RELIABILITY ANALYSIS OF DUAL-PURPOSE (POWER & WATER) PRODUCTION STATION

VOLUME I

A THESIS SUBMITTED

TO

THE UNIVERSITY OF GLASGOW

FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

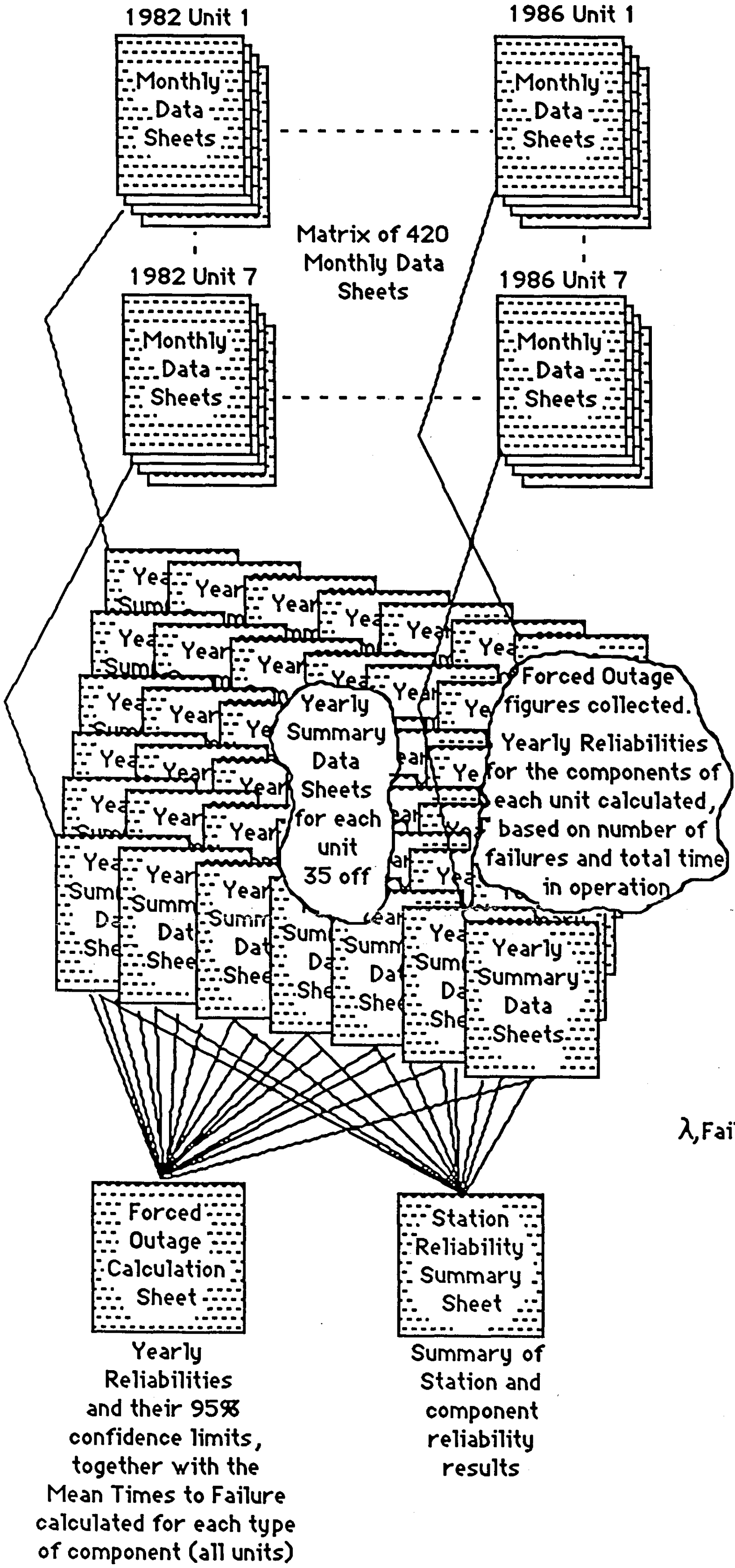
ABDULLAH. HAMAD. BOU-HASAN

DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY OF GLASGOW

April 1990

Figure 131



Information Hierachy and Calculation flow on spreadsheets

Bases of Calculations

$$\lambda\text{, Failure Rate} = \frac{\text{No. of failures of component}}{\text{Operating time of component}} \quad \text{Units} \quad \frac{\text{Numb}}{\text{Time}}$$

$$\text{Mean Time Between Failures} = \frac{1}{\text{Failure Rate}}$$

R(t) = Reliability = Probability of component not failing in a given time (t)

For constant failure rate $R(t) = e^{-\lambda t}$

t, here, being the time period under consideration

ADDENDUM

A. Information Hierarchy and Calculation Flow on Spreadsheets.

Figure 131 attached gives a summary on the hierarchy and calculation flow on the spreadsheets.

As may be seen from the figure, the reference station monthly data sheets for the 7 production units for the years (1982-1986) were incorporated into computer spreadsheets, and the cumulative result was a matrix of 420 monthly data sheets. This matrix was used to produce

1 - 35 anual summary data sheets, a set for each unit.

2 - A sheet of forced outage figures, yearly reliabilities and mean times to failure for the components of each unit, and a station reliability sheet

The yearly summary data sheets are used to produce forced outage calculation sheets. The forced outage calculation sheets are used to calculate yearly reliabilities and their 95% confidence limits using the chi-square distribution estimates (refer to Section 8.5.8 Page 317 of Volume I of the thesis). Furthermore, the yearly summary sheets are used to produce station reliability summary sheets, which in turn are used to calculate summary of station components reliability results.

B. Difference between result of Figure 121-A page 336 and Table no. 65 Page 337

Figure 121-A shows that the boiler has the highest total number of failures (102) than the turbine (29), generator (46), and distiller (72); whereas Table 65 indicates that the average failure rate over the 5 year period for the boiler is less than that of the distiller (4.50 E04 for the boiler compared to 6.96 E04 for the distiller). This might seem odd at first glance, however, if we look closer on the basis of the calculation, we will find that they are not comparable, because the bases of the calculation are different. Figure No.121-A is based on the total time of operation, whereas the failure rate values are based on the actual operating time.

C. Expansion of the Work

The work of the thesis was confined to reliability analysis. The definition of reliability is the probability of a device or system performing its function adequately, for the period of time intended, under specified operating conditions. From this definition reliability is defined through the mathematical concept of probability. Therefore, reliability analysis will lead to the calculation of establishing the failure rates for the production unit sub-systems. These failure rates of the various parts of the production unit indicate the frequency of occurrence upon which the distribution of maintenance downtimes are dependent. Therefore, in order to establish that "the components can be made to remain within their useful life period for the bulk of their economically feasible life" (36) the concept of preventive maintenance has to be introduced. Since reliability analysis is a tool to put forward such concept, then maintainability analysis has to be initiated to complement the work of the thesis. Maintainability is concerned with mean time to repair and the repair time. "Maintainability models are related to reliability to determine frequency of occurrence of maintenance requirements" (70). "The maintainability model is made up of several repair time elements, such as localization, isolation, disassembly, interchange or repair, reassembly, repair (MTTR) is expressed mathematically as (70)

$$\text{MTTR} = \text{antilog} \frac{\sum_{1}^{N} \text{Failure rate x log (repair time)}}{\sum_{1}^{N} \text{Failure rate i}}$$

$$\sum F$$

A combination of repair times and failure rates lead to the MTTR and down time and are used to evaluate the production unit maintainability. Once the production unit maintainability is established, then improvements in operational planning and design may be attempted.

Another area where the work of this thesis can be expanded, is that a state space reliability assessment of the (power and water) production station could be conducted in order to take into account load variation, production capacity reserve, and operating reserve. The basis of the analysis was the work of Chapter 6 of the thesis.

To my father, mother, and beloved wife Adelah

Acknowledgments

The author would like to thank the Government of Kuwait for providing the scholarship grant under which this research project was undertaken.

He is also very grateful to his technical supervisor Dr. W.T. Hanbury for his constant guidance, encouragement and technical support throughout the research work.

Finally the author would like to thank Mr. Al-Adwi Bader Ibrahim and Mr. Mohamed Jalal Motewi of the Doha East power and water production station (Kuwait) for their constant help during the course of the study.

SUMMARY

This thesis presents the outcome of applying reliability engineering analysis techniques to a thermal dual - purpose (power&water) production station. The thermal cycle of the station is a fossil fueled steam boiler, condensing - extraction steam turbine, a generator, and a multi - stage flash evaporator.

Full description and analysis of the station, and the production unit configurations were investigated in order to acquire a detailed information about the functional and physical interconnections of the various sub - systems and associated systems making up the (power&water) production units and hence, the station. Based on this analysis, the production unit was found to be composed of four sub - systems and eleven associated systems (chapter III).

Based on the work of (chapter III), the operational interlocking logical sequence models for the station, boiler, turbine, generator, distiller, and their sub - systems were developed (chapter I V).

As a consequential step to the previously mentioned two analysis, reliability network analysis was performed, and reliability models for the production station, production unit, unit sub - systems, unit associated, and their sub - sub systems were developed (chapter V).

State - space reliability models for production station and the unit sub - systems were developed and are presented in (chapter V I).

Doha East (power&water) production station of the State of Kuwait was selected as an actual operating reference station. This station is composed of seven production units.The installed capacity of reference station is 1050 (MW) of power and 191 X 10^3 cubic meters per day (42 million imperial gallons). The outages data for all the seven units were collected over a period of five years (1982 - 1986). These original outages data were analysed and processed in newly designed forms. The processed outages data are found in appendix (I) in volume (II) of the thesis.

All the processed outages data for the seven production units were entered in a computer spread sheet program, and the various reliability calculations were performed on them.(chapter V III).

Based on these calculations the reliability models for the production station, boiler, turbine, generator, distiller, and their sub - systems which were developed in (chapter V) were found to be fairly representative and adequate for reliability calculations of the production station, boiler, turbine, generator, distiller, and their sub - systems.

The results of the calculations indicate that the average reliability of the reference station production unit is 1.36×10^{-4} over a period of a year , 0.27 over a month , 0.71 over a week, and 0.95 over a day. The average availability is 49 %.

The average failure rate for the boiler is 4.50×10^{-4}, for the turbine 1.28×10^{-4}, for the generator 1.97 E $\times 10^{-4}$, and for the distiller 6.96×10^{-4}.

The mean time to repair (MTTR) for the boiler is (64) hours, for the turbine 108 hours, for the generator 55 hours, and for the distiller 45 hours.

The mean time between failure (MTBF) for the boiler is 2250 hours, for the turbine is 7750 hours, for the generator is 5000 hours, and for the distiller is 1500 hours.

The number of successfully operating units out of seven units of the reference station over a period of a month is 3, with a probability of success of 40 %.

Conclusions and recommendation for further work and development are given.

Table of Contents

Page No

Page No

Chapter V I

Dual - Purpose (power&water) Production Station State - Space Analysis Approach

Chapter V II

Dual - Purpose (power&water) Production Station Outage Data Collection Forms

Chapter V III

Reference station outage data analysis - conclusions and recommendations

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Symbol	Definition	Unit
A	Availability	%
(Btu)	British thermal unit	
e	Napierian base	
(MW)	Mega-Watts	
m^3	Cubic meters	
(M.I.G.P.D)	Million imperial gallon per day	
(M.I.G)	Million imperial gallon	
(MGD)	Million gallon per day	
(MSF)	Multi - stage flash	
(ME)	Multiple effect evaporator	
(VTE - MSF)	Multiple effect evaporator - Multi - stage flash evaporator	
(VC - ME)	Vapor compression - Multiple effect evaporator	
(HTME)	Horizontal - tube multiple - effect evaporator	
(Ib / in^2)	Pound per square inch	
(WPPR)	Water power product ratio	
(H.P)	High pressure	
(L.P)	Low pressure	
(M.P)	Medium pressure	
(P.R)	Performance ratio	Ib of distillate per 1000 (Btu)
System	The whole structure	
Sub - system	A major part of the system	
Associated system	A subordinate part of the system	

Symbol	Definition	Unit
Sub - Sub system	A part that belongs to either a sub -system or an associated system	
(K.V)	Kilovolts	
(V)	Volts	
(S.F.6)	Sulphur Fluoride gas	
λ	Failure rate	number of failures per hour
(MTBF)	Mean time between failures	hours
R	Reliability	%
Q	Unreliability	%
f	function	
P	Probability	%
t	time	hours
μ	Repair rate	Number of failures per repair times
(MTTR)	Mean time to repair	
hr.min	Hour - minute	

CHAPTER I

THE OBJECTIVES AND METHODOLOGY OF APPROACH

CHAPTER I

THE OBJECTIVES AND METHODOLOGY OF APPROACH

1.1 Introduction

The modern socioeconomic idiosyncrasy of most societies of the world, regardless of their level of development, leads them to expect the supply of electric power and fresh water to be continuous, in quantity and quality, on demand. Such emphasis on the continuity of supply has caused the electric energy and water industries to emerge as the most vital and capital-intensive sectors of the economy of any country. In order to appreciate the massive capital investment involved in such industries, one can look to the United States as an example, where the electric energy industries investment alone, is expected to exceed U.S $ 70 billions by the year 1990 [1], and the water industries investment was approximately U.S $ 300 billions by the year 1972 [2].

Such colossal investment should stimulate a great deal of interest in improving the productivity (performance-cost-availability-reliability-maintainability) of new and existing power and water systems. Therefore planning, design, and operating criteria and techniques have been proposed over the past five decades in the hope of achieving a trade-off between securing the continuity of supply, with respect to quantity and quality, and the prevailing economic constraints at the time of question. The real objective of the trade-off in practice is to account for the random stochastic nature of power and water system's inevitable failures. Inadequate planning for such failures can lead to power and water shortages of varying intensities. Therefore, ideal power and water systems that unfailingly supplies power and fresh water to consumers whenever wanted are by definition a perfectly desirable and reliable ones, and conversely, the power and water systems that are unable to supply electric energy and fresh water to the end users could be termed totally undesirable and unreliable. Unfortunately, all real life power and water systems lie between these two extremes. The probabilities of interruptions in electric and water services can be abated by investment intensification during a project's planning, specification, design, and tendering phases. However over-investment can lead to undesirable effects on the operating and capital cost of the systems, which in turn will be reflected in the tariff structure of the two commodities. On the other hand, under-investment can lead to operational limitations and ultimately curtailment of services which is in direct conflict with the anticipated norms. The over or under investment dilemma requires hard managerial decisions at both the planning and operating phases. Such decisions can not be left to personal intuition and judgment alone, but should be arrived at by a proper evaluation of the probabilistic operational behaviour of the power and water systems and load forecasting over the required period. The probabilistic operational behaviour of the power and water systems can be attained by the application of qualitative and quantitative reliability analysis of past operational data if available [3]. As for the load forecasting and its uncertainties of prediction, sound statistical analysis should be employed based on past demand trends and future anticipated social and industrial developments.

Every country and its power and water systems have unique characteristics. Most countries of the world enjoy different level of separation between these two vital industries in terms of planning, design, and operation. This is due to the fact that in these countries the power supply is industrially generated in thermal, hydro, or nuclear power stations, and the water resources, for the fresh water supply, are naturally available (e.g. rivers, fresh water lakes, rain, underground fresh water aquifers). Therefore, the problems of planning, design, and operation that have to be encountered by each of these industries can be distinct and different. Furthermore, these tasks are entrusted to different group of technically specialized people, and in most cases they are run by different corporations or agencies. On the other hand, there exist in this world some unfortunate countries which have to cope with the problems of planning, design and specifications, and operation of these two vital industries simultaneously. These countries have to manufacture both power and water supplies, and in most cases the problems of planning, specifying, designing, and operating are handled by one technically specialized group of people, and they are run normally by a single corporation or agency. Practically, most, if not all, of these countries are located in the arid zones of the world. These zones are physically characterized by severe weather conditions, scarcity of rain, absence of rivers and lakes, and have limited underground fresh water aquifers. However, they enjoy an ample supply of oil and gas, which are a prime sources of fuel needed for the production of power and fresh water.

Modernization and industrialization of these arid countries requires, as is the case for other countries, relatively large quantities of fresh water as well as an ample supply of electrical power. In order to meet such requirements, most arid countries turned to conventional thermal power stations utilizing the available fuel for power generation, and for the fresh water supply they relied on desalination.

Capital and operational costs savings, efficient utilization of fuel, and the state of the art of desalination technology [4, 5, 6, 7, 8, 9, 10], as we shall discuss later in chapter (**III**), influenced the decision that large land based desalination plants, which most of these arid countries need, are based on sea water thermal distillation processes. Furthermore, a unique characteristic that most of these countries share is that both utilities (power&water) are constructed and operated side by side on the same site, in what are commonly known as "dual-purpose" (power&water) production stations. Chapter (**III**) will deal with the full description and the various technical aspects of such stations.

Over the past three decades an ever increasing number of such dual-purpose (power&water) production stations have been built and operated in most of the arid countries of the world. Rapid technological advancement in the field of power and desalination opened the doors for such stations to be enormous in size and outputs [11, 12, 13, 14]. Single stations of this nature having installed capacities of 2400 mega-watts (MW) of power and approximately 4.4×10^5 cubic-meters (m^3) per day (96 million imperial gallons) (MIG) of distilled water are common today in the countries of the Middle East, particularly in the State of Kuwait and the Kingdom of Saudi Arabia

[14, 15]. As of 1987 the world wide installed capacity of this class of stations is approximately 15101 (MW) of power and 4.7 x 10^6 (m^3) (1034 MIG) per day of distilled water [15].

For most of the arid countries, such electricity and water supply stations were built during the oil boom era (late 1960's to the early 1980's). During this era adequate financial resources were available and the emphasis was on rapid construction to meet the ever increasing demand. Therefore, owners, consultants, and designers were more concerned with short construction time and competitive low cost bids. Such practice, unfortunately, can only be achieved at the expense of reliability and maintainability. Designers had little involvement with the subsequent operation and maintenance of these stations and even less appreciation of the routine and not-so-routine problems of the day-to-day operations and outages. This lack of feed back meant that the designers were not aware of the deficiencies of their design.

The high demand on the availability, (the proportion of time, in the long run, that the (power&water) production units in station are in service, or ready for, service), of these stations has led in most cases to setting up stations with over capacities (inherited redundancy) to accommodate losses or failures. And to combat further any unexpected malfunction in the electrical supply most, if not all, countries which have more than one station of this type, also resorted, like most other countries of the world, to interconnected systems design; that is to link the power side of these stations in a national electrical grid system to compensate for any losses that might take place from any station of the national system. As for water, normally, huge water reservoirs are built and interconnected by a network of piping and pumping stations to overcome any shortages in supply due to failures or disturbances in the water side of these stations. Upgrading of one of the commodities at the expense of the other or vice versa to meet certain peak load demand is another operational procedure that is also employed in these stations to offset failures or losses. It is customary to design and construct these station in such a way that enable any one commodity to be produced independently of the other, i.e. to be able to produce full or partial power without distilled water or produce full or partial distilled water without power. This practice, even though helpful, will defeat the benefits of duality for which these stations were built.

The foregoing demonstrated the importance that should be attached to the operational availability of any electrical energy and fresh water systems and in particular for these special class of (power&water) production stations. For the "dual-purpose" (power&water) production stations, it is true, that these precautionary planning steps of over design, over capacity, and operational manoeuvrability have, no doubt, enhanced the availability and maintenance of supply. However, these measures are not the ideal ones because they are self-defeating and, as mentioned earlier, will lead to over investment and its inevitable consequences. Therefore, there exists a pressing need to set up planning, specification, design , and operational management criteria for such stations to enforce the benefit of their duality and demonstrate that with such criterion a safe and sound reliable operational availability can be achieved. Reliability analysis techniques form one of the most successful and useful tools in this endeavour, due to the fact that economic and management decision-making process cannot be divorced from these analyses. This fact constitutes a good and legitimate reason for this research study to be devoted to reliability analysis of dual-purpose (power&water) production stations. It is of value to mention at this stage that such reliability analysis alone, cannot fulfill the requirements needed to set up the above stated goals of sound criteria. However, it is the first step forward in such endeavour, and without such an analysis the whole question cannot be answered at all in a scientific manner.

1.2 The problem

There is ample evidence that dual-purpose (power&water) production units have consistently proven maintenance-intensive [17,18,19,20,21,22,23,24]. This is due to the fact that most, if not all, equipment used in such units are of a repairable type, and thus their life histories consist of alternating operating and repair periods. On the one hand, such inevitable conditions requires a precise and foresighted operation and maintenance planning strategy on the part of the management in order to accommodate any planned or forced outages and minimize the mean time to repair (MTTR) of outages; and on the other hand, it requires sound design and proper material selection on the part of the designers and consultants inorder to improve the productivity and prolong the mean time between failures (MTBF) of outages. Furthermore, such conditions requires the availability of financial and specialized human resources to provide adequate level of operation and maintenance. So the achievement of the optimium utilization of design, operation, maintenance, and increasing the effectiveness of all maintenance staff, are planning problems that have to be faced in order to increase the availability and reliability of "dual purpose" unit and hence the station. In order to tackle these planning problems effectively a qualitative and quantitative reliability appraisal of the (power&water) production unit components and of the mode of success and failure of operation within and between the sub-systems and associated systems making up the total unit is required.

As the name implies, the components of any dual-purpose (power&water) production unit comprises of equipment for power generation as well as for sea water desalination. Thermal (fossil or nuclear fueled) or hydro-powered single-purpose power generation stations are universally used by practically all countries of the world; and for some industrially advanced countries such as U.S.A., U.K., West Germany, France, and Japan they have been used for the last fifty years. Consequently, for power systems incorporating these type of single-purpose power generation stations only, the planning, design, and operation techniques such as :

1. Load forecasting and its uncertainty including peak load and load duration.
2. Static generating capacity reliability including reserve requirements.
3. Operating generating capacity reliability including spinning reserve.
4. Transmission and distribution systems reliability.
5. Bulk power system reliability.
6. Area supply system reliability.

7. Equipment outage data collection and analysis.

have been recognized since 1947 [25]. Since then, an ever increasing interest to study and solve such problems, has been embodied in the research and development programs of the electric utility companies and agencies in the industrially advanced western countries. The outcome of the research and development projects in the field of power system reliability over the years, as we shall see in chapter (**II**), have produced and are still producing reliability models, indices, and deterministic and probabilistic reliability evaluation techniques. Furthermore, specialized agencies such as the National Electric Reliability Council in the U.S.A. and the National Centre for System Reliability in the U.K. have been established to co-ordinate reliability research activities. Therefore, a fair amount of information and solutions to the reliability problems of the single-purpose power generation stations and power systems are available. On the other hand, the dual-purpose (power&water) production stations are relatively recent and their utilization is confined to a limited number of countries which are undergoing development. Therefore, little activity, or nothing at all, in terms of research and development in the field of reliability of these specialized class of "dual purpose" (power&water) producing stations has taken place (as we shall see in chapter (**II**)). It is worthy to note that, even though the "dual-purpose" (power&water) unit and stations contain power production equipment, the reliability models established for the single-purpose power generation unit and stations can not be applied directly to represent the reliability models of the "dual-purpose" (power&water) unit and stations because the duality requires some very different models. Hence, the following reliability problems pertaining to the power and water system incorporating dual-purpose (power&water) production stations have to be investigated :

1. Static production (power&water) capacity reliability including generation and desalination reserve requirements.
2. Operating production (power&water) capacity reliability including generation spinning reserve.

3. Interconnected systems reliability.
4. Bulk power and water system reliability.
5. Equipment outage data collection and analysis.

1.3 The Objectives

The five research areas (1-5) pertaining to the power and water system incorporating dual-purpose (power&water) production stations mentioned in section (1.2) above cover a wide range of research activities that are required in order to establish a comprehensive reliability model for the power and water system as one entity. It is quite unrealistic to address all of these requirements in one single research study, therefore, one has to identify the order of priority that the present research study should address itself to. Since the production stations are the fundamental building blocks of the power and water system in question, therefore, they should receive the first attention. Hence, this research study will be confined to the reliability analysis of the dual-purpose (power&water) production station only. For such production stations, the basic planning and operation problem confronting them is the determination of the required quantity of power and water production in order to secure an adequate supply. This basic problem as a whole can be solved by applying three conceptually distinct reliability analysis areas commonly known as static production (power&water) capacity, operating production (power&water) capacity, and equipment scheduled (planned) and forced outages. The static production (power&water) capacity requirement refers to the installed capacity that must be planned and constructed. This static requirement includes reserves; that must be sufficient to cover for the required annual equipment overhaul, outages that are not scheduled (forced) and load growth needs in excess of the anticipated estimates. This reliability analysis area relates to the long term evaluation of the power and water system and provides an analytical basis for production capacity planning. The operating production (power&water) capacity refers to operating reserve. For the power side production, this means the spinning reserve which is synchronized and ready to take up load whenever needed as well as rapid start electrical generation unit(s) such as gas turbines; and for the water side production this could mean either a cold reserve (completely shut down distiller ready for operation whenever wanted) or rapid start desalination plant(s) utilizing such method as vapour compression or sea water reverse osmosis. This reliability analysis area relates to the short-term evaluation of the actual production (power&water) capacity needed to cover a required load level. The reliability analysis area concerned with the forced outages of equipment of the sub-systems and associated systems, that make-up the (power&water) production units which in turn constitute the production station, encounters the effects of these sub-systems and associated systems on the overall availability (the proportion of time, in the long run, that the unit is in, or ready for, service) of the production units and hence on the overall availability of the dual-purpose (power&water) production station. From the foregoing, the operating production (power&water) capacity is a daily operating problem and the solution can not be generalized to fit every production station. Hence, it is more meaningful that each individual production station develop their own production model based on their own localized design configuration. Therefore, this research study will not encompus this reliability problem. The reliability analysis of the static production (power&water) capacity and the outages of equipment are interrelated and their solutions can be generalized and used for improving future design and capacity planning. Therefore, this study will be confined to these two areas of reliability analysis. Hence, the objectives of this study will be the following :

1. Establishment of the sub-systems and associated systems and sub-sub systems of a dual-purpose (power&water) production unit
2. Setting up an operational interlock logic diagrams for the dual- purpose (power&water) production station, production unit, and the sub-systems and associated systems and sub-sub systems of the production unit.
3. Development of dual-purpose (power&water) production unit model.
4. Development of dual-purpose (power&water) production station model.

5. Setting up reliability block diagram models for the dual- purpose (power&water) production station, unit, and sub-systems and associated systems of the production unit.
6. Setting up state space models for the Dual-purpose (power&water) production station and the production unit.
7. Setting up reliability data collection forms for the dual- purpose (power&water) production station and the sub-systems and associated systems of the production unit.
8. Using collected actual operating and outages data for a period of five years (1982-1986) from a reference station, reliability calculations will be performed based on the above models to establish their significance.

1.4 Methodology of approach

In general, system reliability analysis can be divided into six basic steps. These steps will involve "system definition, logic model construction, failure mode determination, quantitative and qualitative data evaluation, uncertainty analysis, and formulation of conclusions and recommendations" [26]. However, in our study these general steps will not be adhered to exactly. In order to achieve the set goals of this thesis the following "topics/subjects" will be studied. These topics are arranged in such a way that each one, as well as being a sequential part of the thesis, is in itself an integral essay, reporting and concluding on a phase of the overall study.

1.4.1 System definition

Here, a full description and study of the dual-purpose (power&water) production unit configuration, and hence the station, will be conducted and investigated in order to acquire a detailed information about the functional and physical interconnections of the various sub- systems and associated systems making up the (power&water) production units and the station.This discussion will be the subject of chapter (**III**) of the thesis.

1.4.2. Operational interlock logic analysis approach

Under this approach, the operational interlocking logical sequences of the production station, production unit, unit sub-systems, unit associated systems, and unit sub-sub systems are investigated and analysed, in order to group the various pieces of equipment under the appropriate unit sub-systems, associated systems or unit sub-sub systems. Furthermore this analysis will facilitate an understanding of the operational interrelationship between the various unit sub-systems and associated systems and will enable us to split the production unit into it's proper sub-systems and associated systems. Moreover, from this understanding, the "duality" aspects of the production station, and the production unit will be demonstrated. The analysis will be presented in a graphical forms in order to avoid a lengthy and boring repeated description of the various sub-systems,associated systems, and sub-sub systems and also for quick reference. Each graph (figure) is a distinctive self explanatory operational model for the sub-system, associated system, or sub-sub system in question.This work will be the subject of chapter (**IV**) of the thesis.

1.4.3. Reliability network analysis approach.

This work is a consequential step to the previously mentioned two analysis approaches due to the fact that one of the most important goal of this reliability study is to predict suitable reliability indices for the dual-purpose (power&water) production units and hence for the production station on the basis of the unit's sub-systems and associated systems failure data and hence use this information for improvement of the unit sub-systems, associated systems and sub-sub-systems configuration and design. This analysis will help to transform the logical operation of the dual-purpose (power&water) production unit's sub-systems, associated systems and sub-sub systems into a structure that consists only of series and parallel component paths. This transformation will be achieved by reliability block diagrams construction for the various production unit sub-systems, associated systems, and their sub-sub systems. This work will be the subject of chapter (V) of the thesis.

1.4.4 State space analysis approach

This analysis will translate the operation of the production units and hence the production station into a state space diagrams that represent the possible relevant states that the production units and station can reside in. Furthermore, they will illustrate the possible known ways in which the transitions between the states can happen. This approach will facilitate the determination of these reliability indices such as the probability, frequency, and mean duration of the units forced failures. Furthermore, this analysis will help to determine the production unit and hence the station state that can be considered as a success or as a failure. This work will be the subject of chapter (VI) of the thesis.

1.4.5 Outage data collection forms

Reliability analysis is based on equipment outages data, therefore setting up forms for recording the outages of the production unit, unit sub-systems, associated systems and their sub-sub systems is important. Such forms have been designed and presented in chapter (V11). These forms will help to develop a comprehensive recording mechanism for the monthly and yearly outages for most equipment of the dual-purpose (power&water) production station.

1.4.6 Reference station outages data analysis

Doha East (Power & Water) production station of the State of Kuwait was selected as an actual operating reference station. The installed capacity of this station is 1050 (MW) of power and 191 x 10^3 (cubic meters (m^3)) (42 million imperial gallons (M.I.G)) per day of distilled water. This production is achieved by the installation of seven production units. Each production unit produces 150 (MW) of power and 27270 (m^3) (6 M.I.G) of distilled water per day. The outages data for all the seven units were collected over a period of five years (1982-1986).

The choice for this particular period is due to the fact that the reference station is in it's usefu life (i.e.passed it's de-bugging phase of life and not in it's wear out phase of life). Therefore the outages data represent a true picture of it's operation. The collected original (raw) data was by no means intended by the station management for reliability analysis, but was collected for the station personnel and the Ministry of Electricity and Water of the State of Kuwait reference and various uses. Therefore such data will be processed in a newly designed forms (tables) to allow reliability calculations for the station, production unit, production unit sub - systems, production unit associated systems, and thier sub - sub systems.The processed data will then be entered and processed in a computer spread sheet program The results of the processing will be the presented in chapter (V111).

1.4.7. Conclusions and recommendations

The conclusions and recommendations will be presented in chapter (V111) of the thesis.

1.4.8. Literature overview

The literature overview will be the subject of chapter (11) of thev thesis

1.4.9. Appendices

The thesis will contain one appendix. This appendix (1) is the reference station units monthly outages processed data. The appendix will be found in volume (II) of the thesis.

CHAPTER I I

LITERATURE OVERVIEW

CHAPTER II

LITERATURE OVERVIEW

2.1 Introduction

Reliability as a concept , in general, should be understood to mean "the probability of a device, item, system, sub-system, associated system, or sub-sub system performing its defined purpose adequately for a specified period of time under the operating conditions encountered.". This simplified definition manifests that reliability is a broad notion that relates to the failure problems of an extremely varied disciplines such as technology, economic, physico-chemical processes, structural mechanics, manufacturing, and industrial complexes etc. Hence it should be an aim and a target for all persons concerned with operation of services or designing and manufacturing of products. Furthermore, it implies that it is an aspect of engineering uncertainty.

Fatigue life studies during the 1930s revealed the use of the extreme value statistical distributions (asympototic distributions of variables describing values which can lead to failure) for reliability assessment. The Weibull distribution was the principal one that was proposed to describe the breaking strength of materials during that era [27].

The preliminary and basic mathematical theory of reliability development can be traced to the first attempt to apply renewal theory (a stochastic independently and identically distributed non-exponential process, e.g. homogeneous Poisson process) to industrial replacement problems in 1939 by Lotka [28]. His basic approach was based on the assumption that the problems of population growth and those of industrial replacement were closely analogous, and therefore he suggested the utilization of the probability functions and their mathematical solutions employed for population growth calculations could be used for industrial parts replacement problems. However complex military weaponry and systems introduction during World War II had played a vital role in the recognition of the pressing need for reliability to be approached in a more organized scientific manner and mathematical theories for it should be developed. The establishment in the U.S.A of the joint Army and Navy (JAN) parts standards, the Vacuum Tube Development Committee (VTDC) in june 1943, and later the Advisory Group on Reliability of Electronic Equipment (AGREE) in 1952 were the real starting points in this endeavour. Full accounts of the historical developmental of reliability activities in general can be found in references [27, 29].

The 1950s activities in the field of life testing , electronic, and missile reliability introduced the exponential distribution function as a more useful distribution in reliability evaluation of systems because it assumes constant failure rates; thus simplifying the evaluation.procedures [27, 30].

The 1960s witnessed the researches on the reliability of coherent structures (general system reliability) [27]. This area of research is still active in the 1980s. The works of Professor B. V. Gnedenko and associates of the Soviet Union in 1965 [31] on repairable systems and standby redundancy with renewal resulted in the emphasis on maintenance and repair reliability models using limiting probability techniques from queueing theory (a mathematical analysis of systems subject to failures whose frequency and duration can in general be specified only probabilistically; or in a more specific manner the use of steady state probability functions based on stationary Markov approach). Furthermore in the same period the concept of fault-tree reliability analysis (FTA) (a systematic analysis of the system failure events and the sub-systems and components failure events that can cause them) was introduced in 1961 by the Bell Telephone Laboratories as a technique with which to perform a safety evaluation of the Minuteman Launch Control System [32].

The nuclear power reactor safety consideration further enhanced the researches and development of the fault-tree analysis as a reliability tool during the 1970s [33, 34] In the late 1970s and in the 1980s the need for reliability analysis in the domain of systems of various states and functions (power plants, computers, etc) was in demand and the outcome of the researches on this topic was the adaptation of several reliability analysis techniques and approaches such as network reliability modeling, Markov process modeling, and Monte Carlo simulation [35, 36, 37, 38, 39]. These approaches are the predominant techniques used for repairable systems reliability analysis at present time.

From the foregoing one can see clearly that reliability as a concept is appreciated and desired by practically all industries; however each industry or utility is trying to develop and utilize the mathematical models and techniques that suit its purpose best. This argument goes to the extent that one can not find a single universal reliability mathematical model and technique that suit all industries and utilities in the same way. Therefore each industry and utility has to adopt to what suit its needs best. The power and water utilities are no exemption from this fact. Since the theme of this thesis is reliability analysis of "dual-purpose" (power & water) production station, therefore, an attempt is made in this overview to follow the activities in the development and application of reliability evaluation techniques for power and thermal desalination systems. It turns out that power and water systems have to be reviewed separately, because as we shall see later, that there scarcely exists a reliability publication that treats them as a combined system.

2.2 Power system literature

There have been considerable activities in the development and application of reliability evaluation techniques in power generation systems over the past 59 years. Therefore, it will be of benefit to review this development historically in segments of ten year intervals in order to single out their significance and input. This overview will be confined to the generating part of the power system. Furthermore, it will be confined to literature published in the English language because of the ease of accessibility.

2.2.1 (1930-1939) period

It is difficult to single out with precision when many significant and useful ideas in the field of power industry reliability criteria and problems first appeared in the published literature. However, as early as 1933 Lyman [40] had suggested that probability methods and techniques could be applied to analyse and solve static generating capacity and other power reserve problems. In 1934 Smith [41] had advocated further Lyman's suggestion and presented two papers [41, 42] illustrating sample calculations based on probability mathematics to solve power system service reliability problems. Smith in [42] was basing his calculations on the concept of "statistical equilibrium." which he defined as "if repeated observations could be made on a very large number of generating systems, each system consisting of the same number of units and each unit having the same characteristics determining its likelihood of failure, it would be found that the proportion of systems in which any given number of units, x , were at any instant simultaneously unavailable would have a value independent of the particular time of observation." This definition implies that after a sufficiently long period of time the state probability of the systems are independent of the initial conditions and remain constant in time The importance of Smith's papers was that they provided a simple mathematical method to calculate the probability of equipment outages which are a key factor in power system planning During this period a total of approximately 6 papers , including the three mentioned above , were published. The main focus of these papers was on planning generating capacity requirements.

2.2.2 (1940-1949) period

This period produced some of the basic reliability concepts upon which, with some modification and expansion, the techniques in use today are based. Approximately 13 papers were published in this decade. The most important group of papers were presented in 1947 by Calabrese[43], Lyman[44], and Seelye [45].

Calabrese realizing that there were no exact methods available which permit the solution of generating reserve problems, therefore suggested a systematic attack on the problem that could be made by a "Judicious." application of probability theory. His model provided the first quantitative analysis of the effect of forced outages on generating reserve requirements. It also permitted the prediction of loss of load probability (duration),which he defined as "the fraction of time during which loss of load may be expected to occur during any future period; and the kilowatt-hour losses expected to result from forced outages." [43]. The loss of load approach is still referred to in the power utilities circles as the "Calabrese Method". Calabrese reliability criterion (measure) was the computed probability that the outage of generating capacity would exceed the reserve available at the time of peak load over a specified time period. Lyman paper presented a short-cut method for evaluating generating outage probabilities to a system with any number of generating units of different sizes; a method of combining two or more outage probability curves for different systems (interconnections) in order to determine the effect of interconnections on the overall reserve requirements; and an approximation method to calculate system outage probability rate using a uniform failure rate for the generating equipment instead of different failure rates in the probability calculations. Lyman in his approach for the short-cut methods has utilized normal or a modified binomial distributions expansions instead of the long and tedious binomial distribution expansion. Seelye's paper presented simple algebraic formulas, based on binomial expansion, for the study of generating reserve necessary to offset the effect of forced outages of generators, and to calculate the average frequency and duration of forced outages which he defined as "the average period between occurrence of individual outages in terms of running time and the average duration of outages, or repair time.". These three papers proposed the fundamental ideas upon which the "loss of load method" and the "frequency and duration approach" in use nowadays for reliability evaluation of power system are based. It is of value to mention here that during this period the first American Institute of Electrical Engineers (AIEE) Subcommittee on the Application of Probability Methods was organized in 1948. The first report of this subcommittee was published in 1949 [46] containing some comprehensive definitions for equipment outages. This Subcommittee has played and is still playing a vital role in the application of reliability techniques for power systems.

2.2.3 (1950-1959) period

During this period about 41 papers were published. Two of which were prepared by the (AIEE) Subcommittee and presented some statistical data on equipment outages[47,48]. These two papers were a continuation of the work which was started in 1947 by the Subcommittee. The papers of the early part of the 1950s were still concerned with generation reserve requirements and the benefits resulting from systems interconnections. They did not produce any significantly new approaches or methods. However, in 1954 Watchorn [49] and Kirchmayer et al [50] while working on the evaluation of economic unit addition in system expansion studies suggested and illustrated the benefits of using digital computers for reliability evaluation calculations. The largest number of papers during this period were published in 1958 and 1959. The input of these papers was the modification and extension of the reliability calculation methods proposed in 1947 (i.e. loss of load and frequency and duration of outages methods) [51, 52, 53]. In December, 1959 two papers [54, 55] were publish which introduced a rather new approach for the solutions of the problems of power generation forced outages. The new idea was advocating the adaptation of system simulation techniques by using "Operational Gaming Theory" to set up a mathematical models for use in the simulation of power generation forced outage distributions. The gaming technique as employed by these authors was based on a combination of system analog (mathematical and logical model of the system), Monte Carlo simulation (a computer simulation of the random occurrences), and simulated human decisions (logic of system operation) to predict future system events which are probabilistic and deterministic in nature and obtain a statistical forecast of future system performance. The system performance in turn is translated into equipment needs and used for economic evaluation of alternate expansion patterns. Interest in the use of the "Game Theory" techniques as a tool for reliability evaluation of power system declined after 1962 [25] and it is not used nowadays. The decline could be attributed to the preference for analytical approaches rather than a simulation techniques by the power industry researchers.

2.2.4. (1960-1969) Period

About 50 papers were introduced in this period, out of which four papers were based on the simulation techniques (Game Theory) that was advocated in the late 1950s, as mentioned above, and ten papers were based on equipment outage data. The most significant publications on equipment outages data were produced by the (AIEE) and (IEEE) Subcommittees [56, 57]. The (AIEE) Subcommittee publication dealt with methods of analyzing forced outages using digital equipment where the (IEEE) Subcommittee paper was concerned with definitions of terms for reporting and analyzing outages of generating equipment. On the other hand, the (AIEE) Subcommittee realizing that the basic reliability methods (namely, loss of load probability, loss of energy probability, and frequency and duration) as introduced in 1947 and modified later were still the routine procedures used by the power systems utilities, therefore, initiated a study to compare the three methods by subjecting them to the same problem. The result was published in 1960 [58], and their final conclusion was stated as "The application of probability methods to generating capacity problems has reached a stage where it should be accepted as a normal tool of the system planner ; but that does not imply that all problems have been solved. Comparison of the basic methods of measuring reliability and discussion of refinements in computation and of the adjustments common to each method reveals a number of limitations and possibilities of improvement that require study beyond the scope of this report. In addition, still other methods of probability application await investigation and development.". This conclusion implied that these methods did not fulfill all requirements and more comprehensive analytical techniques were needed to model the power system effectively. Moreover, the power failure of November 1965 which had left large parts of North-eastern United States and Eastern Canada without power supply for several hours enhanced further the need for the accepted reliability measures (indices) at the time to be reexamined and researched. In addition, more emphasis was being given to the development of more or less standardized reliability indices and methods of calculations for all parts of the electric utility system (generation, transmission, and distribution). One significant outcome of such activities was published in a series of four papers in 1968 and 1969 [59, 60, 61, 62]. The aim of this research work was to find means of integration and modification of the well expended past efforts on reliability analysis and reserve requirement planning of the generation part of the power system with the established techniques of reliability evaluation of the transmission and distribution segments of the power system. Prior to this work, as was mentioned earlier, there were two reliability calculation methods used for the generation part of the power system, namely, the "loss of load" and the "frequency and duration" [58]. In general the "loss of load" method will yield the probability of failure to be able to cover the expected peak load over a certain time period, while the "frequency and duration" calculations allows the computation of the probability of the generation part to suffer an outage state of exactly a specified quantity and the expected frequency of reoccurrence of that exact state. The essence of this new research work was the development of a frequency-duration model for the generation part based on a Markov chain state analysis that enabled the calculation of availabilities, frequencies of occurrence, and cycle durations for both individual and cumulative outage states.

2.2.5. [1970 - 1979] Period.

During this decade many papers were published, however, no completely new ideas or methods have emerged. In general, one can say most of the contributions of these papers were the expansion on the Markov process concept and the frequency and duration method which was introduced in the late 1960s. Billington et al [63, 64] have introduced a multi - derated state model and its associated failure and repair rates and the idea of the effect of partial outage to be used in spinning reserve and generation system planning studies. Marco [65] has presented a semi - Markov model of a three - state generating unit. This approach according to the author would remove the necessity of the outage states of the generating unit to be assumed to follow an exponential distribution. The mathematics involved with this approach is highly tedious and difficult (Laplance transform and numerical inversion routines), therefore, it did not prove to be useful in actual practice, eventhough, it is more accurate than the approximate models. Day et al [66] have introduced a model to calculate a new reliability parameter which the authors refers to as "the conditional expected value of generation deficit for loss - of - load.". This parameter along with the Loss -of - Load Probability would measure the anticipated deficiency of the power system during loss of load. Singh et al [67] have realized that for power system components, in general, their up times can be assumed to be exponentially distributed, however, their down times usually do not follow this pattern. This meant that they had to model the generating unit as a non-exponential model like Marco [65] did. Therefore, they introduced the idea of using the device of stage in reliability modelling of power system to overcome the complexity of the mathematics involved. The overall model is obtained by representing "a non-exponential distributed state by a combination of stages each of which is exponentally distributed." [67]. However, the procedure of the technique is still too complex to be widely used. Ayoub et al [68] have presented a method for computing exactly the frequency and duration of loss of load events as a measures of generating system reliability. This method according to the authors differs from previous ones because it utilizes a cumulative state load model together with an exact state capacity model to permit the computing of the probability, frequency, and average duration, of loss of load and the cumulative margin states (available capacity less the load).

2.2.6. [1980 -1989] period

The 1980s era has witnised the production of numerous papers, however, few of them only yielded new considerations on the reliability evaluation of the generating system. Patton et al [69] have presented a new analytical approach that incorporates operating considerations (such as start up failures, start up time, outage postponability, unit commitment policy, and operating reserve policy) in generating system reliability modeling. This approach has not been covered in previous publications. This modelling methodology is most suitable for operation planning.

2.3. Water system literature

In contrast to the power system, the water system literature is limited to a very few and scattered publications over the years. The total number of publications on the distillation processes (in particular the Multi-Stage Flash (MSF) process) was approximately six papers. The publications on the Reverse Osmosis process was one only. This overview will be confined to the publications on distillation processes.The first publication was a report presented by Hittman Associates, Inc.[70] under contract for the Office of Saline Water of the U.S.A. The reliability analysis employed in the report was based on block diagram modeling of the various sub-systems of the MSF distiller and was confined to the distiller part only. The generation part was not incorporated. Moreover, the capacity of the distiller studied was 9.5 X 10^3 cubic meters per day (2.5 U.S. MGD), which is approximately one third of the existing capacities of MSF distillers operating nowadays. Unione et al [71, 72] have presented two similar papers on the reliability of desalination equipment. The reliability technique used in the analysis was fault tree analysis (FTA). Kutbi et al [73] have presented a paper based on operational history of Jeddah I (Saudi Arabia) MSF plants. Here again the authors have used the fault tree analysis (FTA) approach and confined their analysis to the distillers side only of production units. Both Bailie [74] and Thies et al [75] have presented a paper in which the contents were general and dealt with the importance of employing reliability analysis to desalination plants. None of these publications on water system reliability have introduced new reliability techniques or methodology of modeling.

2.4. The State Of The Art

From the foregoing, it it is clear that power systems have received a considerable amount of attention with regard to the reliability evaluation and analysis techniques, whereas water systems have received little, or practically no, attention. Moreover, there was no published work that considered the the reliability analysis of both the power and water systems combined as they are designed, constructed, and operated in the dual-purpose (power &water) production station. Therefore, the works of this thesis will be a step foreward in that direction. However, it is imperative to mention that the models and analysis that will be evolving out of this research work might not be the ultimate ones, but form a first attempt.

CHAPTER III

DUAL PURPOSE (POWER & WATER) PRODUCTION STATION SYSTEM DEFINITION

CHAPTER III

DUAL PURPOSE (POWER & WATER) PRODUCTION STATION SYSTEM DEFINITION

3.1 Introduction

The main purpose of this chapter is to develop a thorough understanding for the functional operation and design objectives of the thermal dual - purpose (power&water) production station. Furthermore, through this chapter the different power and water cycles configuration that can be employed in such power and water production stations will be investigated and the process structural arrangement that this study will be confined to will be specified and amplified. Based, on such understanding the dual - purpose (power&water) production unit and hence, the station model will be developed. Furthermore, through the discussion of this chapter the various sub-systems and associated systems that comprise the dual - purpose (power&water) production unit and, hence the station will be identified.

3.2. Thermal single-purpose water production station

Thermal single-purpose water production stations are erected mainly for the production of distilled water. Treatment of such distilled water in a post treatment plant will produce potable water. For some thermal single-purpose water production units (such as Multiple - Effect Evaporator and Multi - Stage Flash Evaporator), steam is produced in packaged boilers and fed directly through pressure reducers and desuper-heaters to the thermal desalination process. For the vapour compression process mechanical energy instead of heat energy is used. Such thermal single-purpose desalination plants are normally employed for small output plants or when, the water demand is high and the power demand is non-existent. Over the past 30 years many possible thermal desalination processes have been proposed and some have reached commercial utilization and proved to be reliable and are operating with great success around the world. The following is a list of the most viable ones :

A) Multiple - Effect Evaporators. (Submerged Tube, Vertical Tube, and Horizontal Tube).

B) Multi - Stage Flash Evaporators. (Once - through and Brine Recirculation)

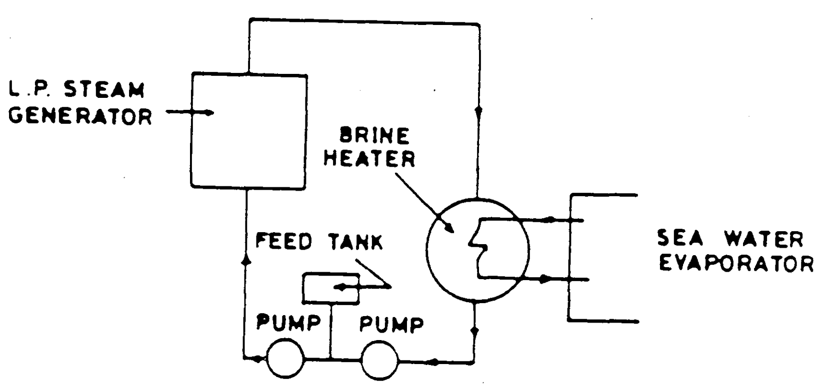
C) Vapor Compression. (Vertical - Tube and Spray Film or Horizontal Tube)

D) Hybrid Systems.

These systems have been proposed but are not commonly used :

1) Vertical - Tube Evaporator Multi - Stage Flash Evaporator (VTE - MSF).
2) Vapor Compression - Multiple Effect Evaporator.(VC - ME).
3) Horizontal - Tube Multiple - Effect Topping Unit (MSF in Series with HTME unit).
4) Multi - Stage Flash - Vapor Compression.

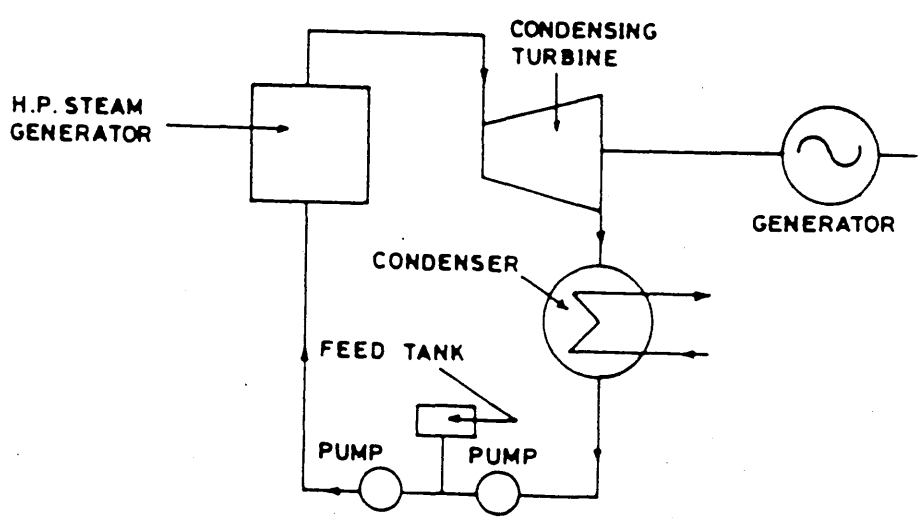
Out of the above listed processes the Multi - Stage Flash (MSF) distillation is the most widely used process for large desalination plant output throughout the world at present time [6, 76, 77, 78,79]. Figure (1 a) below illustrate a simplified flow sheet of a single-purpose thermal desalination unit.



1a SINGLE-PURPOSE DISTILLATION UNIT

3.3. Thermal Single - Purpose Power production Station

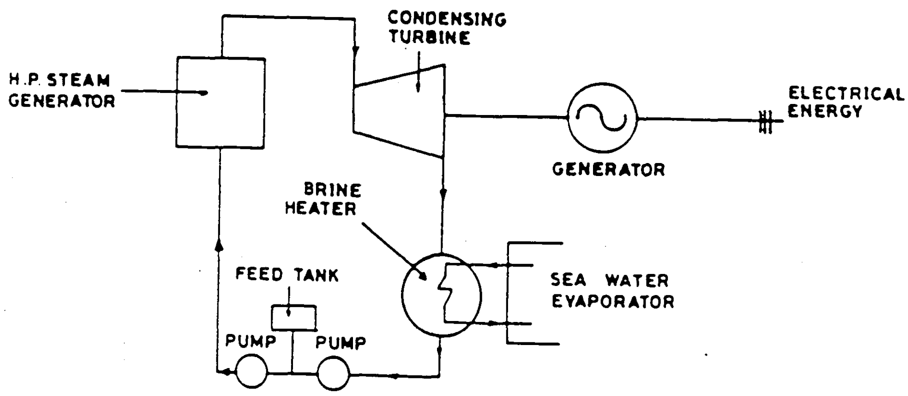
Thermal single-purpose power stations are constructed for the production of electrical power also. For the fossil fuel plants, normally, combustible matter such as natural gas, crude oil, heavy fuel oil, gas oil and coal etc are burned to furnish a single product which is electrical power. In such single-purpose plant, approximately half of the useful heat is rejected in the condenser cooling water. Other losses amount to nearly 10-15% therefore, the net resulting overall efficiency of the cycle is 30-40 %. By increasing the working steam temperature higher efficiencies can be obtained, however, there are economic and technical limitations to the freedom for such increases. The thermal generating unit consists mainly of the basic three sub-systems which are the generator, the turbine, and the boiler along with various associated systems (auxiliaries). There are many ways in which these sub-systems and associate systems can be configurated. Normally, the turbine and the generator are in series and the steam generator can be either in series with them (unit type) or they can be connected in series with a steam header. Figure (1 b) below illustrate a simplified flow sheet of a single-purpose power unit.



