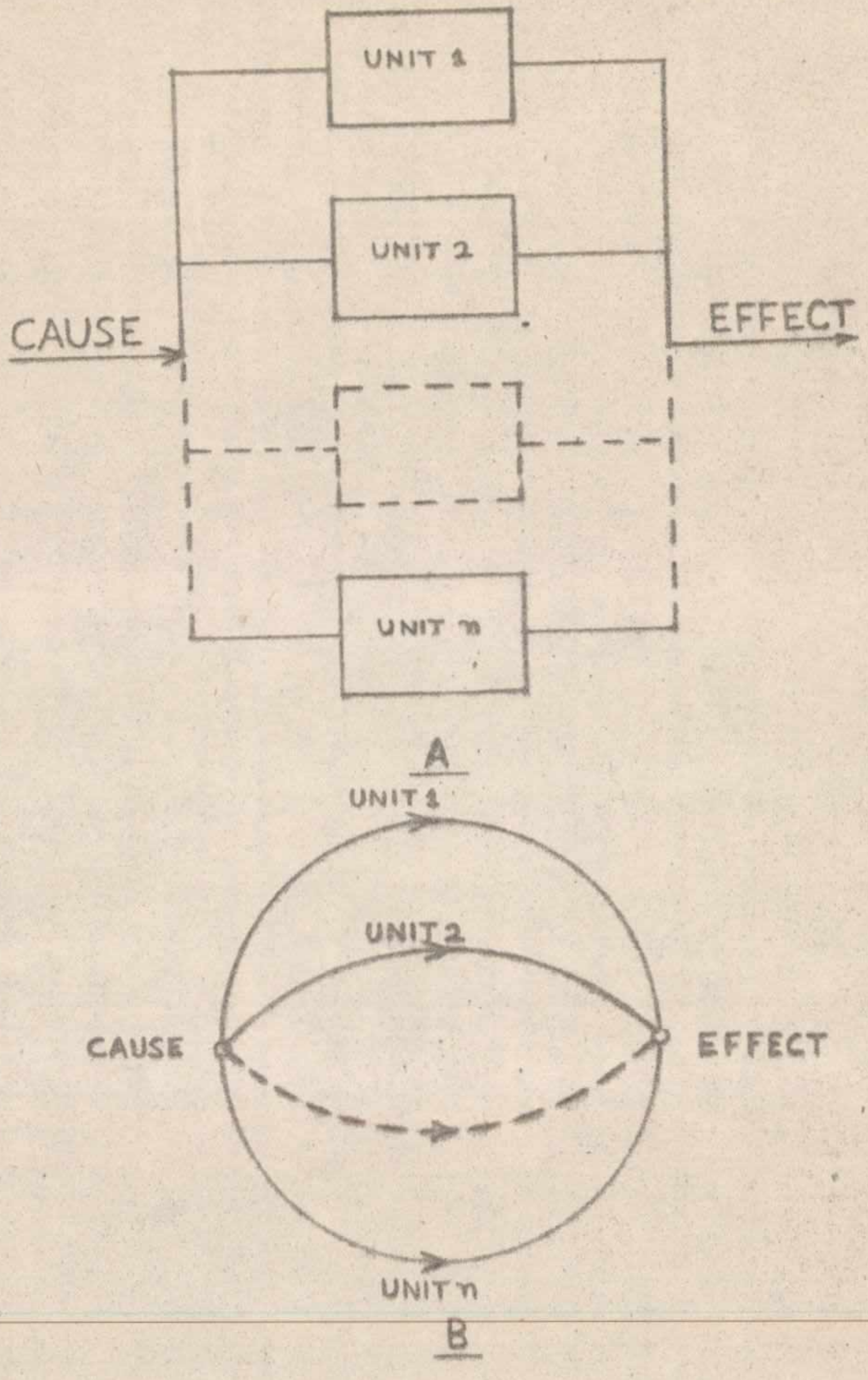