1b SINGLE – PURPOSE POWER UNIT

3.4. Thermal Dual-Purpose (Power&Water) Production Station

A thermal dual -purpose (power&water) production station is an interconnected complex factory structure for the conversion of the energy stored in the fuel into electrical energy and the desalting of sea water into distilled water. In such operations two products are produced from a single source of heat energy. Figure (1 c) below illustrate a simplified flow sheet of a dual-purpose (power&water) production unit.



1C DUAL–PURPOSE (POWER & WATER) UNIT (Back Pressure Turbine System)

Basically the overall principal of operation of such production unit is to employ the normal thermal closed cycle (Modified Rankin Cycle) interlinked, usually, with a thermal desalination process. The interrelationship of the power cycle and the thermal desalination process is not physical but rather in the sharing of some of the energy in the working fluid (steam) or heat of the thermal power cycle. It is noteworthy to mention here that from a technological point of view, the interconnection between power generation and sea water desalination is not a must, since it is possible to produce separately fresh water or electrical power by utilizing the available technologies as long as the required source of energy is available. Besides, the development of both of these technologies (power and desalination) will not be much affected by interconnection or non-interconnection.

From an energy point of view, the sharing is utilized by means of bled steam from specified tapping points on an extraction turbine, or the exhaust steam from a back pressure turbine of the thermal power cycle, or a simple gas turbine with waste heat boiler cycle, or a combined gas turbine - back pressure steam turbine cycle. Another aspect of the sharing, is the common utilization of the site, sea water intake structure, brine and sea water discharge structure, administrative manpower, operational manpower, and maintenance manpower.

It is appropriate to think of the sub-systems, associate systems, and machinery of the thermal dual - purpose (power &water) production unit as falling into three broad categories; those which are " in line " on the sequence of converting fuel into power (boiler, turbine, and generator), those which are " in line " on the sequence of converting sea water into distilled water (boiler, turbine, and distiller), and those which provide some services to the two " in line " categories mentioned above to ensure their safe and efficient operation. Figure (2) below shows a schematic process flow diagram of a dual-purpose (power&water) production unit utilizing Multi - Stage Flash Evaporator (MSF) and a condensing turbine arrangement.

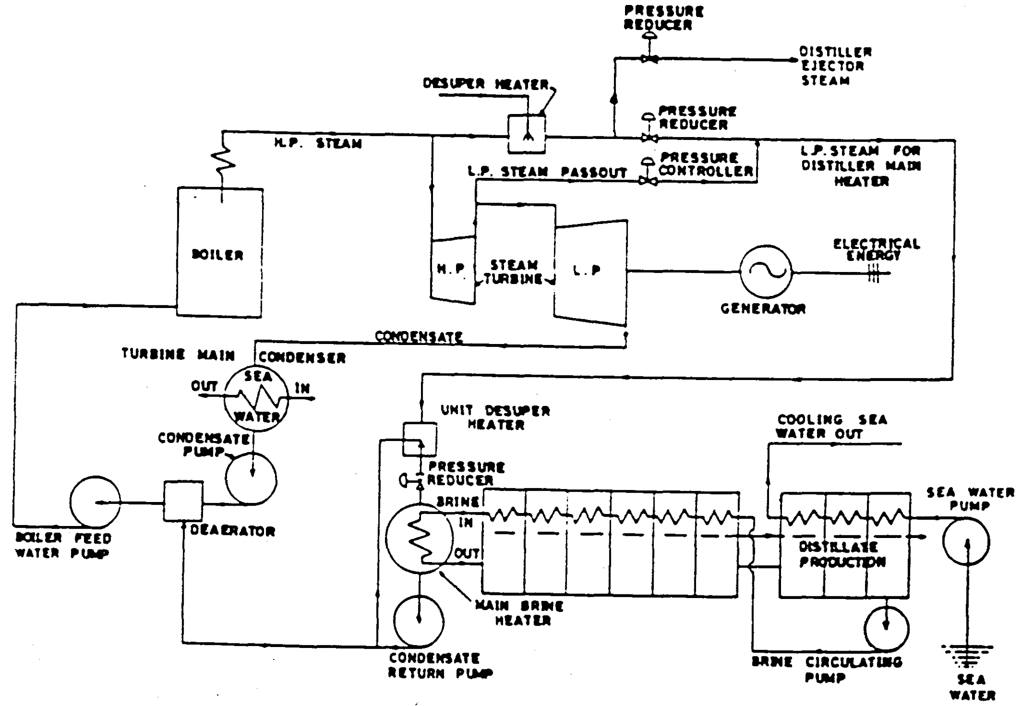


FIG.NO: 2

SCHEMATIC PROCESS FLOW DIAGRAM OF A DUAL - PURPOSE (POWER & WATER) UNIT

It is worthwhile to mention here, that such dual - purpose stations produces two distinct products which are not inevitably consumed by a single market and furthermore, one of these products is storeable (water) and the other is not (power). Therefore, in order to successfully interconnect the power and thermal desalination cycles in such stations, certain technical and economic criteria should be implemented. It has been reported [79] that the most important of these design measures are as follows :

1- The machineries of the power and the thermal desalination side of the production unit should be able to start up and shout down independently.
2- Load factor alteration for either side of the production unit should not automatically affect the other.
3- At full load of the power and thermal desalination side of the production unit, the heat rejection rate of the power side cycle should, as much as possible, match the heat consumption of the thermal desalination side cycle.

There are another two significant technical aspects that have also to be incorporated in the design of such stations. These features can be summed up as follows :

1- Both , the power generation and the thermal desalination cycles should be designed to baseload, because the desalination cycle, particularly the Multi - Stage Flash process(MSF), is inherently slow to respond to load changes.
2- For the thermal desalination cycle, the steam and sea water supply should be maintained in a non-changing condition with respect to flow, pressure, and temperature.

3.4.1. Advantages Of Dual - Purpose Station

As was mentioned earlier, one of the main overriding advantage of the dual - purpose (power&water) production station is the potential savings in capital, operating, and maintenance costs relative to single - purpose desalting and electric power facilities of equivalent capacity. The economic advantages of such stations are obtained from tow principal sources. The first one, is the savings in the thermal energy requirements and the associated economic benefits that will be resulting from the merger of the thermal cycles of high - pressure, high - temperature power generation with the relatively low - pressure, low - temperature evaporation based desalting processes. The other source of potential saving, which will be reflected in the operating and maintenance costs of the station, is the results of the common sharing of certain facilities as compared to two separate single - purpose stations. Another source of saving is the reduction in unit capital costs due to the increase in installed capacities of certain common sub-systems and associated systems or components as compared to two separate stations. Furthermore, the interconnection of the thermodynamic cycles of power generation and distillation - type desalination process will improve the overall cycle utilization of the thermal energy employed.

3.4.2. Disadvantages Of Dual - Purpose Station

The major disadvantage of such station is that the daily operation will become rather difficult to control because the machineries of both side of the production unit are interdependent. Therefore, failure of the power side of the unit to operate will result in the inability of the water side to operate, because there will not be steam. And, on the other hand, if the water side of the production unit does not operate, therefore, there will be no condenser for the power side in the case of back - pressure turbine configuration. It is true, that in such stations this difficulty can be overcome by the installation of auxiliary and standby equipment (e. g. steam pass out and stand by condensers) to keep both side of the production unit operating regardless of what happens to one side or the other. Most, if not all, existing stations incorporate such facilities in their layout. The alternative steam supply to the thermal desalination side of the production unit will be discussed in more detailed later in this chapter. Another inherited weakness in the dual-purpose (power&water) production unit and hence the station, is the limited adaptability in the economic design to accomplish the proper balance between the power and water demand.

3.4.3. Water Power Product Ratio (WPPR)

In order to economically optimize the operation of the dual - purpose (power&water) production unit and hence, the station, the (WPPR) for the production unit should be analysed and determined. It is defined as the static water output capacity in million - gallon - per - day (MGD) divided by the static power capability in million - watt (MW) Hence,

$$WPPR = MGD / MW \quad \text{-------------------------} \quad (1)$$

The (WPPR) values lies between 0.1 and 1. However, its value may vary between 0 and ∞ for power - only and water - only units, respectively. Larger values for the (WPPR) tend to increase the fuel economy of the such stations. For the different power cycle arrangement, the typical range of values for (WPPR) are as follows [80] :

for extraction turbine unit :	0.12 - 0.08	MGD / MW
for back pressure turbine unit :	0.33 - 0.20	MGD / MW
for gas turbine arrangement :	0.12 - 0.08	MGD / MW

Since the power output is governed chiefly by the inlet and outlet temperatures of the turbine, and the distilled water production is regulated by the heat transfer surface available and the temperatures of the heat of supply and discharge, therefore, the (WPPR) value for practical dual - purpose (power&water) production unit is less than 0.5 [6], because of the limitation of the steam conditions at the turbine throttle and by the maximum brine temperature the thermal desalination cycle can take.

3.4.4. Alternative Thermal Desalination Cycles Duality Schemes

As was mentioned earlier in section (3.2), there are a number of possible thermal desalination processes and their hybridization that can be employed in the thermal dual - purpose (power&water) production unit cycle. However, from a practical, economic and technical point of view, at least for large distilled water output evaporators in the range of (approximately 2.3 - 4.5 X 10^4 cubic meters per day or 5 - 10 million imperial gallons per day (MIGPD)), the Multi - Stage Flash (MSF) distillation process (brine recirculation type) is the most widely employed system world - wide [6, 7, 10, 14, 79, 81, 82]. Therefore, this research work will be confined to the coupling of the (MSF) process with the power cycle that will be selected in the next section of this chapter.

3.4.4.1. Multi - Stage Flash (MSF) Distillation Process

From a design point of view, there are four basic types of (MSF) process configuration that are employed nowadays all over the world. These are as follows :

1. The long - tube (acid or high temperature additive) dosed once - through type.
2. The cross - tube (acid or high temperature additive) dosed brine recirculation type.
3. The long - tube polyphosphate dosed once - through type.
4. The cross - tube polyphosphate dosed brine recirculation type.

Each of these process configurations has its own advantages and disadvantages. Furthermore, there is no common consensus among the desalination experts regarding the best process configuration [6, 82, 83, 84, 85, 86]. However, out of the four types mentioned above, the cross - tube (polyphosphate), and the cross - tube (high temperature additive) dosed brine recirculation type are the most widely used configuration world - wide. This preference in the choice of the cross - tube configuration over the long - tube type is due to the facts that this arrangement has advantages in chemical treatment, desolved gases removal, feed sea water deareation, temperature control, less corrosion / erosion problems, and less shell volume requirement resulting in less plant cost. Based on the above discussions, therefore, this research work will consider only the Multi - Stage Flash (MSF) cross - tube (polyphosphat or high temperature additive) dosed brine recirculation process configuration. The reliability models that this research work will investigate and develop can easily be adapted to the other process configurations.

The basic thermodynamic principal of flash distillation is based on the fact that vapour can be created from a saturated warm liquid in an enclosed space by a sudden pressure reduction over the liquid. This boiling process is termed "flashing". The evolved vapour can then be condensed and collected. Pure water separation from sea water in the (MSF) process is basically based on above mentioned principal. Figure (3) below represents a schematic process flow diagram of an (MSF) evaporator with brine recirculation.

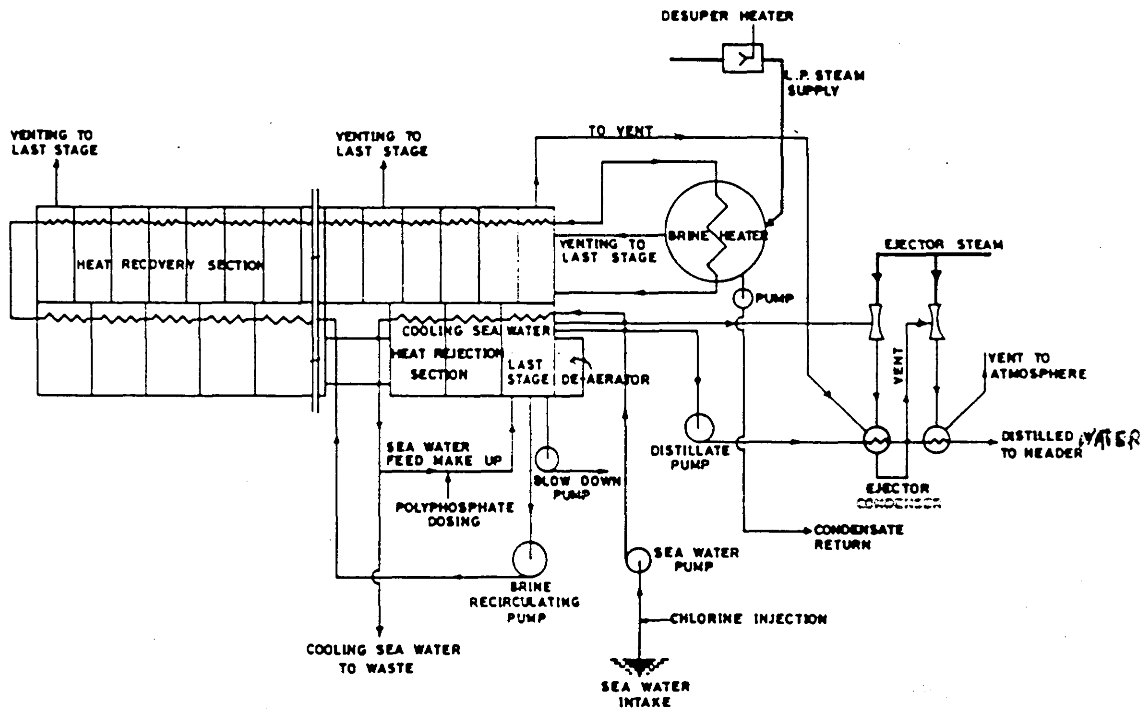


FIG. NO.: 3

SCHEMATIC PROCESS FLOW DIAGRAM OF MULTI-STAGE FLASH DISTILLATION EVAPORATOR

From the above schematic diagram, the (MSF) evaporator is essentially composed of the following four parts :

1. The heat rejection section.
2. The heat recovery section.
3. The brine heater.
4. The ejector.

Chlorinated cold sea water is pumped from the sea water intake to the inlet of the heat rejection stages of the (MSF) evaporator. As the sea water flows through the condenser tubes in these stages it will be heated by the condensing vapour evolved in each heat rejection stage. As the term cross - tube configuration implies, the condenser tubes in which the sea water flows in each stage are perpendicular to the flashing brine flow in the stage. From a thermodynamic balance point of view, normally the number of these stages are three. After the heated sea water leaves the heat rejection section, part of it is returned to the sea via the discharge system. The remainder (sea water make - up) is then chemically treated and flows to the deaerator.The function of the deaerator is to remove the air from the sea water make - up. The deaerator can be designed as an external or internal one. In the case of low brine temperature operation (approximately 90 ^{o}C or 195 ^{o}F) the chemical used normally is a mixture of sodium tri - polyphosphate, lignin sulfonate, and anti - foam agent and it is commonly known as the polyphosphate additive. And in the case of high temperature operation (approximately 105 - 110 ^{o}C or 220 - 230 ^{o}F) the chemical used is an organic polymer additives such as the commercially known Belgard EVN [14, 19, 86]. The chemical addition is performed on a thershhold bases. The treated sea water make - up, then, mixes with the highly concentrated brine leaving the last stage of the heat rejection section. Part of the concentrated brine from the last stage is blown down to the sea before mixing with the incoming treated sea water make - up. The blow down operation is to maintain a proper brine concentration in the evaporator so as to minimize calcium carbonate, magnesium hydroxide, and calcium sulphate scaling. Normally the brine concentration is maintained at approximately 1.5 to 2. The recycle brine then enters the brine reciculation pump and is pumped through the condenser tubes of the entire heat recovery section, receiving heat from the condensing product water vapour and reflashing distillate.The recycle brine leaves the heat recovery section and enters the brine heater where it is further heated by a relatively low pressure (L.P) steam (approximately 0.8 bar or 12 psi for polyphosphate operation) which is coming from either the turbine or the boiler or the common header. In section (3.4.6.1) of this chapter, this steam provision will be discussed in detail. The brine temperature (95 - 110 - 120 ^{o}C) after leaving the brine heater is determined by the chemical used for the treatment of the sea water make - up. The hot brine, after leaving the brine heater, passes through to the flash chamber of first stage of the heat recovery section of the evaporator. The pressure in this stage is the highest of all stages and it is less than the saturation pressure of the incoming brine, therefore, a portion of the brine flashes to vapour. The evolved vapour condenses over the condenser tubes in the stage by transferring its latent heat of vaporization to the recycle brine flowing in the tubes. The unflashed brine passes through to the next adjacent stage, where the pressure is lower again and the same process is repeated. The flashing process continues at lower pressure and temperature as the brine is cascaded down through the entire stages of the heat recovery section till it reaches the last stage of the heat reject section where the pressure is the lowest. A portion of the concentrated brine is blown down after it leaves the last stage and the remainder is mixed again with a freshly treated sea water make - up and recycled again to go through the same process.

The fresh water produced by the condensing vapour in each stage is collected in the distillate tray and flows along from stage to stage in the same direction as the flashing brine until it reaches the last stage of the heat rejection section where it leaves the evaporator as distilled water.

The function of the steam ejector condenser is to maintaining the design vacuum in each stage at full load, and the removal of air and non-condensable gases from the stages of the evaporator and the brine heater. The Pressure reduction in the stages is essential for flashing. And the removal of air and non - condensable gases is vital for the proper condensation of the evolved vapour at the condenser tubes in each stage of the evaporator. The steam ejector condenser receives relatively high pressure (H.P) steam (approximately 14 bar or 203 psi for polyphosphate operation) either from the boiler or the common header. Some desalination consultants, engineers and operators refer to this pressure as medium pressure steam (M.P). However, in this theses this pressure will be referred to as (H.P). In section (3.4.6.2) of this chapter, this (H.P) steam provision will be discussed in detail. Most designs of (MSF) evaporators allows the first flash chamber, the second to seventh flash chambers in cascade, and the brine heater to be vented directly to the steam ejector condenser. And for the other flash chambers the venting is done in group or cascade through the ejector condenser.

Full account of the theory, heat and mass balance, economics, and process optimization for (MSF) distillation process can be found in the following references [5, 6, 81, 88, 89, 90].

3.4.5. Alternative Thermal Power Cycles Schemes

As was mentioned earlier in section (3.4.4.1) of this chapter, the (MSF) evaporator requires relatively low and high pressure steam for its operation. Furthermore, it requires a supply of electrical power for the operation of it pumps, control, and instrumentation. For an (MSF) evaporator of (2.7 X 10^4 m^3 per day or 6 MIGPD) capacity, the electrical supply is approximately 5 Megawatt - Hour. In some design these pumps are steam turbine driven, and in this case further steam is required to drive the turbines. According to the present state of the art, there are a number of possible thermal power cycles that can be combined with the (MSF) cycle to form the dual - purpose (power&water) production unit. Each of these cycles has its own advantages and disadvantages. However, the most determining factors that influence the choice of the appropriate cycle to be used are the rated production capacity of the proposed unit, the operational flexibility of the turbine to meet the instantaneous changes in the electrical generation load and to a lesser extent the distilled water demand, and the fuel flexibility. The following list represents the thermodynamic power cycles that are normally used in such combination :

1. Diesel generator set with waste heat boiler.
2. Gas turbine with waste heat boiler.
3. Steam boiler, back - pressure steam turbine.
4. Steam boiler, condensing - extraction steam turbine.

3.4.5.1. Diesel Generator Set With Waste Heat Boiler Scheme

The idea behind this combined thermal cycle, is to let the diesel engine drives an electric generator. Then, the required steam for the (MSF) evaporator operation is generated in a heat recovery boiler that uses the diesel engine exhaust as heat source. The capacities of the commercially available diesel engines are in the range of 20 - 25 megawatt (MW), and their air to fuel ratio (excess air) is very low. Therefore, the diesel engine has the lowest steam to power ratio and as a result of that, it has a very low water to power ratio. Diesel engine co - production cycle is suitable for small output. of water and power, therefore, most of the dual - purpose (power&water) production stations operating at present do not employ such a cycle because of their large output. Hence this research work will not consider such combination cycle.

3.4.5.2. Gas Turbine With Waste Heat Boiler Scheme

In this co - production cycle, the relatively high temperature flue gases from the gas turbine, are fed into a waste heat boiler to recover the waste heat in the flue gases. The steam produced in the boiler can then be used for the (MSF) evaporator operation. It is worth mentioning that in such thermal cycle the water to power product ratio (WPPR) is fixed and depend on the (MSF) evaporator performance ratio (P.R). This ratio is defined as the number of (kilogramme or pounds (kg or lbs) of distillate produced per (1.055 X 10^6 joules or 1000 Btu) of heat input in the brine heater for heating the brine. Commonly this ratio is expressed as follows :

P.R = lb of distillate / 1000 Btu in put in the brine heater ----------------------2

The fixation of the (WPPR) in such away will hinder the flexibility of operation for this combined cycle, because any reduction in power generation will result in lower distilled water production. Therefore, to enhance the operational flexibility and obtain a higher distilled water production in comparison with power generation , refired waste heat boiler can be used. Since the exhaust gas available for the waste heat boiler is at a relatively high temperature (approximately 500 ^oC - 932 ^oF) and it contains oxygen in sufficient amount (this apply to high air / fuel ratio gas turbines, i.e. less efficient turbines), therefore, this condition allows refiring additional fuel in the exhaust stream for the co - production cycle that is requiring more heat than is obtainable from the exhaust only, and for more operational flexibility. For further flexibility of matching the steam output to the (MSF) evaporator requirements some design configuration will incorporate any or all of the following additional equipment [6] :

1. "Auxiliary boilers to provide steam when the power demand is low (exhaust temperature varies with the electrical load) or when the gas turbine is not in operation."
2. "Bypass dampers, which can send excess exhaust gases to the atmosphere (when the power demand is high and water demand is low."

Inorder to increase the thermal efficiency of the combined thermal cycle, some installation add a steam turbine (back pressure or extraction type) to the gas turbine, heat recovery boiler, and (MSF) evaporator. In this scheme the steam generated in the waste heat boiler is not sent to the (MSF) evaporator, but instead it is sent to the steam turbine to generate more power. The (MSF) evaporator receives it's process steam either from the waste heat boiler or the steam turbine. Even though, this combination seems attractive from a thermodynamic point of view, however, its process optimization and operation is more complex than the gas turbine / Waste heat boiler / (MSF) evaporator one.

The gas turbine / waste heat boiler / (MSF) evaporator scheme has many advantages such as [6, 7, 91] :

1. Lower capital cost.
2. Short installation period.
3. Ability for quick start , loading up, and delivering the process heat required for the thermal cycle.

However, it has many disadvantages such as :

1. Normally the fuel used for the gas turbine is high grade natural gas or light fuel oil.

This feature leads to less fuel flexibility and hence increases the operation cost.

2. Usually the gas turbine has less reliability than steam turbine.
3. The gas turbine efficiency and output is influenced by the ambient temperature.
4. The gas turbine maintenance costs are relatively high.
5. The gas turbine is suitable for small and medium capacities (at present 130 Megawatt (MW)). This will limit its applicability for large (MSF) evaporator output of 6 (MIGPD) and over and a power generation output of 150 - 350 Megawatt (MW).

Based on the above disadvantages therefore, only a minority of the large dual - purpose (power&water) production stations operating at present employ the combined gas turbine thermal cycle because the gas turbine can not fulfill the large output requirement. Hence this research work will not consider such combination cycle.

3.4.5.3. Steam Boiler, Back - Pressure Steam Turbine.Scheme

In this configuration, the exhaust steam from the turbine is sent directly to the brine heater of the (MSF) evaporator, where it releases its latent heat of vaporization. The pressure at which the turbine is backpressured will vary according to the top brine temperature operation of the (MSF) evaporator. The attractiveness of this combination lies in the fact that this scheme has the highest water to power production ratio (WPPR). Therefore, this configuration will produce the least amount of power for a given amount of water. Hence, this combination is favorable for the mainly water production station in which power generation is considered less important than the water production. This scheme has a higher thermal efficiency in comparison to a condensing turbine, because its exhaust steam is fully utilized in the brine heater of the (MSF) evaporator [6]. It should be noted, however, that the (WPPR) for this scheme is fixed and depends mainly on the performance ratio (P.R) of the (MSF) evaporator. This condition is similar to the the gas turbine scheme. Here again like the case of the gas turbine combination, the operational flexibility can not be assured because any reduction in power load will entail a reduction in water production. Therefore, this combination is best suited for constant base load power production to make certain that the required quantity of distillate is produced. To enhance the flexibility of operation, some design incorporate a dump condenser in the set up.or use part of the (MSF) evaporator brine heater, to condense the excess steam in the case of of the distiller failure, and a bypass to supply enough steam to the distiller in the case of the turbo - generator failure. From the above discussion one can see that this scheme is not really a dual - purpose in the strict definition of the application, because in a true dual - purpose station both the power and water have to be equal in importance. Therefore, most large dual - purpose (power&water) production units (2.7 X 10^4 m^3 per day or 6 (MIGPD) and above of distillate and 150 - 350 (MW). of power) in which both the power and water are at equal importance do not employ such thermal cycle. And since this research work is concerned with a true dual - purpose station, therefore, this research work will not consider such combination cycle.

3.4.5.4. Steam Boiler, Condensing - Extraction Steam Turbine.Scheme

A steam turbine is made of a number of stages, and as a consequence of that, the steam flows through these stages in ordered succession until it is expanded to the condenser exhaust pressure. As the live steam from the boiler, is expanded in the various turbine stages for power generation its temperature and pressure drop from high to low in a series of steps that is matching to each turbine stage. Therefore, if it is required, the necessary quantity of heating low pressure steam at a specified pressure and temperature can be extracted as a pass - out and be sent, usually through a pressure reducing station, to the brine heater of the (MSF) evaporator, where it will condense and give its latent heat vaporization to the circulating brine. The condensate from the brine heater will be pumped back to boiler circuit. The rest of the low pressure steam in the turbine is then completely expanded in the lower stages to the condenser exhaust pressure, thus providing additional power to be generated. This is the principle upon which this thermal combined cycle is based. The bleed stream can be extracted from one or more stages of the turbine. The extraction points have to be selected carefully, because of their effect on the overall steam cost and thermal efficiency of the combined cycle. Therefore, the selection of the extraction points entails a balance between low steam cost versus high steam cost. If the criterion of the design is to increased the distilled water production or reduced (MSF) evaporator capital cost then in this case higher steam pressure is preferred. However, the solubility limits of calcium bicarbonate, magnesium salts, and calcium sulphate, which are present in the circulating brine, will limit the extraction temperature, because it is important to control the scale formation on the heat transfer surfaces of the (MSF) evaporator [87]. There is also a limitation on the extent of how low the extraction pressure should be, because the lower the temperature the higher the specific volume of the steam. Thus if the extraction pressure is very low, the volume of the extracted steam will be so large that extraction difficulties aries. It should be noted that, the steam can not be extracted to the (MSF) evaporator until the turbine load reaches a certain value normally about 60 (MW). In this combination, both power generation and distilled water production are equaily important. Therefore, the design should be so flexible to secure that one part of the combined unit is not totally dependent on the other. This combined scheme is characterized by an extremely good operational flexibility. The (WPPR) in this scheme can be varied from very low values to values as high as for the back pressure scheme. Furthermore, this combination allows the operation to produce power only or water only. Variation in power load is met by an appropriate changes in the steam flow in the low pressure section of the turbine. A control valve located on the turbine is used to regulate the steam flow through the low pressure section of the turbine so that the rates and temperature of the extracted steam can be adjusted as appropriate. In this scheme, if a failure does occur to the turbine or generator, the (MSF) evaporator can be provided with the appropriate steam supply by a bypass systems (including pressure reducing station and desuperheater) either from the boiler directly or from the high and low pressure headers. And if the boiler is at fault, then, the appropriate steam is supplied from the high and low pressure headers. In this scheme, the turbine is designed in a way such that, if the (MSF) evaporator is shut down, then the low pressure section of the turbine and the condenser can expand and condense the whole low pressure steam flow. In the this combination the thermal efficiency of the cycle will be varying and will depend on the conditions of the extracted steam to the (MSF) evaporator.

From the above discussions, it is clear that this combined cycle is the most versatile one and represent a true dual - purpose (power&water) production unit. Almost all true dual - purpose (power&water) production stations all over the world adopt this combination. And since this research work is concerned with a true dual - purpose station, therefore, this research work will adopt this combined thermal cycle for the production unit.

3.4.6. High And Low Pressure steam Supply To The (MSF) Evaporator

The thermal cycle selected for this research work is a combination of an (MSF) brine recirculated evaporator with a fossil fueled steam boiler and a condensing - extraction steam turbine. Furthermore, the rated capacities of the evaporator and the turbine are in the range of (2.7 X 10^4 m^3 per day or 6 (MIGPD)) and above of distillate and 150 - 350 (MW). of power generation. All the motors of the combined unit are electricity driven. Therefore, the (MSF) evaporator requires high pressure (H.P) steam for the ejector - condenser operation, high pressure (H.P) steam to be used as an atomizing steam for the desuperheater, and low pressure (L.P) steam for heating the circulating brine in the brine heater.

3.4.6.1. Low Pressure (L.P) Steam Supply To The (MSF) Evaporator

The following are the alternative methods of low pressure (L.P) steam supply to the (MSF) evaporator side of the dual - purpose production unit :

1. If the turbine is operating and the load is at least 60 (MW) and over, the steam will be extracted from the turbine. Since, the pressure and temperature of the extracted steam will be over the conditions required for the (MSF)

evaporator operation, therefore, it is passed through a pressure control valve to adjust the steam pressure to normally about (0.8 bar or 12 psi for polyphosphate operation), then it is passed through the (MSF) evaporator desuperheater to reduce its temperature. The (L.P) steam prior to its entry to the brine heater should be slightly super heated at more than zero Kg / m^2 for polyphosphate operation.

2. If the the load on the turbine is less than 60 (MW), or the turbine is down for either a forced or planed outage, then the low pressure (L.P) steam is normally supplied from the (L.P) steam common header or from the boiler if the boiler is operating (and this operational procedure is very rare indeed)
3. If the steam supply is from the low pressure (L.P) steam common header, then the slightly super heated steam is passed through the distiller desuperheater prior to its entry to the brine heater. The steam in the (L.P) steam common header is collected from any of the operating boilers or turbines of the station, after the proper pressure and temperature reduction.
4. If the steam supply is directly from the boiler, the high temperature steam (normally about 500 ^oC and above) is first passed through a desuperheater at the boiler side, then through a pressure reducing station to reduce its pressure, after that it is passed through the (MSF) evaporator desuperheater to come out slightly super heated prior to its entry to the brine heater.

3.4.6.2. High Pressure (H.P) Steam Supply To The (MSF) Evaporator

The following are the alternative methods of high pressure (H.P) steam supply to the (MSF) evaporator side of the dual - purpose production unit :

1. If the boiler is operating then, the steam will be supplied directly from it. Since,the pressure and temperature of the steam coming out of the boiler are very high for the ejector and desuperheater of the (MSF) evaporator operation, therefore, it is first passed through a desuperheater at the boiler side, then through a pressure reducing station to reduce its pressure to normally about (14 bars or 203 psi). Part of this pressure reduced steam is fed

to the desuperheater of the evaporator as an atomizing steam, and the rest it pass to the starting ejector while the evaporator is under start up conditions , then to the operating main ejector (each evaporator is normally provided with two main ejectors, one in service and the other is stand - by).

2. If the boiler is down for either a forced or planed outage, the steam will then be supplied from the (H.P) steam common header. The steam in the (H.P) steam common header is collected from any of the operating boilers of the station, after the proper pressure and temperature reduction.

Figure No (4), which will be found in the next page, illustrate a flow sheet of the distiller high (H.P) and low (L.P) pressure steam supply direct from the boiler and from the common headers.

3.4.7. The Dual - Purpose Production Unit Sub And Associated Systems

Figure No (5), which will be found at the end of this volume of the thesis, shows the process flow diagram , sub - systems, and associated systems of a dual - purpose (power&water) production units of the station as whole. From the figure and the discussions of the proceeding sections of this chapter, it can be deduced that the the production unit is composed of four (4) sub - systems and eleven (11) associated systems.These are as follows :

A. Unit Sub - Systems.

1. Boiler.
2. Turbine.
3. Generator.
4. Distiller.

B. Unit Associated Systems.

1. Fuel.
2. Electrical Supply (1). [Station Main Busbar - (S.F.6) Switch Gear].
3. Electrical Supply (2). [Unit Power Side Electrical Supply].
4. Electrical Supply (3). [Unit Water Side Electrical Supply].

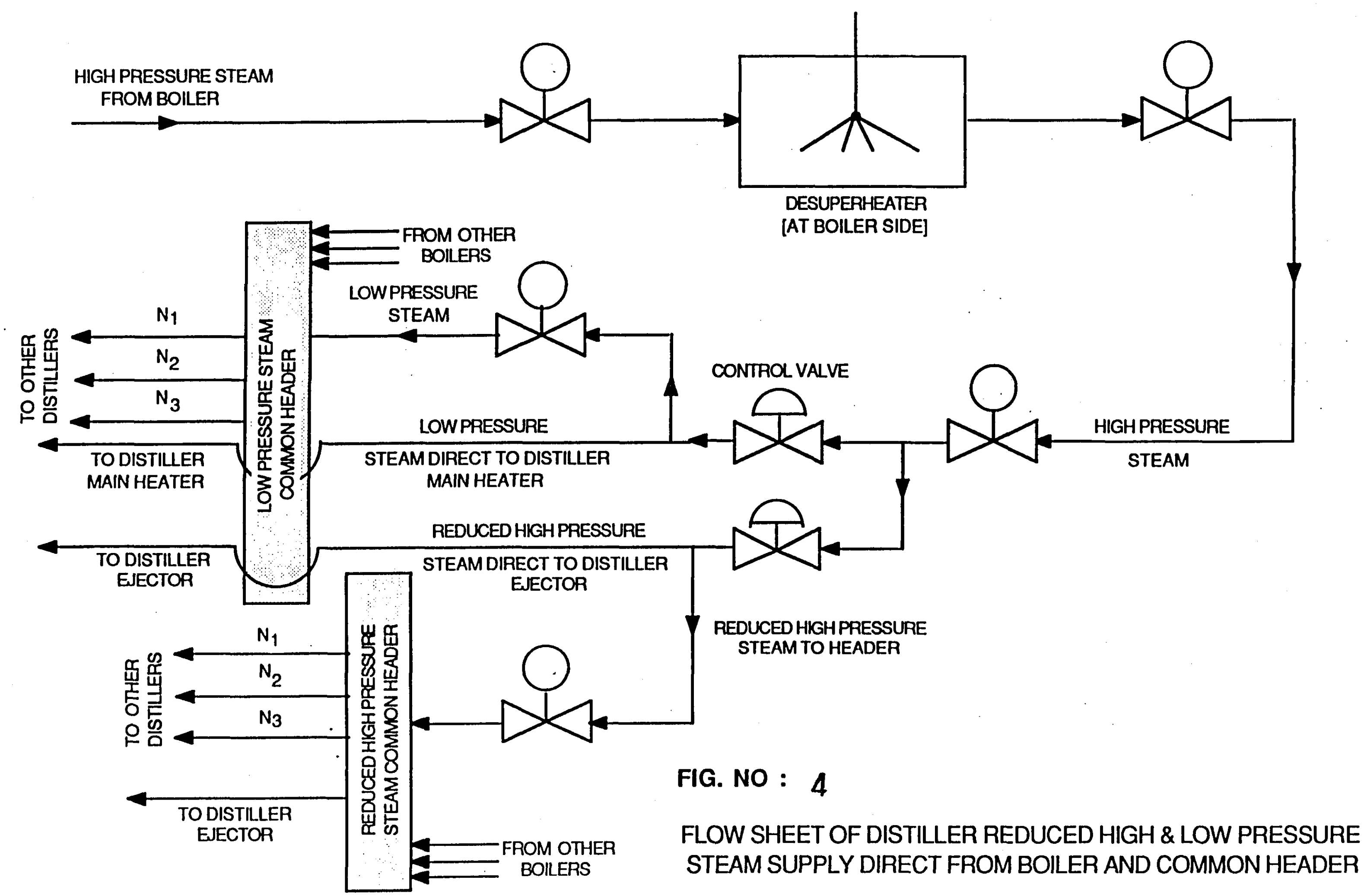


FIG. NO : 4

FLOW SHEET OF DISTILLER REDUCED HIGH & LOW PRESSURE STEAM SUPPLY DIRECT FROM BOILER AND COMMON HEADER

Unit Associated Systems Continued

5. Sea Water Intake.

6. Turbine Cooling.

7. Distiller Cooling.

8. Turbine Discharge.

9. Distiller Discharge.

10. Distiller High Pressure (H.P) Steam Supply.

11. Distiller Low pressure (L.P) Steam Supply.

Chapter (IV) of the theses will discuss the sub - systems, associated systems, and their interaction in unit operation.

CHAPTER IV

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION OPERATIONAL INTERLOCK LOGIC ANALYSIS APPROACH

CHAPTER IV

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION OPERATIONAL INTERLOCK LOGIC ANALYSIS APPROACH

4.1. Introduction

As it was mentioned earlier in section (1.4.2) of chapter (I), the work of this chapter is to analyse the operational interlocking logical sequences of the station, production unit, unit sub - systems, unit associated systems, and unit sub - sub systems, in order to establish the interrelationship between the various parts of the production unit and hence the station. This analysis will facilitate the development of the operational models for the sub - systems, and associated systems of the production units of the station. Furthermore, the analysis will establish the boundaries of the production unit sub - systems, associated systems, and their sub - sub systems.

4.2. Unit Sub And Associated Systems Boundaries

In section (3.4.7) of chapter (III) it was established that the production unit consists of four (4) sub - systems and eleven (11) associated systems. In the following two sections (4.2.1 &4.2.2) the boundaries of these parts will be identified.

4.2.1. Unit Sub - Systems

There are four unit sub - systems, namely, the boiler, turbine, generator, and distiller.

4.2.1.1. Boiler Sub - System Boundaries

Referring to figure (5) of chapter (III), and the construction of the boiler proper, it can be deduced that the boundaries of the boiler should be confined to following sub - sub - systems :

1. The feed and make - up water.
2. The heat recovery area.
3. The boiler drum.

4. The boiler furnace.

5. The combustion air.

6. The main stop valve.

4.2.1.2. Turbine Sub - System Boundaries

Referring to figure (5) of chapter (**III**), and the construction of the turbine, it can be deduced that the boundaries of the turbine should be confined to following sub - sub - systems :

1. The main steam supply line.
2. The auxiliary steam line (from boiler) for main ejector and turbine gland seal.
3. The load control.
4. The high pressure (H.P) turbine.
5. The low pressure (L.P) turbine.
6. The lubricating and hydraulic oil system.
7. The condenser system.
8. The condensate system.

4.2.1.3. Generator Sub - System Boundaries

The generator boundaries should be confined to the following sub - sub systems :

1. The generator rotor.
2. The stator.
3. The hydrogen cooling.
4. The sealing oil system.
5. The pilot exciter.
6. The exciter.
7. The voltage control.

4.2.1.4. Distiller Sub - System Boundaries

Referring to figure (5) of chapter (**III**), and the construction of the (MSF) distiller it can be deduced that the boundaries of the distiller should be confined to following sub - sub - systems :

1. The brine heater.
2. The heat recovery section.
3. The heat rejection section.
4. The distiller discharge.
5. The air ejectors.

4.2.2. Unit Associated Systems

There are eleven (11) unit associated systems. In the following eleven (11) sections (4.2.2.1) to (4.2.2.11) the boundaries of these parts will be identified.

4.2.2.1. Fuel Associated System Boundaries

Referring to figure (5) of chapter (**III**), and since most of these stations are build with flexible fuel strategies therefore, the boundaries of this associated system should be confined to the following sub -sub systems :

1. The fuel gas (natural gas) and ignition gas (natural gas or propane gas).
2. The crude oil.
3. The gas oil.
4. The heavy oil.

4.2.2.2. Main Electrical Supply [Electrical Supply (1)] Boundaries

Referring to figure (5) of chapter (**III**), and the practical understanding of the operation of these stations, the general overall main electrical supply associated system (station main busbar) [electrical supply (1)] should be confined to the following sub - sub systems :

1. The unit generator transformers (step down transformers) [N unit generators].
2. The national electrical distribution system (grid net work).
3. The station auxiliaries power supply (e.g. gas turbines).

However, since the national electrical distribution system (grid net work) and the station auxiliaries power supply are needed only in emergency situation, moreover, they are on the periphery of this associated system and their inclusion will divert the efforts of the reliability analysis, therefore, they will be omitted from this associated system. Based on that, this associated system will be reduced and confined to the unit generators (step down) sub - sub system. It should be noted here, that this associated system, supply all the unit sub - systems with electrical power, therefore if this associated system fails, then both parts (power&water) of the production unit will be down.

4.2.2.3. Power Side Electrical Supply [Electrical Supply (2)] Boundaries

Referring to figure (5) of chapter (**III**), and the practical understanding of the operation of these stations, the electrical supply (2) associated system should be confined to the following sub - sub systems :

1. The unit transformer (step down) [15 / 6.6 Kilovolts (K.V)].
2. The 132 (K.V) main busbar [(S.F.6) switch gear].
3. The power side auxiliaries transformers (step down) [132 (K.V) / 6.6 (K.V)].
4. The power side auxiliaries transformer (step down) [6.6 (K.V) / 415 volts (V)].

4.2.2.4. Water Side Electrical Supply [Electrical Supply (3)] Boundaries

Referring to figure (5) of chapter (**III**), and the practical understanding of the operation of these station, the electrical supply (3) associated system should be confined to the following sub - sub systems :

1. The 132 (K.V) main busbar [(S.F.6) switch gear].
2. The water side auxiliaries transformer (step down) [132 (K.V) / 11 (K.V)].
3. The water side auxiliaries transformers (step down) [11 (K.V) / 415 (v)].

4.2.2.5. Sea Water Intake Associated System Boundaries

Referring to the practical understanding of the operation of these stations, this associated system should be confined to the following sub - sub systems :

1. The sea water intake open forebay channel.
2. The oil protection system (e.g. oil booms).

It should be noted here, that this associated system supply both the (MSF) evaporator and the turbine condenser of each production unit in the station with sea water, therefore if this associated system fails, then both parts (power&water) of all the production units in the station will be down and accordingly the whole production of the station will be out of production..

4.2.2.6. Turbine Cooling Associated System Boundaries

Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub systems :

1. The trash rack.
2. The disinfiction system (e.g.chlorination).
3. The travelling screens.
4. Theturbine condenser cooling water transfer pumps.

4.2.2.7. Distiller Cooling Associated System Boundaries

Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub systems :

1. The trash rack.
2. The disinfection system (e.g.chlorination).
3. The travelling screens.
4. The distiller cooling and make - up water transfer pumps.
5. The distiller cooling and make - up water common header culvert.

4.2.2.8. Turbine Discharge Associated System Boundaries

Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub system the concrete channel.

4.2.2.9. Distiller Discharge Associated System Boundaries

Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub systems the concrete channel.

4.2.2.10. Distiller High Pressure (H.P) Steam Supply Associated System Boundaries

Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub systems :

1. The reduced high pressure (H.P) steam direct from the boiler.

2. The reduced high pressure (H.P) steam direct from the common header.

4.2.2.11. Distiller Low Pressure (L.P) Steam Supply Associated System Boundaries

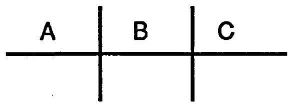
Referring to figure (5) of chapter (III), this associated system should be confined to the following sub - sub systems :

1. The low pressure (L.P) steam direct from the boiler.
2. The low pressure (L.P) steam direct from the common header.
3. The low pressure (L.P) steam direct from the turbine.

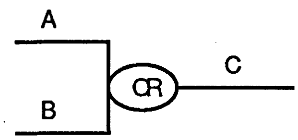
4.3. Unit Sub - Systems And Associated Systems Operational Interlock Logic Diagrams

It was mentioned earlier in section (1.4.2) of chapter (I) this logical and sequential analysis of the operation of the station and the production unit is necessary for the establishment of the operational interlocking logical sequences of the production station, production unit, unit sub-systems, unit associated systems, and unit sub-sub systems. This will in turn facilitate the grouping the various pieces of equipment under the appropriate unit sub-systems, unit associated systems, and their sub-sub systems. Furthermore, this operational analysis will facilitate an understanding of the interrelationship between the various unit sub-systems and associated systems Moreover, from this understanding, the "duality" aspects of the production station, and the production unit will be demonstrated. As it was mentioned in section (1.4.2) of chapter (I) the analysis will be presented in a graphical forms in order to avoid a lengthy and boring repeated description of the various sub-systems, associated systems, and their sub-sub systems and also for quick reference. Each graph (figure) is a distinctive self explanatory operational model for the sub-system, associated system, or sub-sub system in question. Figures (6) to (61), which will be found in a hierarchical order at the end of the text of this chapter, represent this analysis. The logic symbols used in the graph (figure) are as follows :

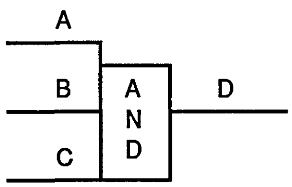
LOGIC SYMBOLS :



OPERATION OF "A", "B", AND "C" HAVE TO BE OPERATED IN THAT ORDER.



EITHER OPERATION "A"OR "B" HAVE TO BE COMPLETED FOR "C " TO WORK.



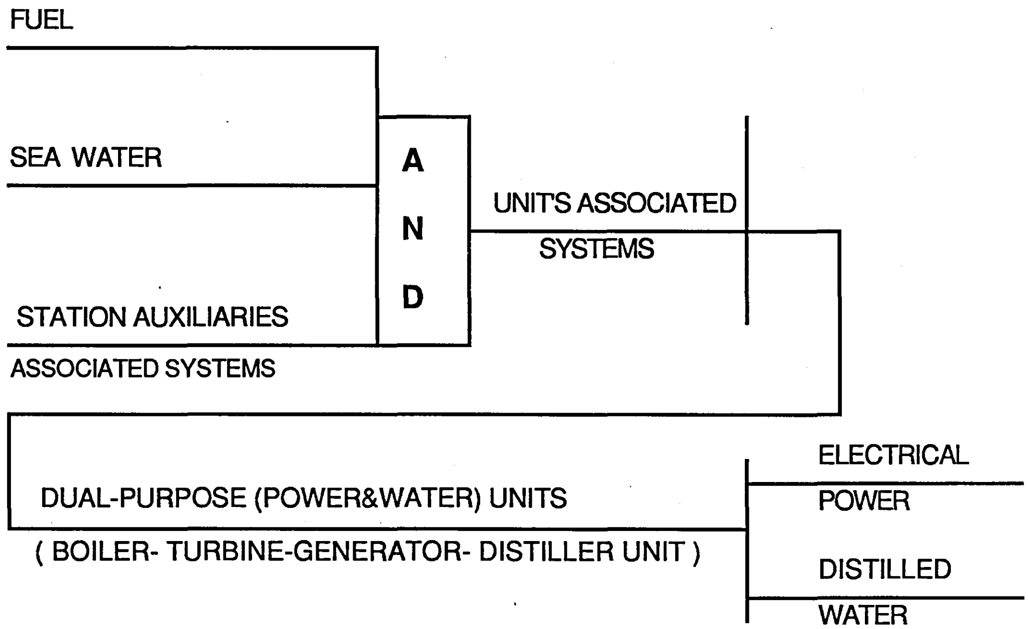
BOTH OPERATION OF " A ", " B " AND " C " HAVE TO BE COMPLETED FOR" D" TO WORK.

Figure (6) represent the overall dual - purpose (power&water) station operational interlock logic diagram. This figure incorporate the station auxiliaries associated systems which are defined as :

STATION AUXILIARIES = REFER TO ELECTRICAL CONTROL (BOTH DIRECT AND Alternating CURRENT), AUXILIARY POWER (e.g. GAS TURBINE etc), INSTRUMENT AIR FOR POWER AND WATER SIDE, SERVICE AIR FOR POWER AND WATER SIDE, SERVICE WATER FOR POWER AND WATER SIDE, STATION LIGHTING, FIRE FIGHTING SYSTEM, AND COMMUNICATION SYSTEM etc.

From this definition , the station auxiliaries associated systems involve a wide range of systems that requires a detailed analysis by them self, moreover, they are on the periphery of the operational interlock logic of dual - purpose (power&water) station, therefore, their inclusion in the operational interlock logic model will divert the efforts of the reliability analysis. For this reason, figure (6) will be replaced by figure (7) which represents a reduced version of figure (6). Figure (8) represent the general overall dual - purpose (power&water) unit combined systems operational interlock logic diagram. Also this figure incorporate the station auxiliaries associated systems, therefore, it will be replaced by figure (9). Figures (10) to (14) represents the fuel associated system and its various sub -Sub systems. Figure (15) represents the general overall main electrical supply [electrical supply (1)] associated system operational interlock logic diagram. This figure incorporates the national electrical distribution system (grid net work) and the station auxiliaries power supply. Since the national electrical distribution system (grid net work) and the station auxiliaries power supply are needed only in emergency situation, moreover, they are on the periphery of this associated system and their inclusion will divert the efforts of the reliability analysis, therefore, figure (15) will be replaced by figure (16) which represents a reduced version of figure (15). Figure (17) represents the unit power side electrical supply [electrical supply (2)] associated systems operational interlock logic diagrams. Figure (18) represents the unit water side electrical supply [electrical supply (3)] associated system operational interlock logic diagrams. Figure (19) represents the sea water intake associated system operational interlock logic diagrams. Figure (20) represents the turbine cooling associated system operational interlock logic diagrams. Figure (21) represents the distiller cooling associated system operational interlock logic diagrams. Figure (22) represents the turbine discharge associated system operational interlock logic diagrams. Figure (23) represents the distiller discharge associated system operational interlock logic diagrams. Figures (24) to (29) represents the boiler sub - system and its various sub -sub systems operational interlock logic diagrams. Figures (30) to (39) represents the turbine sub - system and its various sub -sub systems operational interlock logic diagrams. Figures (40) to (47) represents the generator sub - system and its various sub -sub systems operational interlock logic diagrams. Figures (48) to (50) represents the distiller high pressure (H.P.) steam supply associated system and its various sub - sub systems operational interlock logic diagrams. Figures (51) to (54) represents the distiller low pressure (L.P.) steam supply associated system and its various sub - sub systems operational interlock logic diagrams. Figures (55) to (61) represents the distiller sub - system and its various sub - systems operational interlock logic diagrams.

FIGURE NO 6



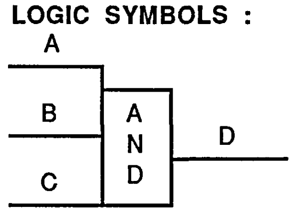
LEGEND :

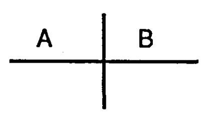
FUEL = REFER TO FUEL ASSOCIATED SYSTEM.

SEA WATER = REFER TO SEA WATER INTAKE ASSOCIATED SYSTEM.

STATION AUXILIARIES = REFER TO ELECTRICAL CONTROL(BOTH DIRECT AND ALTERNATING CURRENT), AUXILIARY POWER (e.g. GAS TURBINE etc.) , INSTRUMENT AIR FOR POWER AND WATER SIDE, SERVICE AIR FOR POWER AND WATER SIDE, SERVICE WATER FOR POWER AND WATER SIDE, STATION LIGHTING, FIRE FIGHTING SYSTEM,AND COMUNICATION SYSTEM etc.

LOGIC SYMBOLS :





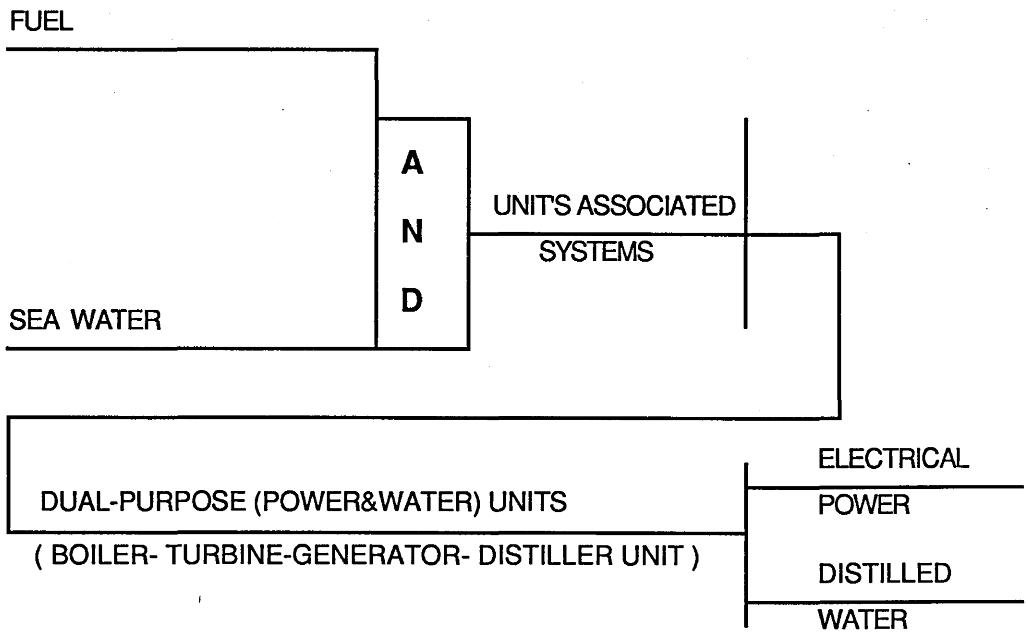
OPERATION OF " A " AND " B " HAVE TO BE OPERATED IN THAT ORDER.

BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOE " D " TO WORK.

OVERALL DUAL-PURPOSE(POWER&WATER)

STATION OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 7

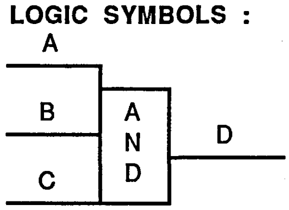


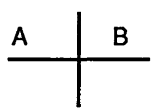
LEGEND :

FUEL = REFER TO FUEL ASSOCIATED SYSTEM.

SEA WATER = REFER TO SEA WATER INTAKE ASSOCIATED SYSTEM.

LOGIC SYMBOLS :





OPERATION OF " A " AND " B " HAVE TO BE OPERATED IN THAT ORDER.

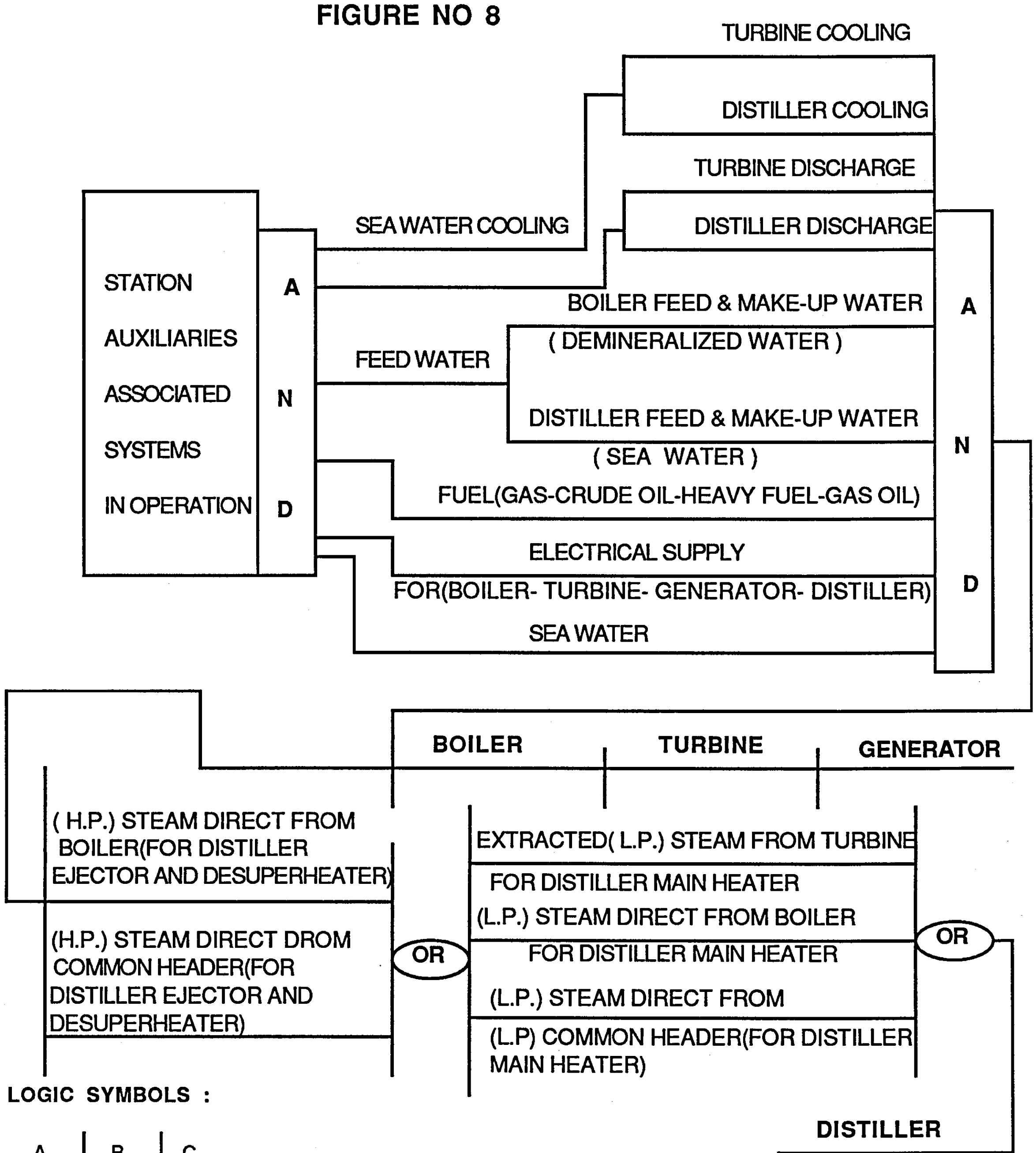
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK..

REDUCED

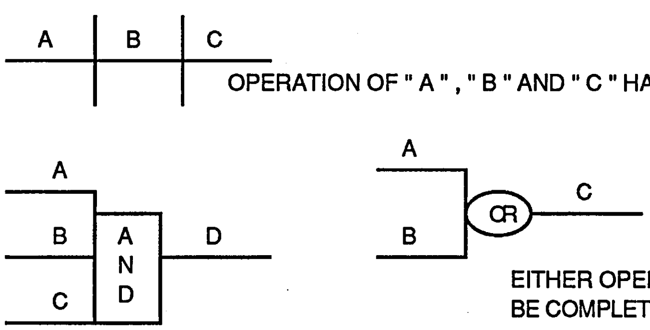
OVERALL DUAL-PURPOSE(POWER&WATER)

STATION OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 8



LOGIC SYMBOLS :



OPERATION OF " A " , " B " AND " C " HAVE TO BE OPERATED IN THAT ORDER.

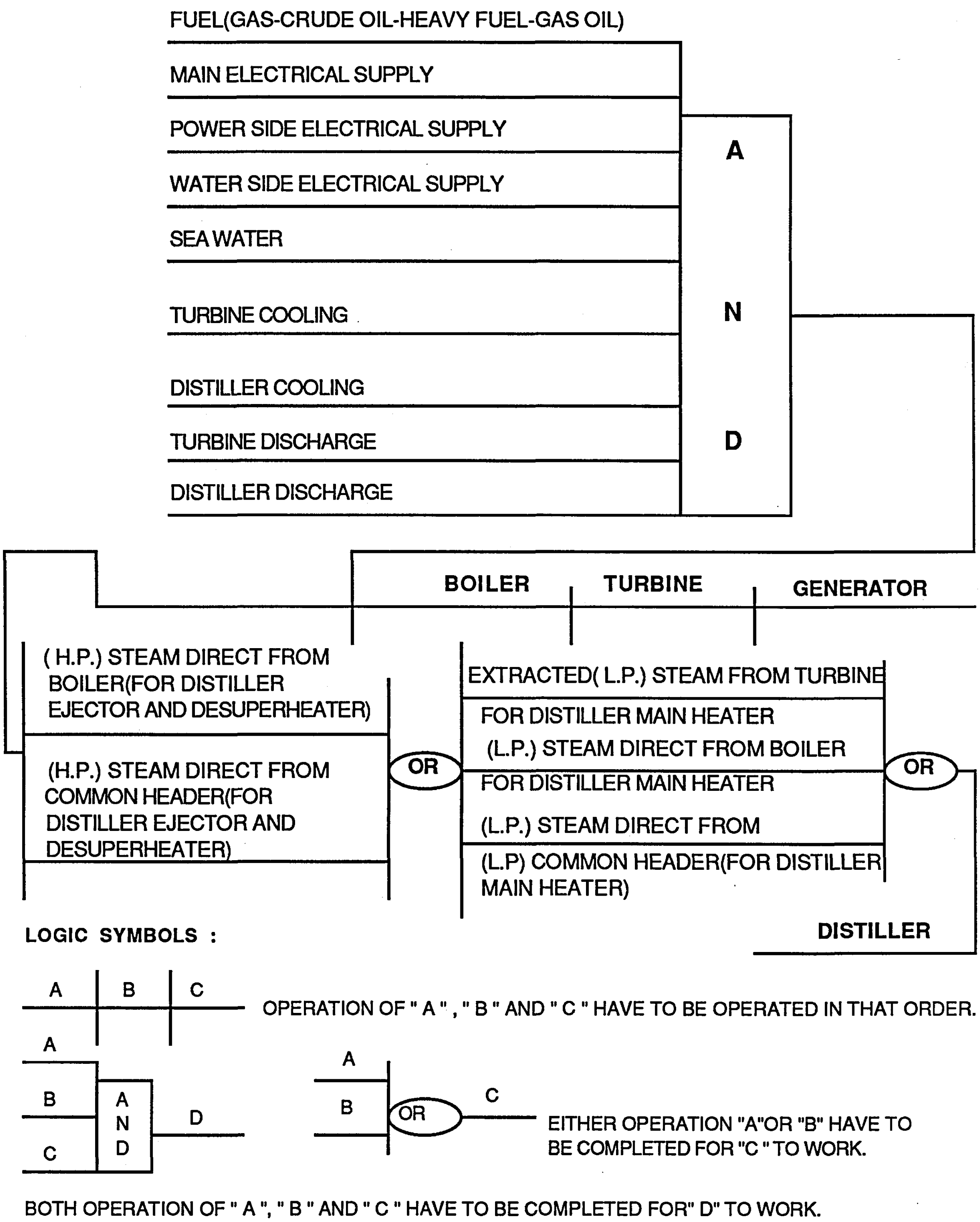
EITHER OPERATION "A"OR "B" HAVE TO BE COMPLETED FOR "C " TO WORK.

BOTH OPERATION OF " A ", " B " AND " C " HAVE TO BE COMPLETED FOR" D" TO WORK.

GENERAL OVERALL DUAL-PURPOSE(POWER&WATER)

UNIT COMBINED SYSTEMS OPERATIONAL INTERLOCK LOGIC DIAGRAM

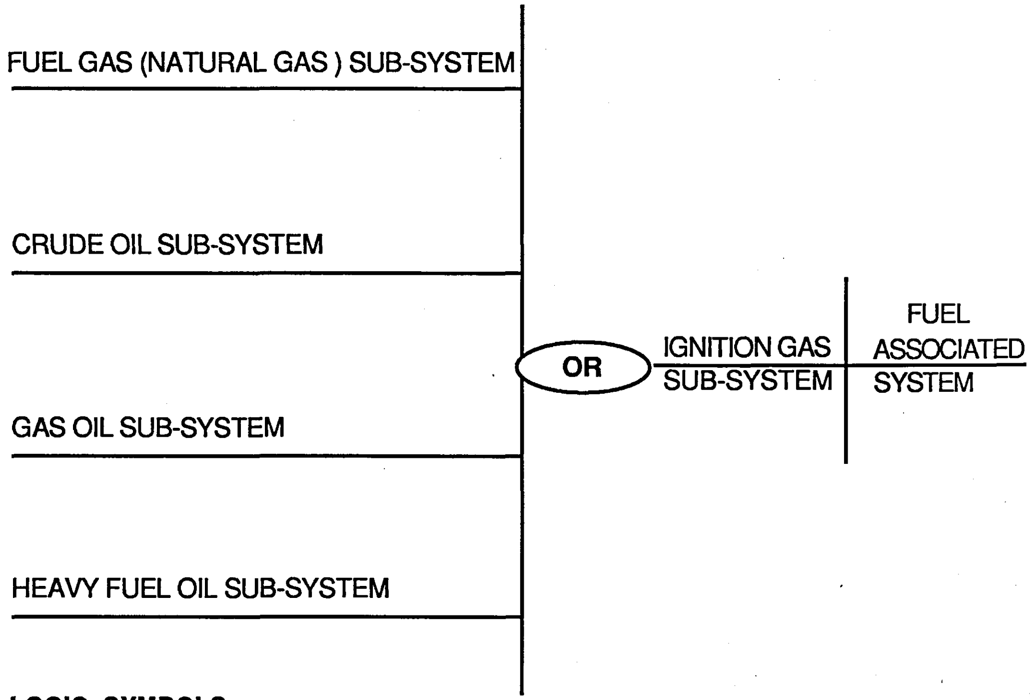
FIGURE NO 9



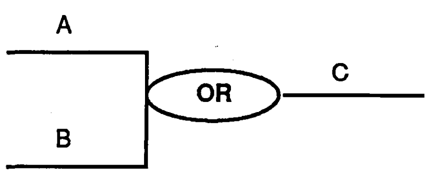
REDUCED GENERAL OVERALL DUAL-PURPOSE(POWER&WATER)

UNIT COMBINED SYSTEMS OPERATIONAL INTERLOCK LOGIC DIAGRAM

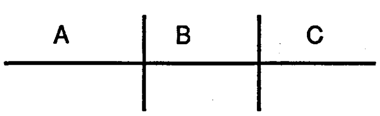
FIGURE NO 10



LOGIC SYMBOLS :



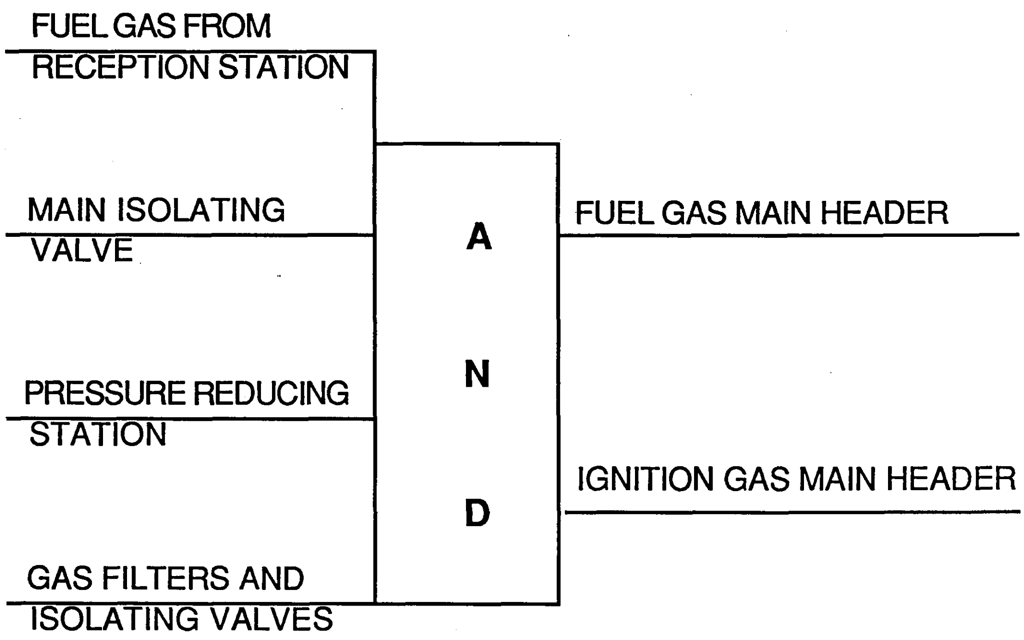
EITHER OPERATION "A" OR "B" HAVE TO BE COMPLETED FOR OPERATION "C" TO WORK.



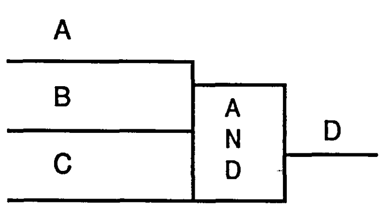
OPERATION OF "A" , "B" AND "C" HAVE TO BE OPERATED IN THAT ORDER.

FUEL ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 11



LOGIC SYMBOLS :

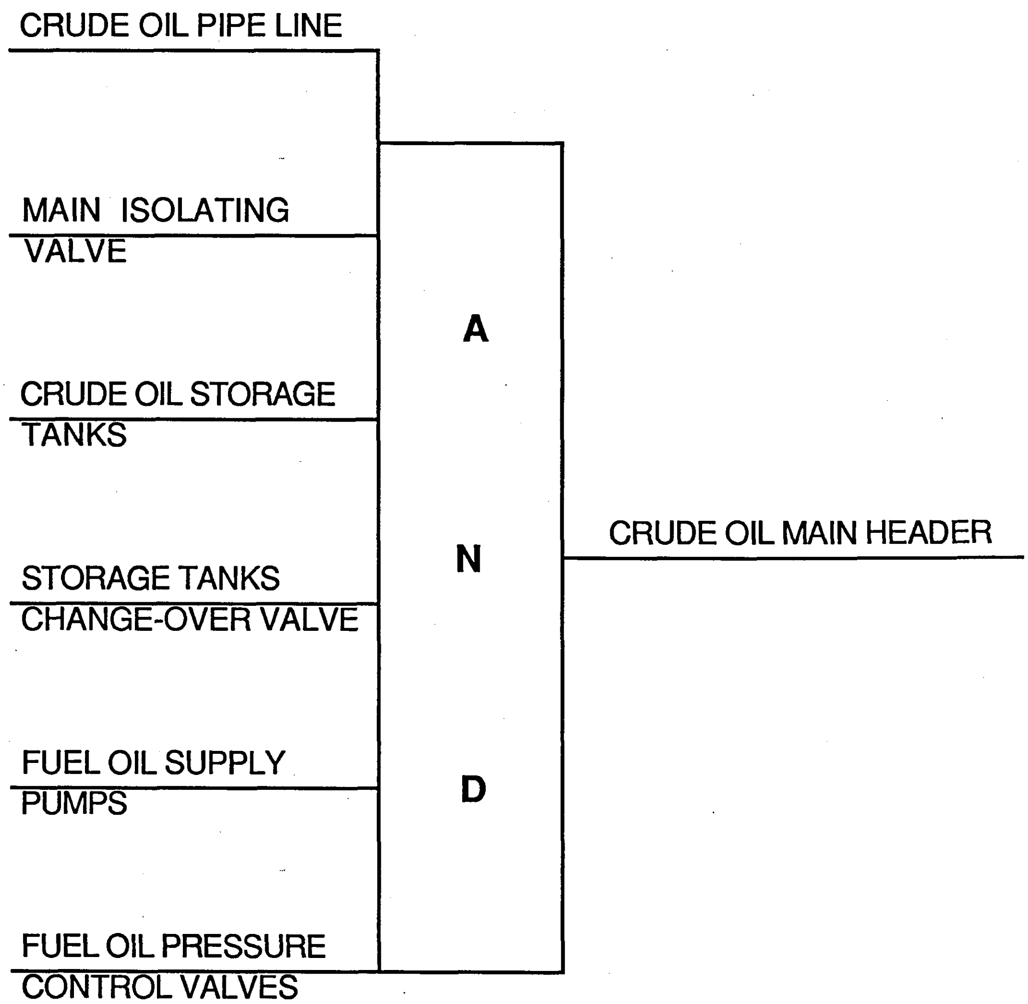


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE
COMPLETED BEFORE " D " TO WORK.

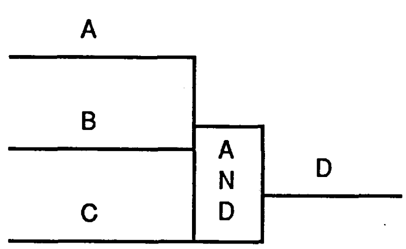
FUEL ASSOCIATED SYSTEM FUEL AND IGNITION

GAS SUB-SUB SYSTEM , OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 12



LOGIC SYMBOLS :

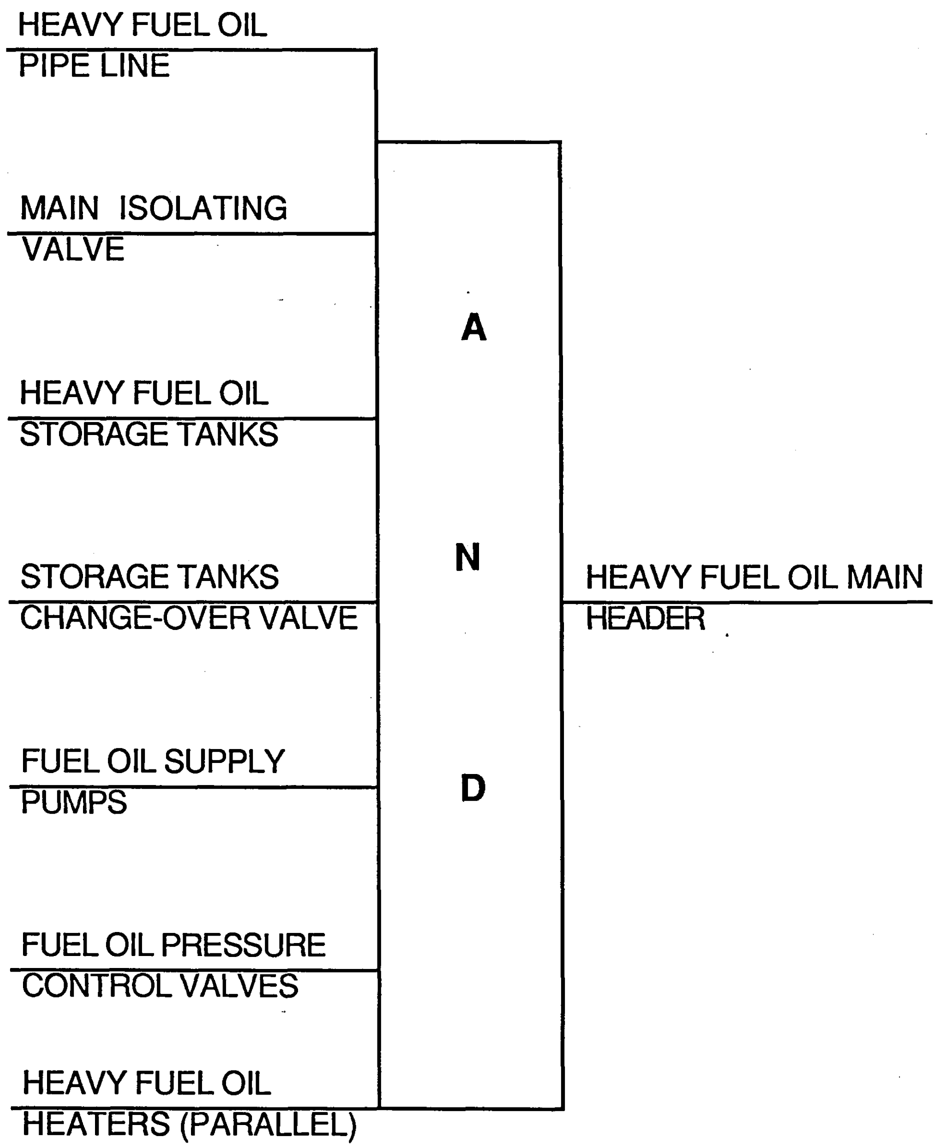


BOTH OPERATION OF " A " , " B " AND " C " HAVE
TO BE COMPLETED BEFORE " D " TO WORK.

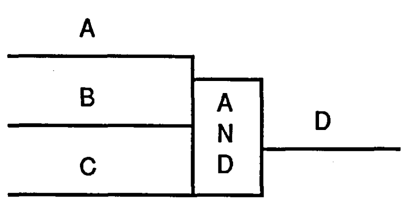
FUEL ASSOCIATED SYSTEM

CRUDE OIL SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 13



LOGIC SYMBOLS :

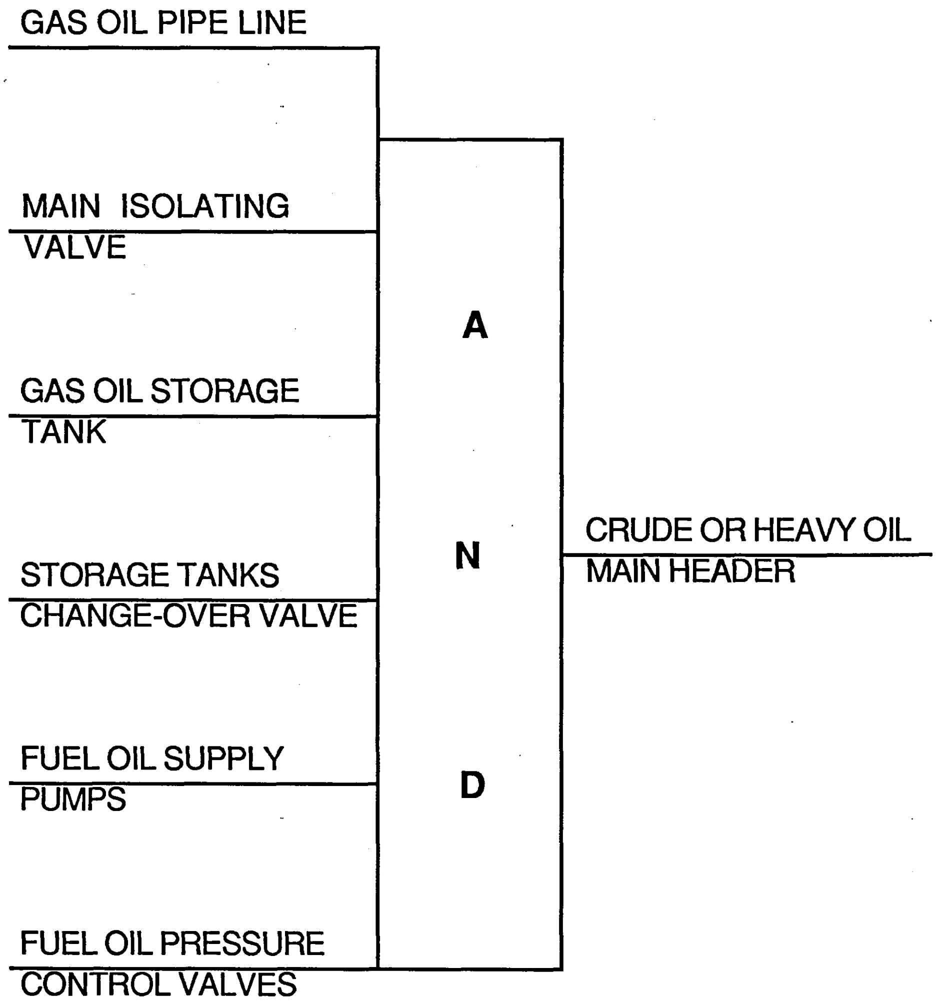


BOTH OPERATION OF " A ", " B " AND " C " HAVE
TO BE COMPLETED BEFORE " D " TO WORK.

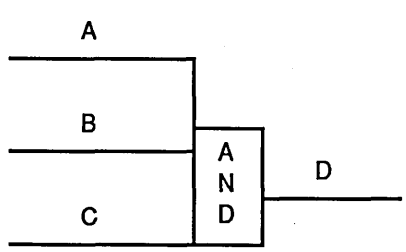
FUEL ASSOCIATED SYSTEM HEAVY FUEL

OIL SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 14



LOGIC SYMBOLS :

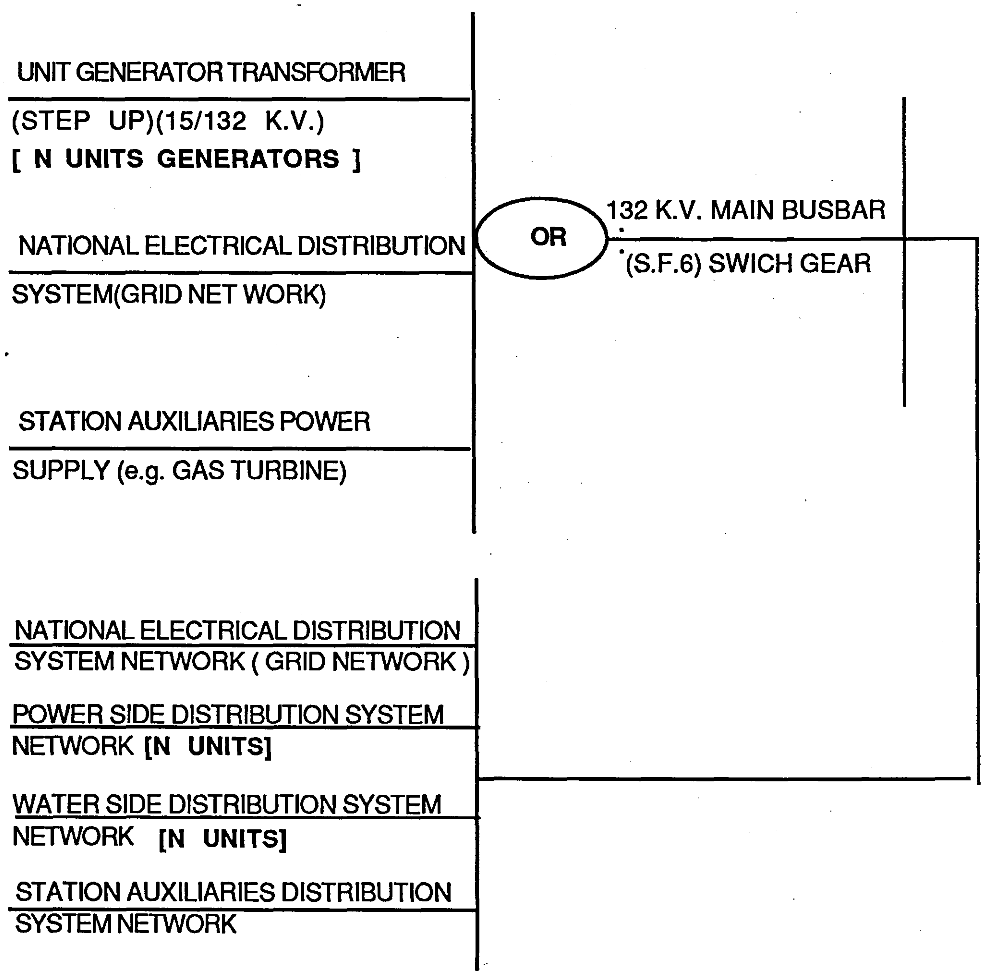


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED BEFORE " D " TO WORK.

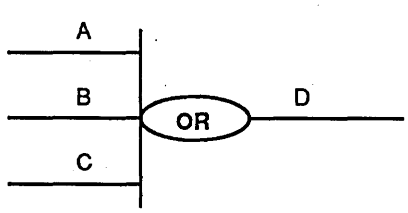
FUEL ASSOCIATED SYSTEM

GAS OIL SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

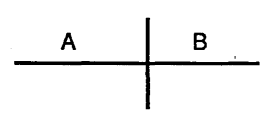
FIGURE NO 15



LOGIC SYMBOLS :



EITHER OPERATION "A" , "B" OR "C" HAVE TO BE COMPLETED FOR "C" TO WORK.

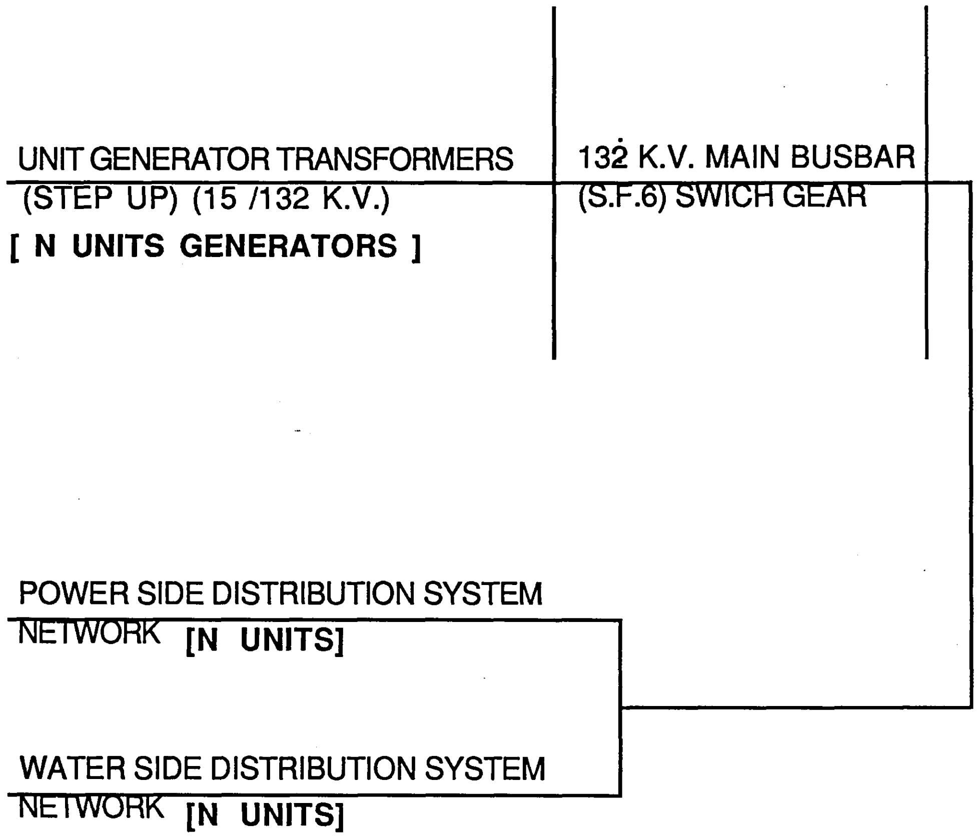


OPERATION "A" AND "B" HAVE TO BE OPERATED IN THAT ORDER

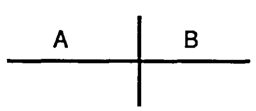
GENERAL OVERALL MAIN ELECTICAL SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK DIAGRAM

FIGURE NO 16



LOGIC SYMBOLS :

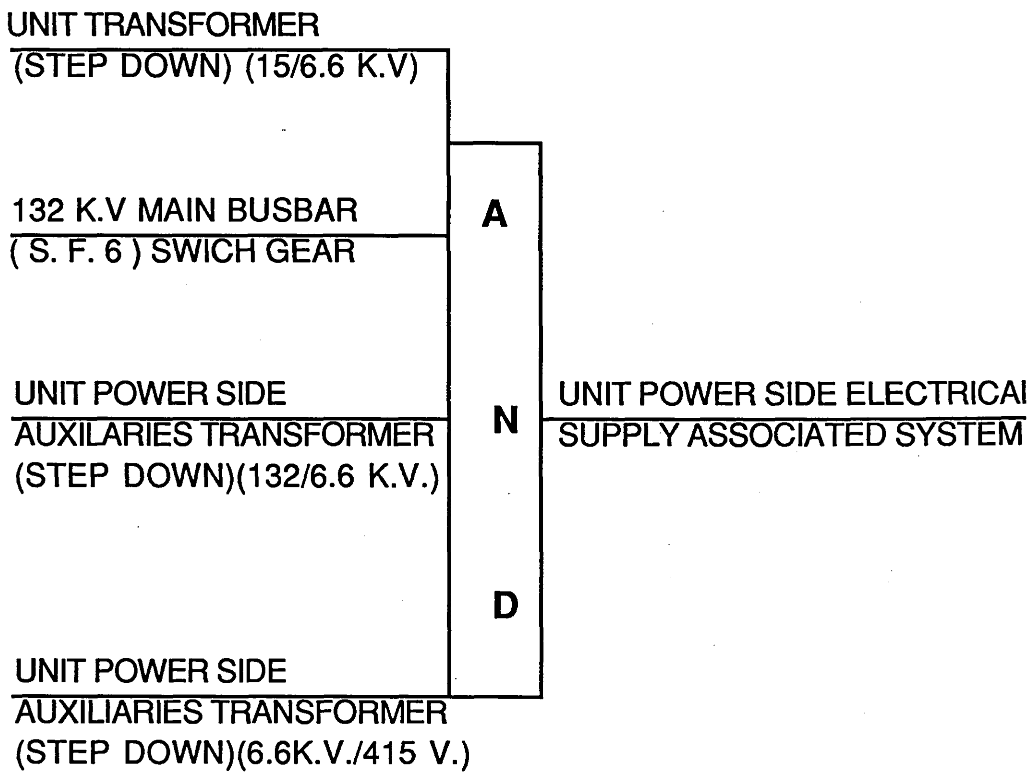


OPERATION "A" AND "B" HAVE
TO BE OPERATED IN THAT ORDER

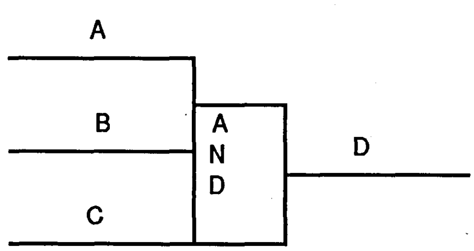
REDUCED GENERAL OVERALL MAIN ELECTRICAL SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 17



LOGIC SYMBOLS :

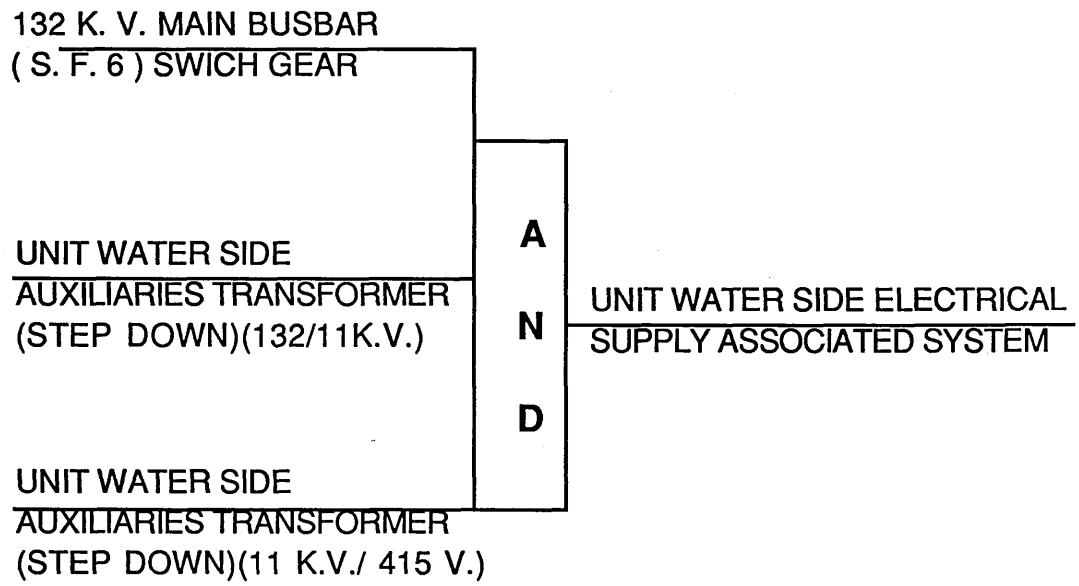


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE
COMPLETED FOR " D " TO WORK.

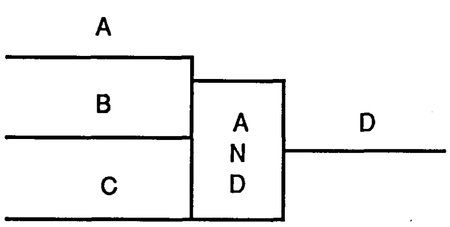
UNIT POWER SIDE ELECTRICAL SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 18



LOGIC SYMBOLS :

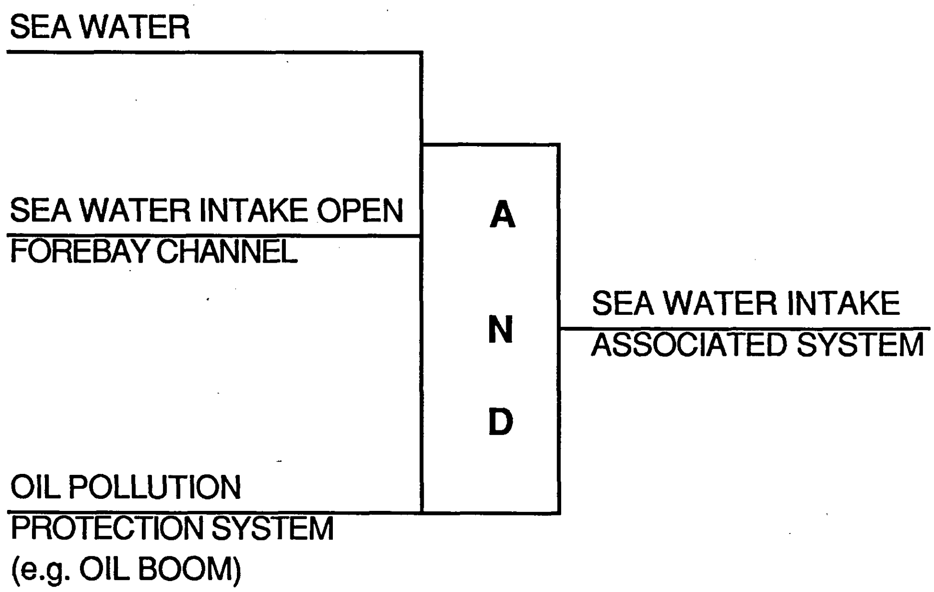


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

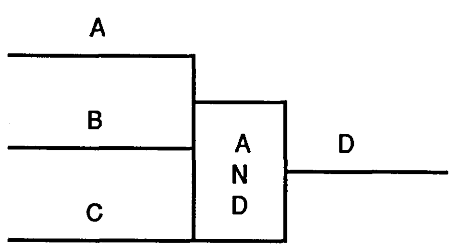
UNIT WATER SIDE ELECTRICAL SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIGRAM

FIGURE NO 19



LOGIC SYMBOLS :

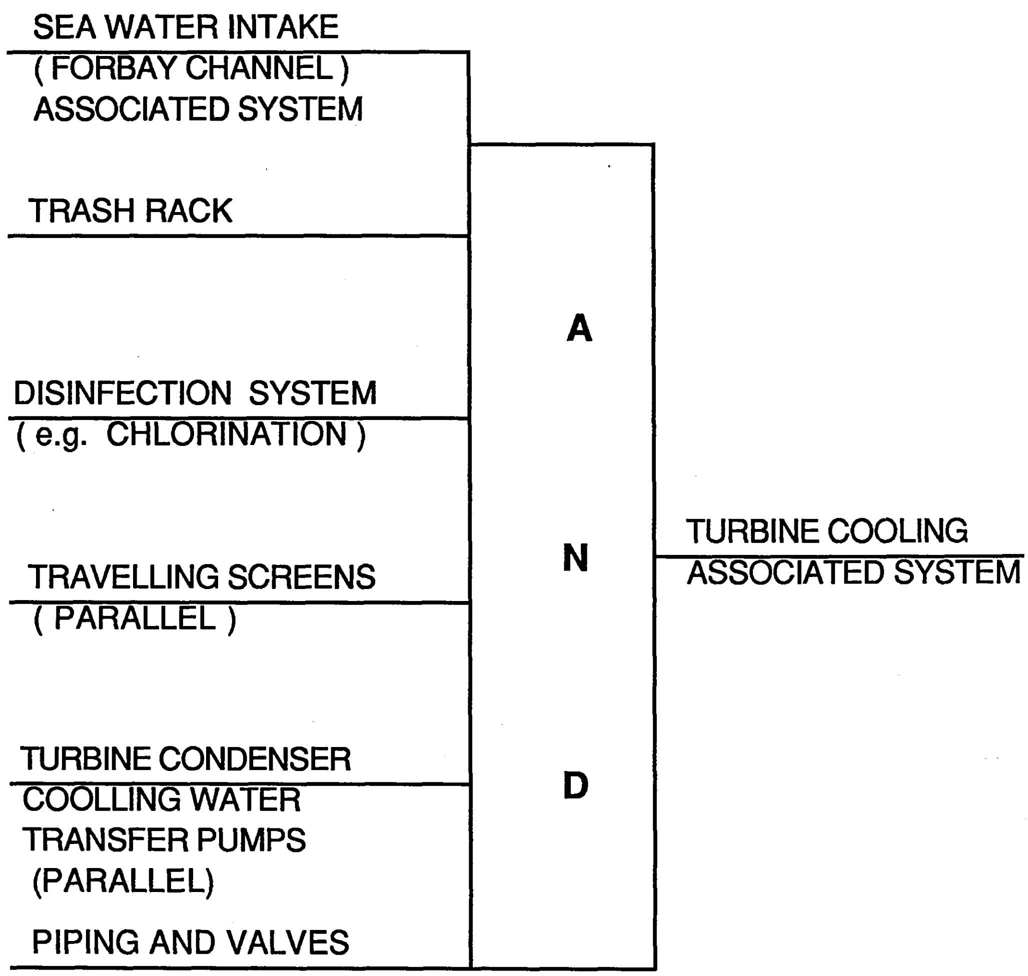


BOTH OPERATION OF " A ", " B " AND " C " HAVE TO BE
COMPLETED FOR " D " TO WORK.

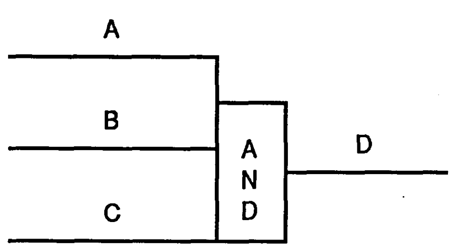
SEA WATER INTAKE ASSOCIATED

SYSTEM OPERATIONAL INTERLOCK DIAGRAM

FIGURE NO 20



LOGIC SYMBOLS :

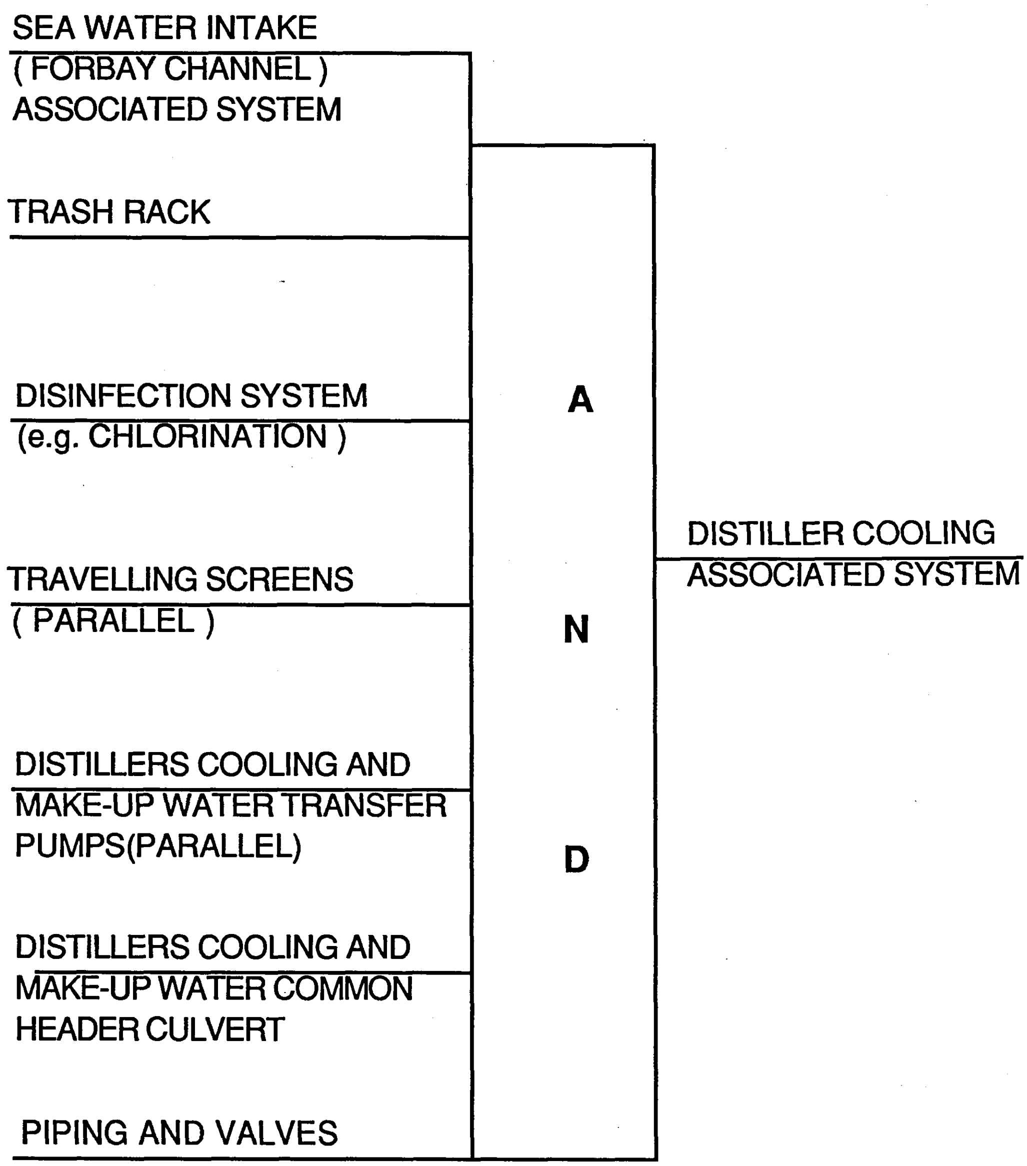


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR" D " TO WORK.

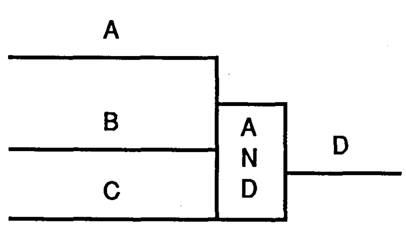
TURBINE COOLING

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 21



LOGIC SYMBOLS :

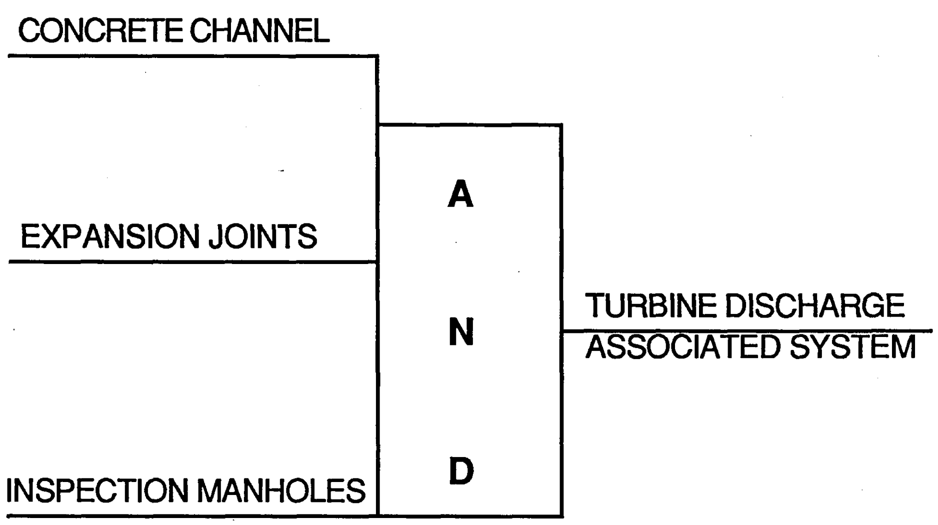


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE
COMPLETED FOR " D " TO WORK.

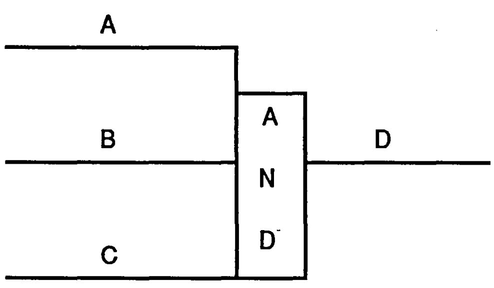
DISTILLER COOLING

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 22



LOGIC SYMBOLS :

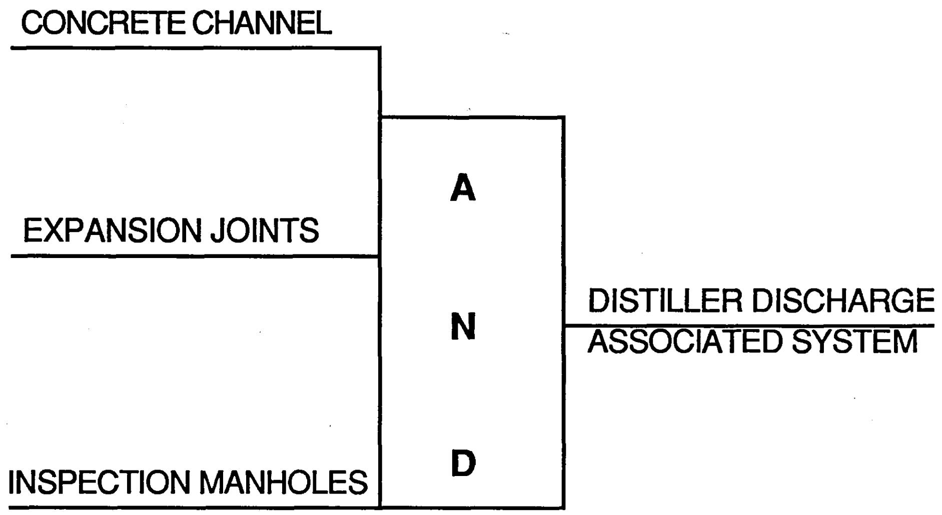


BOTH OPERATION OF "A", "B" AND "C" HAVE TO COMPLETED
FOR "D" TO WORK.