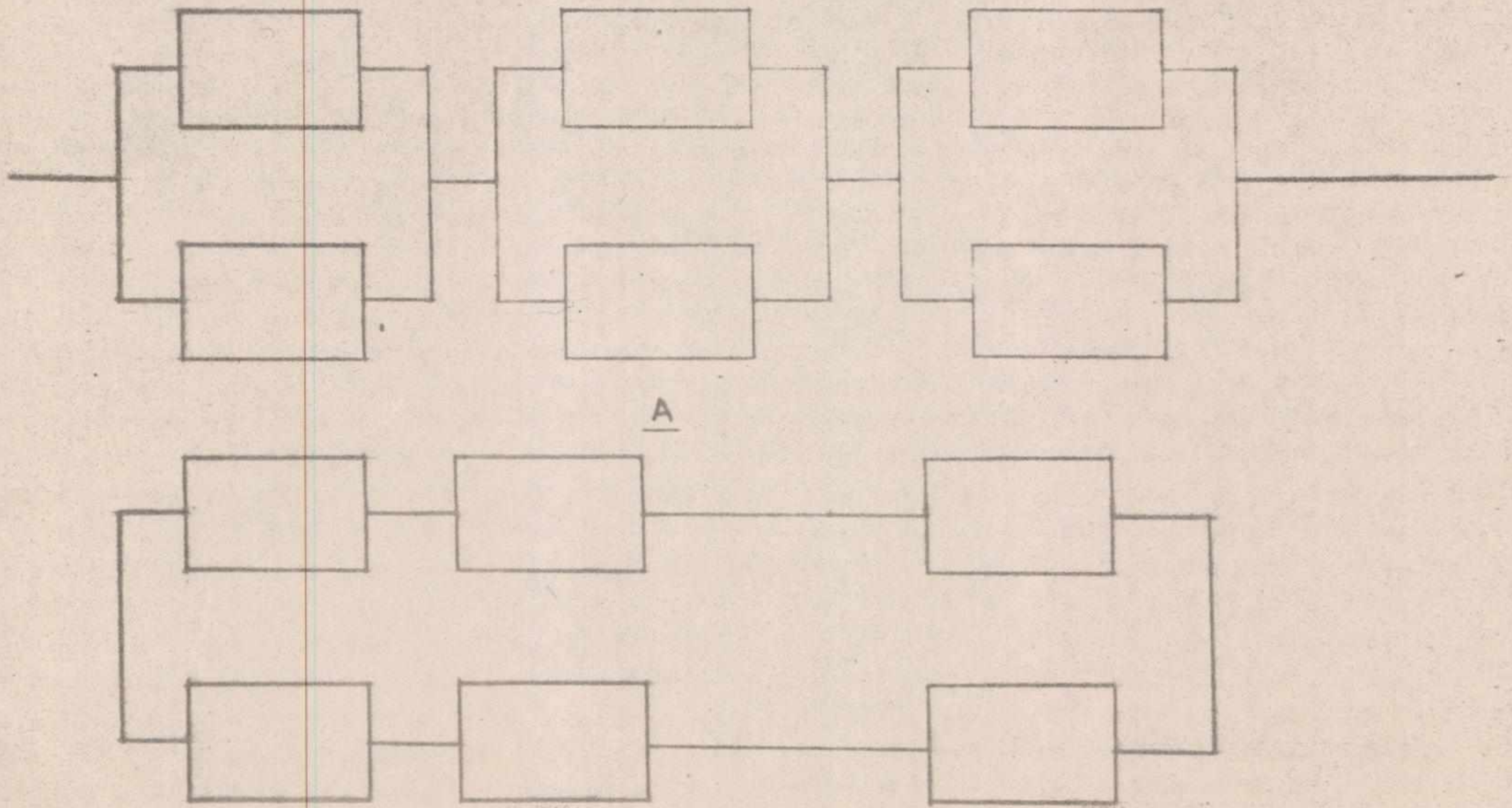