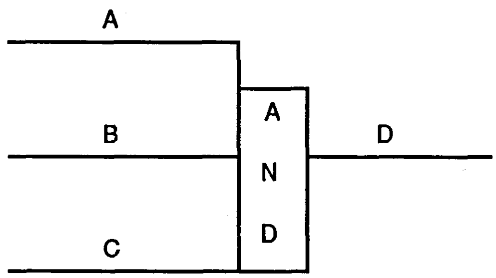
TURBINE DISCHARGE

ASSOCIATED SYSTEM OPERATIONAL INTERLCK LOGIC DIAGRAM

FIGURE NO 23



LOGIC SYMBOLS :

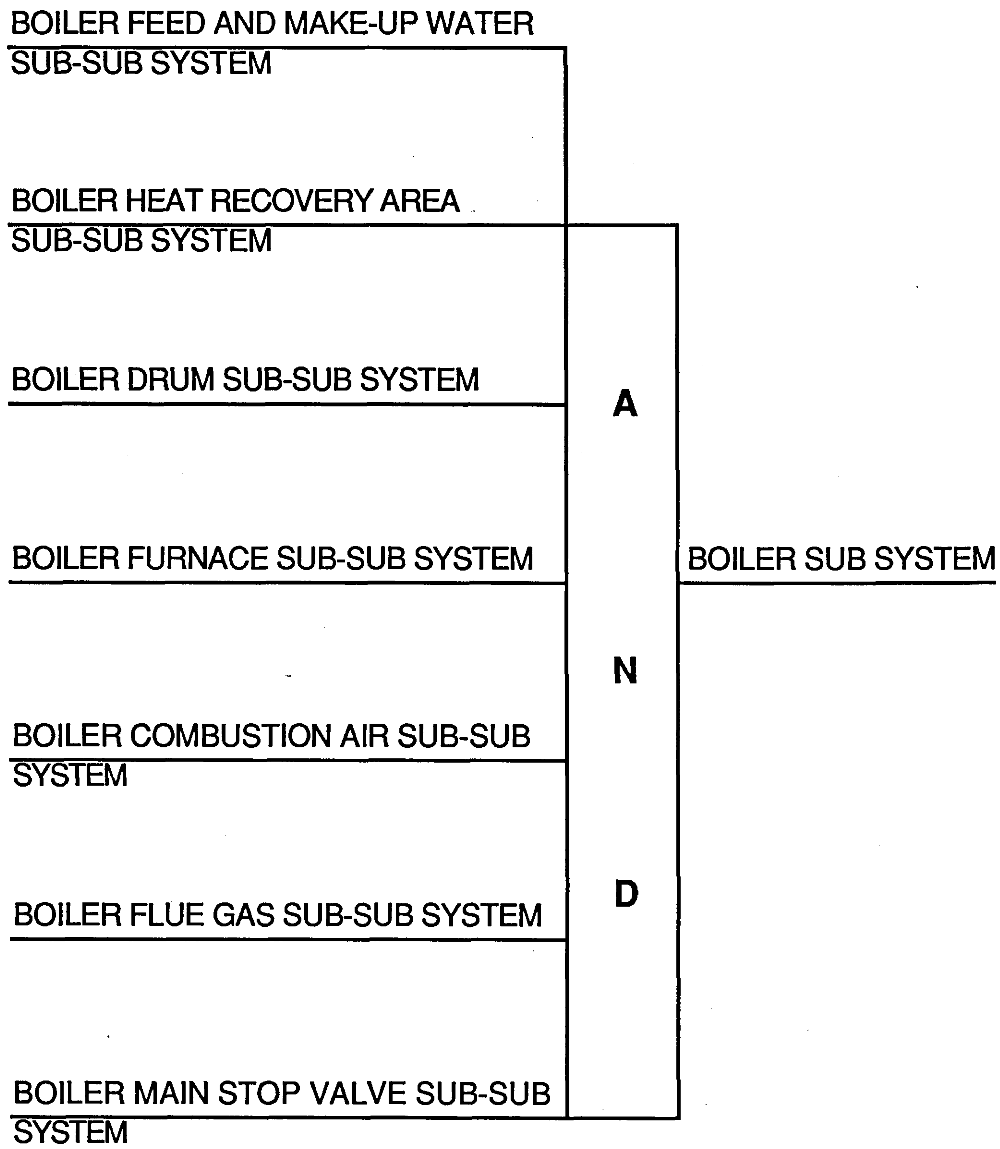


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO COMPLETED
FOR " D" TO WORK.

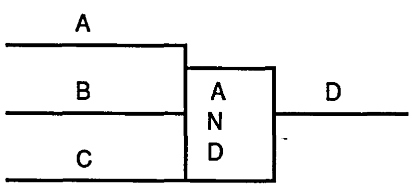
DISTILLER DISCHARGE

ASSOCIATED SYSTEM OPERATIONAL INTERLCK LOGIC DIAGRAM

FIGURE NO 24



LOGIC SYMBOLS :

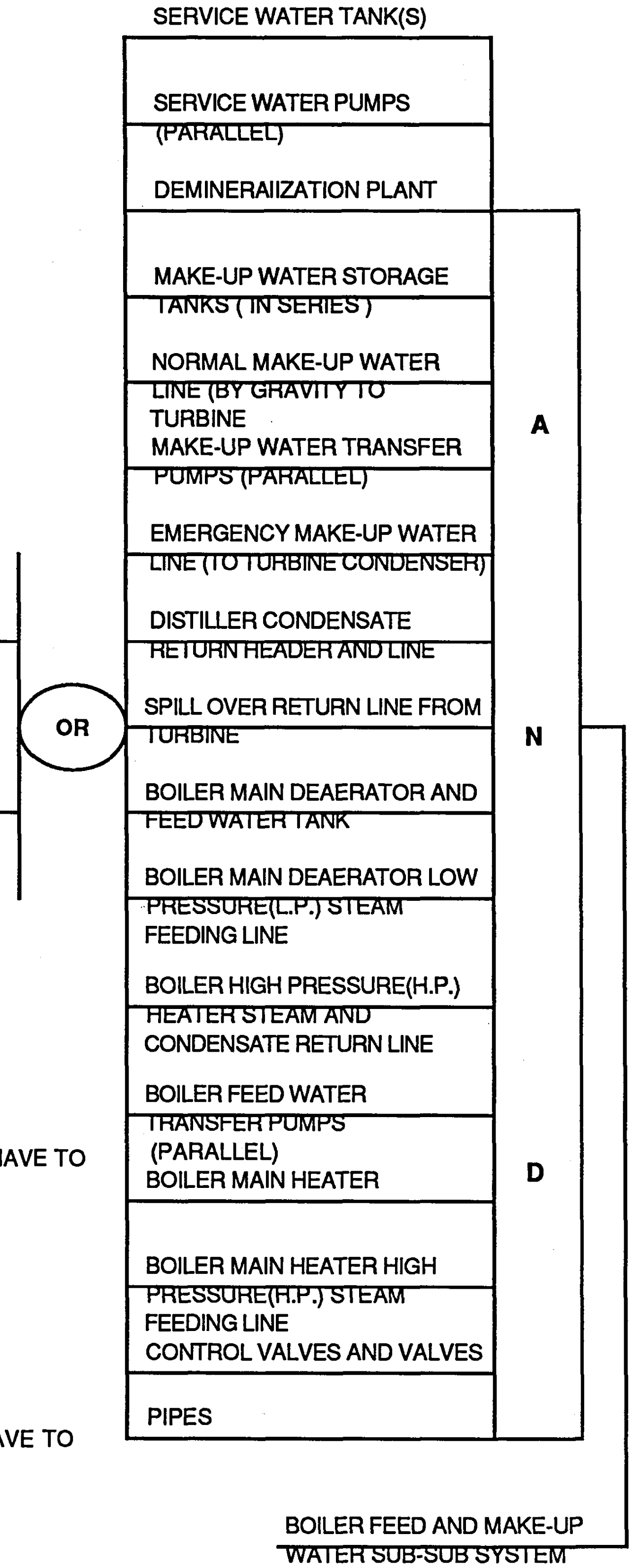


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPELETED FOR "D" TO WORK.

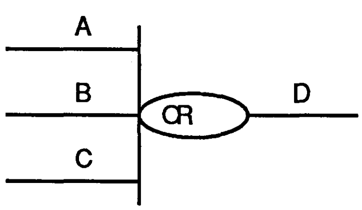
BOILER

SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

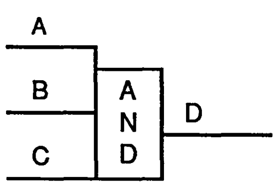
FIGURE NO 25



LOGIC SYMBOLS :



EITHER OPERATION "A" , "B" OR "C" HAVE TO BE COMPLETED FOR "C" TO WORK.

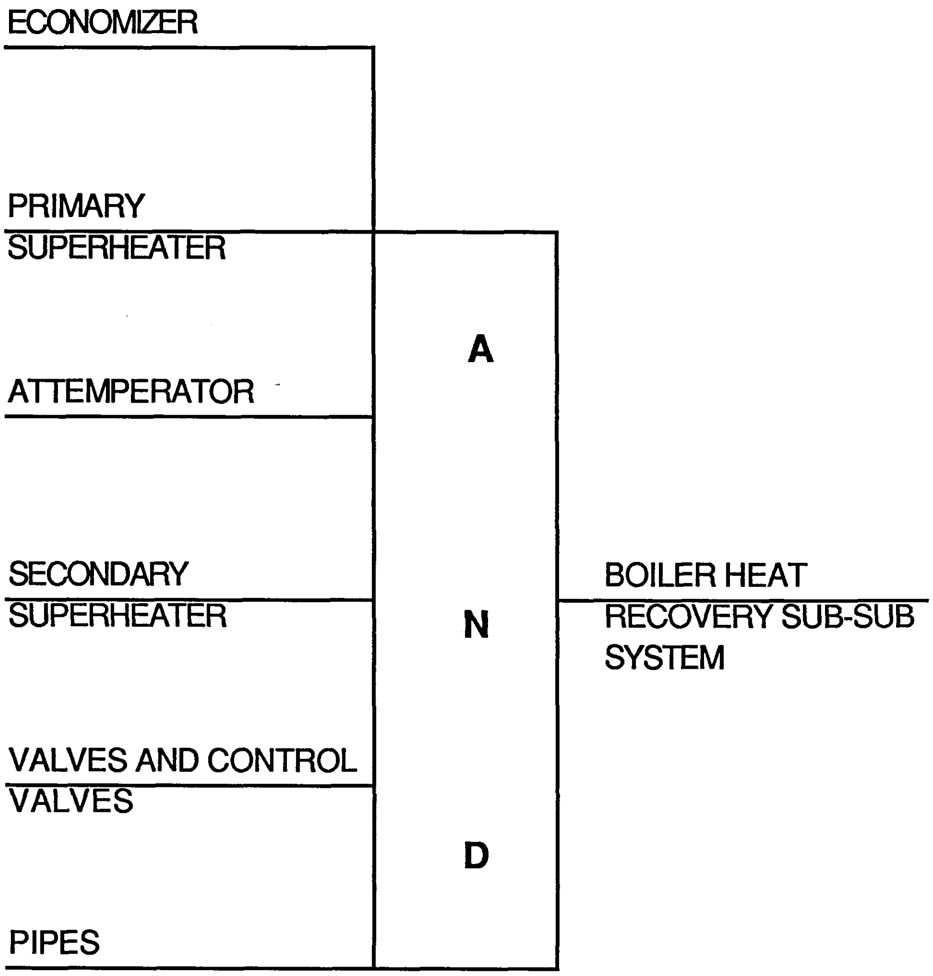


BOTH OPERATION "A","B",AND "C" HAVE TO COMPLETED FOR "D" TO WORK.

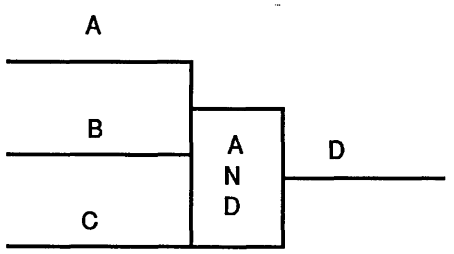
BOILER FEED AND MAKE-UP WATER

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 26



LOGIC SYMBOLS :

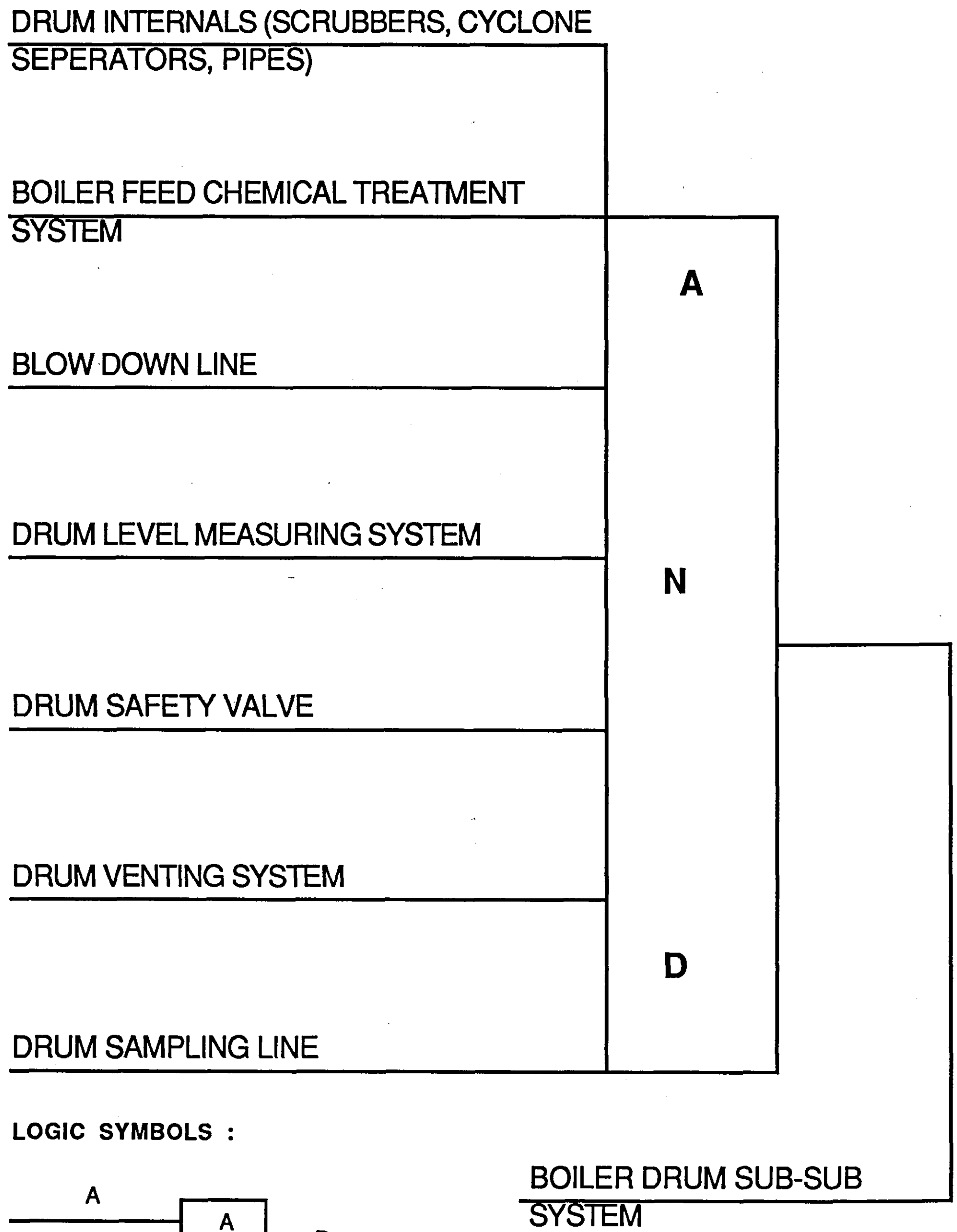


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR"D" TO WORK.

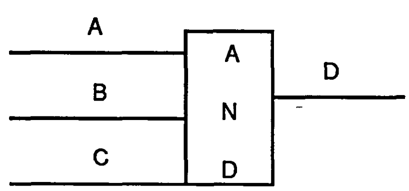
BOILER HEAT RECOVERY AREA

SUB-SUB SYSTEM OPERATIONAL INTERLOCK DIAGRAM

FIGURE NO 27



LOGIC SYMBOLS :

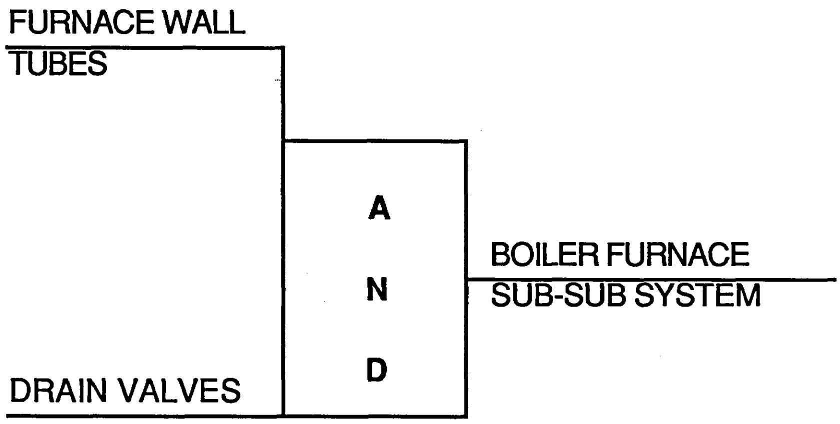


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

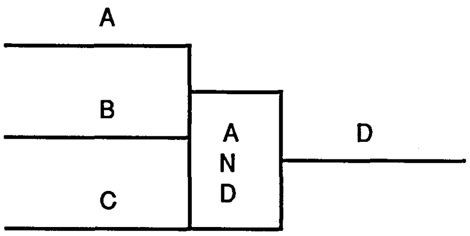
BOILER DRUM

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 28



LOGIC SYMBOLS :

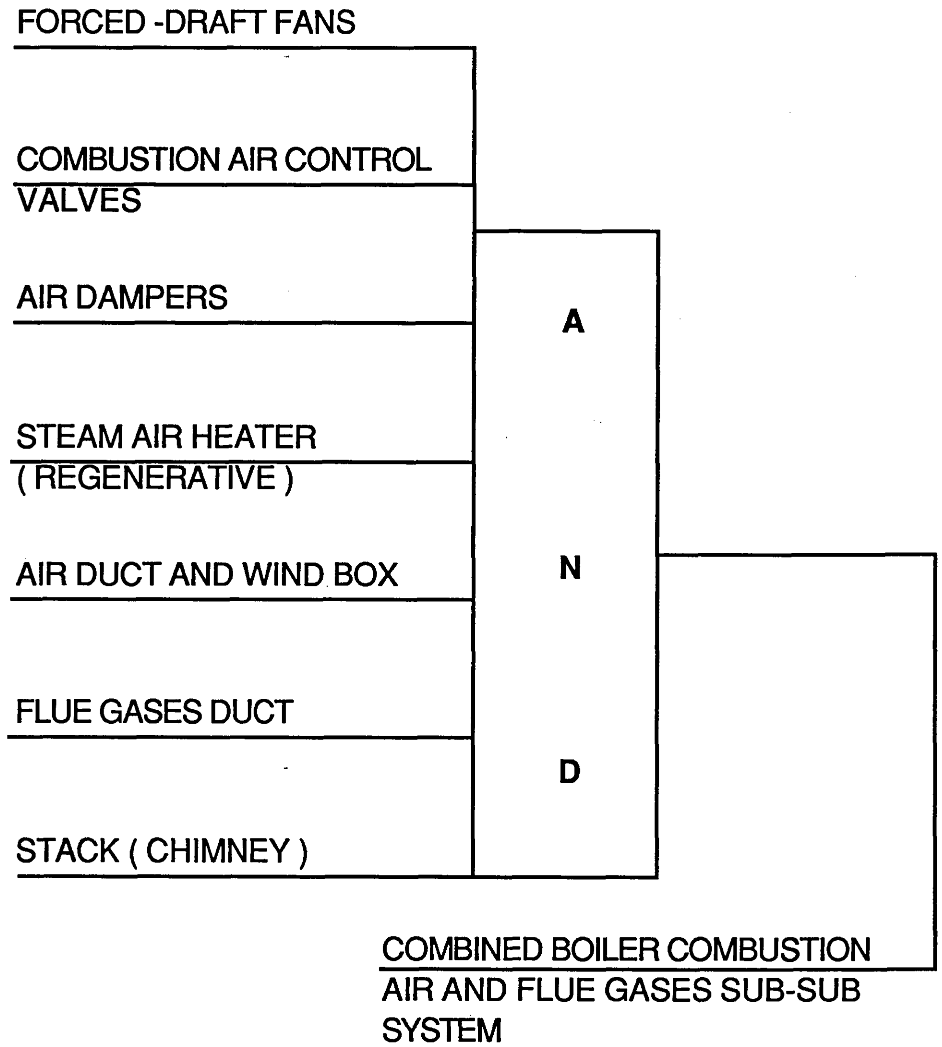


BOTH OPERATION OF "A", "B" AND "C" HAVE TO
BE COMPLETED FOR"D" TO WORK.

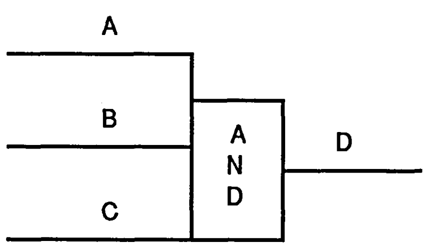
BOILER FURNACE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 29



LOGIC SYMBOLS :

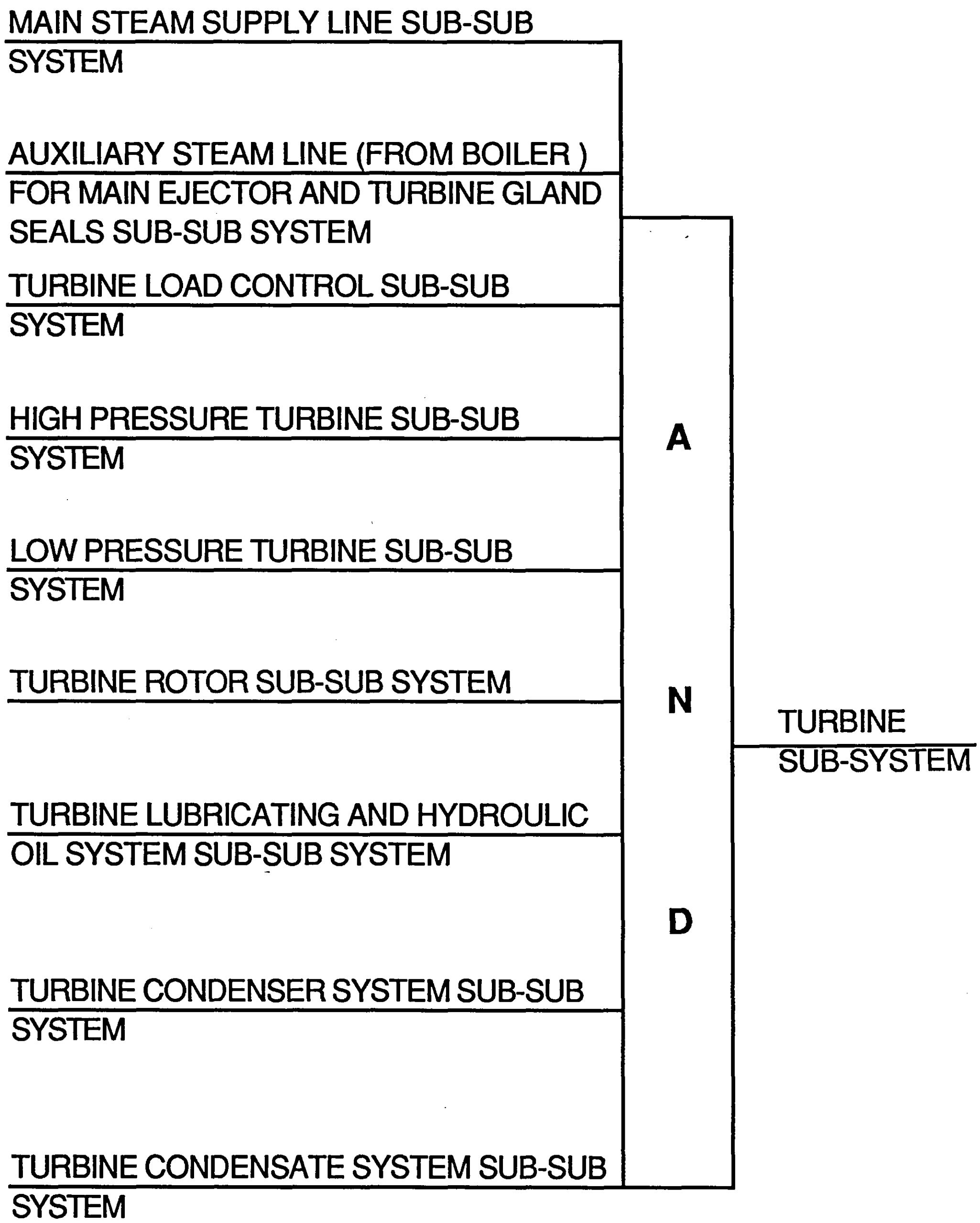


BOTH OPERATION OF "A", " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

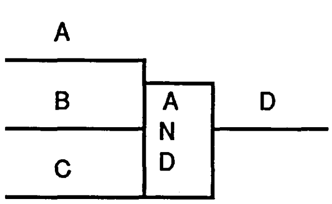
COMBINED BOILER COMBUSTION AIR AND FLUE GASES

SUB-SUB SYSTEMS OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 30



LOGIC SYMBOLS :

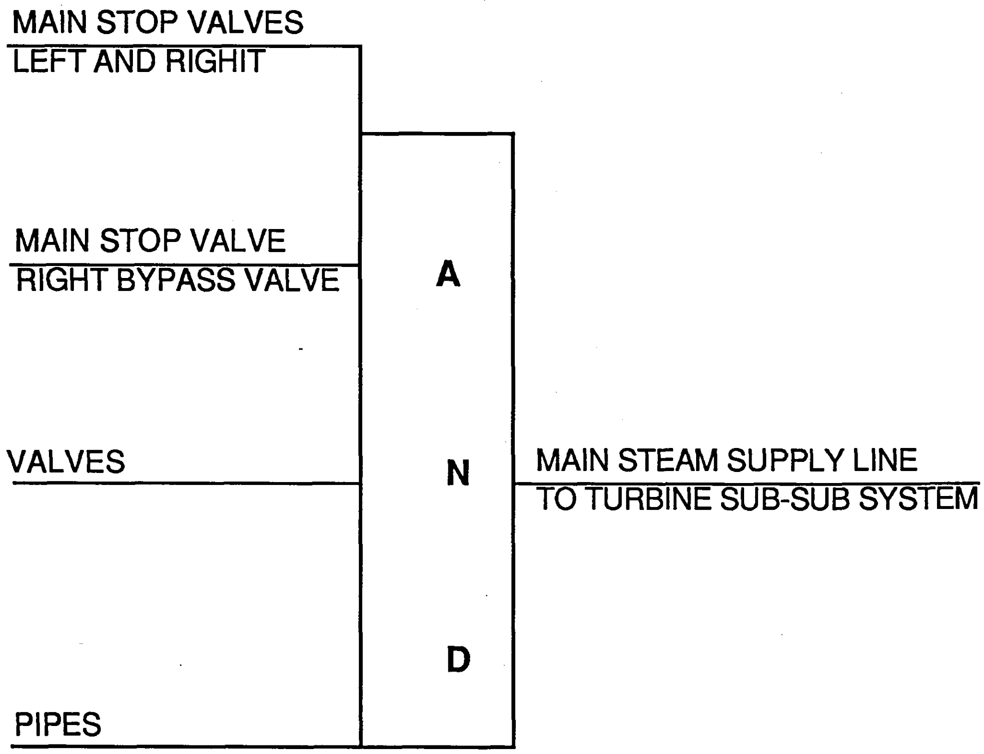


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO
BE COMPELETED FOR"D" TO WORK.

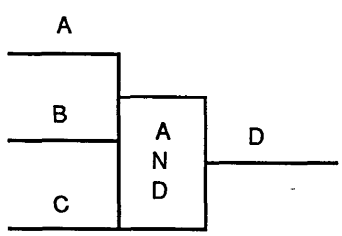
TURBINE

SUB-SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 31



LOGIC SYMBOLS :

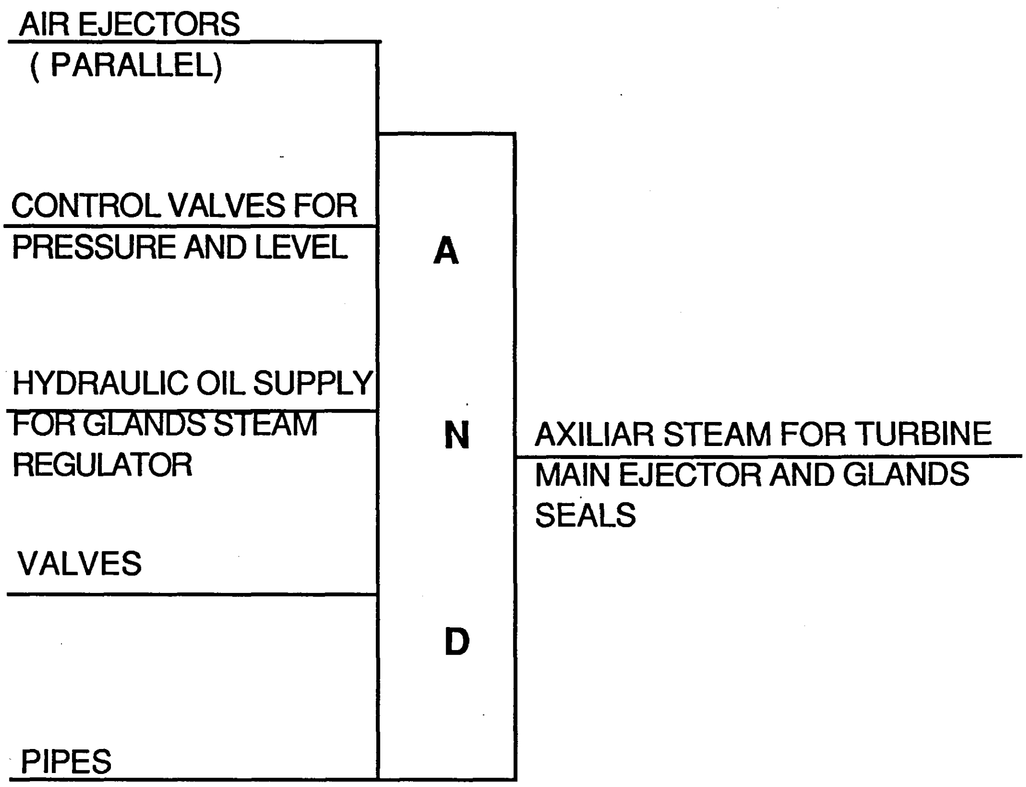


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR" D " TO WORK.

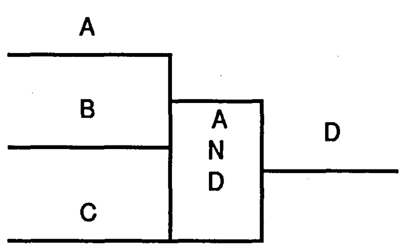
MAIN STEAM SUPPLY LINE TO TURBINE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 32



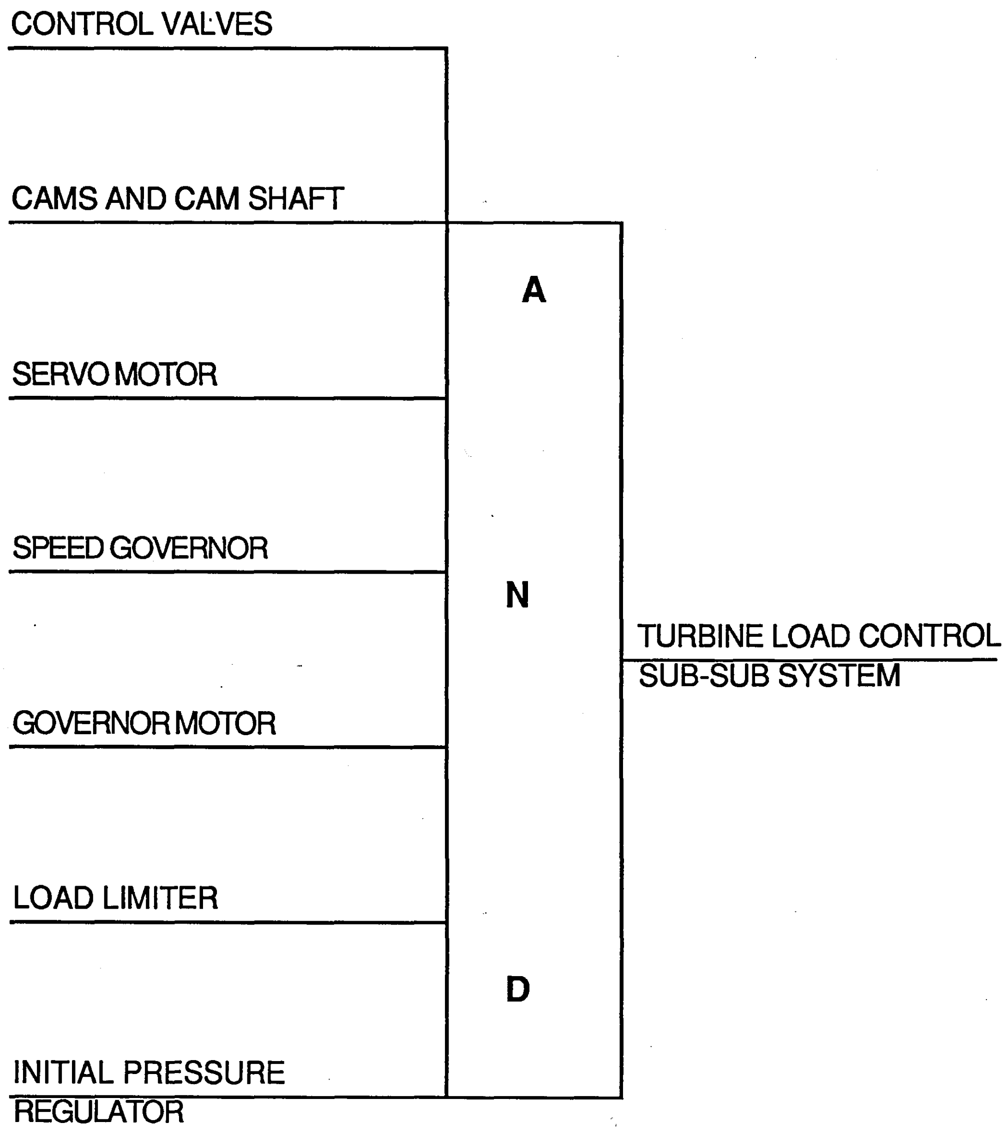
LOGIC SYMBOLS :



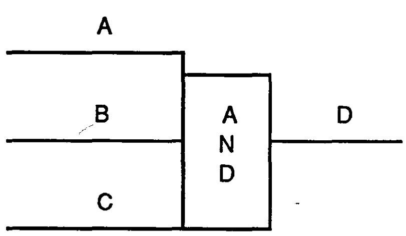
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR" D " TO WORK.

AXILIARY STEAM LINE (FROM BOILER) FOR TURBINE MAIN AIR EJECTOR AND GLAND SEALS SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAG

FIGURE NO 33



LOGIC SYMBOLS :

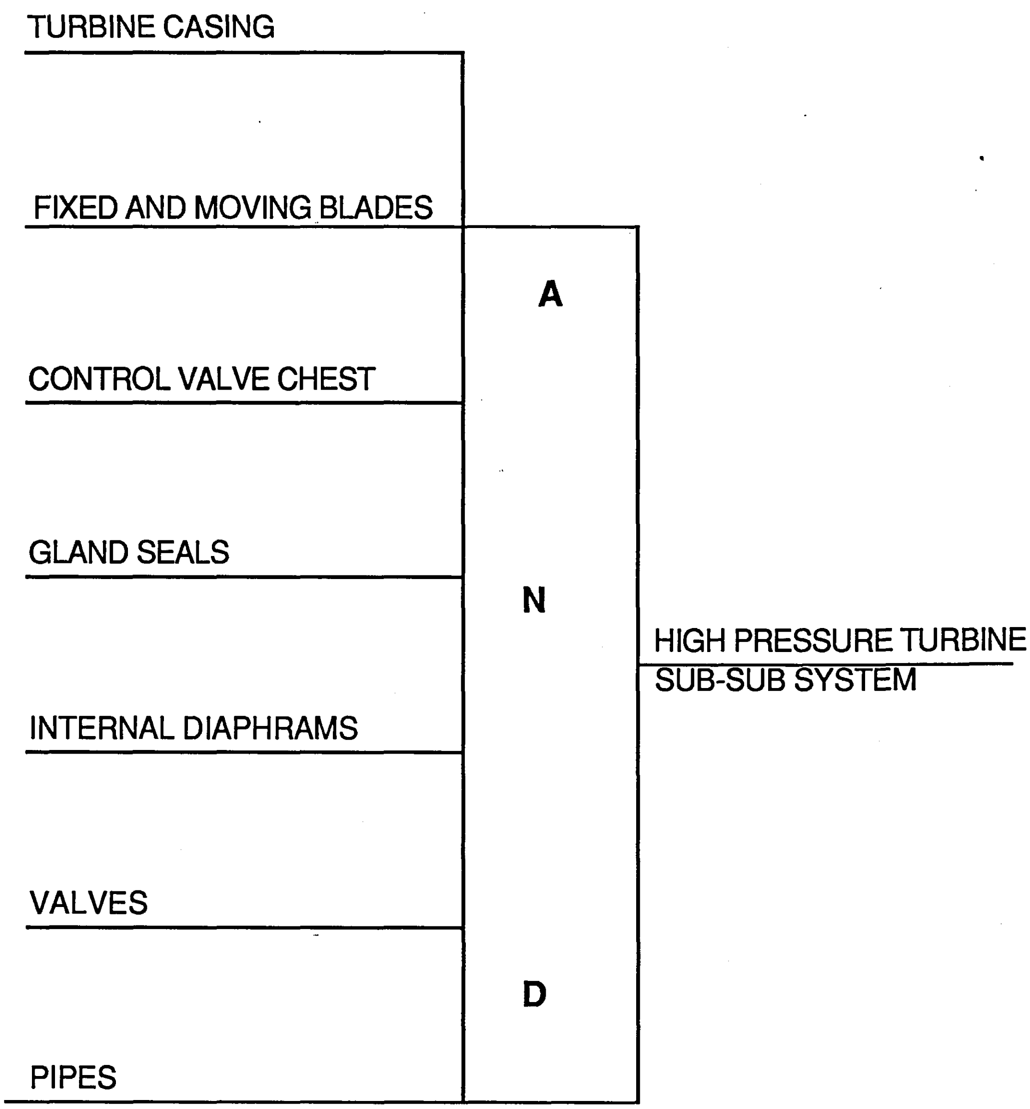


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED BEFORE "D" BEGINES.

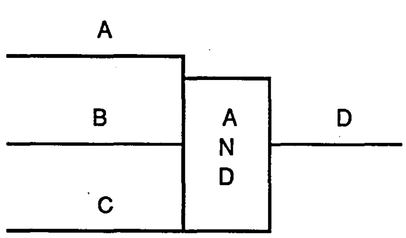
TURBINE LOAD CONTROL

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 34



LOGIC SYMBOLS :

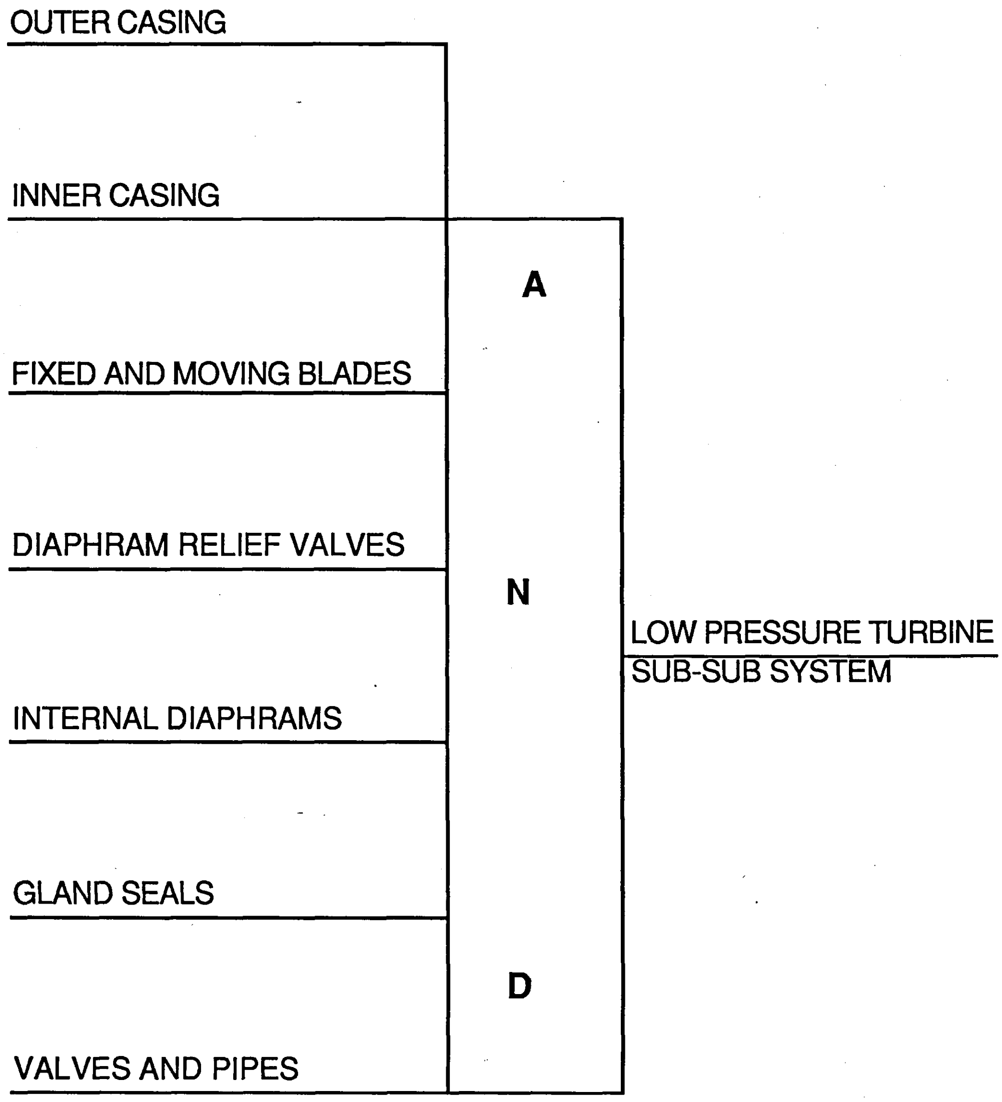


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

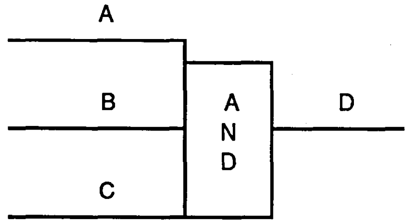
HIGH PRESSURE TURBINE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 35



LOGIC SYMBOLS :

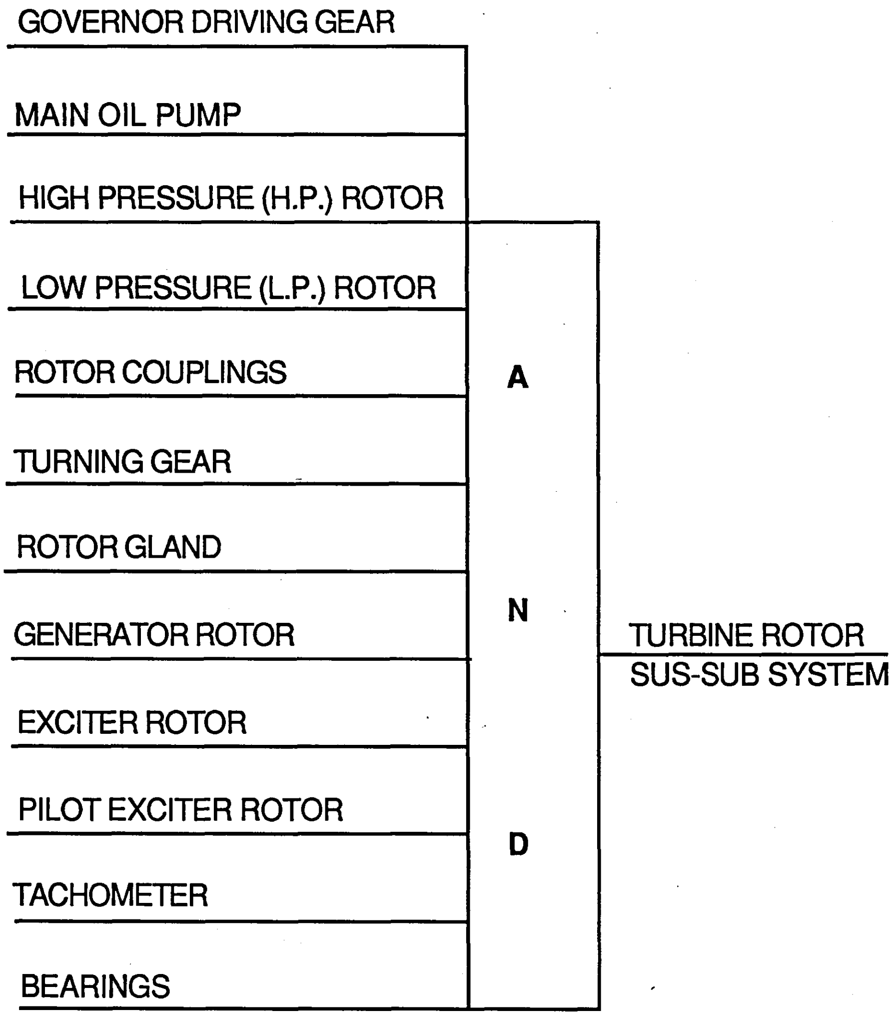


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

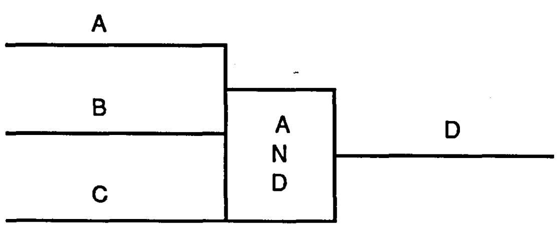
LOW PRESSURE TURBINE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 36



LOGIC SYMBOLS :

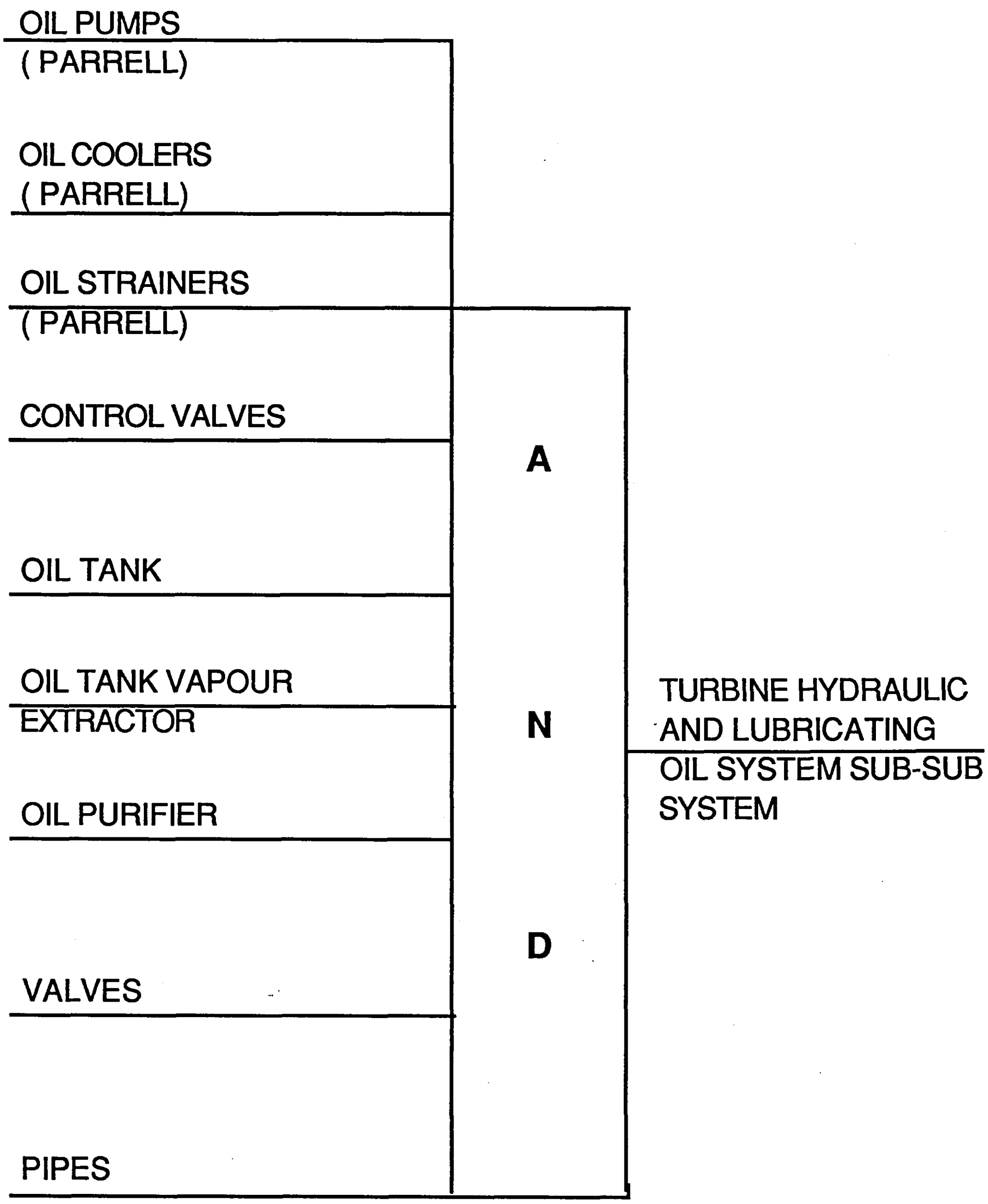


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

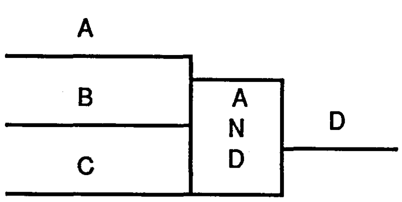
TURBINE ROTOR

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 37



LOGIC SYMBOLS :

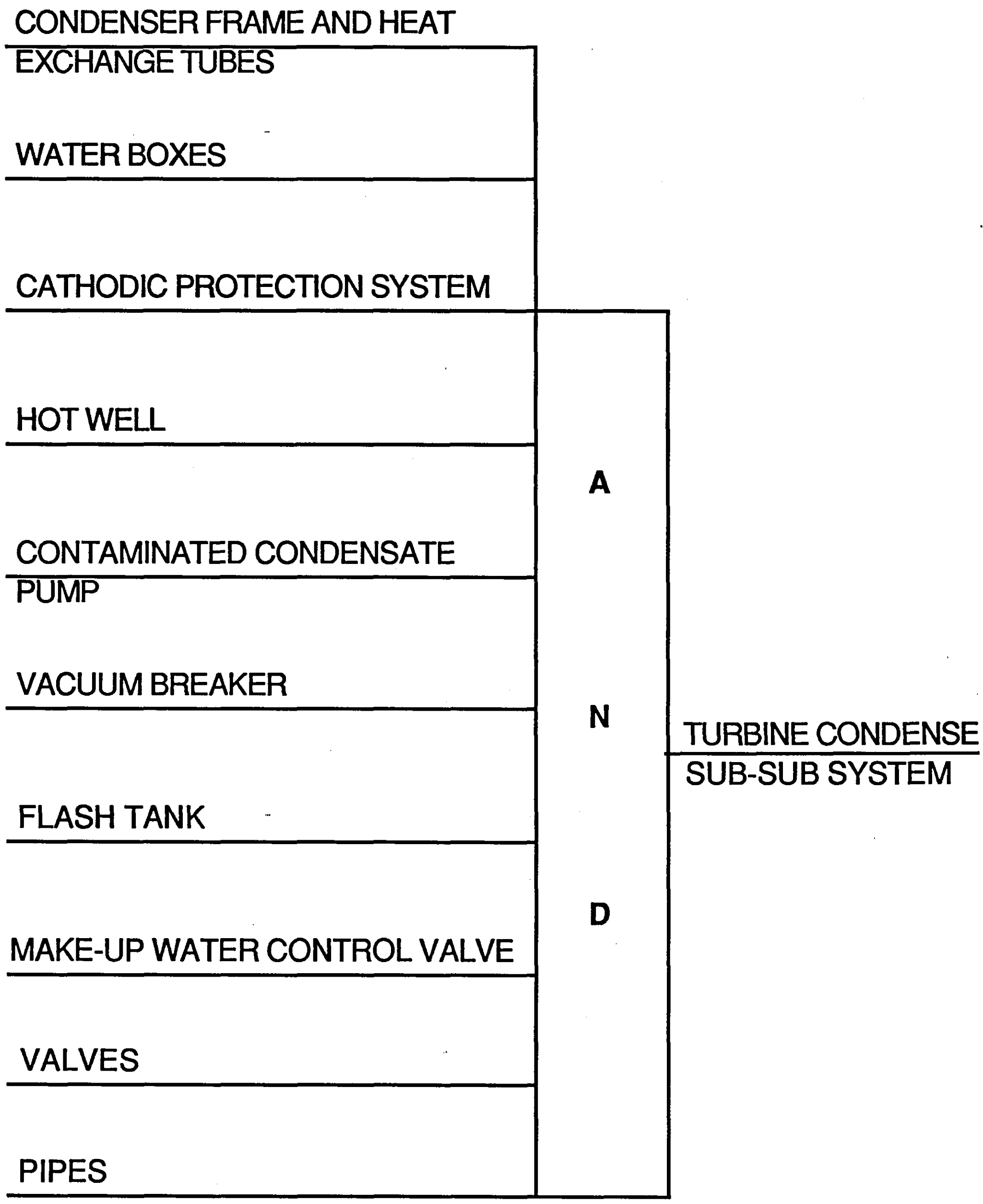


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPELETED FOR "D" TO WORK.