FIG.5. PARALLEL RELIABILITY CONFIGURATION

A. BLOCK DIAGRAM

B. RELIABILITY GRAPH



A

B

FIG. 6(A,B) COMBINED SERIES-PARALLEL CONFIGURATION

A. SERIES-PARALLEL

B. PARALLEL-SERIES

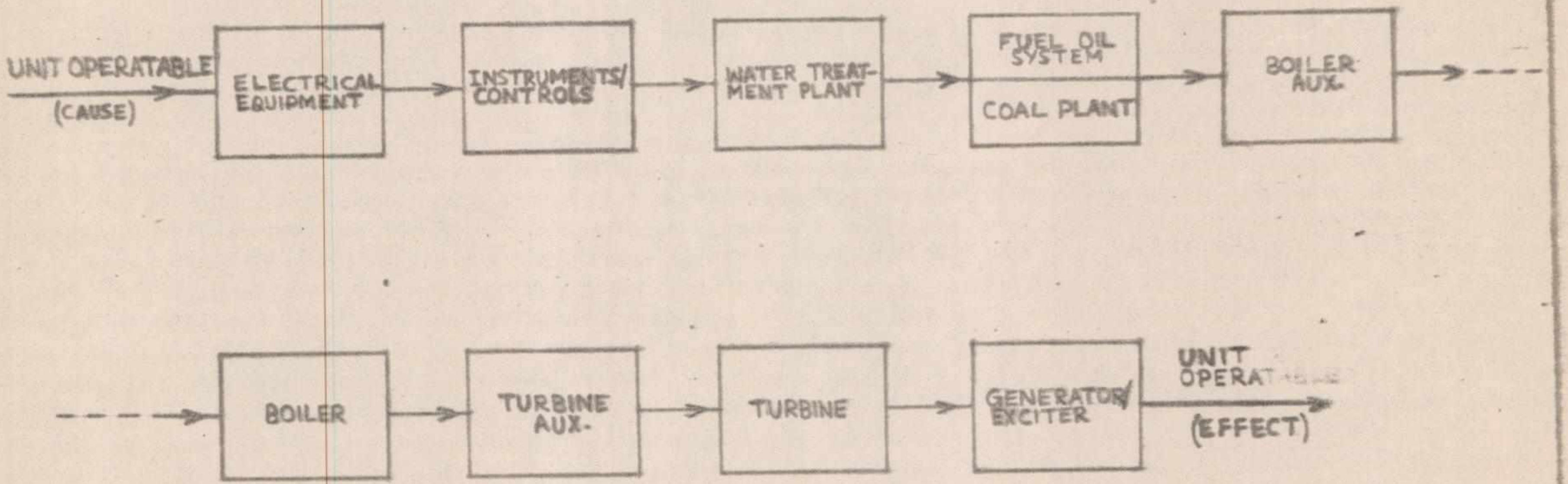


FIG.7. FUNCTIONAL BLOCK DIAGRAM

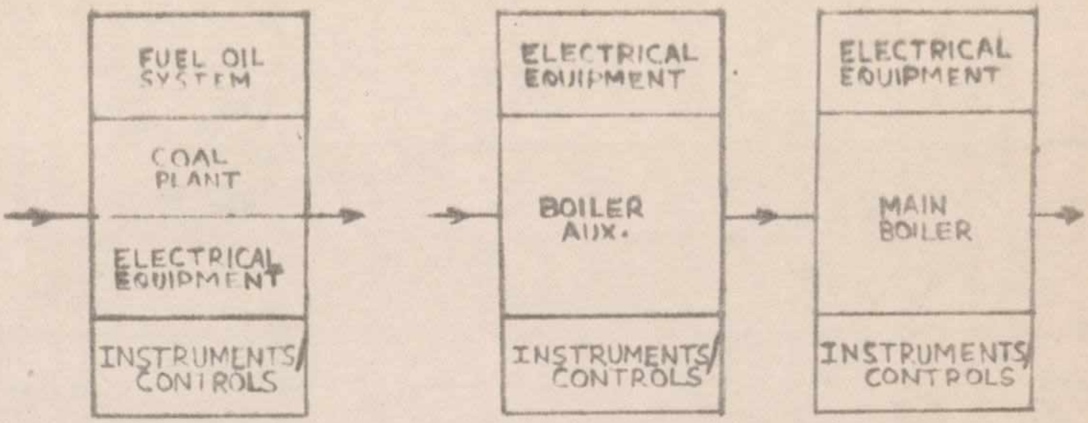


FIG.8(A). SUB-SYSTEM (S_1)

FIG.8(B). SUB-SYSTEM (S_2)

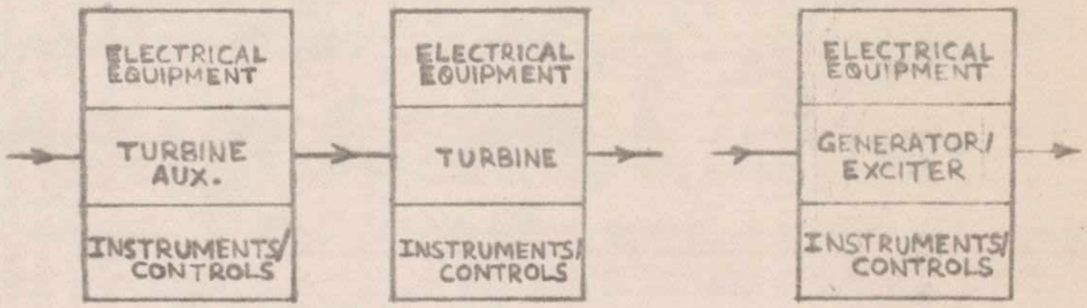


FIG.8(C). SUB-SYSTEM (S_3)

FIG.8(D). SUB-SYSTEM (S_4)

FIG.8(A,B,C,D) RELIABILITY BLOCK OF THE VARIOUS SUB-SYSTEM

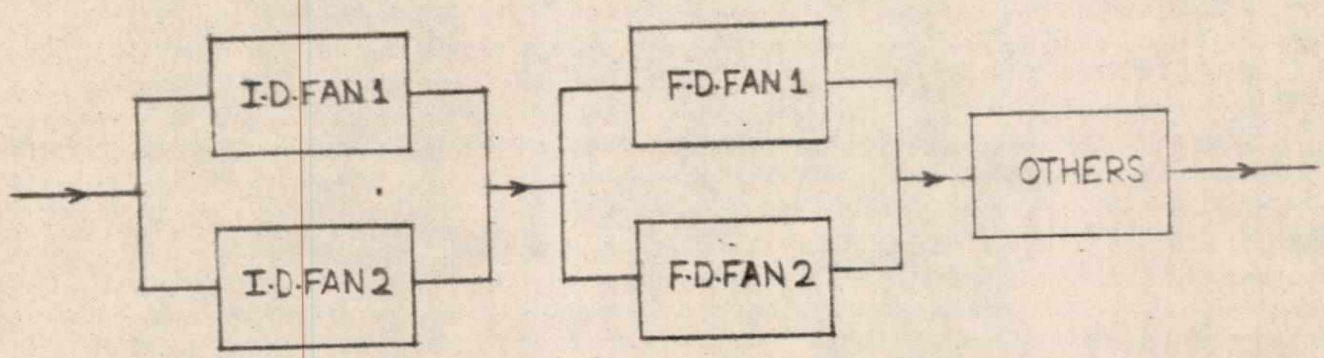


FIG.9 RELIABILITY BLOCK DIAGRAM OF BOILER AUXILLARIES

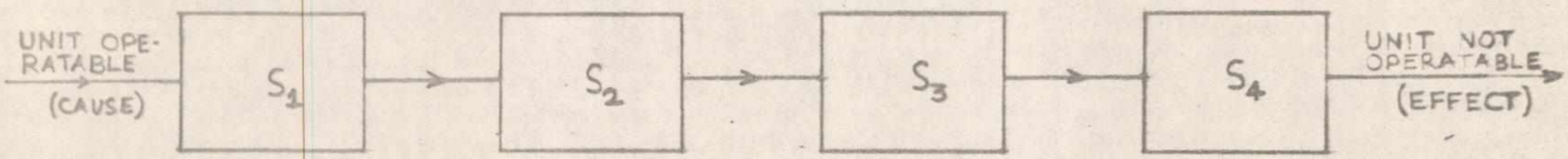


FIG.10 RELIABILITY BLOCK DIAGRAM OF THE SYSTEM

APPENDIX I

Fig. 3 represents a general case of number of articles surviving at any time plotted against time. Take a small interval of time t to t + dt, during which the number surviving changes by d N_s (t), we can say that d N_s(t) failures have occurred in time dt. As is evident from Fig.3, N_s (t) is a decreasing quantity, and hence d N_s (t) is negative. The failure rate at time t, in other words the instantaneous failure rate, is given by

$$\lambda(t) = -\frac{d\,N_s(t)}{N_s(t)\,dt}$$

Multiplying numerator and denominator by N_o,

$$\lambda(t) = -\frac{d\,N_s(t)}{N_s(t)\,dt}\;\frac{N_o}{N_o}$$

or, rearranging,

$$\lambda(t) = -\frac{d\,N_s(t)}{N_o}\;\frac{N_o}{N_s(t)}\;\frac{1}{dt}$$

Since R (t) = N_s (t) / N_o

$$\lambda(t) = -d\,R(t)\;\frac{1}{R(t)}\;\frac{1}{dt}$$

Therefore

$$-\lambda(t)\,dt = \frac{d\,R(t)}{R(t)}$$

Therefore,

$$-\int_0^t \lambda(t)\,dt = \frac{d\,R(t)}{R(t)}$$

λ (t) is integrated with respect to time from 0 to t. 1/R (t), however, is being integrated with respect to R (t). Now, when t = 0, R (t)= 1 (the probability of not

not failing in no time is, ofcourse, 1). At time t the reliability is R (t) by definition.