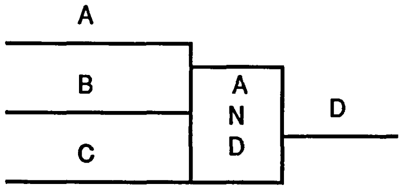
TURBINE HYDRAULIC AND LUBRICATING OIL SYSTEM

SUB- SUB SYSTEMS OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 38



LOGIC SYMBOLS :

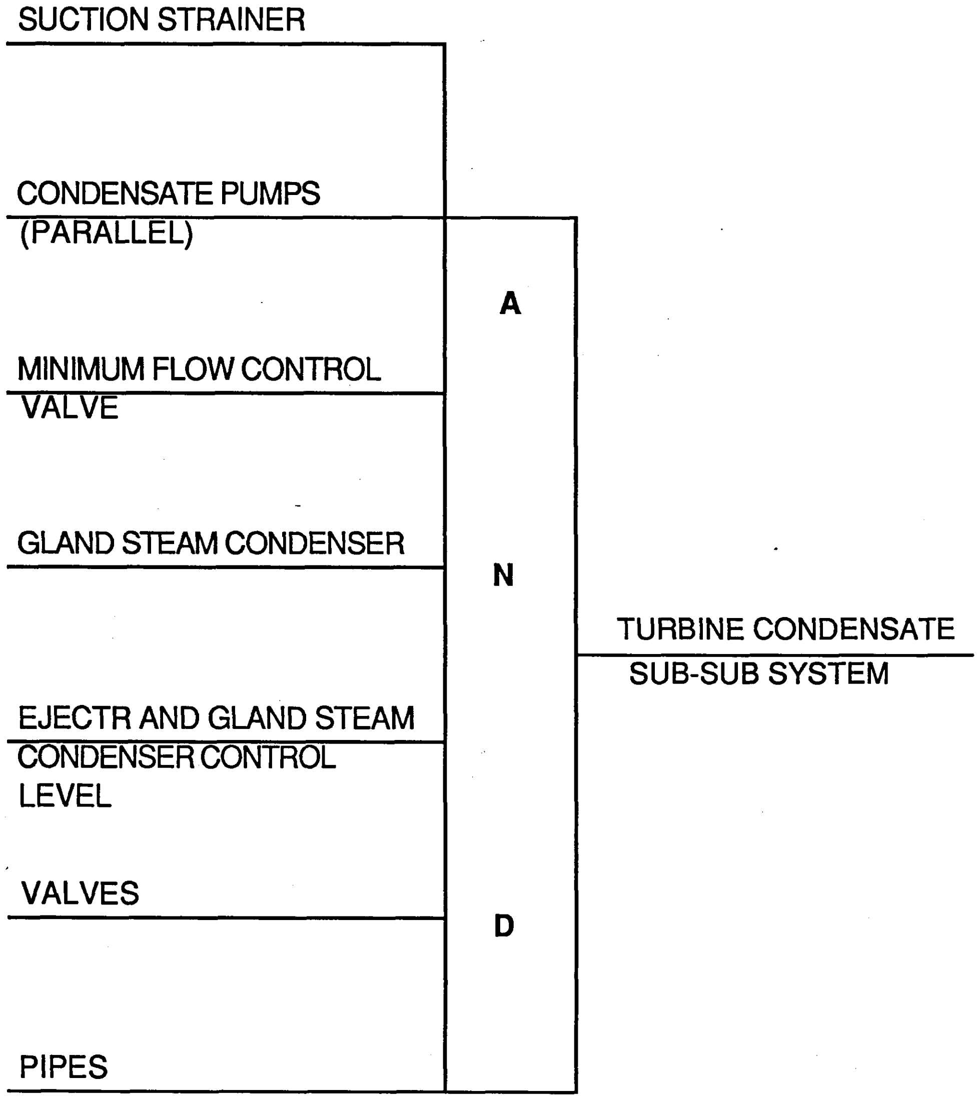


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPELETED FOR "D" TO WORK.

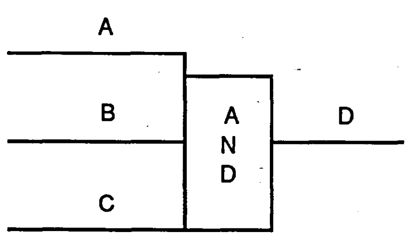
TURBINE CONDENSER

SUB SUB-SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 39



LOGIC SYMBOLS :

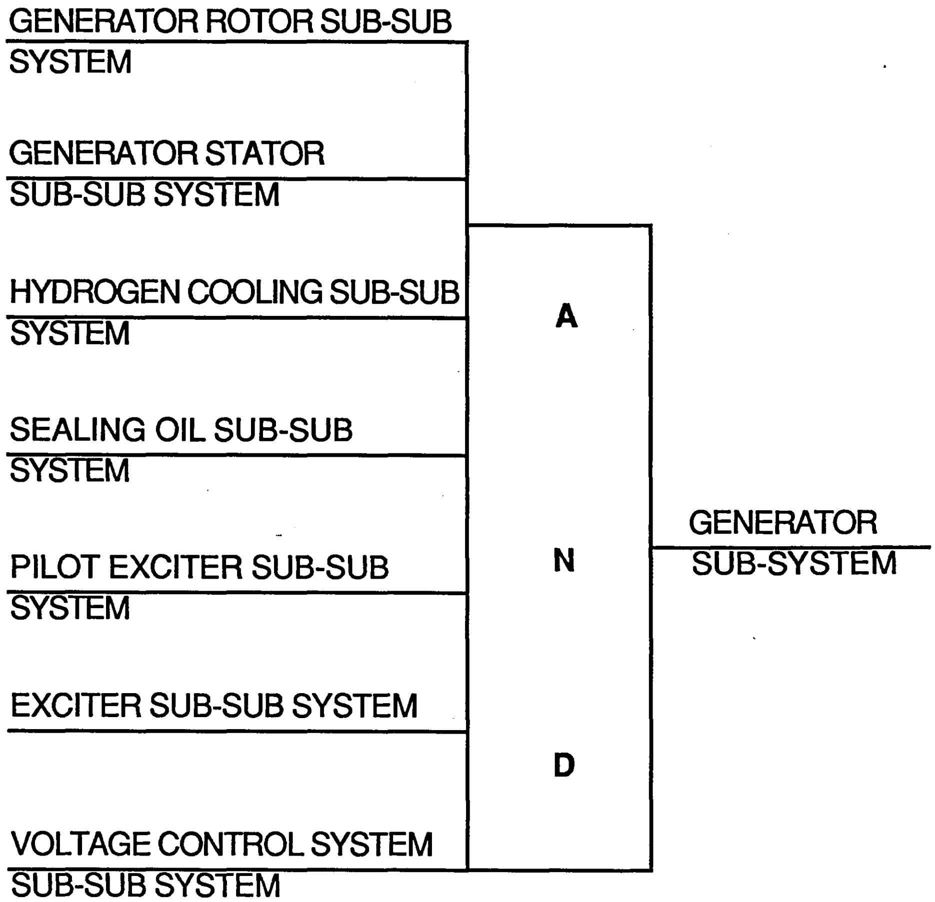


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

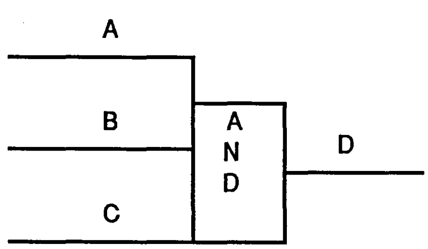
TURBINE CONDENSATE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 40



LOGIC SYMBOLS :

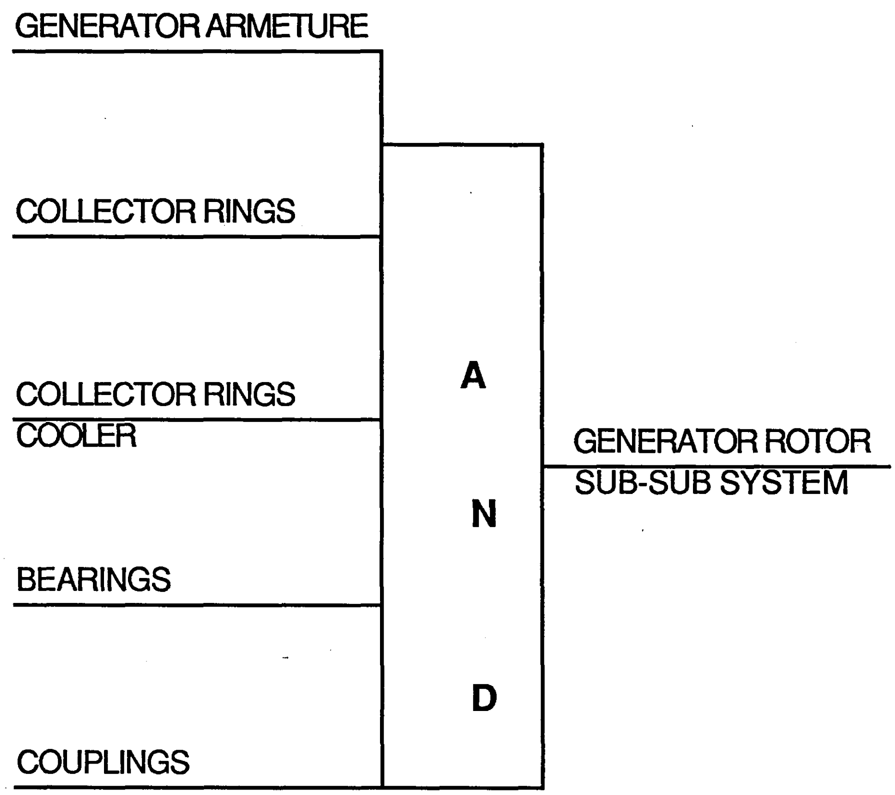


BOTH OPERATION OF "A", " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

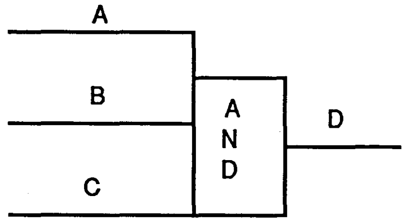
GENERATOR

SUB-SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 41



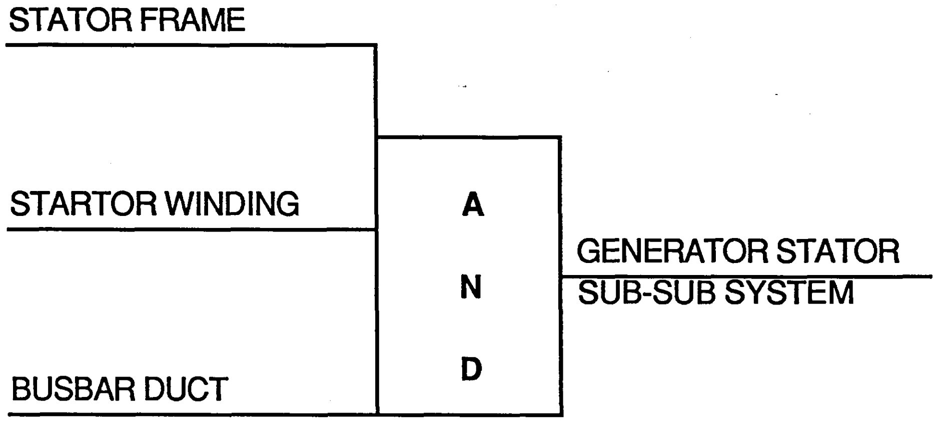
LOGIC SYMBOLS :



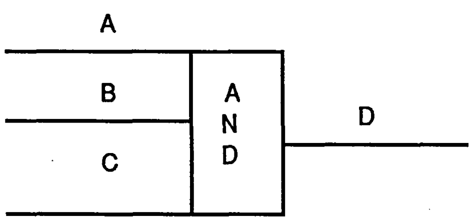
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

GENERATOR ROTOR
SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAI

FIGURE NO 42



LOGIC SYMBOLS :

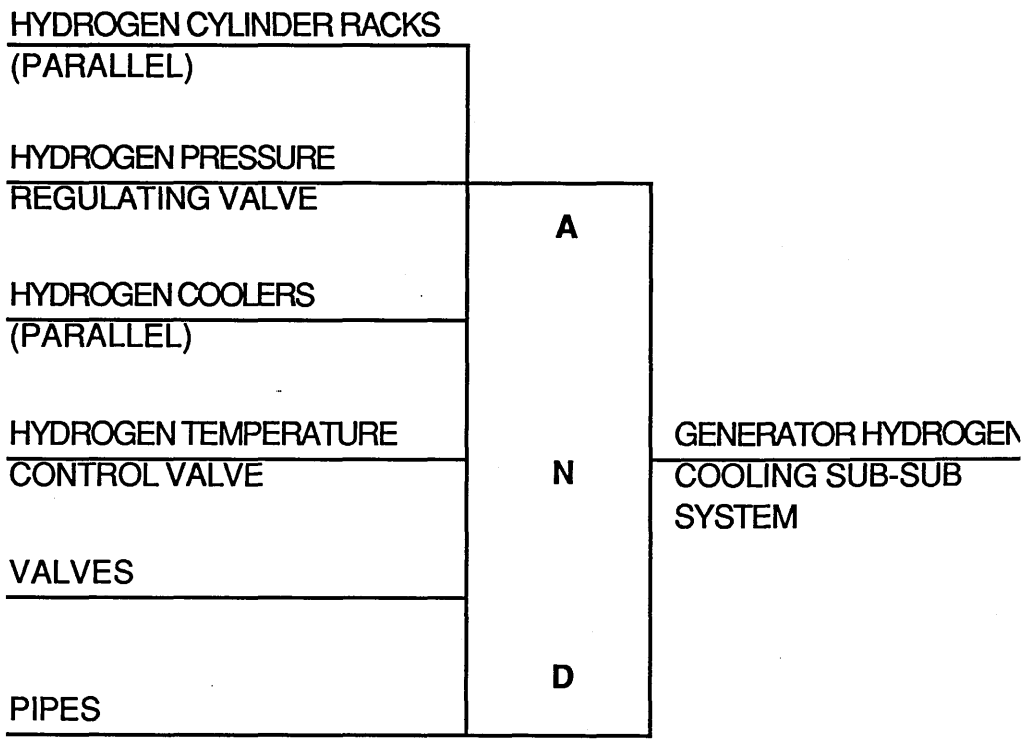


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

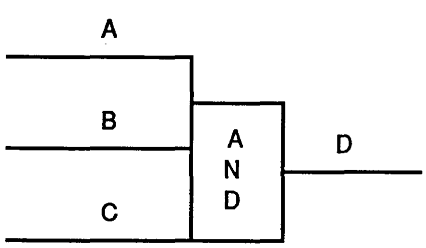
GENERATOR STATOR

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAI

FIGURE NO 43



LOGIC SYMBOLS :

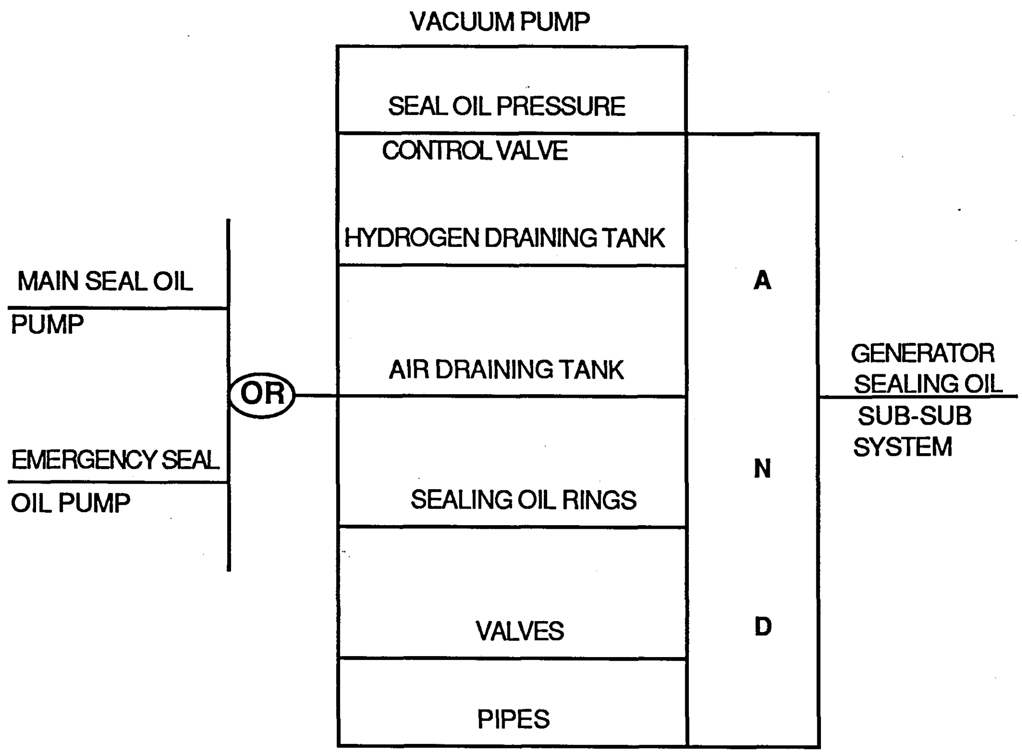


BOTH OPERATION OF "A", " B " AND " C " HAVE TO
BE COMPLETED FOR " D " TO WORK.

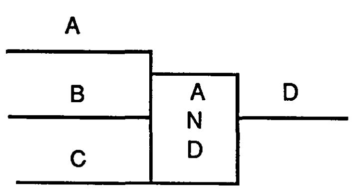
GENERATOR HYDROGEN COOLING

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRA

FIGURE NO 44



LOGIC SYMBOLS :

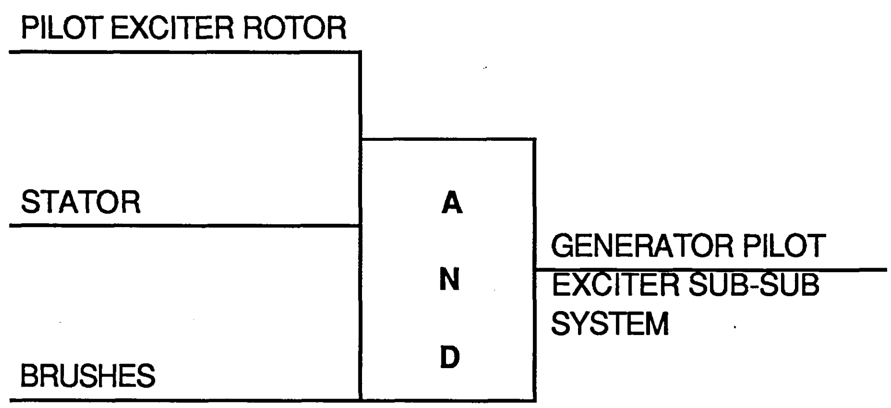


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPELETED FOR " D" TO WORK.

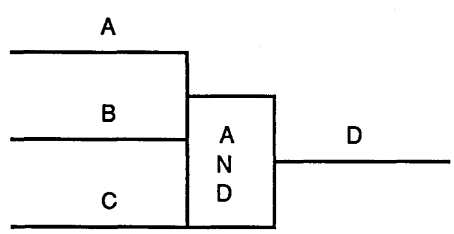
GENERATOR SEALING OIL

SUB SUB-SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 45



LOGIC SYMBOLS :

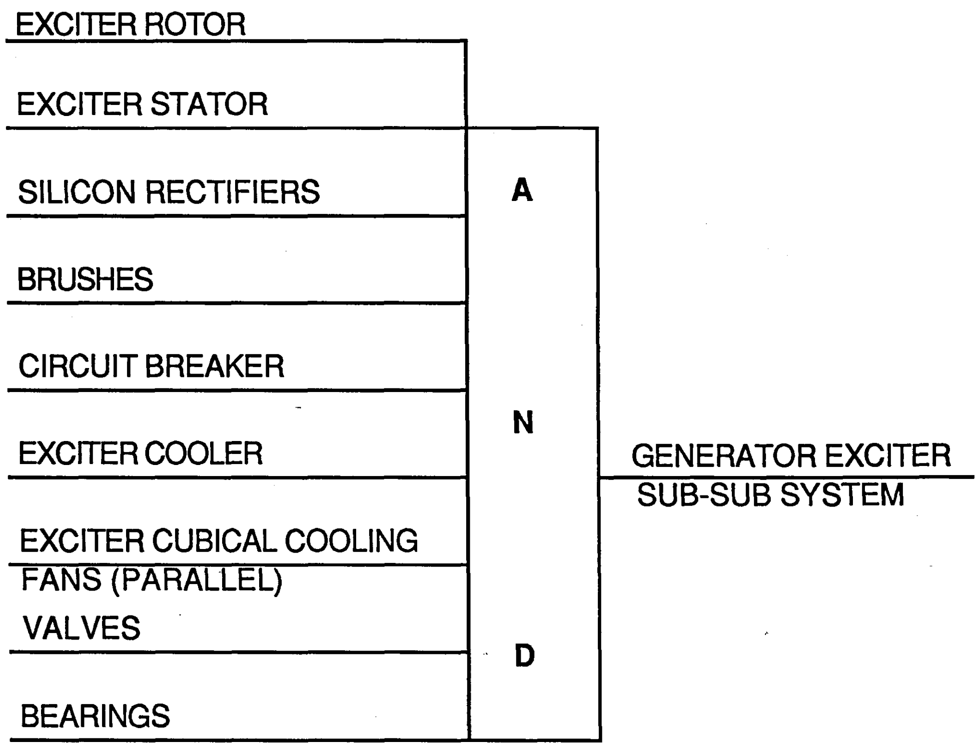


BOTH OPERATION OF "A", "B" AND "C" HAVE TO
BE COMPLETED FOR " D" TO WORK.

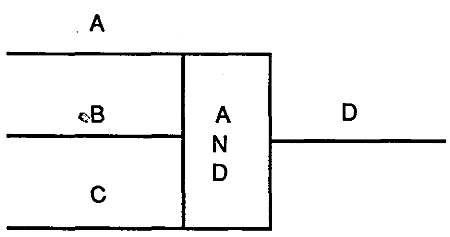
GENERATOR PILOT EXCITER

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 46



LOGIC SYMBOLS :

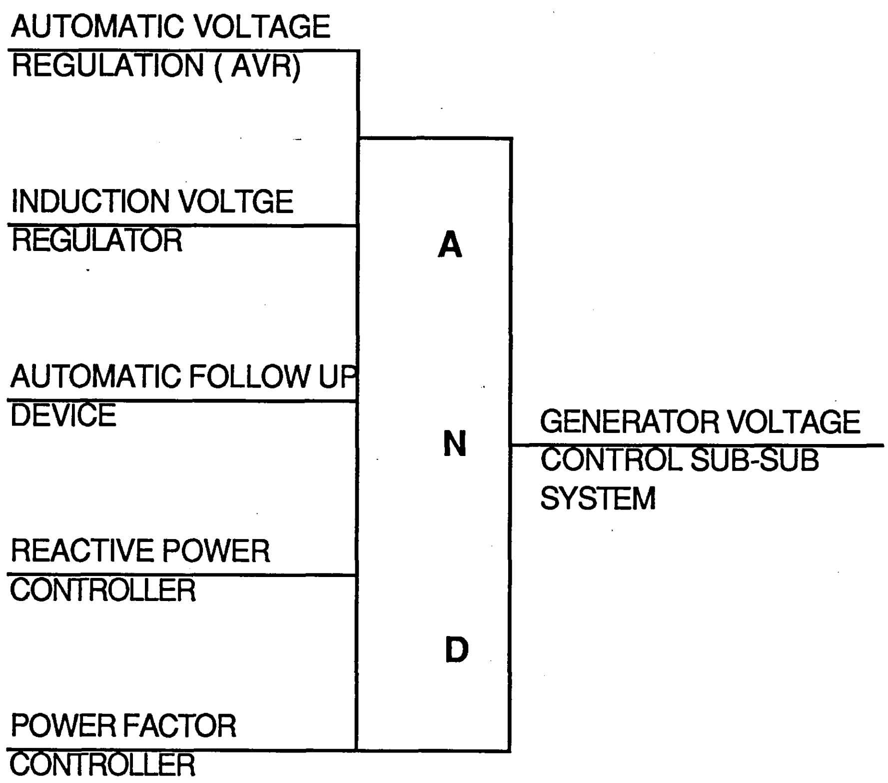


BOTH OPERATION OF "A", "B" AND "C" HAVE TO BE COMPLETED FOR " D" TO WORK.

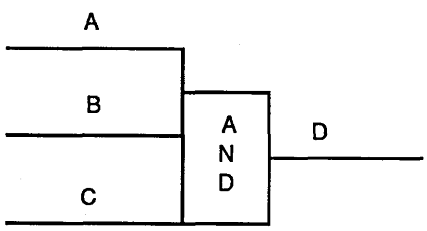
GENERATOR EXCITER

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 47



LOGIC SYMBOLS :

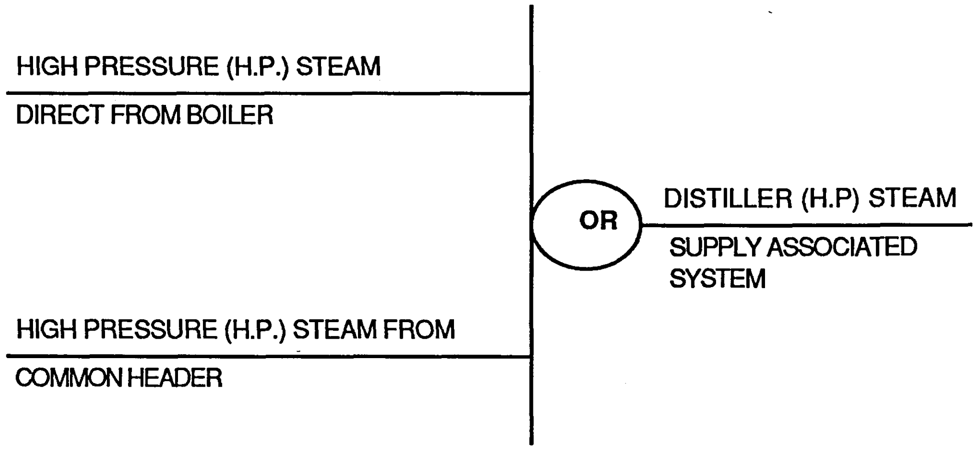


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

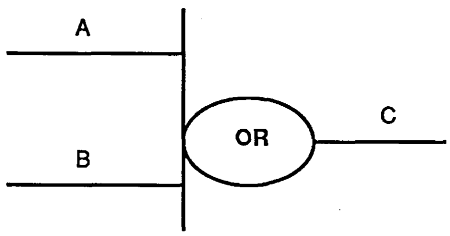
GENERATOR VOLTAGE CONTROL

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 48



LOGIC SYMBOLS :

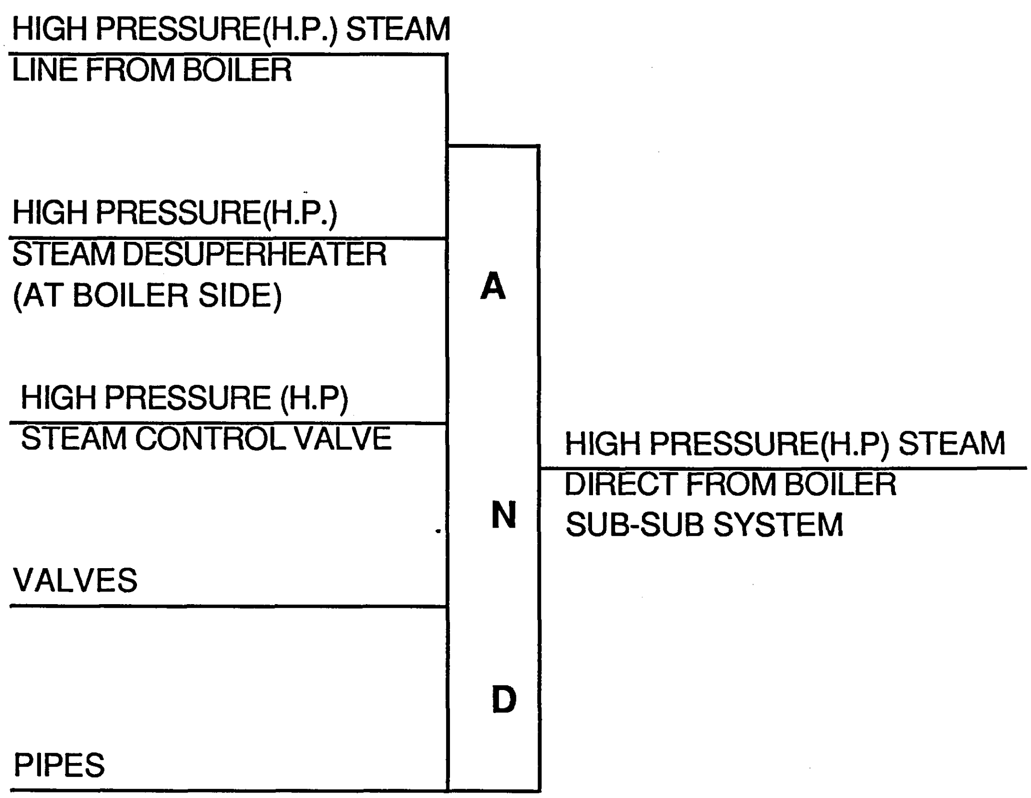


EITHER OPERATION "A" OR "B" HAVE TO BE
COMPLETED FOR " C" TO WORK.

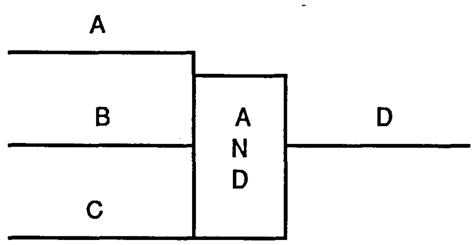
DISTILLER HIGH PRESSURE (H.P.) STEAM SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 49



LOGIC SYMBOLS :

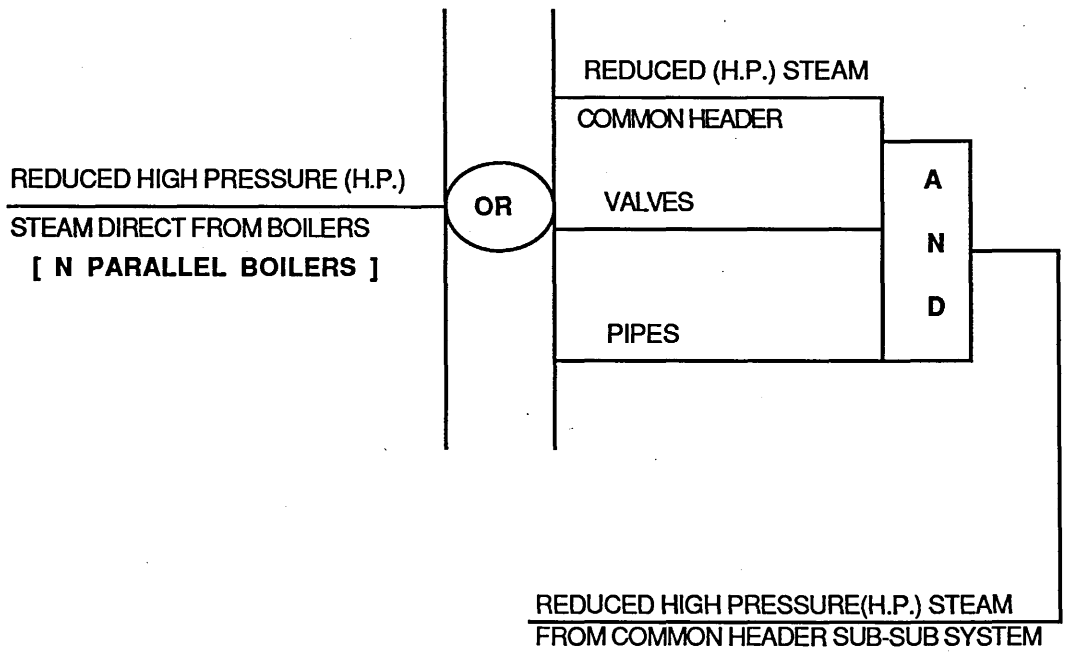


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

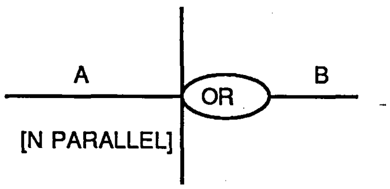
HIGH PRESSURE(H.P.) STEAM DIRECT FROM BOILER

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

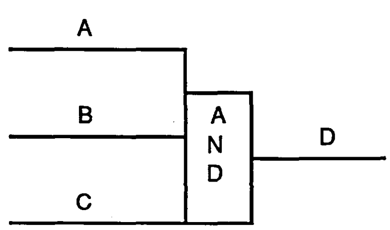
FIGURE NO 50



LOGIC SYMBOLS :



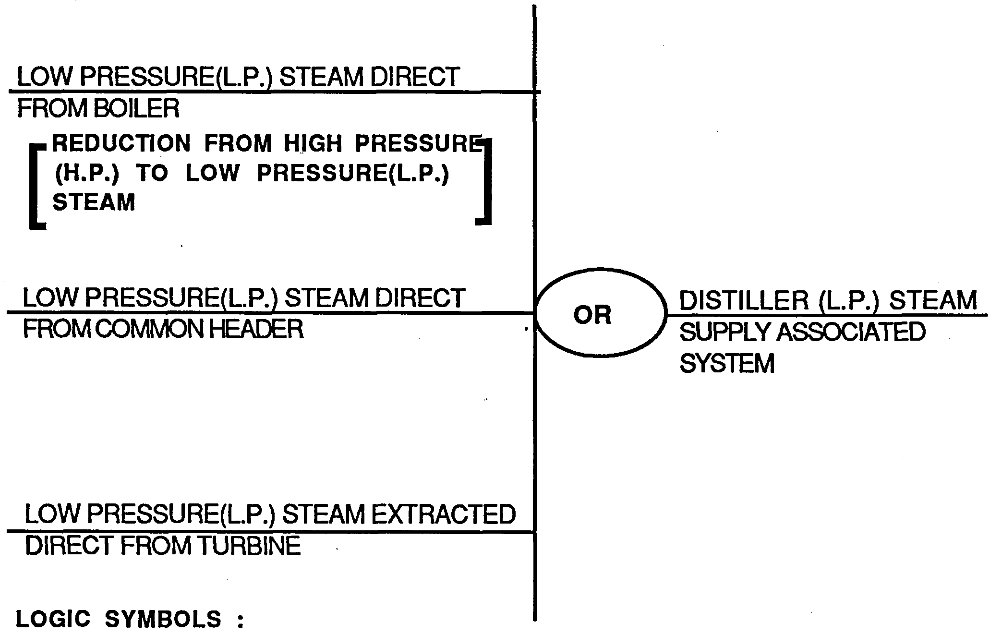
EITHER OPERATION OF ANY OF THE N'S "A"
HAVE TO BE COMPLETED FOR " B " TO WORK.



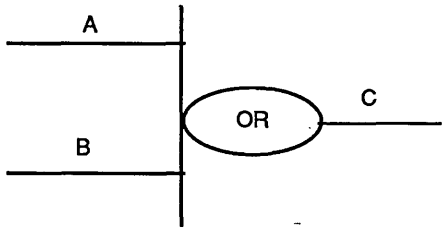
BOTH OPERATION OF 'A' ,"B" AND "C"
HAVE TO BE COMPLETED FOR " D"
TO WORK.

REDUCED HIGH PRESSURE(H.P.) STEAM FROM COMMON HEADER SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 51



LOGIC SYMBOLS :

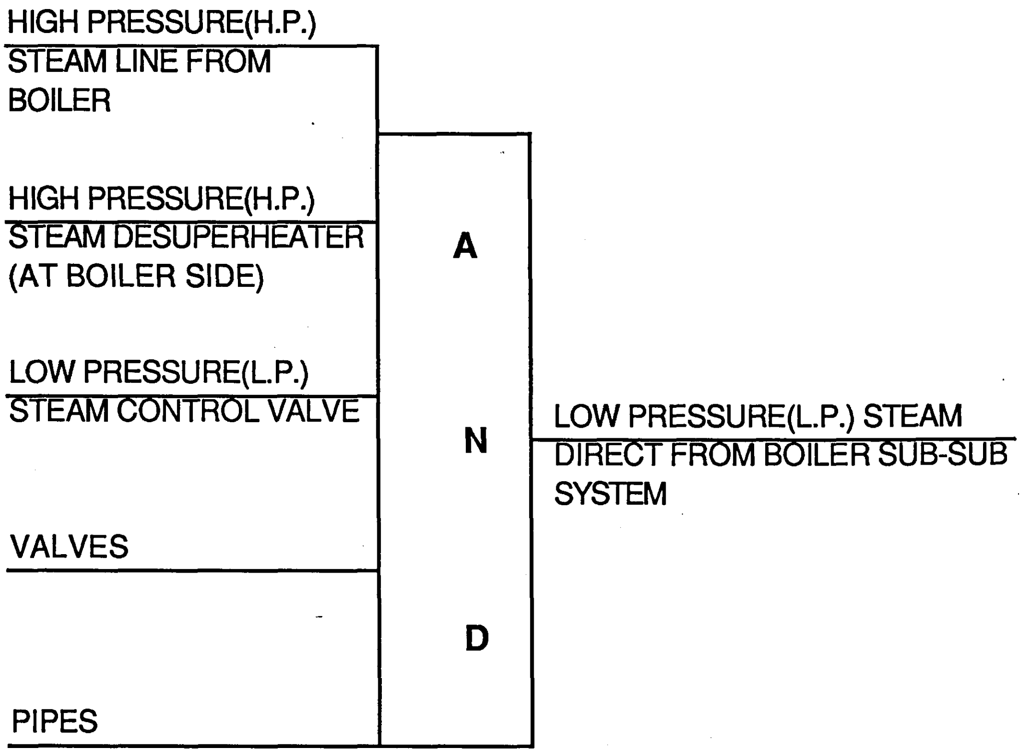


EITHER OPERATION "A" OR "B" HAVE TO BE COMPLETED FOR "C" TO WORK.

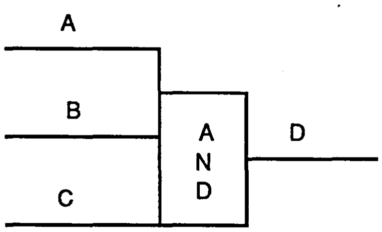
DISTILLER LOW PRESSURE (L.P.) STEAM SUPPLY

ASSOCIATED SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 52



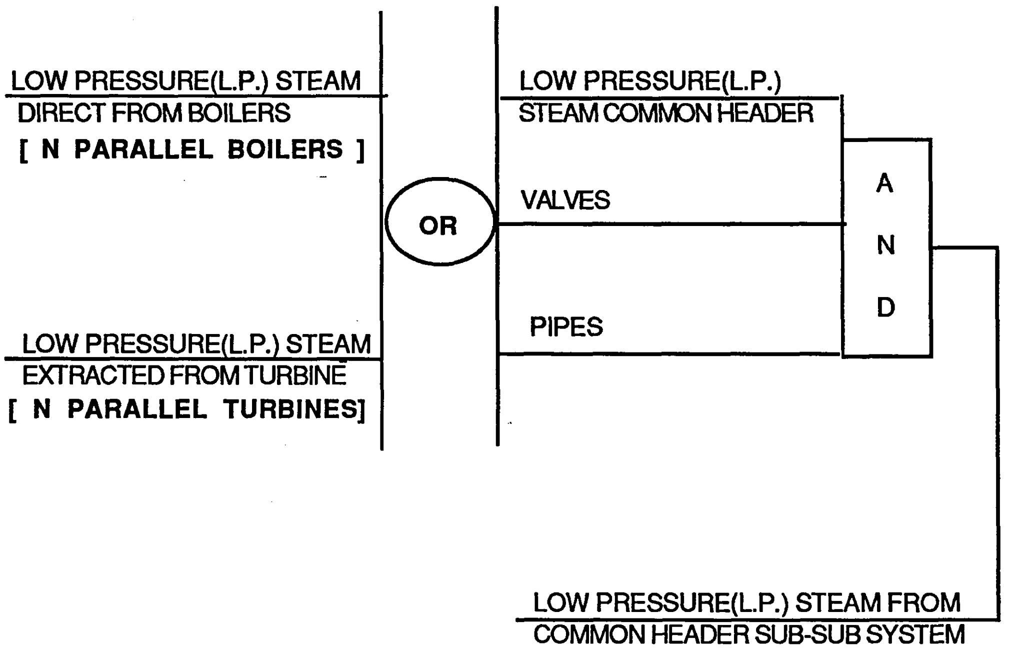
LOGIC SYMBOLS :



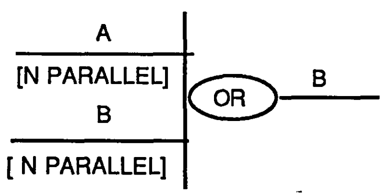
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

LOW PRESSURE(L.P.) STEAM DIRECT FROM BOILER SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

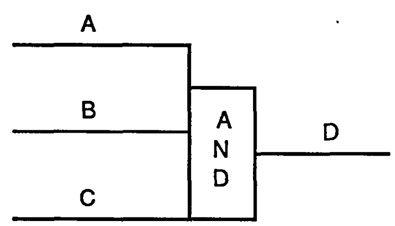
FIGURE NO 53



LOGIC SYMBOLS :



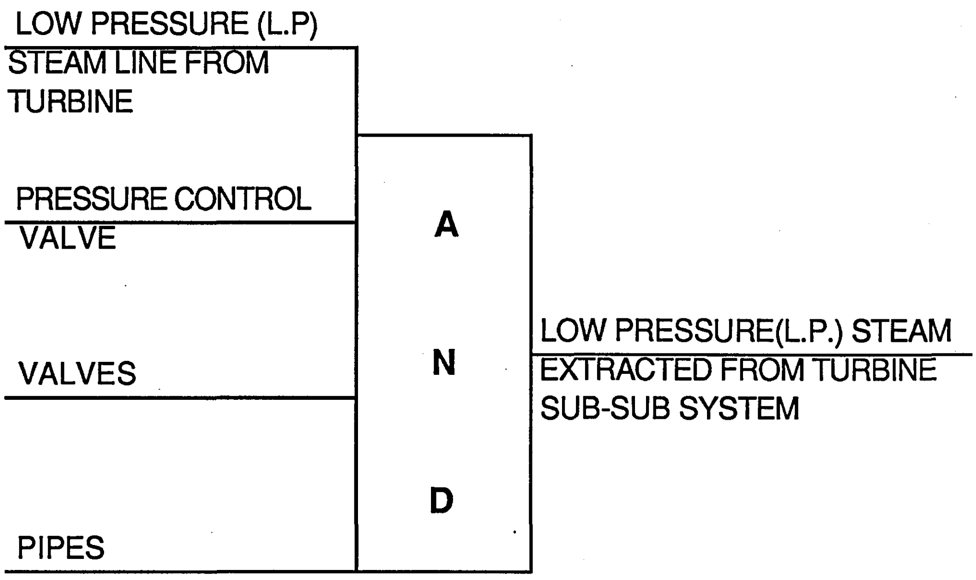
EITHER OPERATION OF ANY OF THE N'S 'A'
HAVE TO BE COMPLETED FOR 'B' TO WORK.



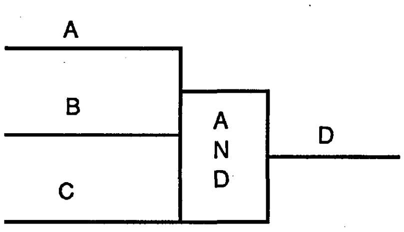
BOTH OPERATION OF 'A' ,"B" AND "C"
HAVE TO BE COMPLETED FOR "D" TO
WORK.

LOW PRESSURE(L.P.) STEAM FROM COMMON HEADER SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 54



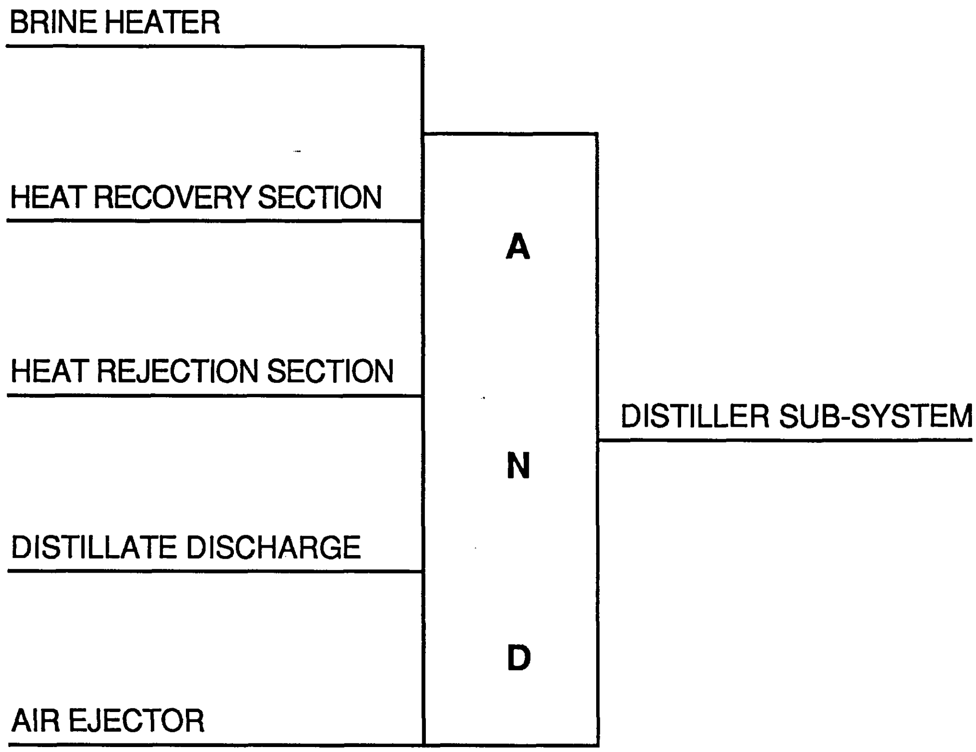
LOGIC SYMBOLS :



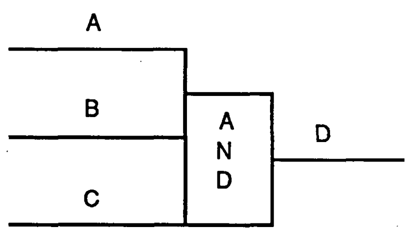
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE
COMPLETED FOR" D " TO WORK,

LOW PRESSURE(L.P.) STEAM EXTRACTED FORM TURBINE SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 55



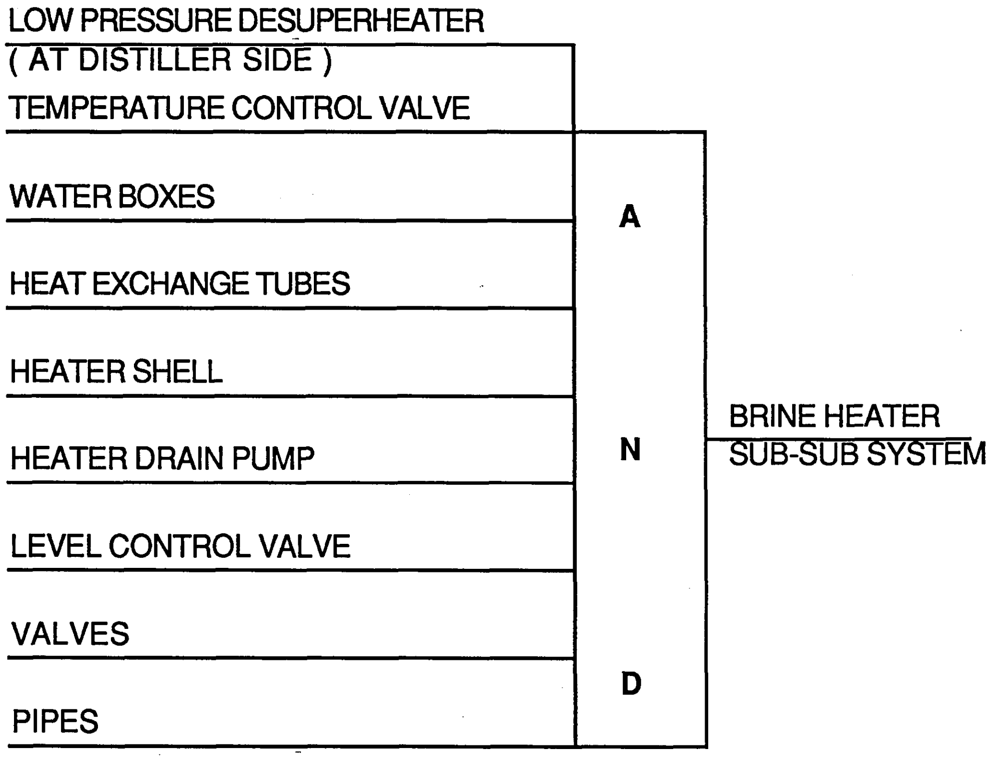
LOGIC SYMBOLS :



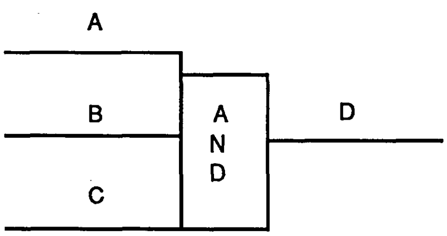
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

DISTILLER
SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 56



LOGIC SYMBOLS :

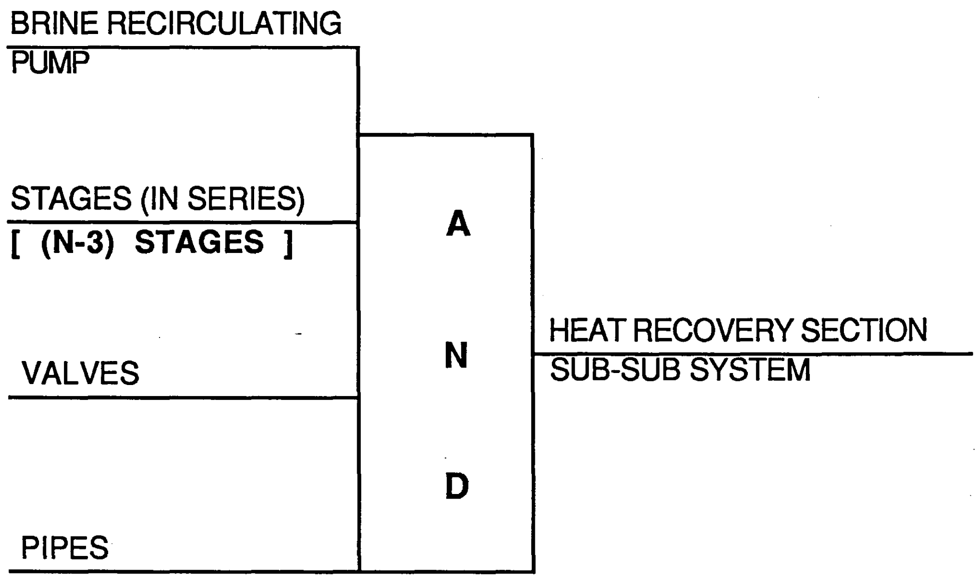


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

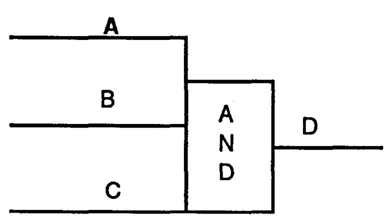
DISTILLER BRINE HEATER

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 57



LOGIC SYMBOLS :



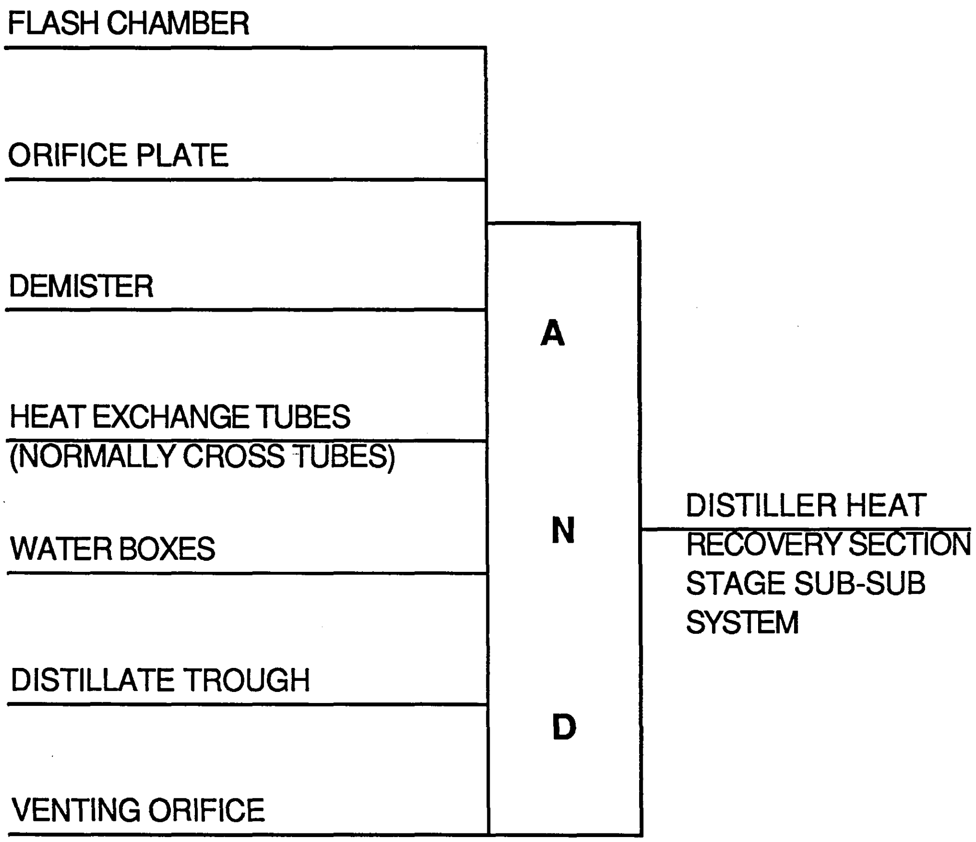
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

NOTE : THE NUMBER OF THE STAGES IN THE HEAT RECOVERY SECTION ARE NORMALLY EQUAL TO TOTAL NUMBER OF STAGES LESS THREE.