Integrating, then,

$$-\int_0^t \lambda(t)\,dt = \log_e R(t)\,\Big|_1^{R(t)}$$

$$= \log_e R(t) - \log_e 1$$

$$= \log_e R(t)$$

But if $a = e^b$ then $b = \log_e a$, so that

$$R(t), \exp\left| -\int_0^t \lambda(t)\,dt \right|$$

If the failure rate is assumed not to vary with time, then $\lambda(t) = \lambda$; therefore

$$R(t) = \exp\left| -\int_0^t \lambda\,dt \right|$$

But $\int_0^t \lambda\,dt = \lambda t\,\Big|_0^t = \lambda t$

Therefore

$$R(t) = e^{-\lambda t}$$

APPENDIX II

Consider Fig. 2. The probability of failure in the interval t_1 to t_2 is $\int_{t_1}^{t_2} f(t)\,dt$.

The probability of failure in the interval from zero to t is the unreliability, given by

$$Q(t) = \int_0^t f(t)\,dt$$

Since the probability of failure between zero and infinity is unity, we can say that

$$\int_0^\infty f(t)\,dt = 1$$

Since $R(t) = 1 - Q(t)$

$$R(t) = \int_0^\infty f(t)\,dt - \int_0^t f(t)\,dt = \int_t^\infty f(t)\,dt$$

Differentiating both sides of this equation, -

$$-d\,R(t) = f(t)\,dt \text{ so that } f(t) = -\frac{d\,R(t)}{dt}$$

Applying this to the constant failure rate,

$$f(t) = -\frac{d\,e^{-\lambda t}}{dt} = \lambda e^{-\lambda t} = \lambda R(t)$$

where $R(t) = e^{-\lambda t}$ --- SEE APPENDIX I

Not constraining ourselves to the constant-failure-rate case, we have

$$f(t) = \frac{-d e^{-\int_0^t \lambda(t)dt}}{dt} = \lambda(t)\, e^{-\int_0^t \lambda(t)dt} = \lambda(t)R(t)$$

Therefore

$$\lambda(t) = \frac{f(t)}{R(t)}$$

which always holds true. However,

$$f(t) = -\frac{d\,R(t)}{dt}$$

Therefore

$$\lambda(t) = -\frac{d\,R(t)}{R(t)dt}$$

This yields a general expresion for failure rate in terms of reliability and is useful when failure rate cannot be derived from M.T.B.F. except when failure rate is constant.

APPENDIX III

Reliability function in case of the variation of failure rate with time takes the form, given by

$$R(t) = \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right]$$

As can be seen from the above expression, the reliability function requires three parameters (γ, β, η) in the Weibull case.

Therefore

$$1 - Q(t) = \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right]$$

So that

$$\frac{1}{1 - Q(t)} = \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right]$$

Whence

$$\log \frac{1}{1-Q(t)} = \left(\frac{t-\gamma}{\eta}\right)^{\beta}$$

and

$$\log\log \frac{1}{1-Q(t)} = \beta \log (t-\gamma) - \beta \log \eta$$

Replacing $(t-\gamma)$ by t',

$$\log \log \frac{1}{1-Q(t)} = \beta \log t' - \beta \log \eta$$

But if

$$\log \log \frac{1}{1-Q(t)} = 0$$

then $\beta \log t' = \beta \log \eta$

so that

$$t' = \eta$$

This occurs if

$$\log \log \frac{1}{1-Q(t)} = 0 \text{ so that } \log \frac{1}{1-Q(t)} = 1$$

i.e. $\frac{1}{1-Q(t)} = e$ and $Q(t) = 0.63$

Assuming then that $\gamma = 0$ & $t' = t$, then

$$\log \log \frac{1}{1-Q(t)} = \beta \log t - \beta \log \eta$$

which is the equation of a straight line of the form

$y = mx + c$, where

$y = \log \log \frac{1}{1-Q(t)}$, $x = \log t$

and the slope is β.

If the group of failures are distributed according to the Weibull function and it is assumed that $\gamma = 0$, then by plotting these failures against time on double logarithmic paper (failure percentage on log log scale & time on log scale), a straight line should be obtained. The Weibull parameters, and hence the expression for reliability, may then be obtained by suitable measurements of slope, etc.