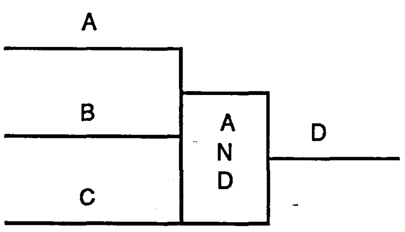
DISTILLER HEAT RECOVERY SECTION

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 58



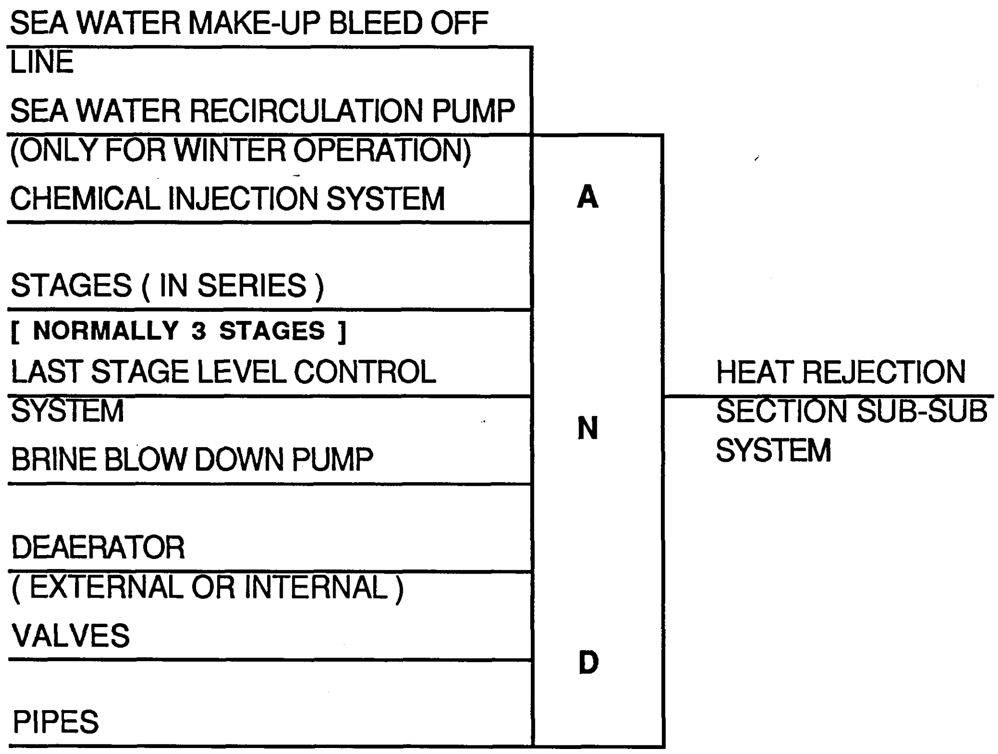
LOGIC SYMBOLS :



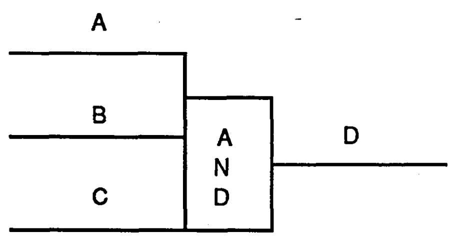
BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

DISTILLER HEAT RECOVERY SECTION STAGE SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 59



LOGIC SYMBOLS :

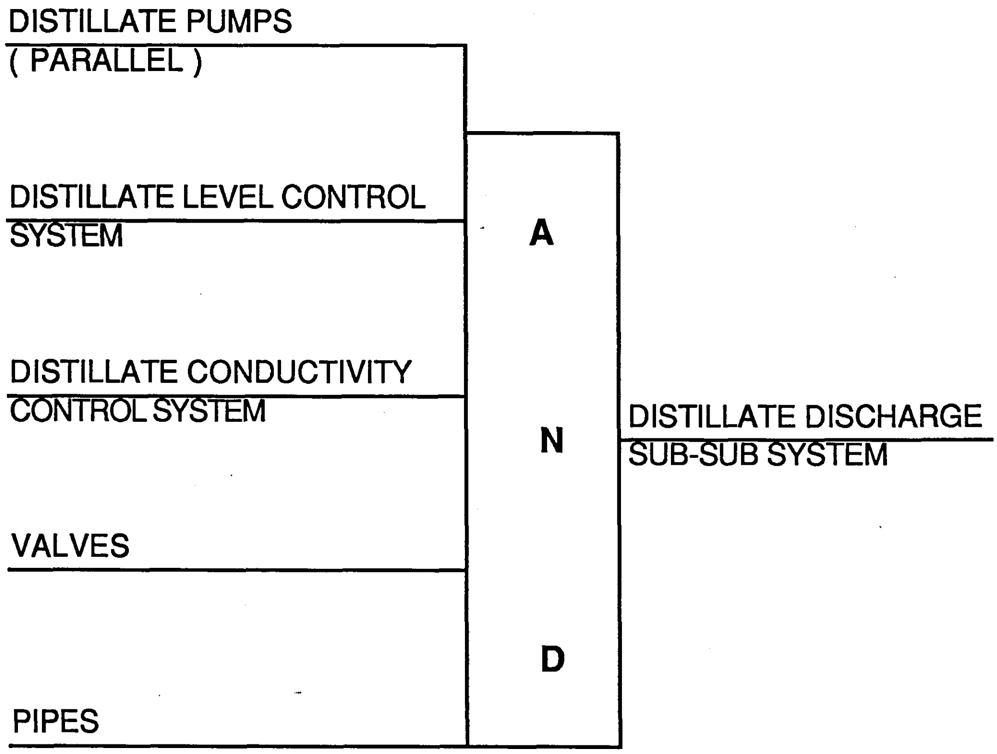


BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

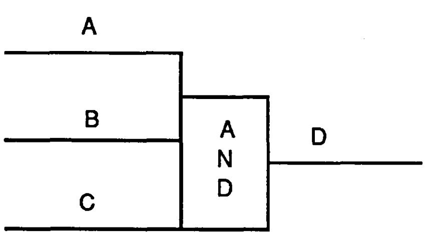
DISTILLER HEAT REJECTION SECTION

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 60



LOGIC SYMBOLS :

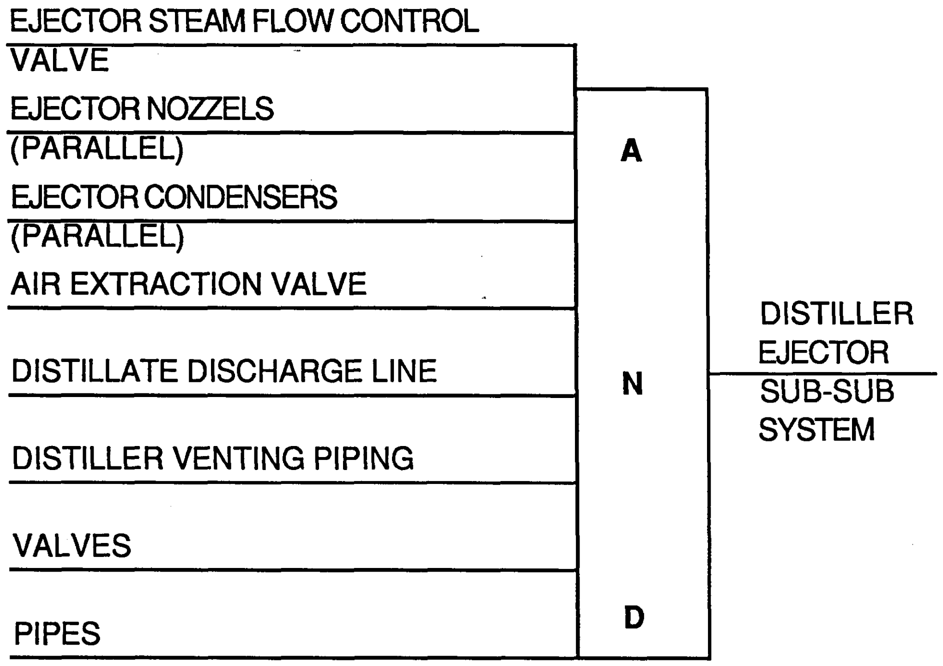


BOTH OPERATION OF " A " , " B " AND " C " HAVE TO BE COMPLETED FOR " D " TO WORK.

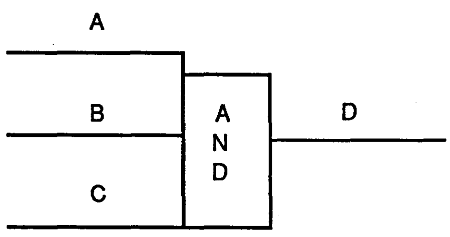
DISTILLATE DISCHARGE

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

FIGURE NO 61



LOGIC SYMBOLS :



BOTH OPERATION OF "A" , "B" AND "C" HAVE TO BE COMPLETED FOR "D" TO WORK.

DISTILLER EJECTOR

SUB-SUB SYSTEM OPERATIONAL INTERLOCK LOGIC DIAGRAM

CHAPTER V

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION RELIABILITY BLOCK DIAGRAM ANALYSIS APPROACH

CHAPTER V

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION RELIABILITY BLOCK DIAGRAM ANALYSIS APPROACH

5.1. Introduction

As it was mentioned earlier in section (1.4.3) of chapter (**I**), the work of this chapter is a consequential step to the work of the system definition analysis (chapter (**III**)) and the operational interlock logic analysis (chapter (**IV**)). The first step in this reliability analysis approach will be, to transform the interlock logical operation of the station, production unit, unit sub - systems, unit associated systems, and their sub - sub systems into a reliability network models (reliability block diagrams) in which the components of the station, production unit, unit sub - systems, unit associated systems, and their sub - sub systems are connected together in formations which may be either in series, parallel, series - parallel, "**r** out of **n**", or a combination of these configurations. It should be noted, that the actual station, production unit, unit sub - systems, unit associated systems, and their sub - sub systems may not necessarily have the same topological structure as the reliability block diagram developed to model them. This analysis is performed with the aid of the the operational interlocking logical analysis developed in chapter (**IV**). The second step will be to use these reliability block diagrams to develop the reliability models for the station, production unit, unit sub - systems, unit associated systems, and their sub - sub systems. These steps will be the subjects of the following sections of this chapter. The analysis will be presented in a graphical form (figures 62 - 114), in order to avoid a lengthy and boring repeated description of the various unit sub-systems, unit associated systems, and their sub-sub systems and also for quick reference. Each graph (figure) is a distinctive reliability block diagram (model) for the station, unit sub-system, unit associated system, and their sub-sub system in question.

5.2. A Simplified Dual - Purpose (Power&Water) Production Station Model

In order to proceed with the reliability analysis a model for the station and production units has to be envisaged. The model assumes the following :

1. The capacity range of the (MSF) distiller part of the production unit is between 5 - 6 (MIGPD) of distilled water.
2. The capacity range of the Boiler - Turbine - Generator part of the production unit is between 150 - 350 (MW) of electrical power, and that the boiler is a fossil fueled steam boiler.
3. All equipment are in their useful life period.(e.g. not in their infant mortality or wear - out life period).
4. All equipment assume a constant hazard rate. (e.g. constant failure rate { λ }), and that it is exponentially distributed. This will be defined in section (5.3.1) of this chapter
5. Successful operation of the production station requires that "{ **r** } out of { **n** }" units must work to produce electrical power and distilled water.
6. All the production units in the station are connected in parallel and they are fully redundant.
7. All the production units in the station are identical in their production capacity.

In view of the above assumptions, let us consider the dual - purpose (power&water) production station to be formed of a multiple number of identical production units { N_1, N_2,...., N } which are connected in parallel. Each production unit produces a specified capacity of electrical power and distilled water. Furthermore, from a reliability point of view each production unit assumes a series connection of boiler - turbine - generator - distiller.

5.3. Definition Of Reliability Indices

It is worth while at this junction to define some of the most commonly used indices in network (block diagrams) reliability analysis. Other indices will be introduced in later chapters as the need arises. In the following sections the term 'device' is used to mean " item, system, sub - system, associated system, or sub - sub system" in order to avoid repeating these words over and over.

5.3.1. Failure Rate (λ) :

The failure rate is defined as the number of failures of a device per unit time [36], hence :

$$\lambda = \frac{\text{number of failure of a component in the given period of time}}{\text{total period of time the component was operating}} \qquad \text{-----------(3)}$$

The failure rate is a state transition rate, because it represent the rate at which the device transit from the operation state to the failure state, furthermore, it is a time dependent rate. The units used for the failure rate are (# of failures per hour, day, month, and year).

5.3.2. Mean Time Between Failures(MTBF)

The mean time between failures(MTBF) is defined as the cycle time between failures of a device , and If the failure rate of the device is exponentially distributed (constant failure rate) then the (MTBT) is equal to the reciprocal of the frequency of failure or failure rate (λ) [70, 93].

$$(\text{MTBF}) = 1/\lambda \qquad \text{(hours, days, months, years)---------------------(4)}$$

5.3.3. Reliability (*R*) :

Reliability (*R*) is defined as the probability of a device, performing its defined purpose adequately for a specified period of time under the operating conditions encountered. The general mathematical expression for the time dependent reliability {*R* (t)} is as follows :

$$R(t) = \exp\left[-\int_0^t \lambda(t)\, dt\right] \qquad \text{---------------------------------------(5)}$$

For a constant failure rate (a case in which {λ (t)} is constant and independent of time), the reliability {R (t)} is defined mathematically by the following exponential distribution function [35, 36] :

$$R(t) = e^{-\lambda \times t} \quad \text{-----(6)}$$

OR,

$$R(t) = e^{-t / MTBF} \quad \text{-----(7)}$$

Where

R (t) = reliability as a function of operating time.

e = Napierian base.

λ = failure rate.

t = operating time.(days or hours).

From Equation (7), the mean time between failure (MTBF) will be :

$$(MTBF) = \int_0^\infty R(t)\, dt \quad \text{-----(8)}$$

5.3.4. Unreliability (Q)

Unreliability (Q) is defined as the probability of a device failure. Since success and failure are mutually exclusive events (e.g. they can not happen at the same time) and complementary [36], therefore

$$R(t) + Q(t) = 1 \quad \text{-----(9)}$$

5.3.5. Availability (*A*) :

Availability (*A*) is defined as the state in which a device, is capable of providing service, whether or not it is actually in service, and regardless of the capacity level that can be provided.[92]. The steady state availability {*A* (t) } can be defined mathematically as :

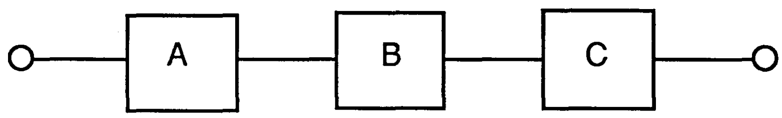
$$A(t) = \frac{\text{Operating Time}}{\text{Operating Time + Down Time}} \quad \text{-----(10)}$$

5.4. Reliability Block Diagram Modelling

From a reliability point of view, there are a number of reliability block diagram configurations that can be used to represent a system, namely, series, parallel, series - parallel, and the "**r** out of **n**". In the following sub - sections, these configurations will be discussed.

5.4.1. Series Configuration

A series configuration is a non - redundant system. Therefore, the successful operation of a system that is composed of a number of components represented in a reliability block diagram by series connection, requires that all components must work to ensure system success. For a system composed of three independent components A, B, and C connected in series, the series reliability block diagram will be as follows :



Let

R_S (t) = the system reliability as a function of operating time (t).

R_A (t) = the reliability of component A as a function of operating time (t).

RB (t) = the reliability of component B as a function of operating time (t).

R_C (t) = the reliability of component C as a function of operating time (t).

And

Q_S (t) = the system unreliability as a function of operating time (t).

Q_A (t) = the unreliability of component A as a function of operating time (t).

Q_B (t) = the unreliability of component B as a function of operating time (t).

Q_C (t) = the unreliability of component C as a function of operating time (t).

Since success and failure are mutually exclusive events (e.g. they cannot happen at the same time) and complementary [36], hence,

$R_A(t) + Q_A(t) = 1$ and $R_B(t) + Q_B(t) = 1$ and $R_C(t) + Q_C(t) = 1$

The requirement for system success is that all components "A, B, and C" must be working, therefore by using the theory of probability for mutually exclusive events, the system reliability mathematical model will be [35, 36] :

$$R_S(t) = R_A(t) \times R_B(t) \times R_C(t) \quad \text{-----------------------------------(11)}$$

If there are n - components connected in series, then Equation (11) can be generalized, hence it becomes [35, 36] :

$$R_S(t) = \prod_{i=1}^{n} R_i(t) \quad \text{--(12)}$$

This equation is called the product rule of reliability, because it demonstrates that the reliability of a series system is the product of the individual component reliabilities. Now if we substitute the failure rates of the components (λ_i (t)) in Equation (12), hence for the system we have [36] :

$$R_S(t) = \prod_{i=1}^{n} \exp \left[- \int_0^t \lambda_i(t)\, dt \right] \quad \text{-----------------------------------(13)}$$

This equation is general and does not require that all the components should have the same probability distribution, therefore each component can be represented by its proper distribution [36]. Now if the the time dependent failure rates (λ_i (t)) in Equation (13) are exponentially distributed (constant failure rates), then Equation (13) will become [36] :

$$R_S(t) = \prod_{i=1}^{n} \exp(-\lambda_i t) \quad \text{--(14)}$$

Also Equation (14) can be written as follows [36] :

$$R_S(t) = \exp\left(-\sum_{i=1}^{n} \lambda_i t\right) \quad \text{---(15)}$$

Now if we donate an overall (equivalent) failure rate for the series connected system by $\{\lambda_S(t)\}$, then from Equation (13) the reliability $\{R_S(t)\}$ will be :

$$R_S(t) = \exp\left[-\int_0^t \lambda_S(t)\, dt\right] \quad \text{---(16)}$$

From Equation (13) and (16), we have for the general case :

$$R_S(t) = \exp\left[-\int_0^t \lambda_S(t)\,dt\right] = \prod_{i=1}^{n} \exp\left[-\int_0^t \lambda_i(t)\,dt\right] \quad \text{------------------(17)}$$

And if we assume the failure rates $\{\lambda_i(t)\}$ to be constant (exponentially distributed), then Equation (17) will become :

$$R_S(t) = \exp[-(\lambda_S)(t)] = \exp[-\sum_{i=1}^{n} (\lambda_i)(t) \quad \text{----------------------------(18)}$$

From Equations (18), we have :

$$\lambda_S(t) = \sum_{i=1}^{n} \lambda_i \quad \text{--(19)}$$

Equation (19) leads to the following conclusion : if the failure rates are constant (i. e exponentially distributed) then the overall failure rate of the system is the summation of the failure rates of the individual series components [36]. If the unreliability of the series system $\{Q_S(t)\}$ is to be evaluated then :

$$Q_S(t) = 1 - [R_A(t) \text{ X } R_B(t) \text{ X } R_C(t)] \quad \text{-----------------------(20)}$$

$$= 1 - [(1 - Q_A(t)) \text{ X } (1 - Q_B(t)) \text{ X } (1 - Q_C(t))]$$

$$Q_S(t) = Q_A(t) + Q_B(t) + Q_C(t)) - Q_A(t) \text{ X } Q_B(t) - Q_B(t) \text{ X } Q_C(t)$$

$$- Q_C(t) \text{ X } Q_A(t) + Q_A(t) \text{ X } Q_B(t) \text{ X } Q_C(t) \quad \text{-------------------(21)}$$

And for n - components $\{Q_S(t)\}$ will be :

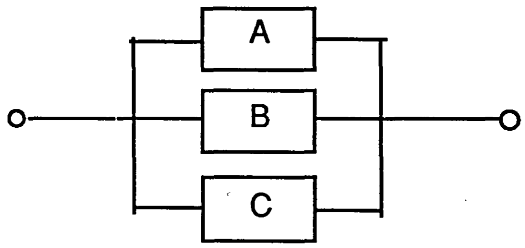
$$Q_S(t) = 1 - \prod_{i=1}^{n} R_i(t) \quad \text{--(22)}$$

Now substituting the failure rates $(\lambda_i(t))$ in Equation (22), we have :

$$Q_S(t) = 1 - \prod_{i=1}^{n} \exp[-(\lambda_i(t))(t)] \quad \text{--------------------------------(23)}$$

5.4.2. Fully Redundant Parallel Configuration

A parallel configuration is a fully redundant system. Therefore, the failure condition of a system that is composed of a number of components represented in a reliability block diagram by a parallel connection, requires that all components must fail. The success operation of the system requires that only one or more components should be working, hence, by using the probability theory of the occurrence of at least one or more events [36] the system reliability ($R_S(t)$) and unreliability ($Q_S(t)$) can be evaluated. For a system composed of three independent components A, B, and C connected in parallel, the parallel reliability block diagram will be as follows :



The system unreliability ($Q_S(t)$) will be :

$$Q_S(t) = Q_A(t) \times Q_B(t) \times Q_C(t) \qquad \text{-----(24)}$$

And the system reliability (R_S) will be :

$$R_S(t) = 1 - [Q_A(t) \times Q_B(t) \times Q_C(t)] \qquad \text{-----(25)}$$

$$R_S(t) = [R_A(t) + R_B(t) + R_C(t)) - R_A(t) \times R_B(t) - R_B(t) \times R_C(t) - R_C(t) \times R_A(t) + R_A(t) \times R_B(t) \times R_C(t)] \qquad \text{------(26)}$$

If we have n - components system then Equations (24) and (25) will become as follows [36] :

$$Q_S(t) = \prod_{i=1}^{n} Q_i(t) \qquad \text{-----(27)}$$

And

$$R_S(t) = 1 - \prod_{i=1}^{n} Q_i(t) \qquad \text{-----(28)}$$

Now if we substitute, the failure rates ($\lambda_i(t)$) in Equations (27) and (28), we have [36]:

$$Q_S(t) = \prod_{i=1}^{n} (1 - \exp [- \int_0^t \lambda_i(t) \, dt]) \quad \text{------------(29)}$$

And

$$R_S(t) = 1 - \prod_{i=1}^{n} (1 - \exp [- \int_0^t \lambda_\iota(t) \quad \text{------------(30)}$$

Equations (29) and (30) applies for any probability distribution. In the case where the failure rates (λ_ι (t)) of the components are exponentially distributed (e.g. constant failure rates) then Equations (29) and (30) will become as follows [36] :

$$Q_S(t) = \prod_{i=1}^{n} [1 - \exp (- \lambda_\iota t] \quad \text{------------(31)}$$

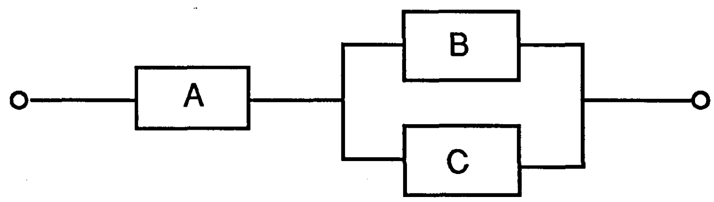
And

$$R_S(t) = 1 - \prod_{i=1}^{n} [1 - \exp (- \lambda_\iota t] \quad \text{------------(32)}$$

From Equations (31) and (32), "a single equivalent failure rate cannot be derived to represent the complete parallel system because, the system reliability cannot be expressed as a single exponential function but only as a series of exponential functions" [36].

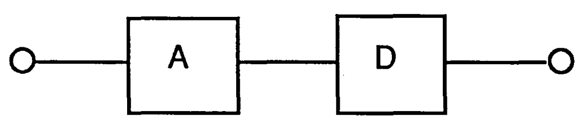
5.4.3. Series - Parallel Configuration

For a system composed of three independent components A, B, and C connected in series - parallel configuration, in which component (A) is connected in series with components (B) and (C) which are connected in parallel. Furthermore, component (B) and (C) are fully redundant. The reliability block diagram of the system will be as follows :



In this configuration, the system will fail if component (A) fails.or both component (B) and (C) fail simultaneously. The system reliability can be evaluated by a process of successive reduction known as a network reduction technique [35, 36]. Components (B) and (C) are combined in parallel and represented by an equivalent block. The new block is then combined in series with component (A). The resultant equivalent reliability or unreliability then represent the reliability or the unreliability of the original configuration. For example :

Let block (D) represent the equivalent of components (B) and (C) which are connected in parallel, then the original reliability block diagram will be reduced to block (A) and (D) connected in series:



From Equation (25) the equivalent reliability of block (D) will be :

$$R_D(t) = 1 - (1 - R_B(t)) \times (1 - R_C(t))$$

$$= R_B(t) + R_C(t) - R_B(t) \times R_C(t)$$

Since (A) and (D) are connected in series, then, the reliability of the original system $[R_S(t)]$ will be :

$$R_S(t) = R_A(t) \times R_D(t)$$

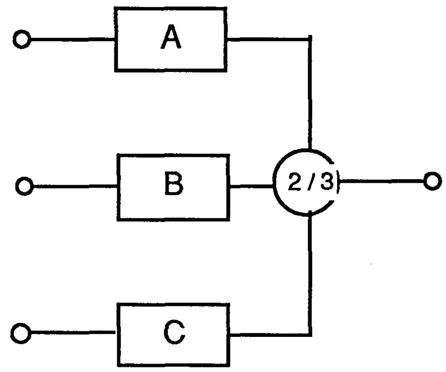
Substituting $\{R_B(t)\}$ and $\{R_C(t)\}$ in $\{R_S(t)\}$ above, we have :

$$R_S(t) = R_A(t) \times [\, R_B(t) + R_C(t) - R_B(t) \times R_C(t) \,]$$

$$= R_A(t) \times R_B(t) + R_A(t) \times R_C(t) - R_A(t) \times R_B(t) \times R_C(t)$$

5.4.4. The " r out of " n " Configuration

This configuration is also known as a partially redundant system. In this configuration there will be "n" components in the system. The successful operation of the system requires that "r" components out of "n" components must be working. For a system composed of three components A, B, and C which are identical and connected in a " **r** out of **n** " configuration, the reliability block diagram will be as follows :



The "n" components of the system can be identical or non - identical, however, in most of the practical cases, these components are identical. The "r" components have to be specified in order to evaluate the reliability models.

In the above illustrated configuration, the success operation of this system requires that two components out of the three must work, (e. g.either components (A) and (B) must work while (C) can fail, Components (A) and (C) must work while (B) can fail, or components (B) and (C) must work while (A) can fail). This condition is known in probability theory as combinational problem. Since in this system, the components are identical, therefore, its reliability and unreliability functions can be evaluated by the application of binomial distribution concept directly [36]. It should be noted, that the binomial distribution concept can not be applied directly if the components in the system are not identical.

The binomial distribution is normally represented by the general expression :

$$(p+q)^n = p^n + n\,p^{n-1}q + \frac{n(n-1)}{2!}\,p^{n-2}q^2 + \ldots\ldots\ldots\ldots$$

$$+ \frac{n(n-1)\ldots.(n-r+1)}{r!}\,p^{n-r}q^r + \ldots. + q^n \quad ----------(33)$$

For the time - dependent reliability $\{R(t)\}$ and unreliability $\{Q(t)\}$ of the system, the expression is modified to become $[\,R(t) + Q(t)\,]^n$ [36]. If the system success requires that no component failure, then the reliability of the system is equal the first term of the binomial expansion, and if the system success requires that only one component can fail, the the reliability of the system is equal to the sum of the first two terms of the binomial expansion, and so on. Since $[R_A]$, $[R_B]$, and$[R_C]$ are equal, and $[Q_A]$, $[Q_B]$, and $[Q_B]$ are equal. Therefore, for the above illustrated " **r** out of **n** " system, the reliability of the system will be

$$R_S(t) = [R_A(t)]^3 + 3\,[R_A(t)]^2 \times [Q_A(t)]$$

Now if we substitute the failure rate (λ), which is assumed to be exponentially distributed (constant failure rate), then the reliability of above illustrated system will be :

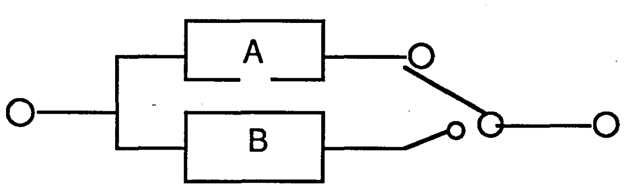
$$R_S(t) = e^{-3\lambda t} + 3\,e^{-2\lambda t}\,(1 - e^{-\lambda t})$$

And the probability of the system failure will be :

$$Q_S(t) = 1 - R_S(t)$$

5.4.5. The Standby Redundant Configuration

In this configuration the components are connected in parallel and are not operating simultaneously. Normally, one or more components are operating continuously (called the normal operating component (s)) while the redundant components are in standby mode ready to operate should the normally operating component (s) fail. For standby redundant system composed of two components (A) and (B), and component (A) is the normal operating component, the reliability block diagram will be as follows :



In the following discussion, it will be assumed that :

1. Components (A) and (B) are non - identical.
2. The failure rates of components (A) and (B) are exponentially distributed (constant failure rate).
3. The changeover mechanism, which bring the standby component into operation when the normally operating component fails, will not fail.

4. The standby component does not fail while in the standby position.

A failure density function f (t) is defined as the derivative of the cumulative failure distribution Q (t), therefore f (t) and Q (t) will be [36] :

$$f(t) = \frac{dQ(t)}{dt} = -\frac{dR(t)}{dt} \quad \text{------(34)}$$

$$Q(t) = \int_0^t f(t)\, dt \quad \text{------(35)}$$

And {R (t)} will be [36] :

$$R(t) = 1 - \int_0^t f(t)\, dt = \int_t^\infty f(t)\, dt \quad \text{------(36)}$$

If component (A) fails at time t_1 then component (B) operates immediately at this time. If component (B) fails at time t, then the time to failure of component (B) (t_2) is equal to [t - t_1]. Therefore, the failure density of component (A) will be [36] :

$$f_{(A)}(t_1) = \lambda_{(A)}\, e^{-\lambda_{(A)} t_1}$$

The failure density of component (B) will be :

$$f_{(B)}(t_1) = \lambda_{(B)}\, e^{-\lambda_{(B)} t_2}$$

Now, the joint density function of both components operating will be [36] :

$$f(t) = [f_{(A)}(t_1)] \times [f_{(B)}(t_2)]$$

$$= [\lambda_{(A)}\, e^{-\lambda_{(A)} t_1}] \times [\lambda_{(B)}\, e^{-\lambda_{(B)} (t - t_1)}] \quad \text{----(37)}$$

If we integrate f (t) with respect to (t_1), we have [36] :

$$f(t) = \int_{t_1 = 0}^{t} (\lambda_{(A)}) (\lambda_{(B)}) \exp[-\lambda_{(A)} t_1] \exp[-\lambda_{(B)} (t - t_1)]\, dt$$

$$= \frac{\lambda_{(A)} \lambda_{(B)}}{\lambda_{(A)} - \lambda_{(B)}} [\exp(-\lambda_{(B)} t) - \exp(-\lambda_{(A)} t)] \quad \text{------(38)}$$

From Equation (36), the system reliability $\{R\ (t)\}$ is equal to the integral of the failure density function f (t) from time (t) to (∞), therefore $\{R\ (t)\}$ will become as follows [36] :

$$R(t) = \int_t^{\infty} f(t)\,dt$$

$$= \frac{\lambda_{(A)}\ \lambda_{(B)}}{\lambda_{(A)} - \lambda_{(B)}} \int_t^{\infty} [\exp(-\lambda_{(B)}t) - \exp(-\lambda_{(A)}t]\,dt \quad \text{------(39)}$$

By integration, we have :

$$R(t) = \frac{\lambda_{(A)}}{\lambda_{(A)} - \lambda_{(B)}} \exp(-\lambda_{(B)}t) + \frac{\lambda_{(B)}}{\lambda_{(A)} - \lambda_{(B)}} \exp(-\lambda_{(A)}t) \quad \text{-------(40)}$$

Equation (40) can also be written as follows [36] :

$$R(t) = \exp(-\lambda_{(A)}t) + \frac{\lambda_{(A)}}{\lambda_{(B)} - \lambda_{(A)}} [\exp(-\lambda_{(A)}t) - \exp(-\lambda_{(B)}t]$$

$$\text{-------------------------------------(41)}$$

Equations (40) and (41) are general and can be used if the two components are identical. In the case when the changeover device is not perfect, then its reliability has to be incorporated in Equations (40) and (41) [36]. From Equation (8), the mean time between failures(MTBF) of the system is equal to :

$$(MTBT)_S = \int_0^{\infty} R(t)\,dt$$

Hence, substituting $\{R\ (t)\}$ from Equation (41) and integrating we have [36] :

$$(MTBT)_S = \frac{1}{\lambda_{(A)}} + \frac{1}{\lambda_{(B)}} \quad \text{-------------------------------------(42)}$$

Now if components (A) and (B) are identical the above models can not be used [36]. In this case the poisson distribution is used to evaluate the reliability functions of the system because "this distribution gives the probability of any number of component failures provided the components are operating in their useful life period" [36]. The poisson distribution is expressed as [36] :

$$P_x(t) = \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad \text{-----(43)}$$

Where,

$P_x(t)$ = the probability that x components will fail in time (t).

x = number of components failing in time (t).

So

$P_0(t) = e^{-\lambda_{(A)} t}$

$P_1(t) = (\lambda t) e^{-\lambda_{(A)} t}$

Hence, the reliability of the system $\{R_S(t)\}$ will be :

$R_S(t) = P_0(t) + P_1(t) = [e^{-\lambda_{(A)} t}] \times [1 + \lambda_{(A)} t]$

Now if there is n - identical standby components, the reliability of the system $\{R_S(t)\}$ will be [36] :

$$R(t) = e^{-\lambda} \left[1 + \lambda t + \frac{(\lambda t)^2}{2!} + \frac{(\lambda t)^3}{3!} + \dots\dots\dots + \frac{(\lambda t)^n}{n!} \right] \quad \text{-----(44)}$$

Equation (43) can be written as :

$$R(t) = \sum_{x=0}^{n} \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad \text{-----(45)}$$

Equations (43) and (44) indicate that the probability of the system failure is equal to the sum of the first (n) terms of the Poisson distribution [36]. Now if we substitute $\{R(t)\}$ from Equation (44) in Equation (8), therefore, the mean time between failures (MTBF) of the system will be [36] :

$$(\text{MTBF}) = \int_0^{\infty} \sum_{x=0}^{n} \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad \text{-----(46)}$$

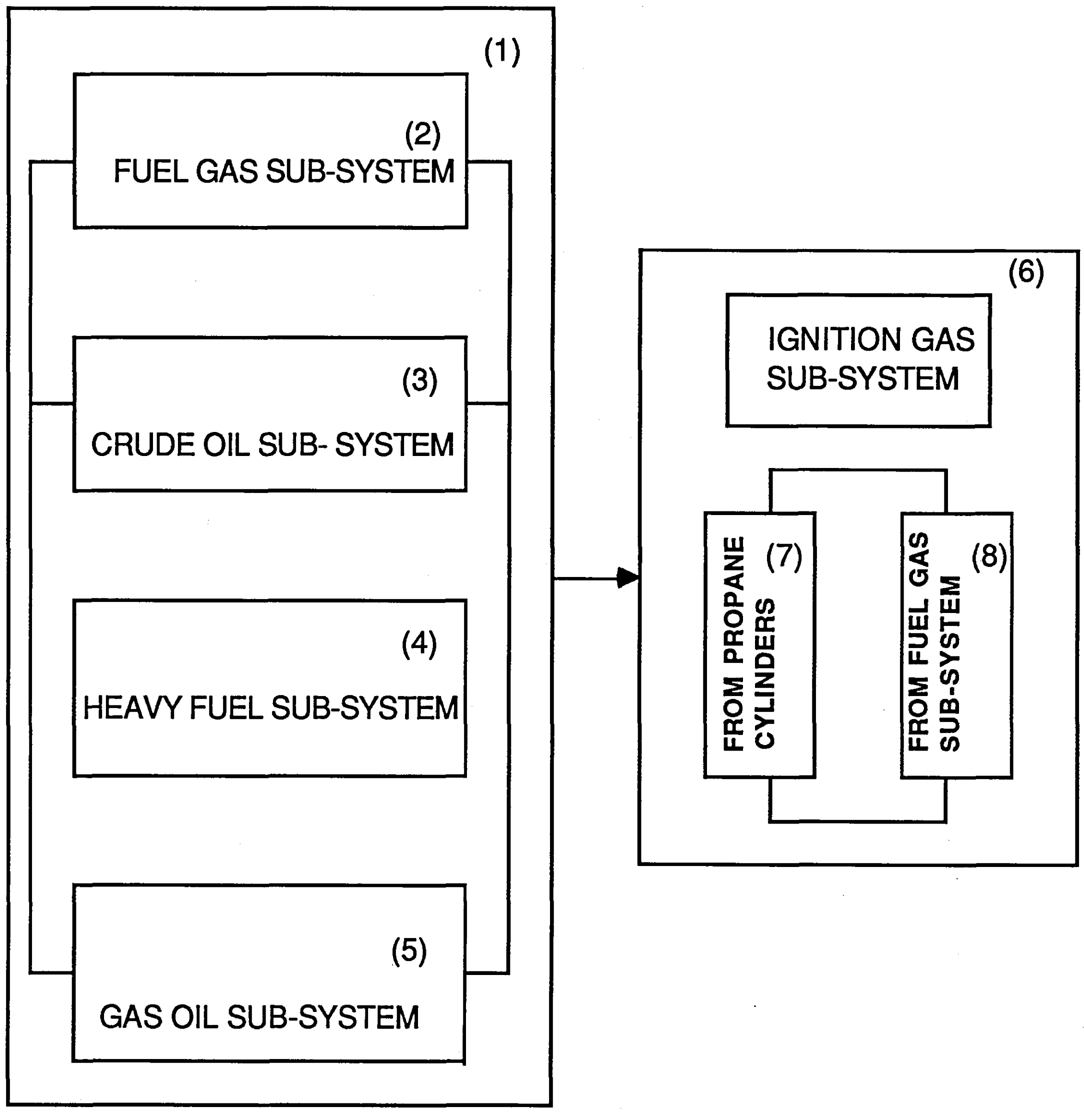
Integrating, we have

$$(\text{MTBF}) = \frac{n+1}{\lambda} \quad \text{-----(47)}$$

5.5. Dual - Purpose (Power&Water) Station - Unit Sub - Systems - Unit Associated Systems. - And Their Sub - Sub Systems Reliability Block Diagrams

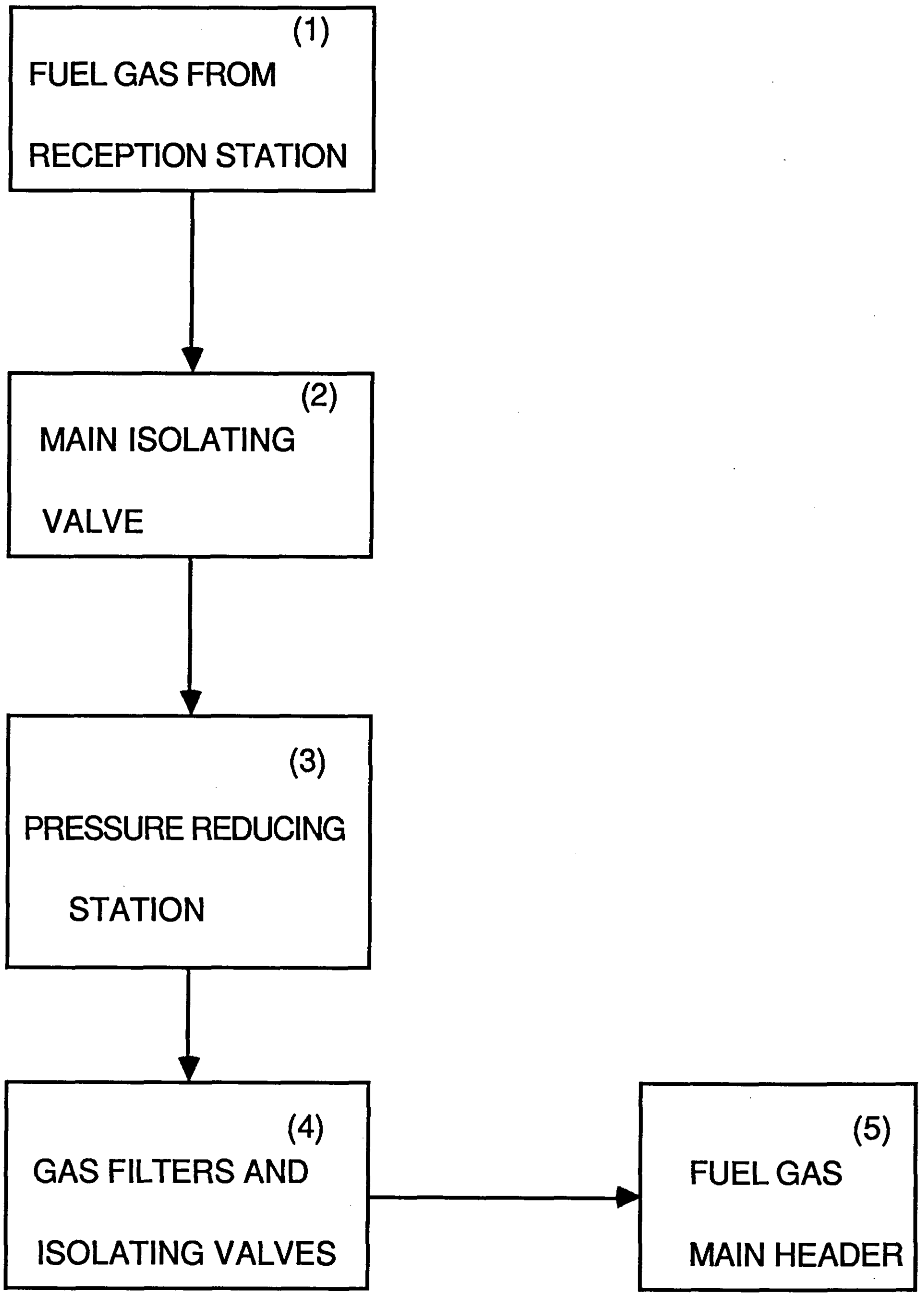
The following figures (62 - 114) represents the developed reliability block diagrams for the station, unit sub - systems, unit associated systems, and their sub - sub systems. Each graph (figure) is a distinctive self explanatory reliability block diagram. In the development of each graph, the corresponding operation interlock logic diagram developed in section (4.3) of chapter **(IV)**, figure (5) of chapter **(III)**, and the simplified dual - dual purpose (power&water) production station model (section 5.2 of this chapter) have to be referred to.

FIGURE NO 62



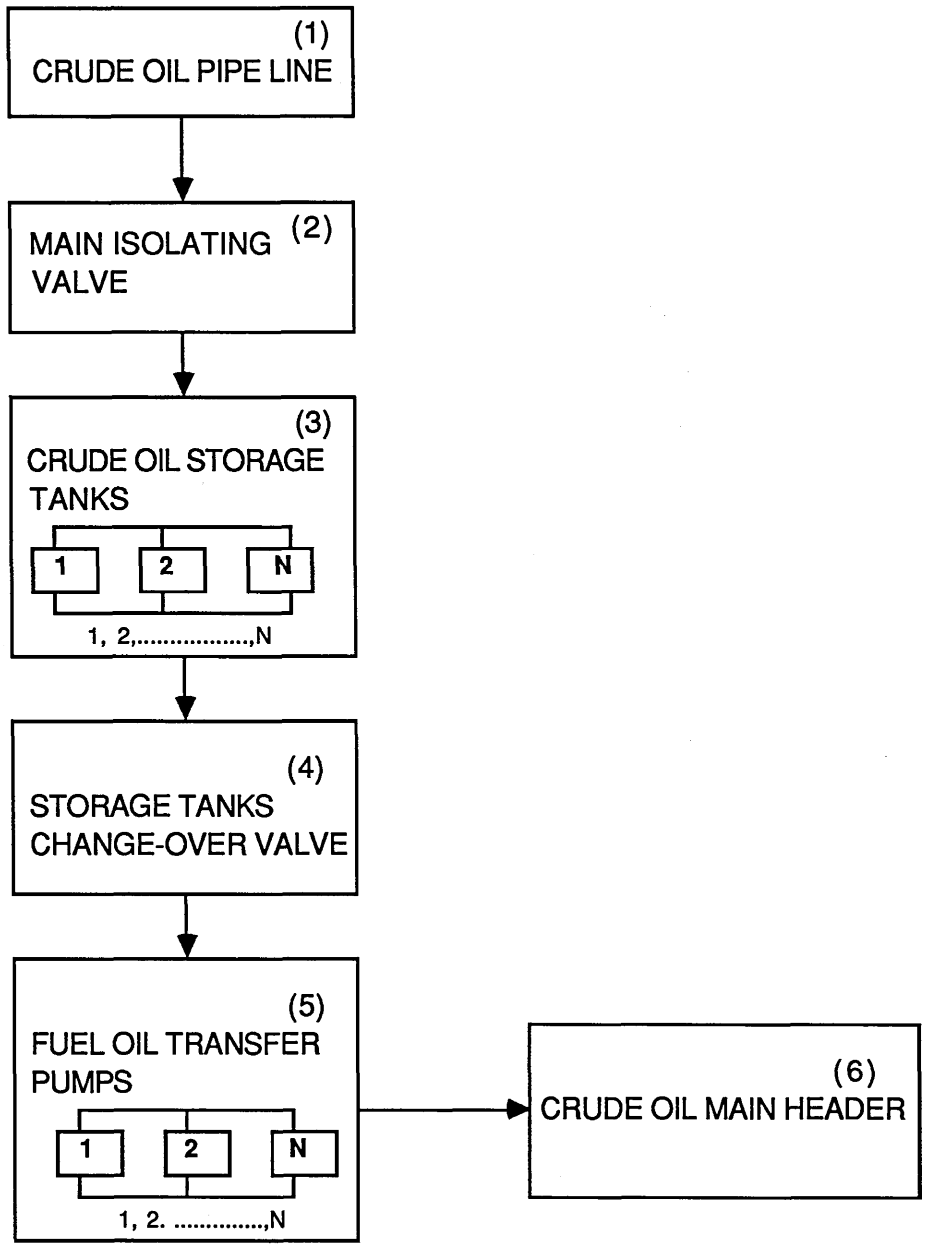
FUEL ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 63



FUEL GAS SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

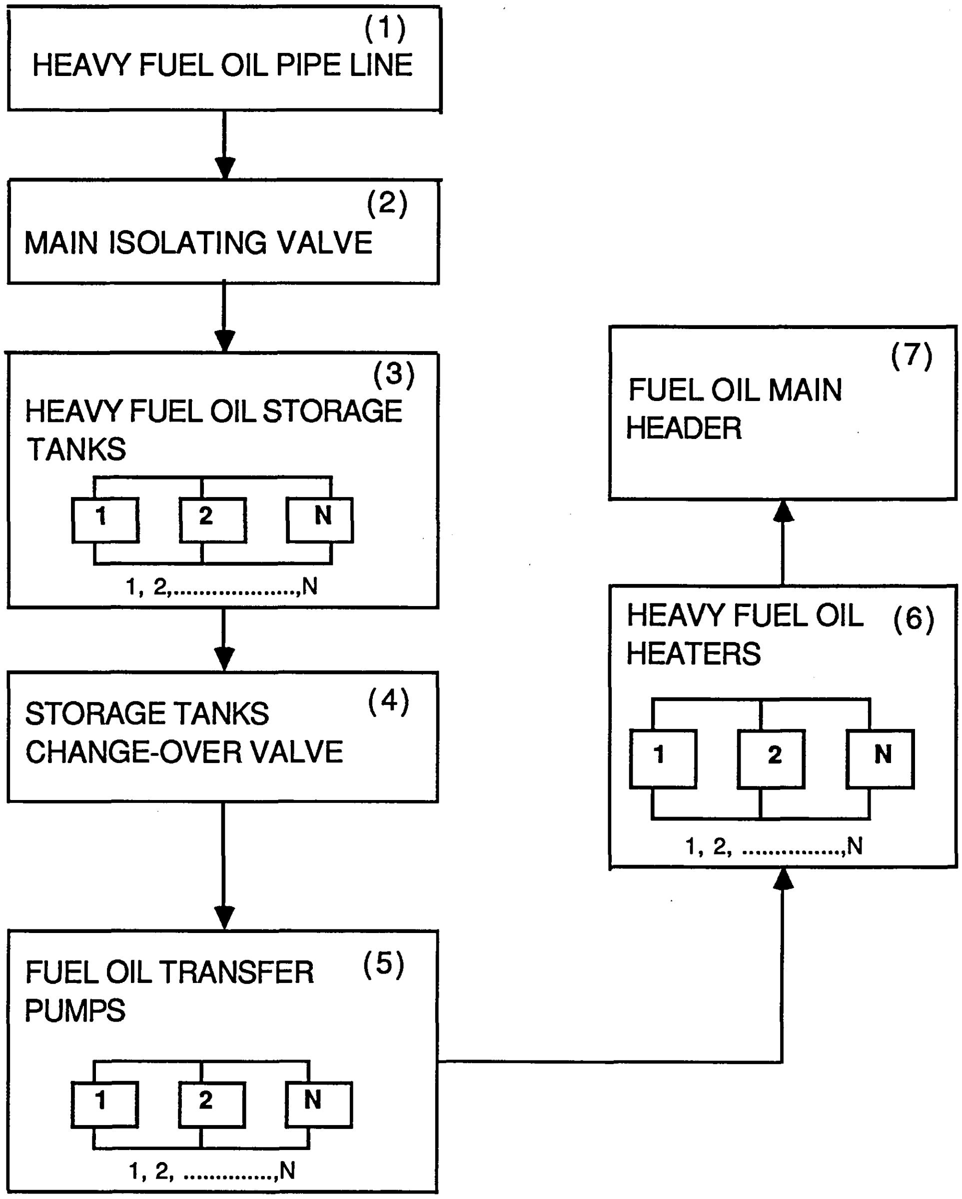
FIGURE NO 64



NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARIL EQUAL.

CRUDE OIL SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

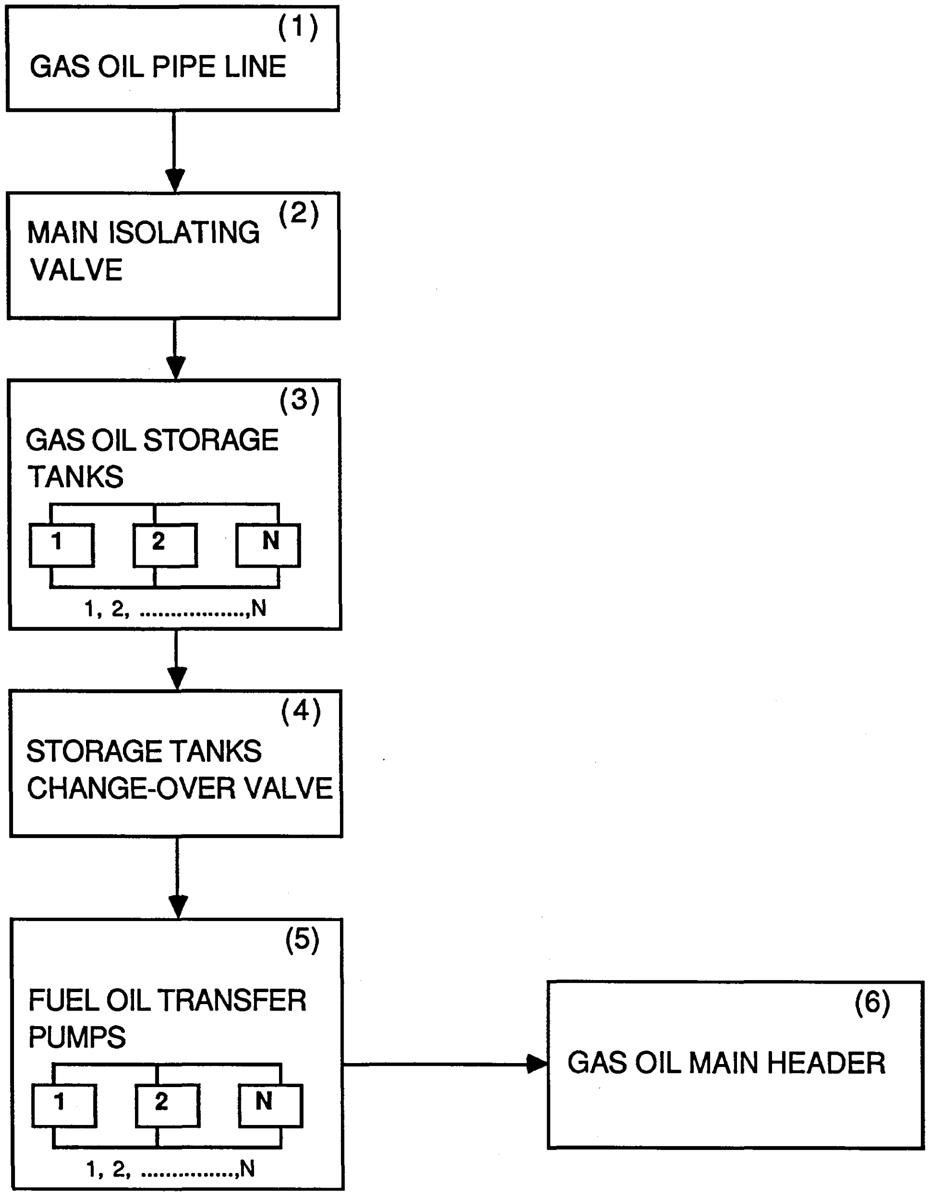
FIGURE NO 65



NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

HEAVY FUEL OIL SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

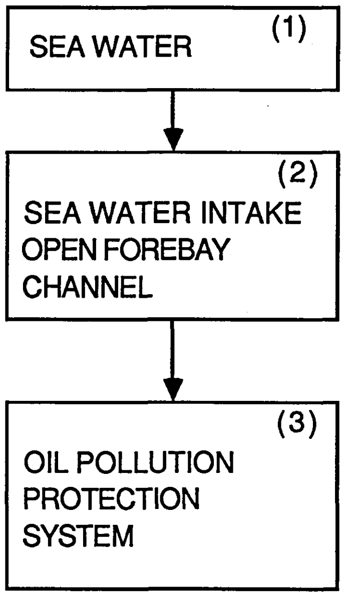
FIGURE NO 66



NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

GAS OIL SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

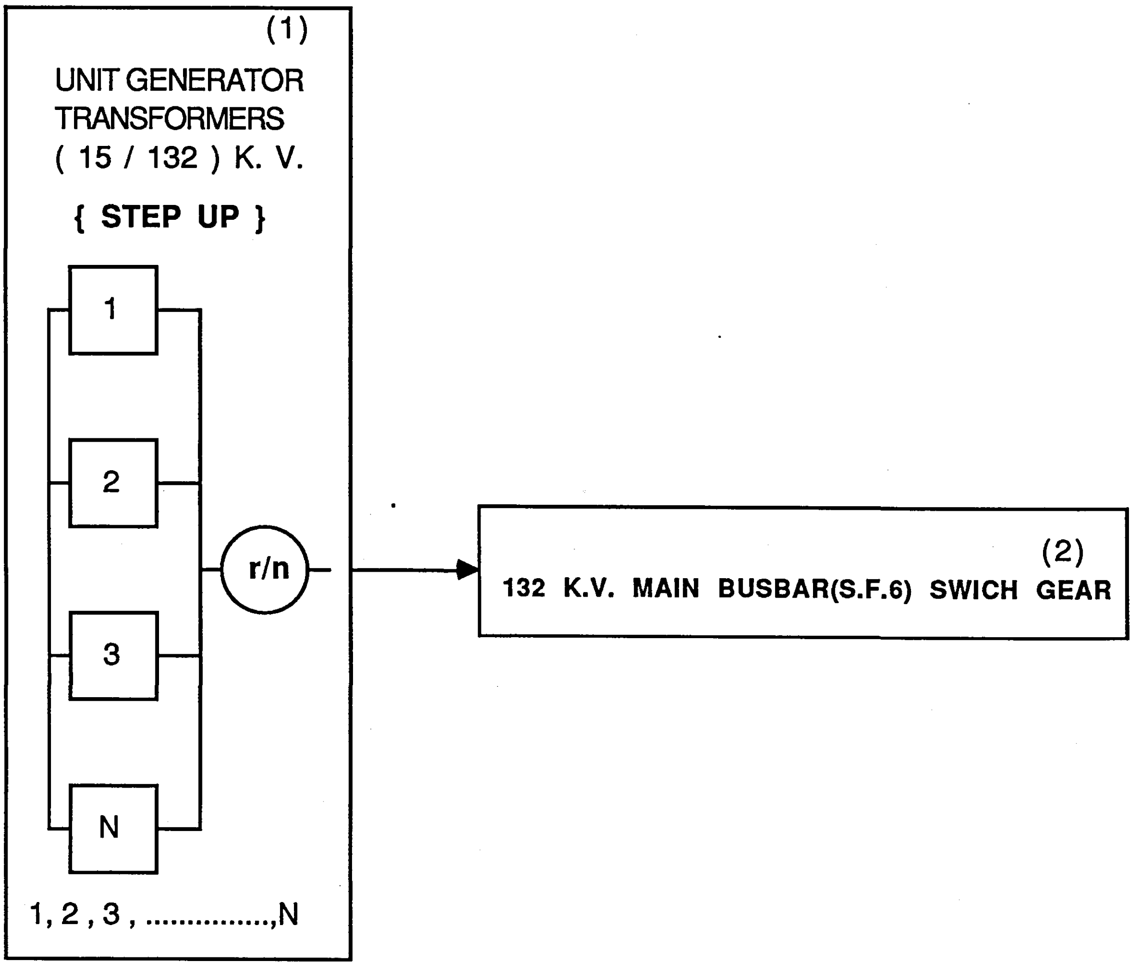
FIGURE NO 67



SEA WATER INTAKE

ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

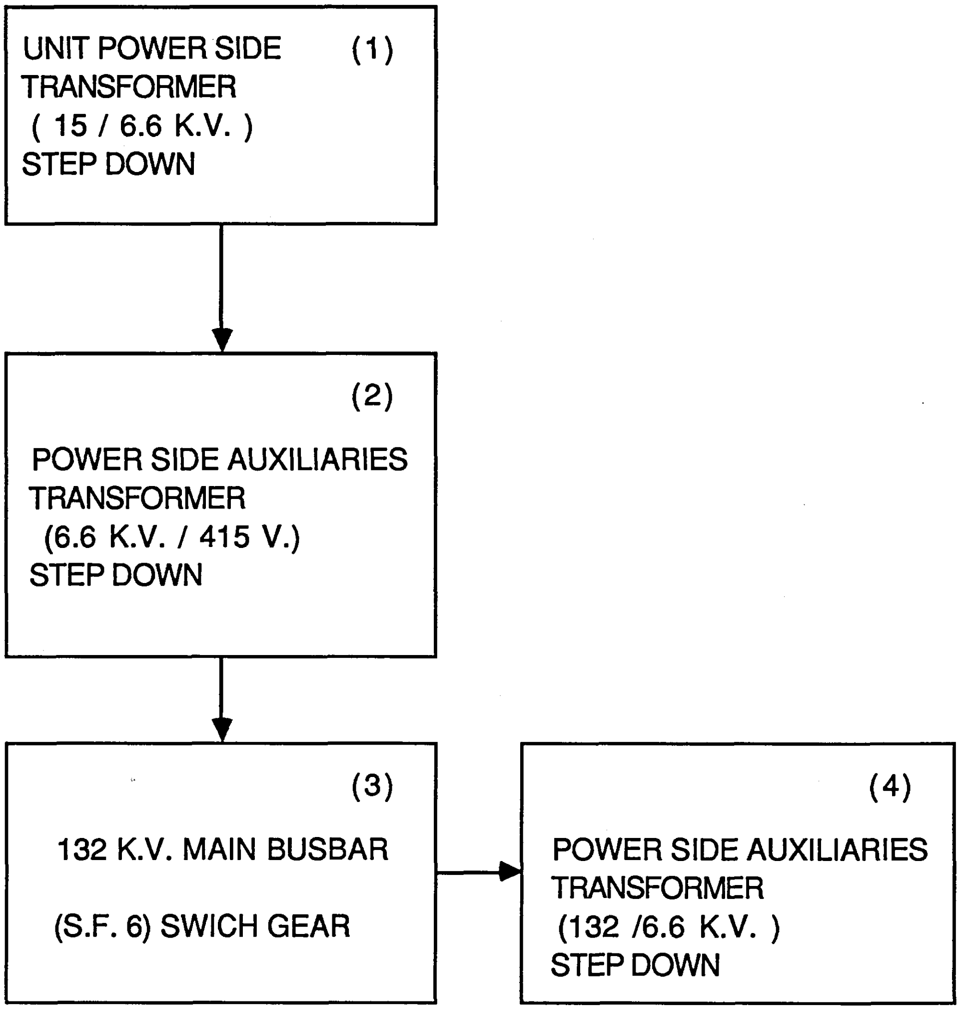
FIGURE NO 68



REDUCED MAIN ELECTRICAL SUPPLY

ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

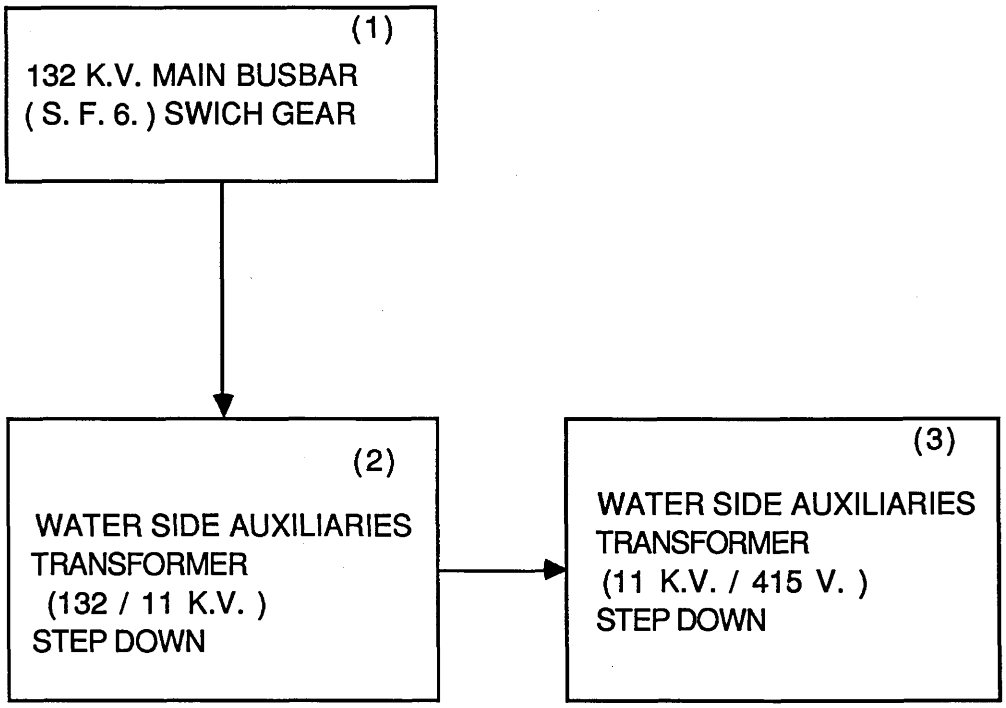
FIGURE NO 69



UNIT POWER SIDE

ELECTRICAL SUPPLY ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

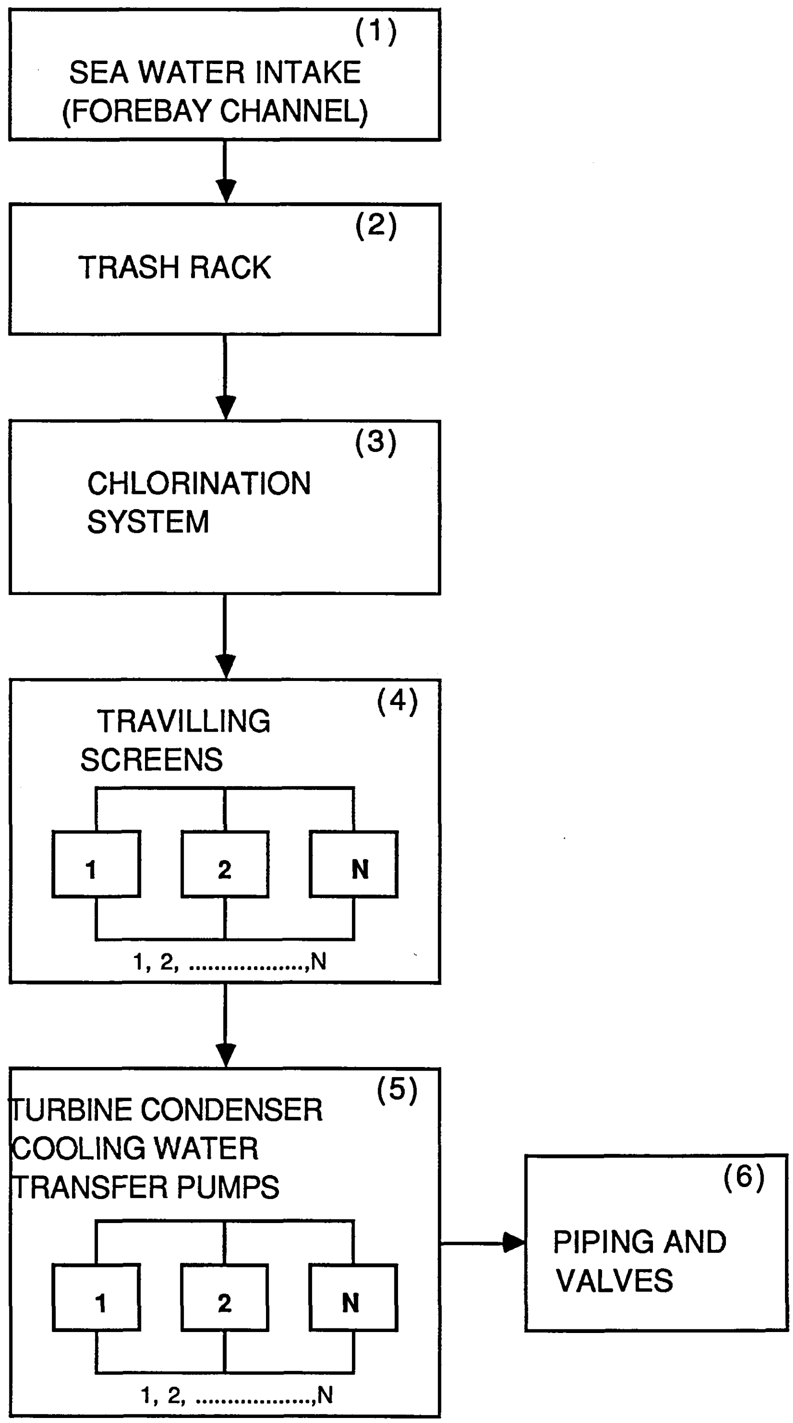
FIGURE NO 70



UNIT WATER SIDE

ELECTRICAL SUPPLY ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 71

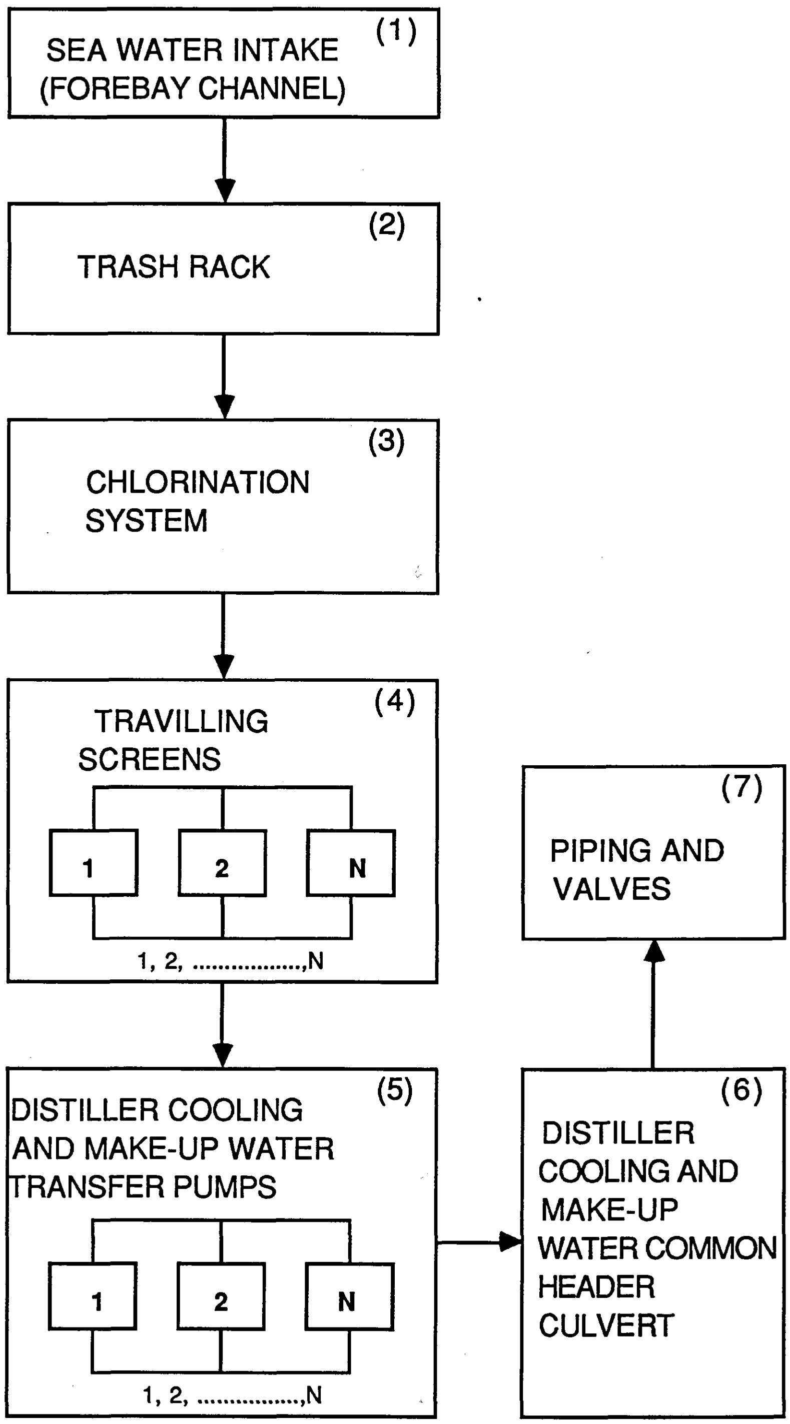


NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT EQUAL.

TURBINE COOLING

ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 72

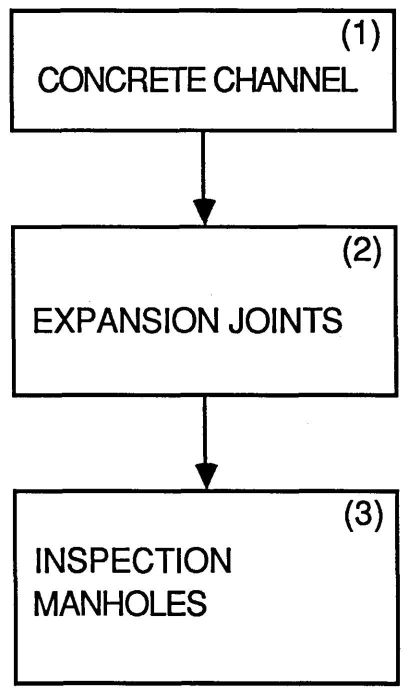


NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NORMALLY EQUAL.

DISTILLER COOLING

ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

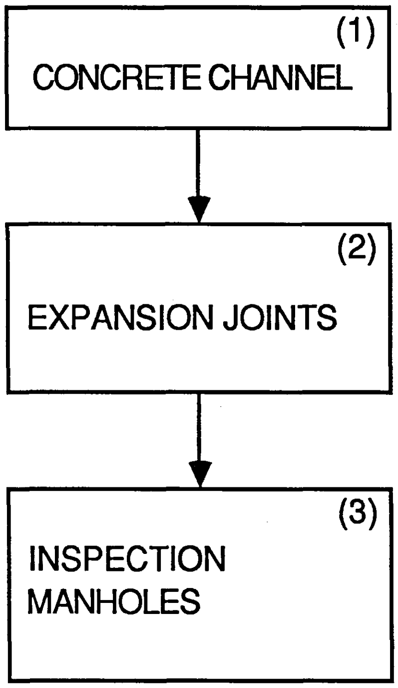
FIGURE NO 73



TURBINE DISCHARGE

ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

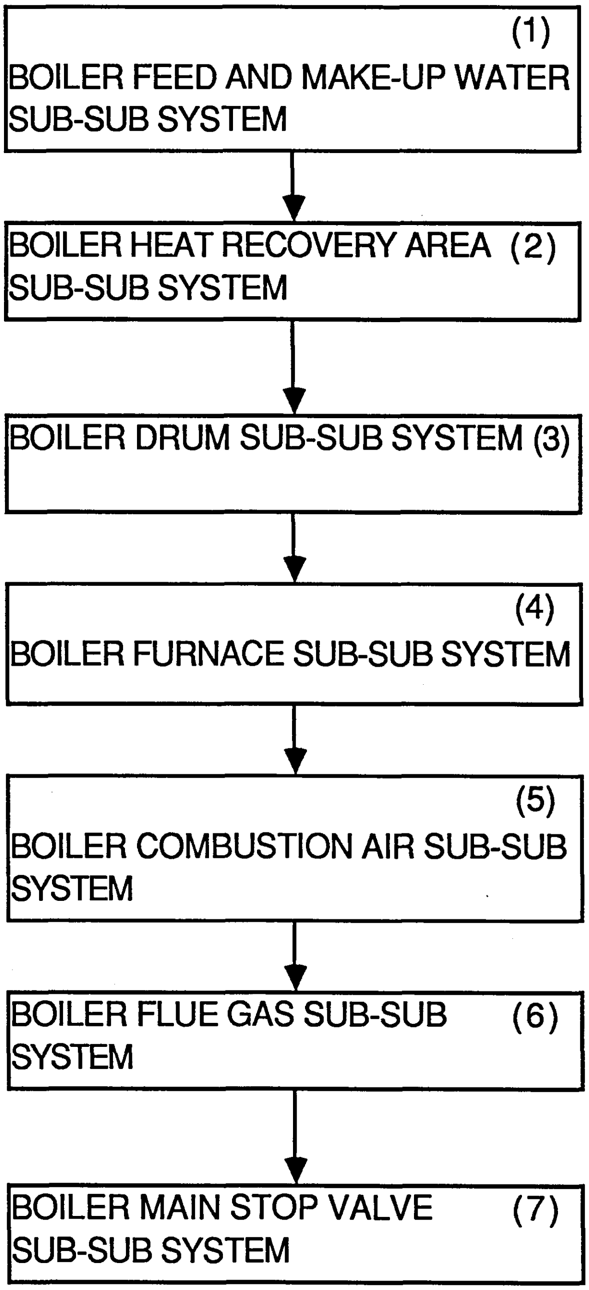
FIGURE NO 74



DISTILLER DISCHARGE

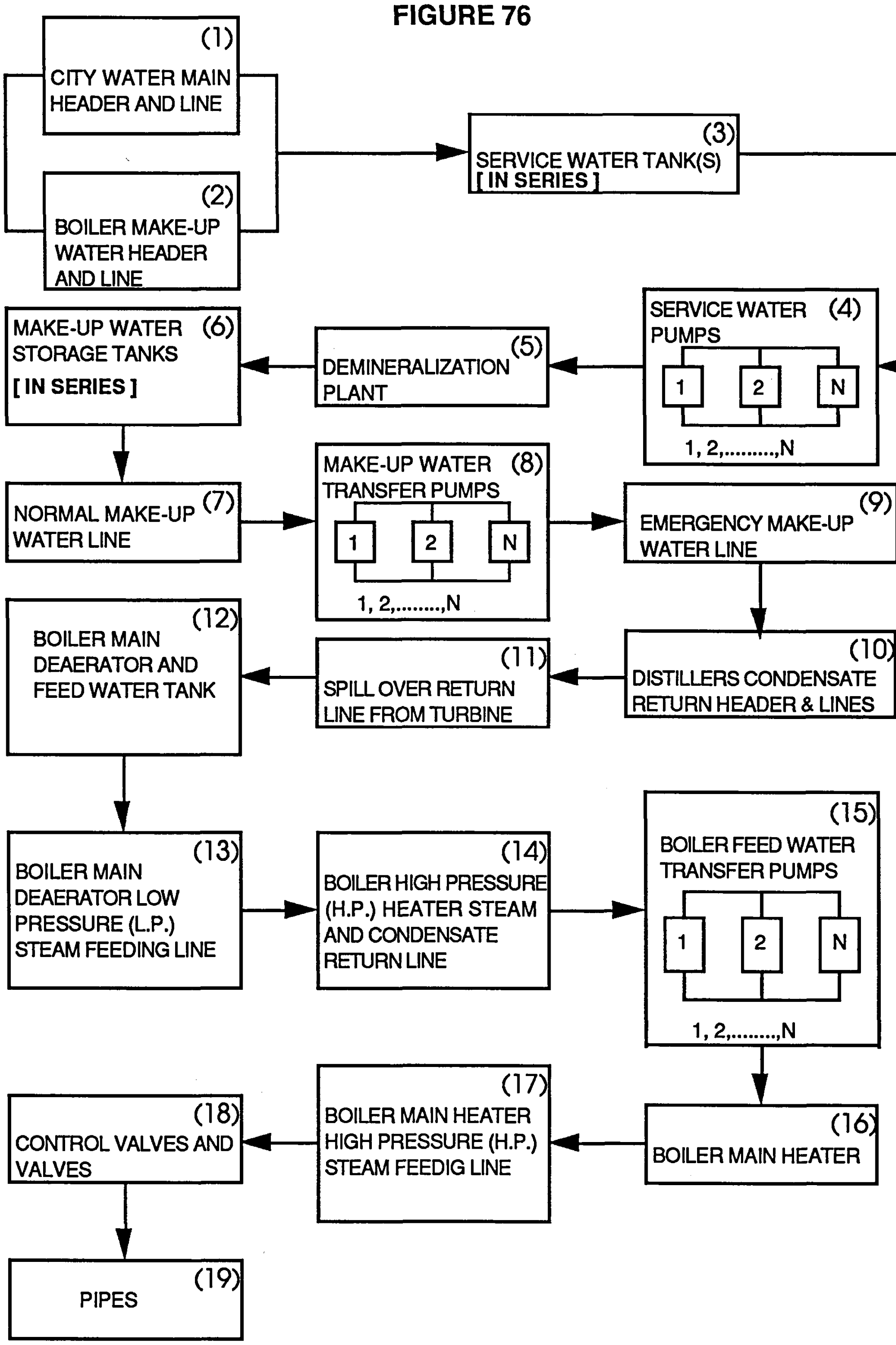
ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 75



BOILER SUB SYSTEM RELIABILITY BLOCK DIAGRAM

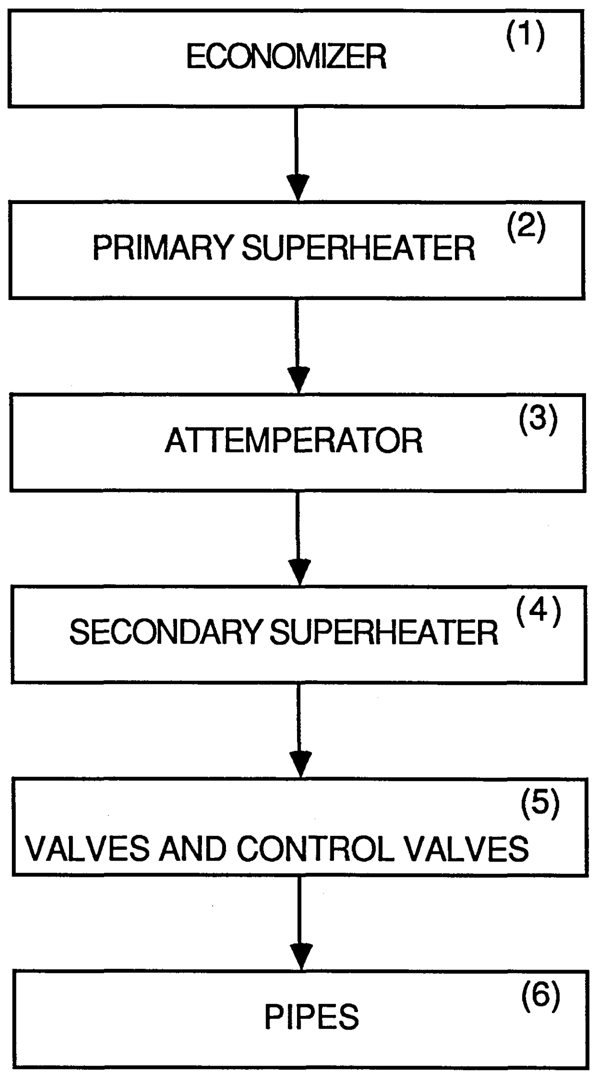
FIGURE 76



NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

BOILER FEED AND MAKE-UP WATER
SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

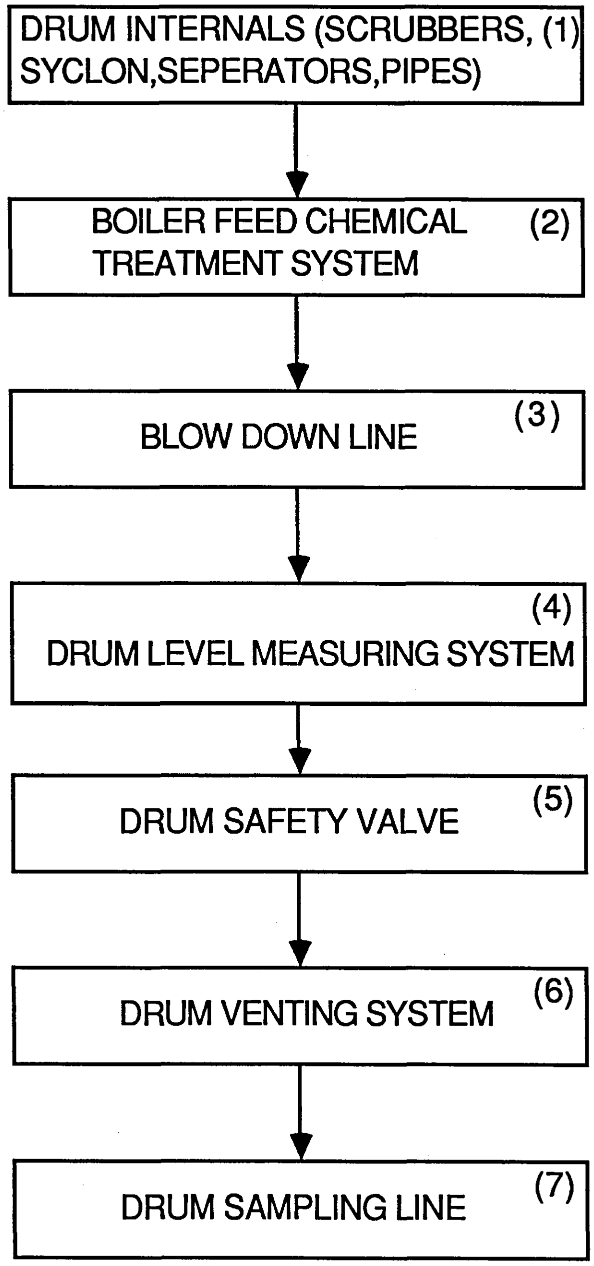
FIGURE NO 77



BOILER HEAT RECOVERY AREA

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

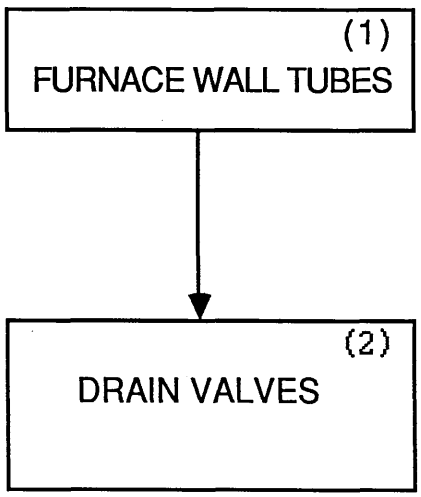
FIGURE NO 78



BOILER DRUM

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

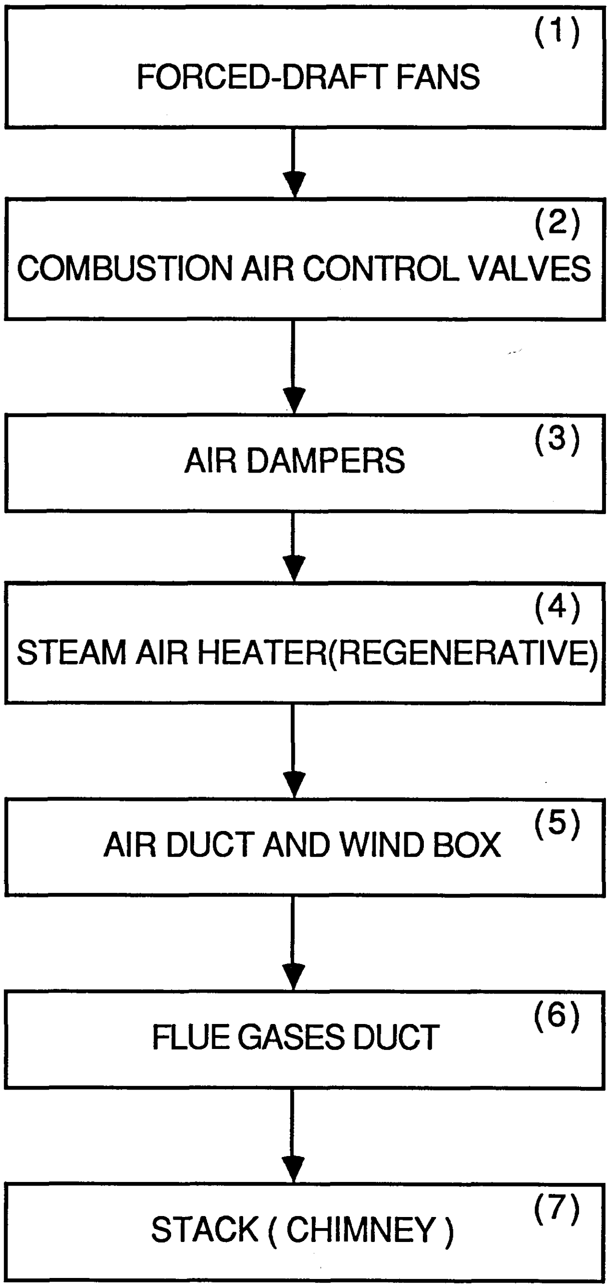
FIGURE NO 79



BOILER FURNACE

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

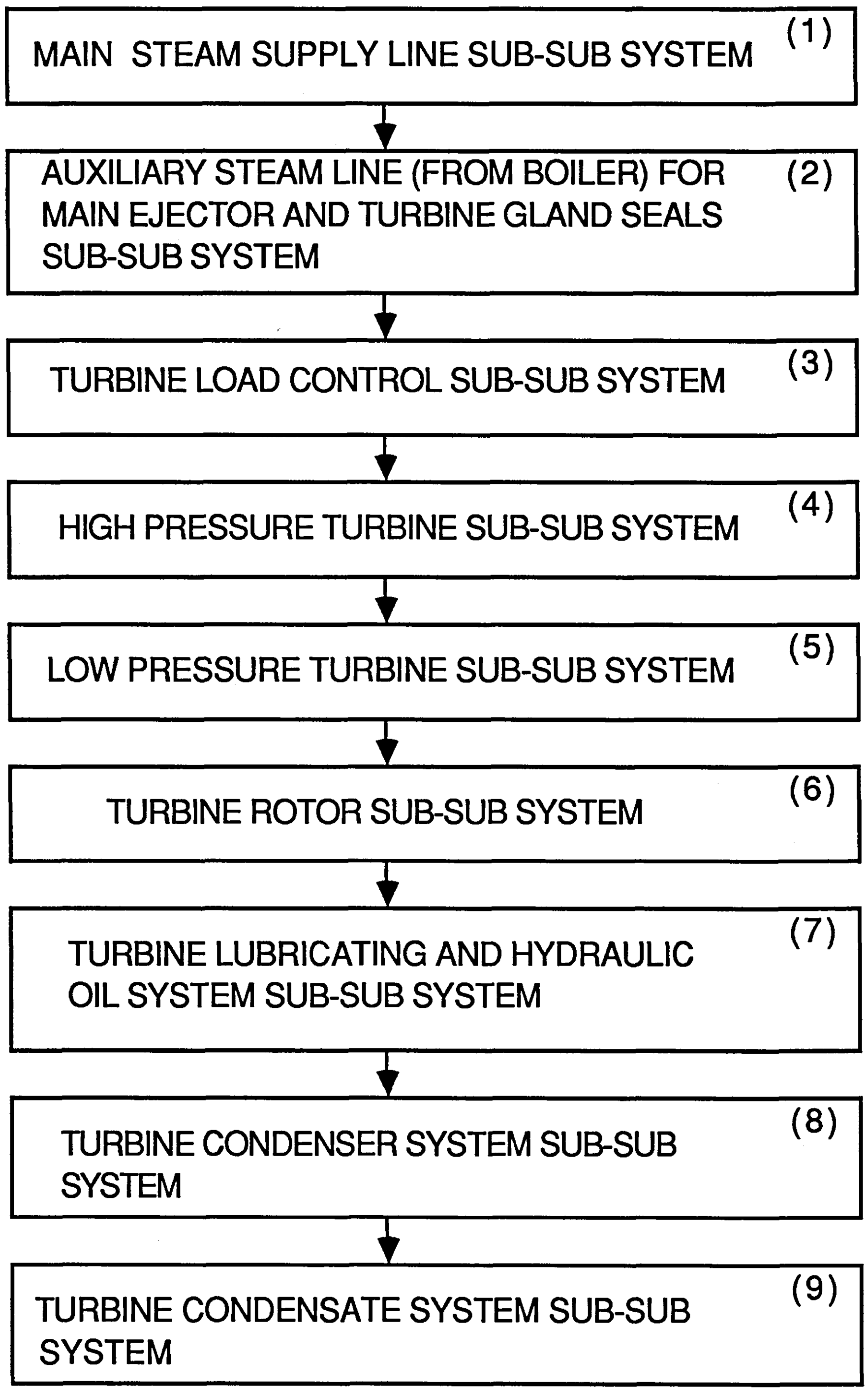
FIGURE NO 80



COMBINED BOILER COMBUSTION AIR & FLUE GASES

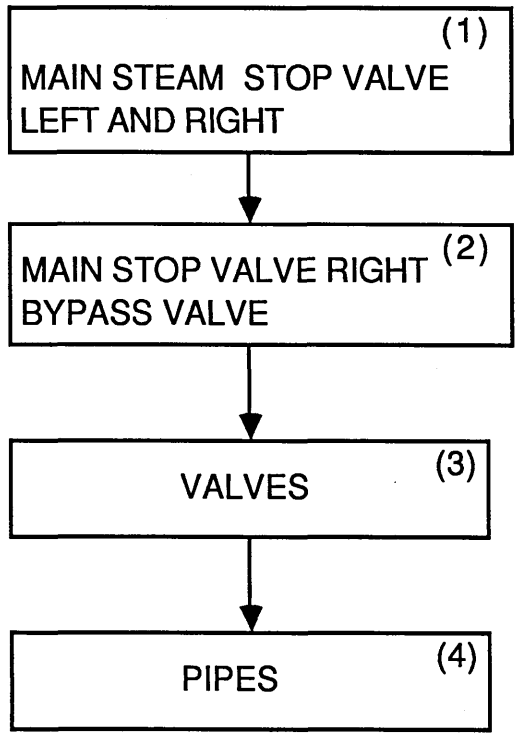
SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 81



TURBINE SUB SYSTEM RELIABILITY BLOCK DIAGRAM

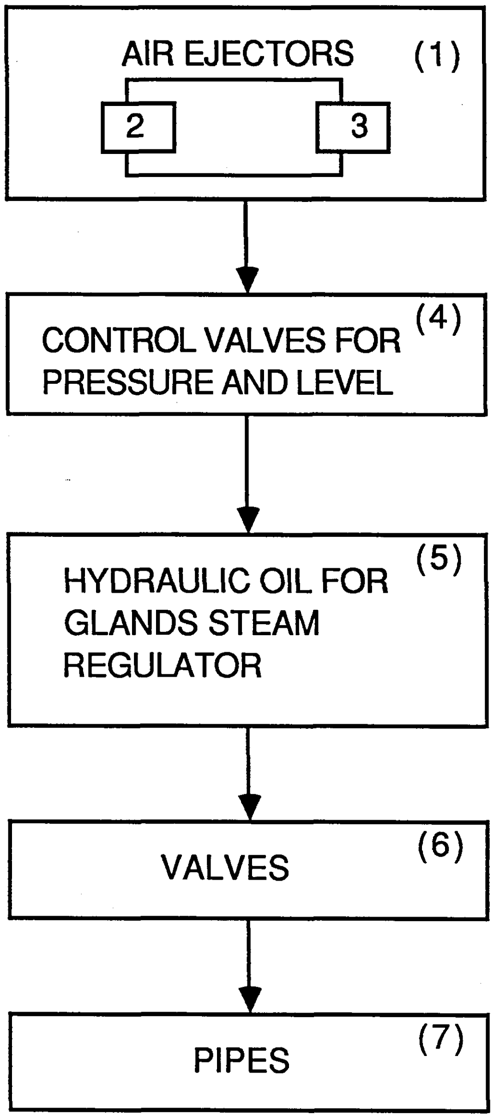
FIGURE NO 82



MAIN STEAM SUPPLY LINE

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

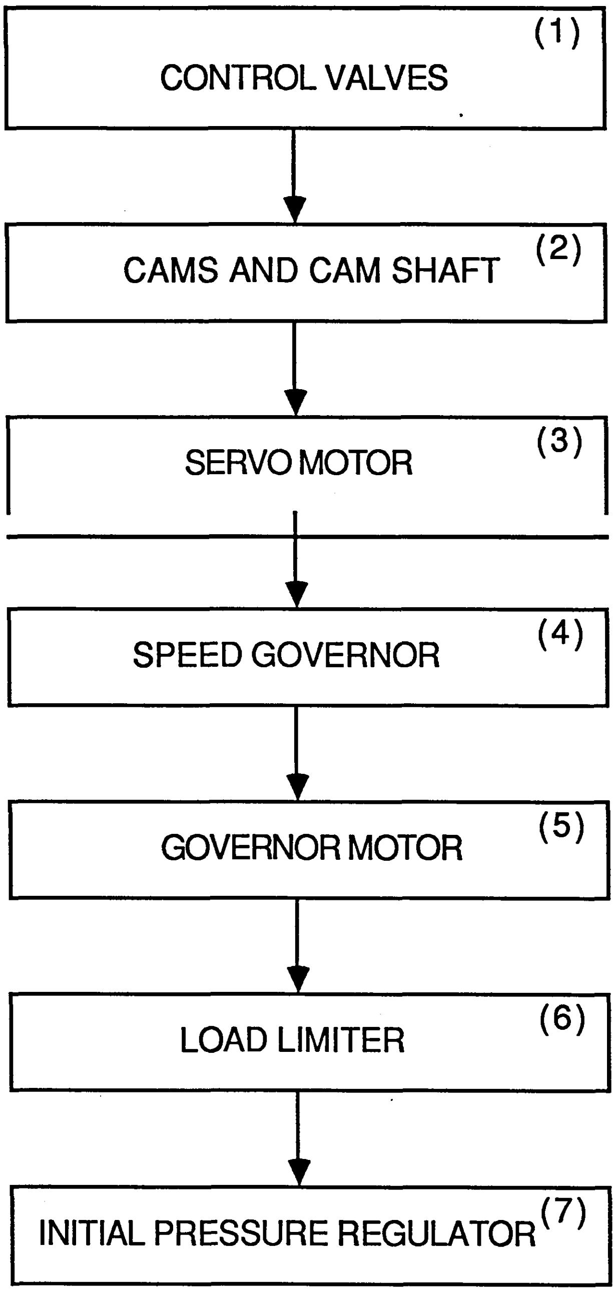
FIGURE NO 83



AXILIARY STEAM FOR TURBINE MAIN AIR EJECTOR

AND GLAND SEALS SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

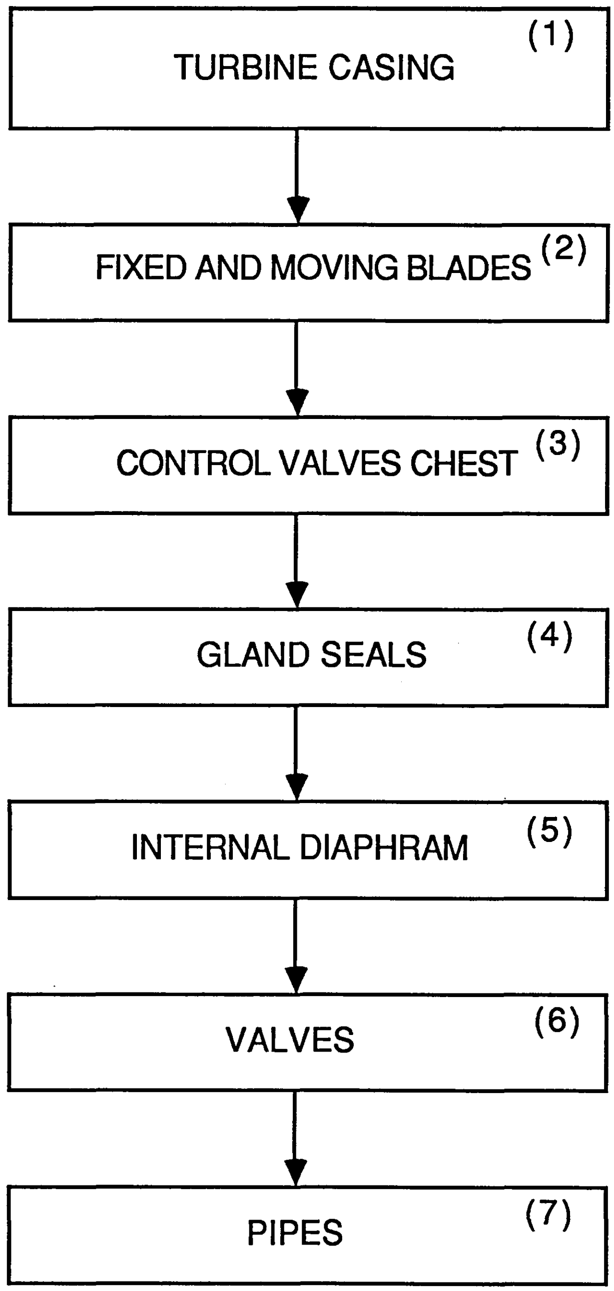
FIGURE NO 84



TURBINE LOAD CONTROL

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

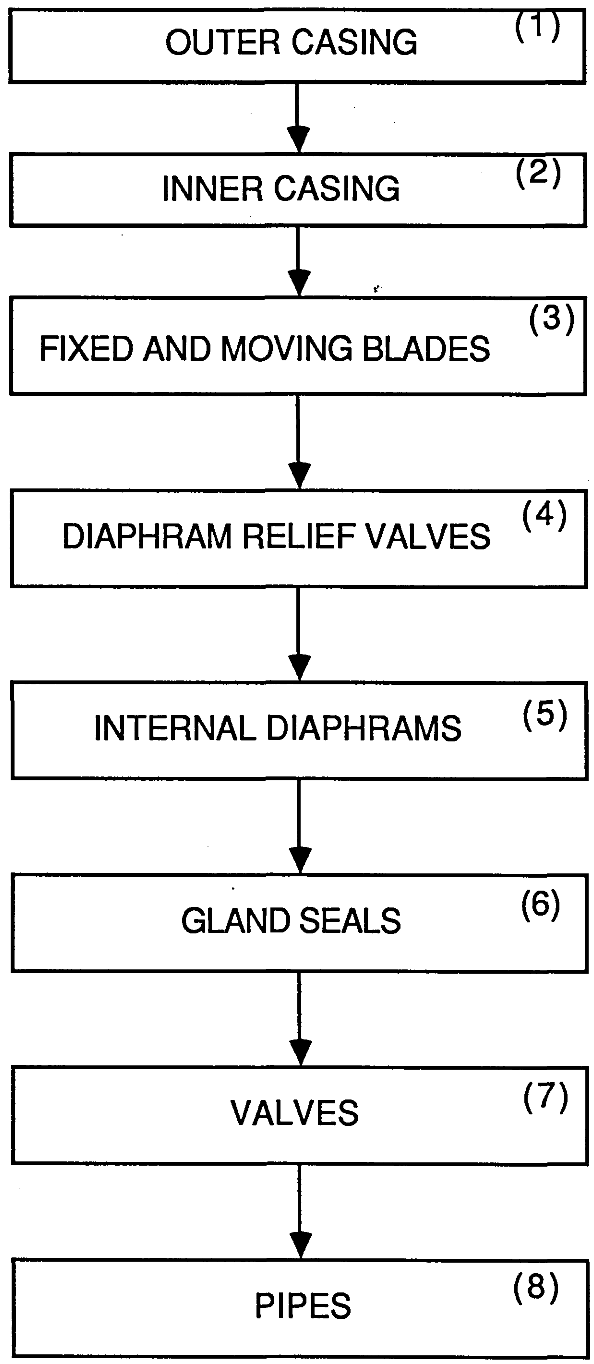
FIGURE NO 85



HIGH PRESSURE TURBINE

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

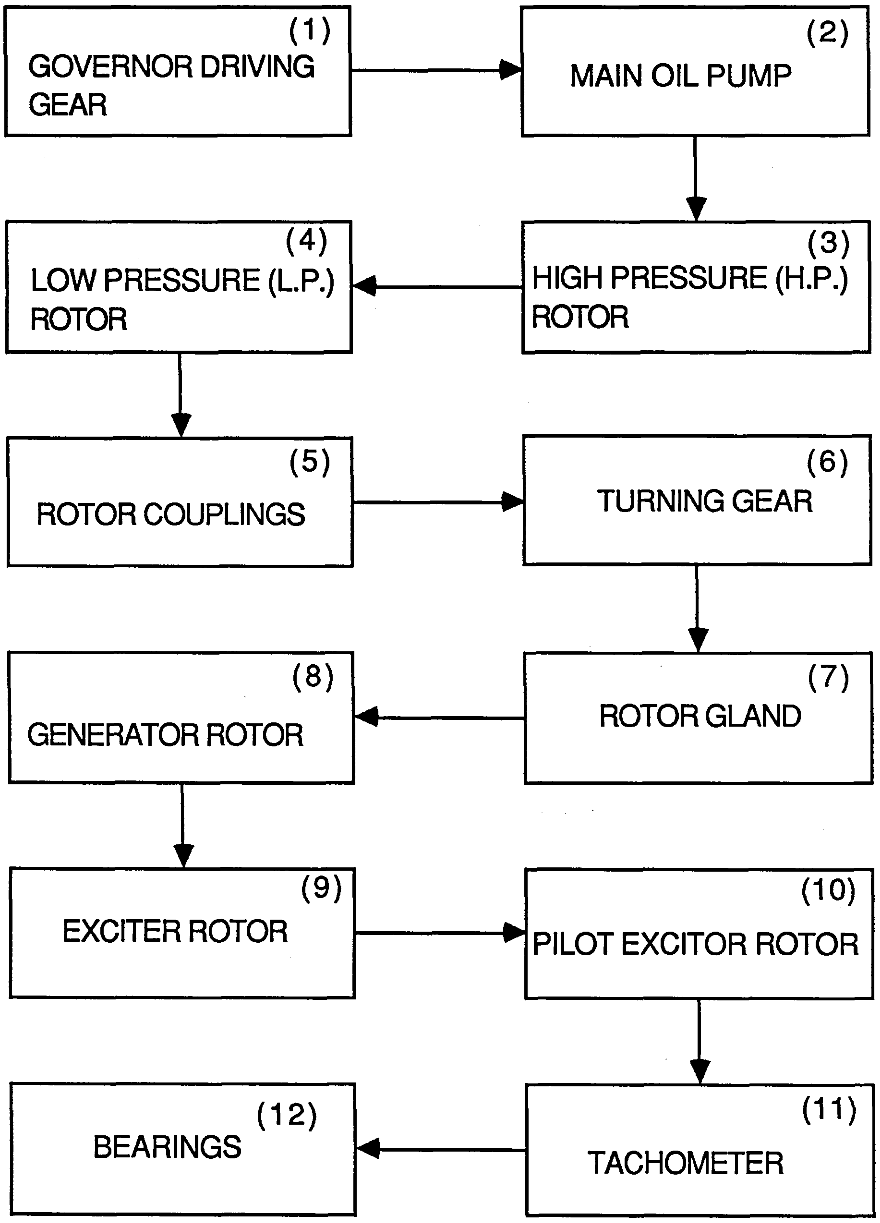
FIGURE NO 86



LOW PRESSURE TURBINE

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

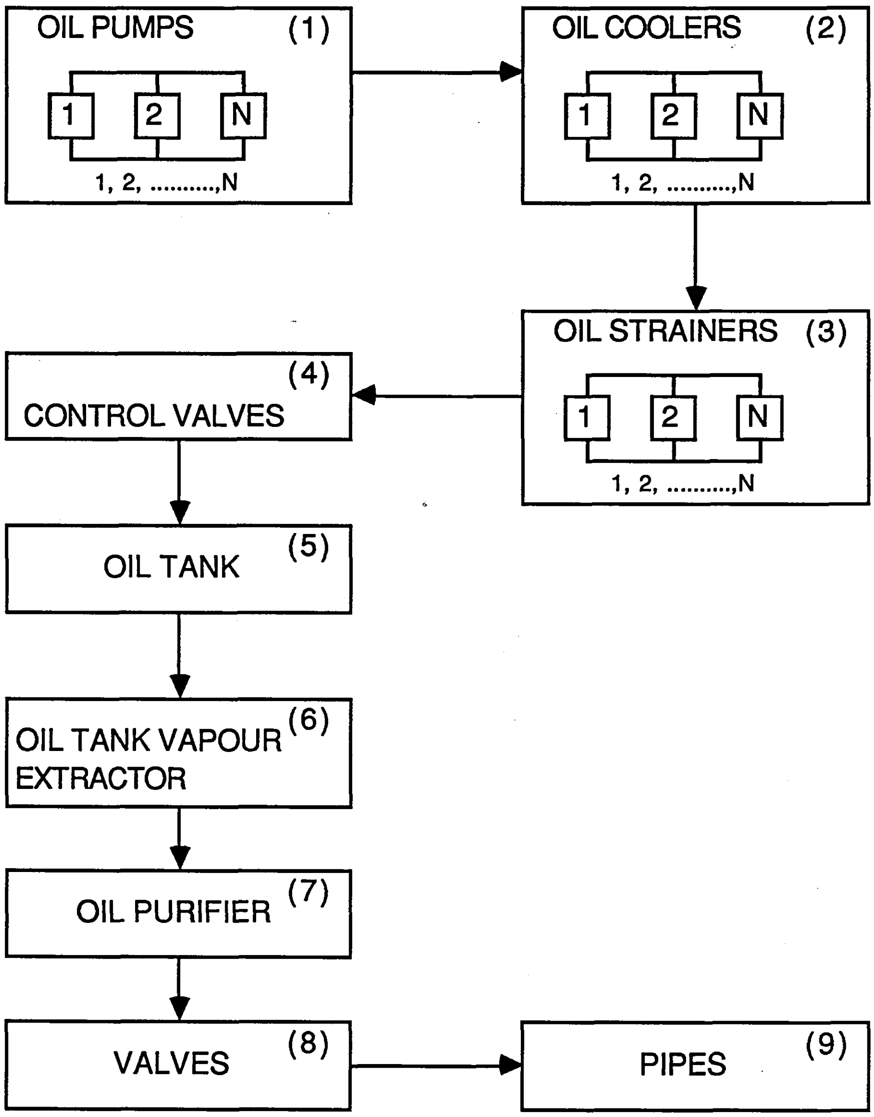
FIGURE NO 87



TURBINE ROTOR

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

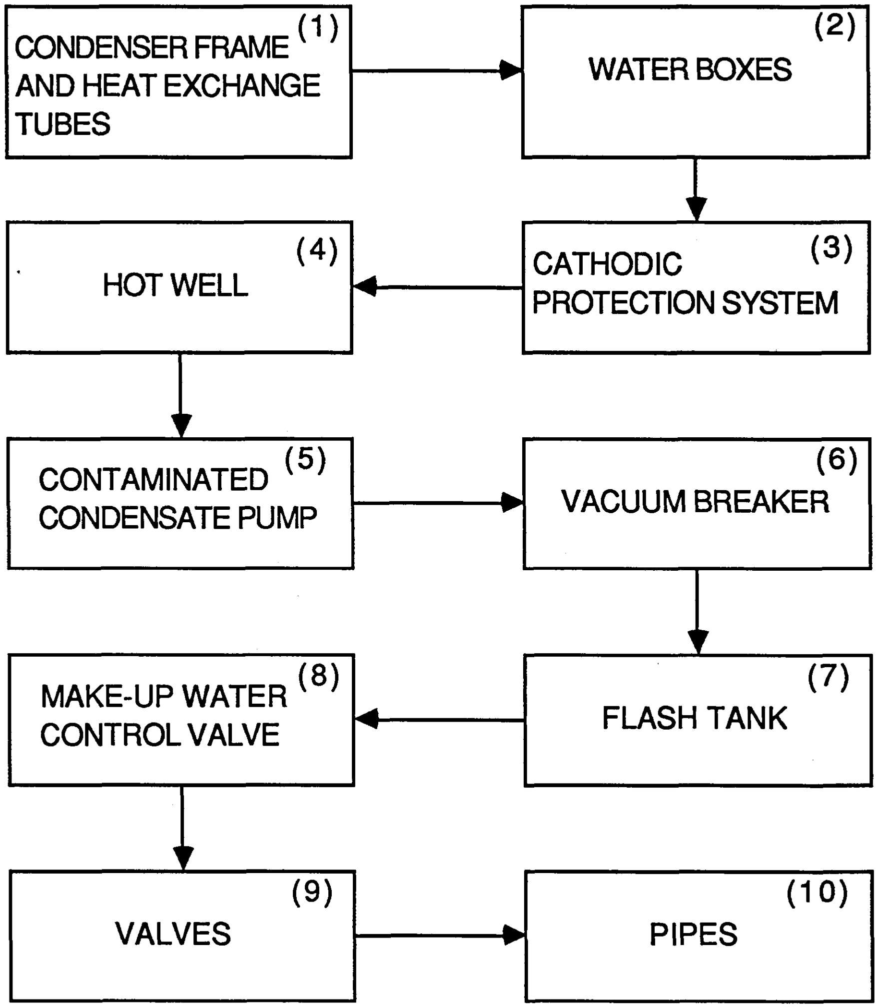
FIGURE NO 88



NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

TURBINE HYDRAULIC AND LUBRICATING OIL SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

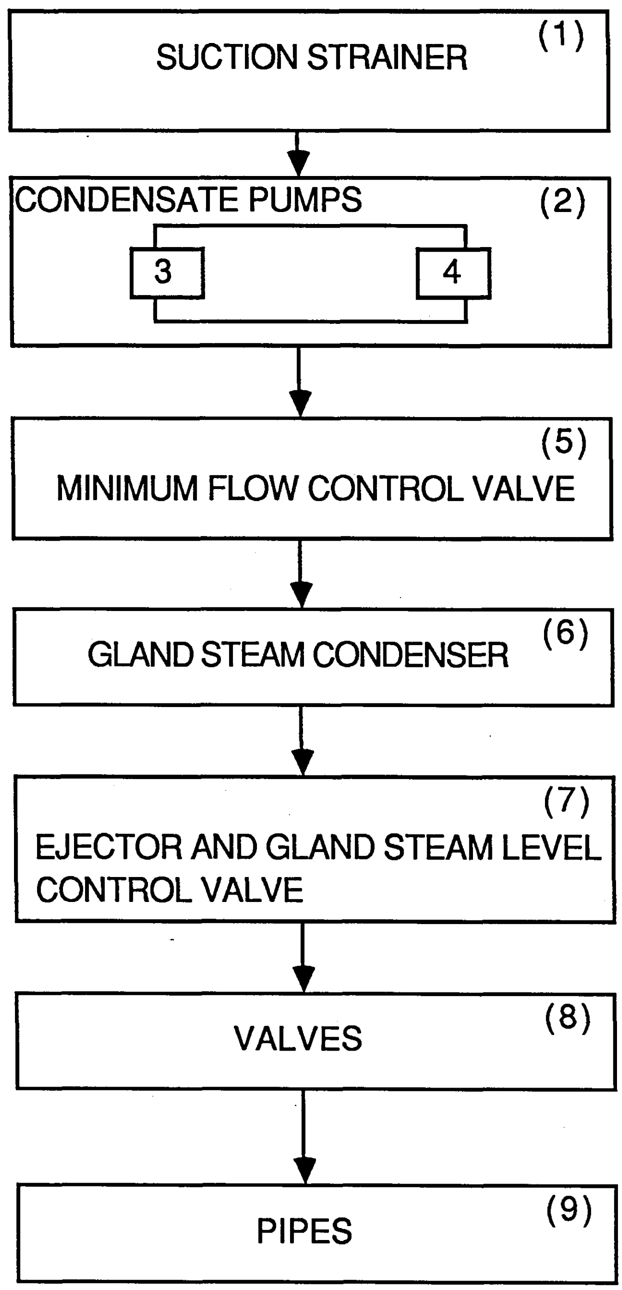
FIGURE NO 89



TURBINE CONDENSER

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

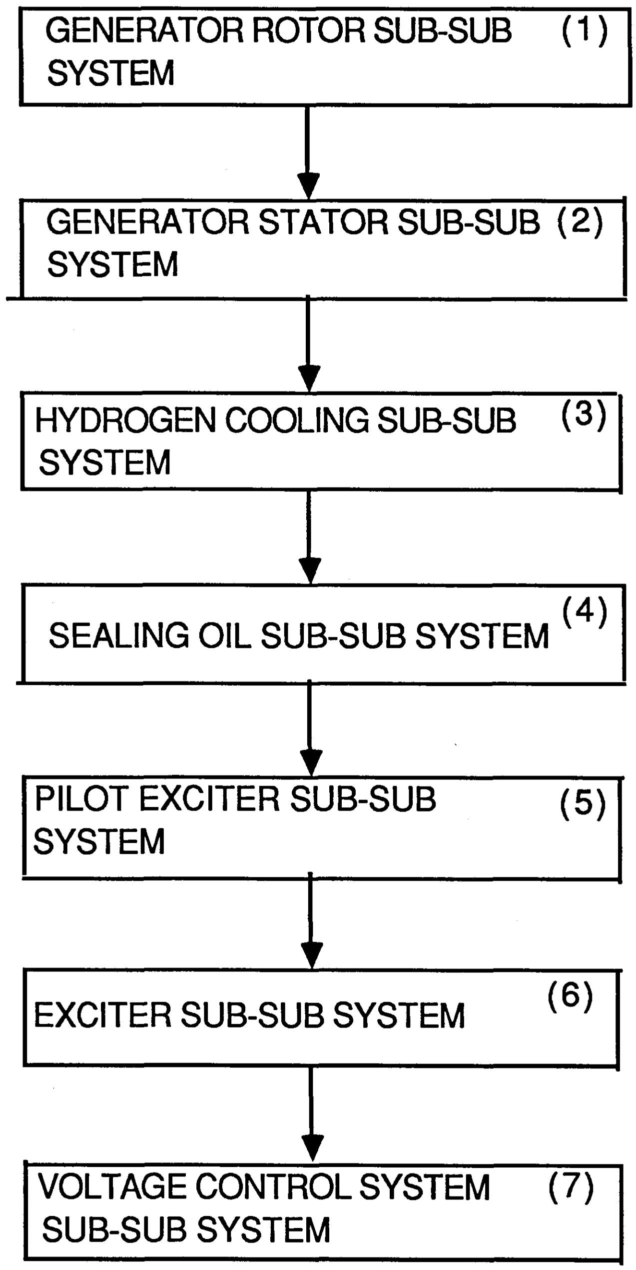
FIGURE NO 90



TURBINE CONDENSATE

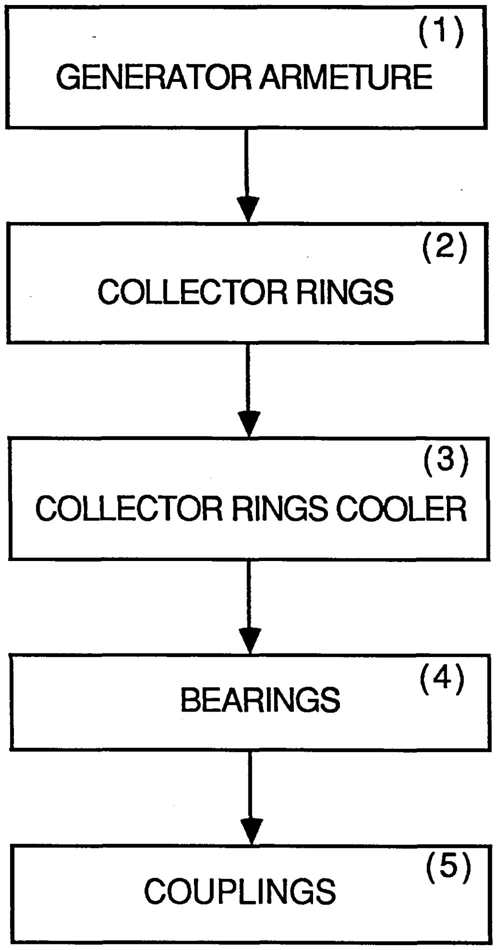
SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 91



GENERATOR SUB SYSTEM RELIABILITY BLOCK DIAGRAM

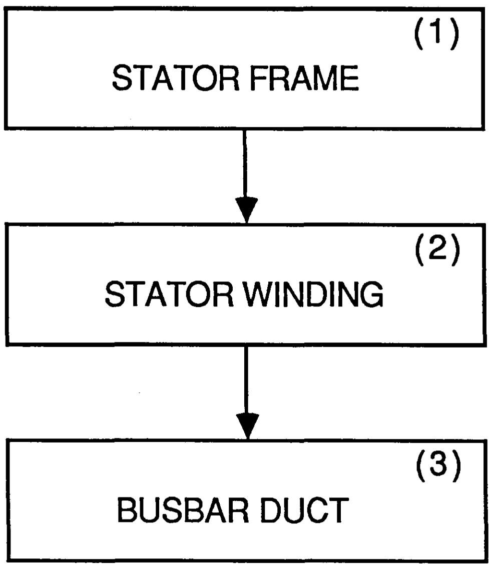
FIGURE NO 92



GENERATOR ROTOR

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

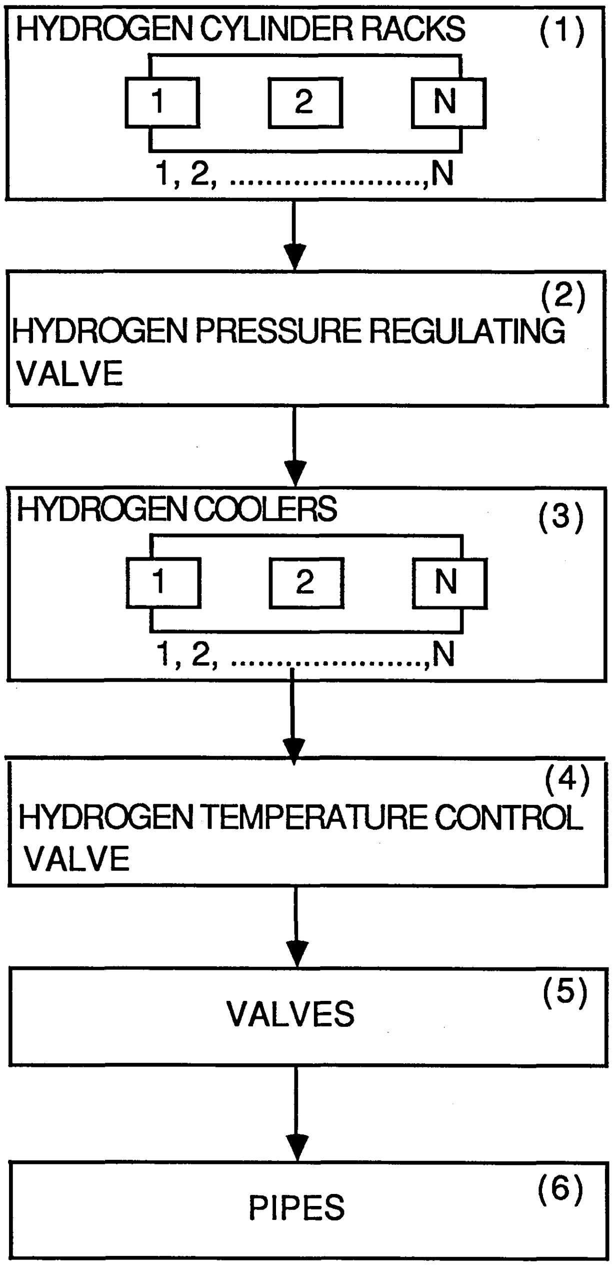
FIGURE NO 93



GENERATOR STATOR

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 94

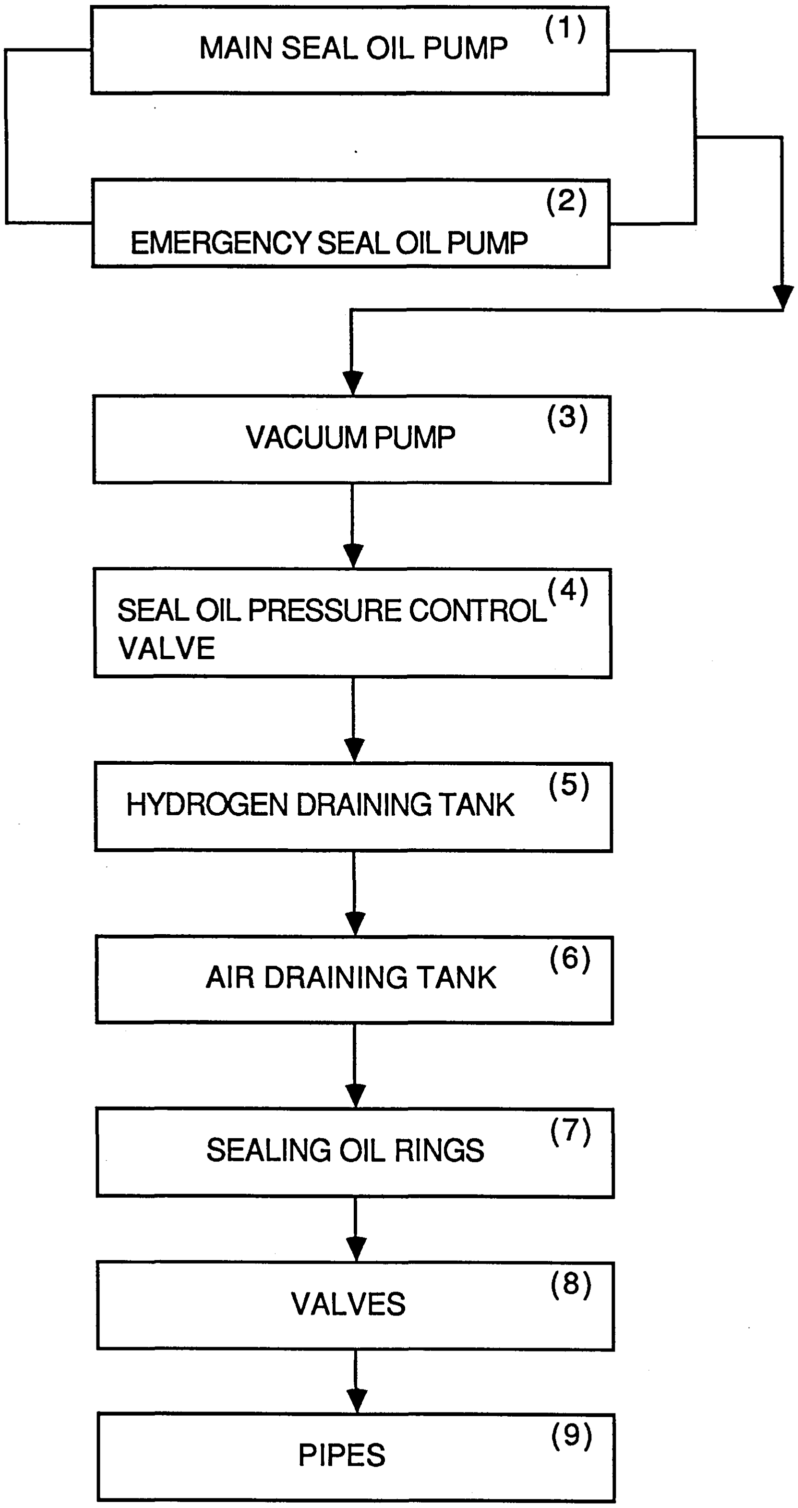


NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

GENERATOR HYDROGEN COOLING

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

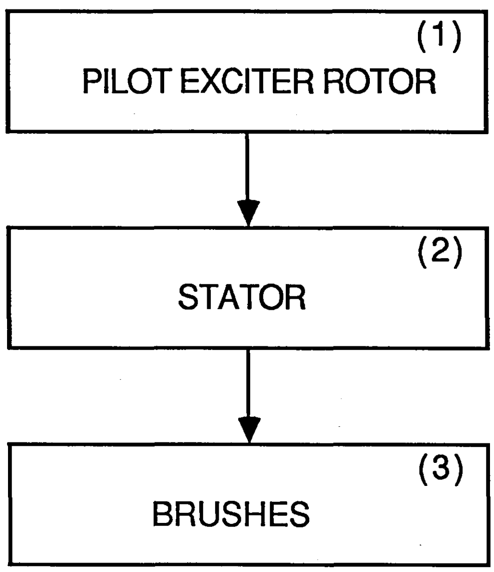
FIGURE NO 95



GENERATOR SEALING OIL

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

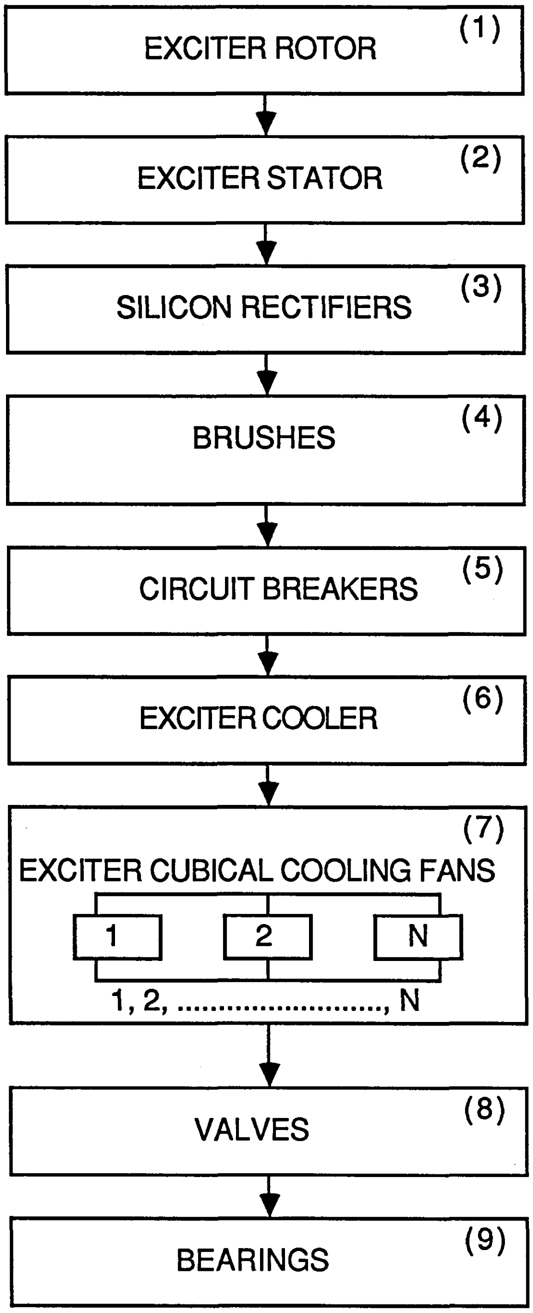
FIGURE NO 96



GENERATOR PILOT EXCITER

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

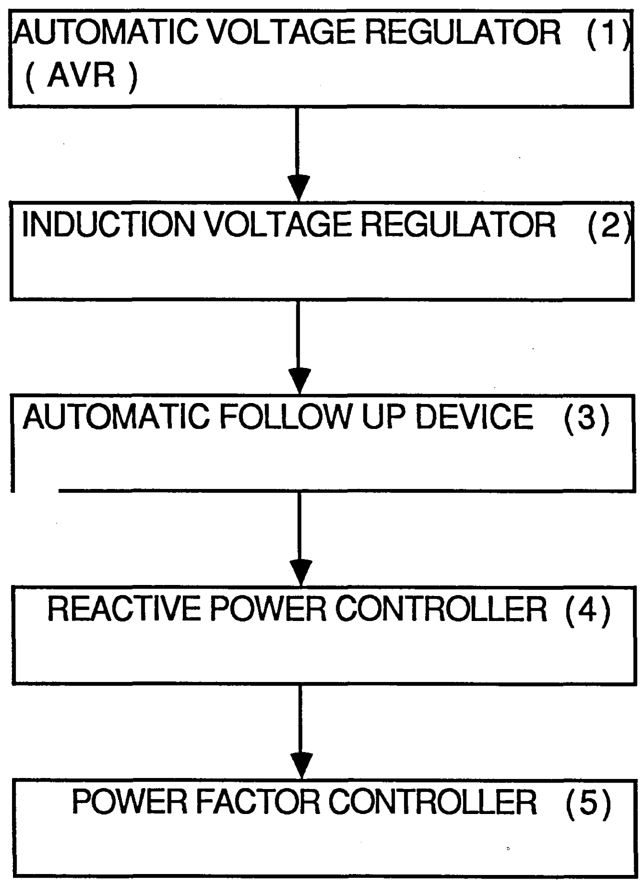
FIGURE NO 97



GENERATOR EXCITER

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

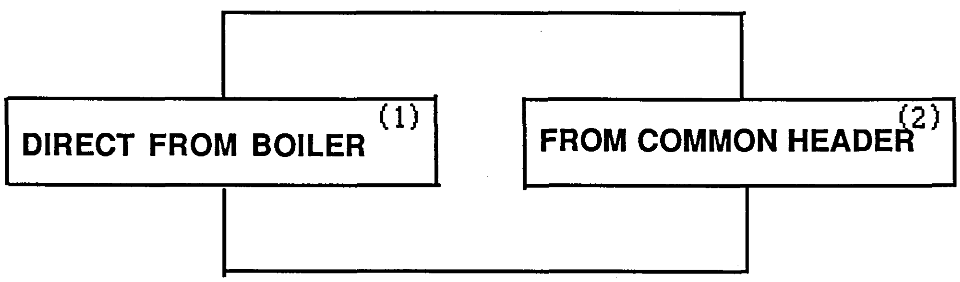
FIGURE NO 98



GENERATOR VOLTAGE CONTORL

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

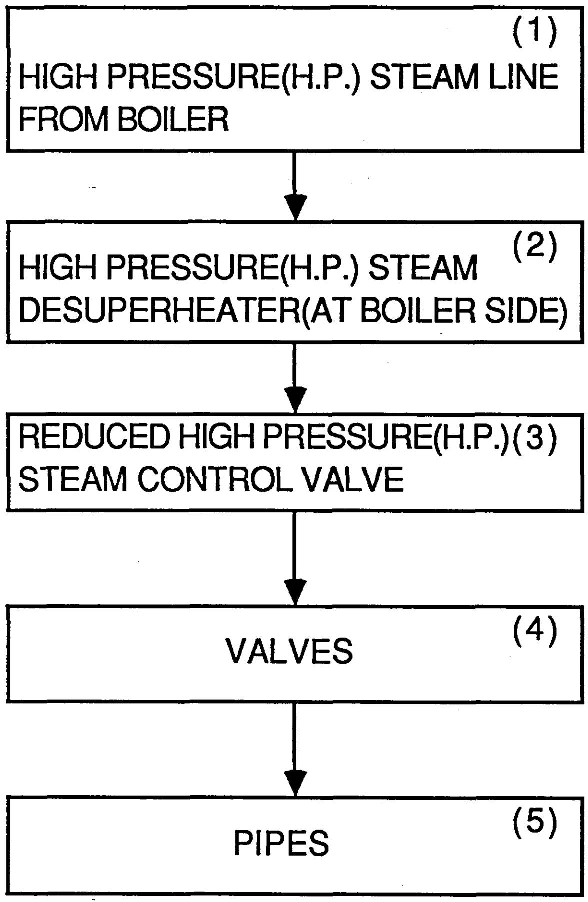
FIGURE NO 99



DISTILLER HIGH PRESSURE (H.P.) STEAM

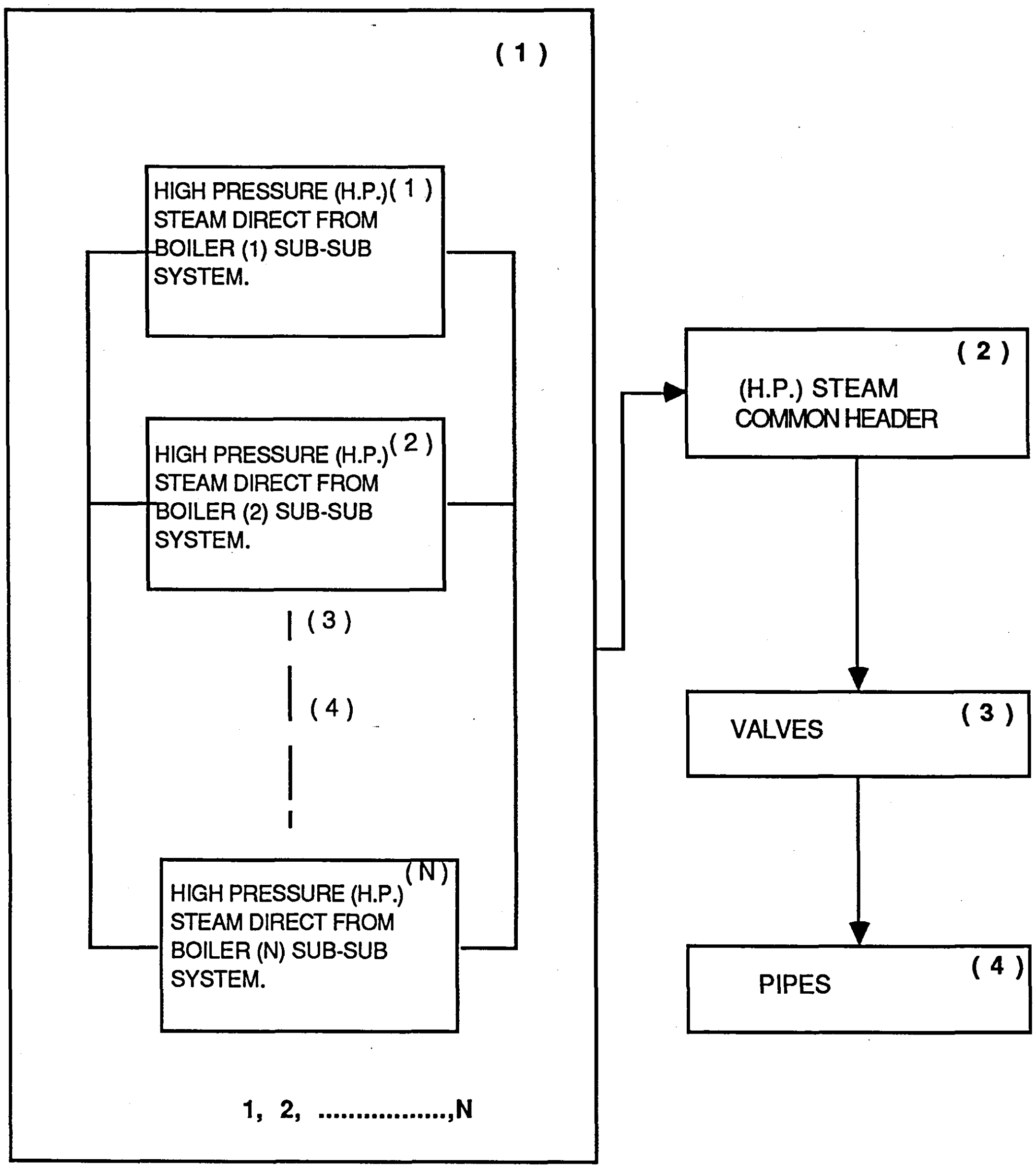
SUPPLY ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 100



HIGH PRESSURE (H.P.) STEAM DIRECT FROM BOILER SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

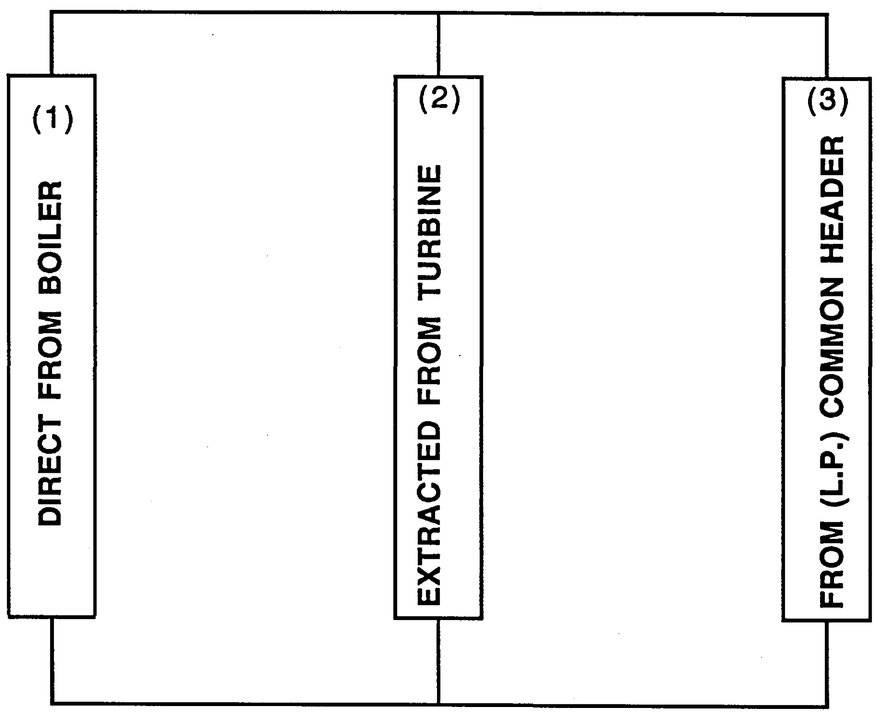
FIGURE NO 101



HIGH (H.P.) STEAM FROM COMMON

HEADER SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

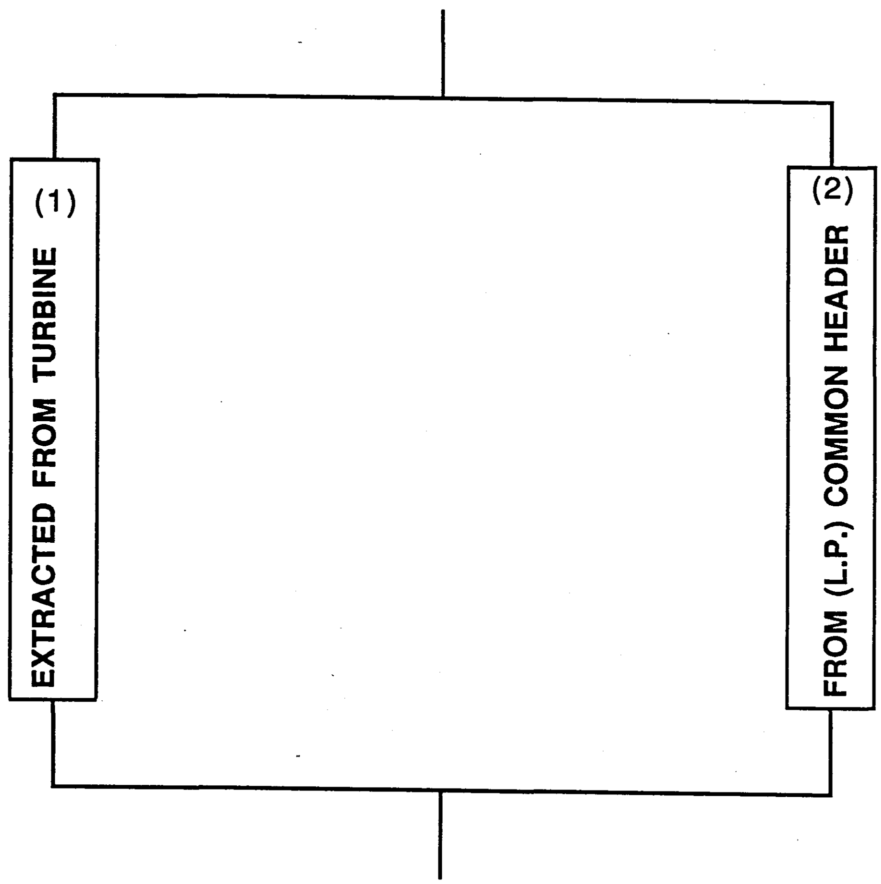
FIGURE NO 102



DISTILLER LOW PRESSURE (L.P.) STEAM

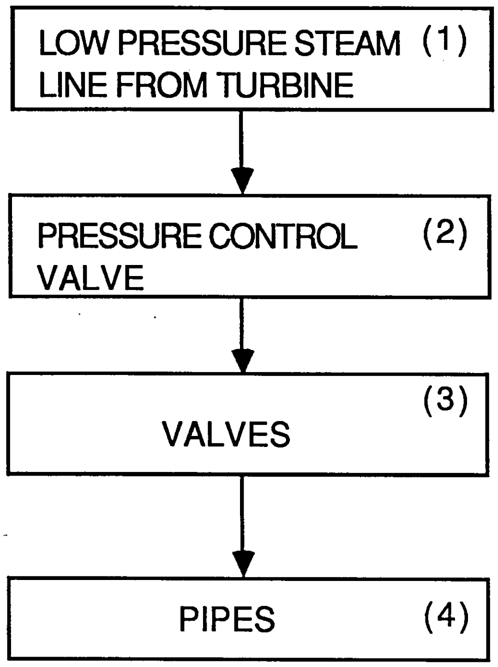
SUPPLY ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 103



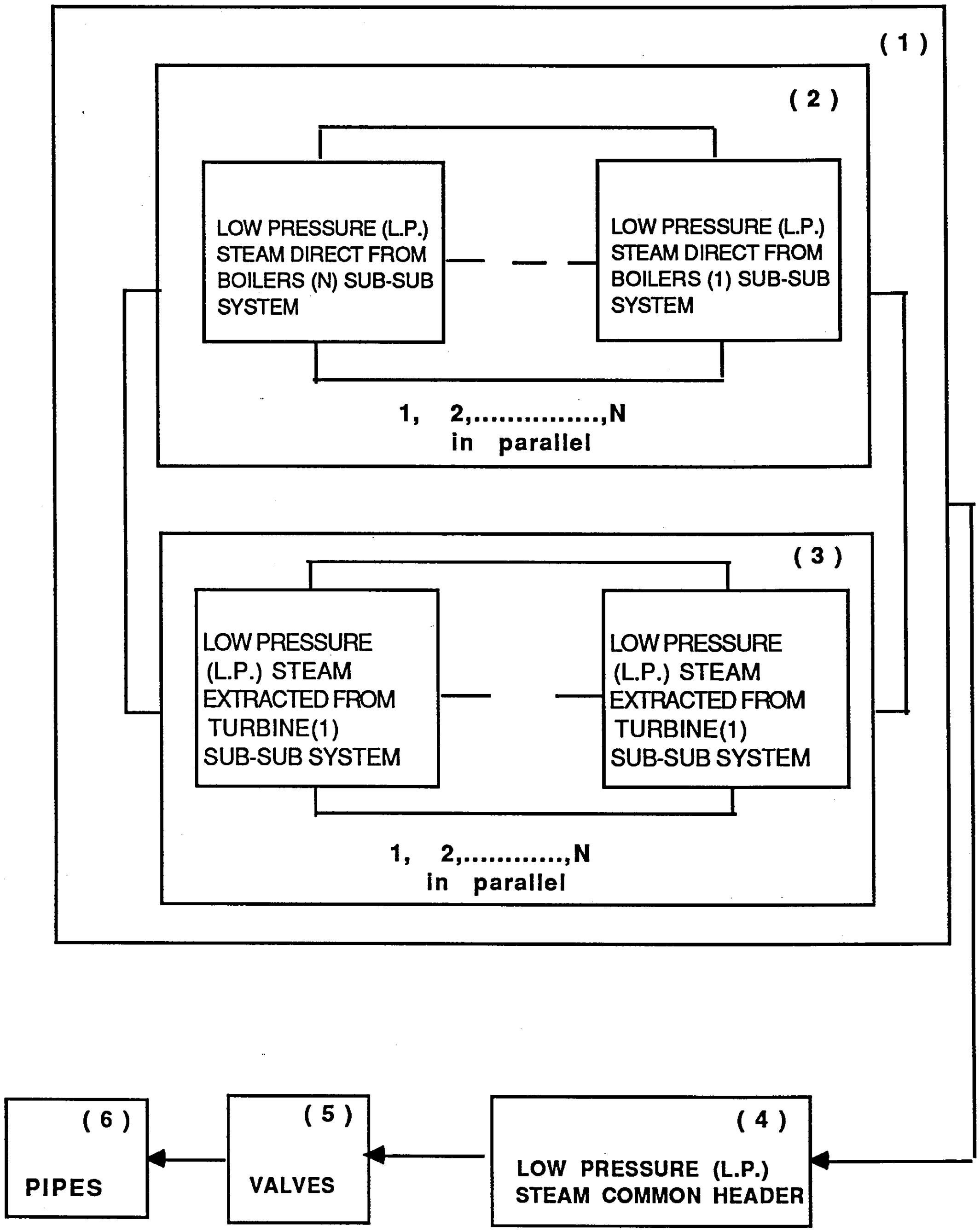
REDUCED DISTILLER LOW PRESSURE (L.P.) STEAM
SUPPLY ASSOCIATED SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 104



LOW PRESSURE (L.P) STEAM EXTRACTED FROM TURBINE SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 105

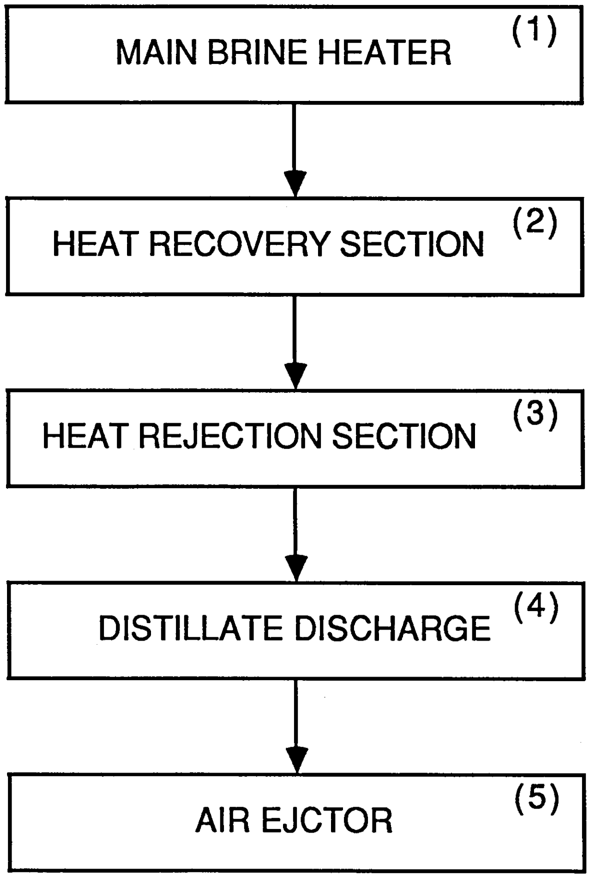


NOTE 3 : THE (N) IN EACH RELIABILITY BLOCK ARE EQUAL.

LOW PRESSURE (L.P.) STEAM FROM COMMON

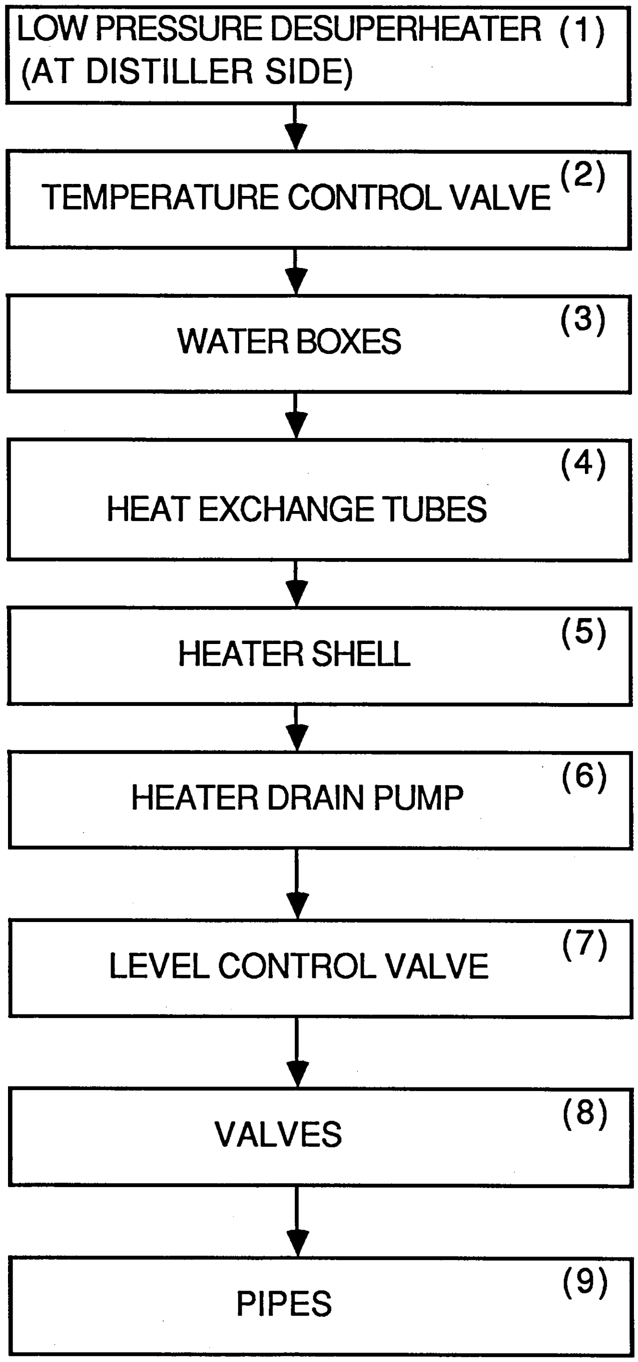
HEADER SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 106



DISTILLER SUB SYSTEM RELIABILITY BLOCK DIAGRAM

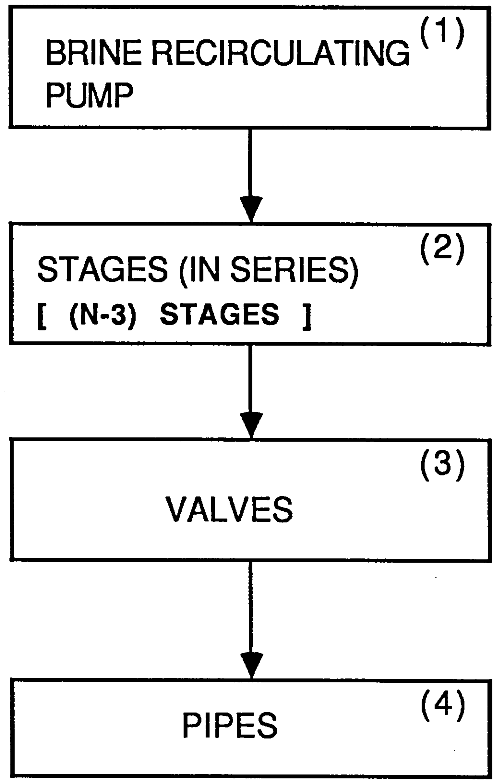
FIGURE NO 107



DISTILLER BRINE HEATER

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

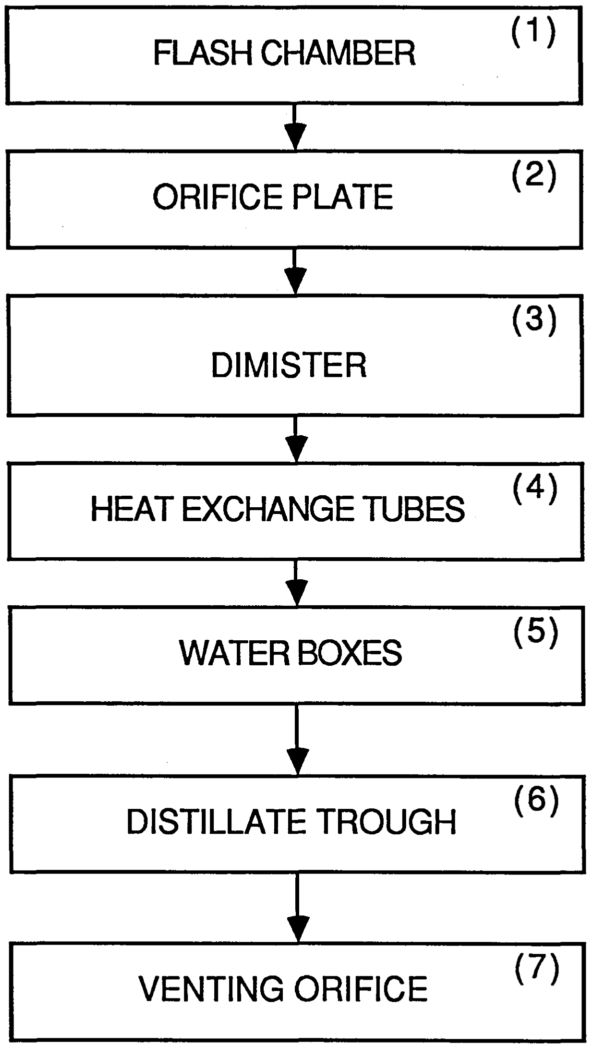
FIGURE NO 108



DISTILLER HEAT RECOVERY SECTION

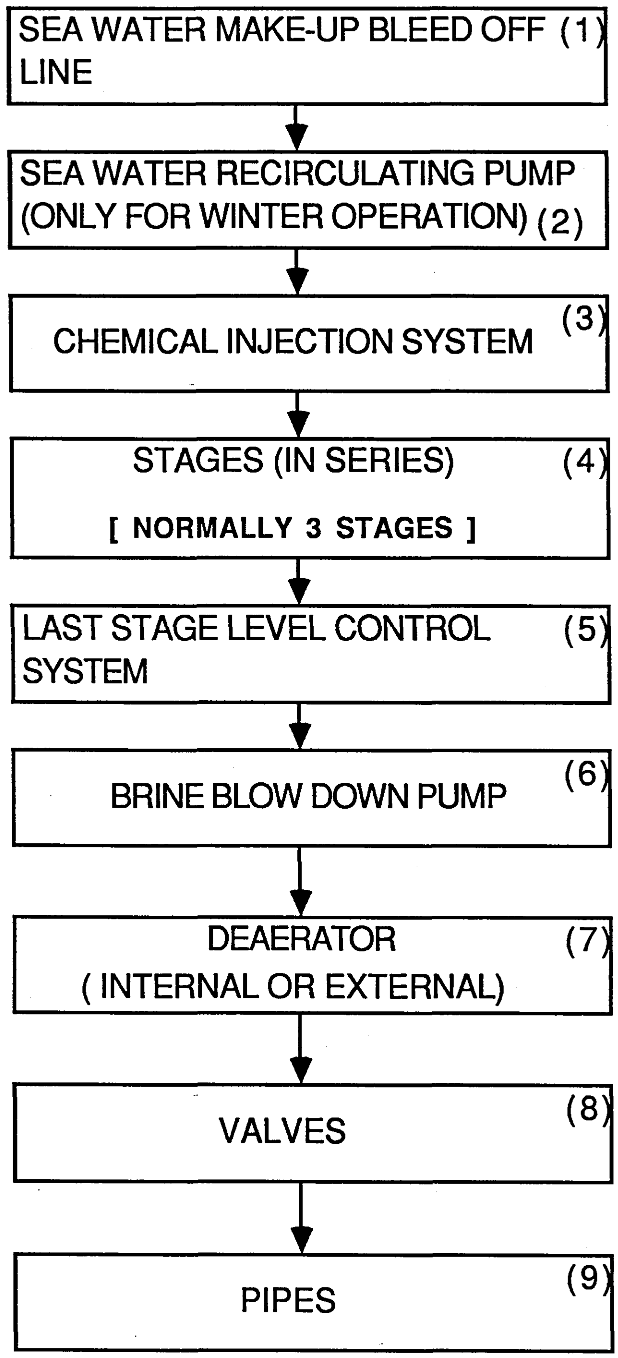
SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 109



DISTILLER HEAT RECOVERY SECTION STAGE SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

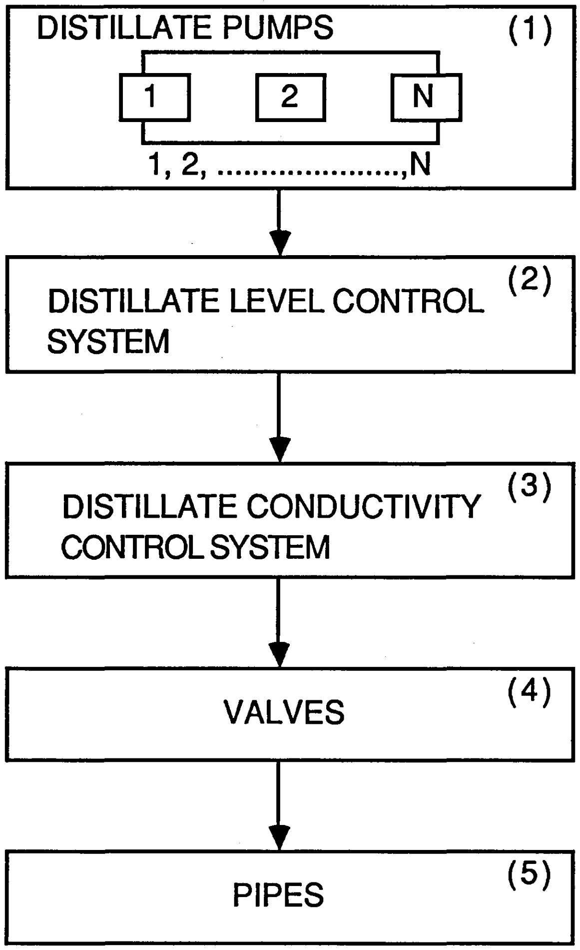
FIGURE NO 110



DISTILLER HEAT REJECTION SECTION

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

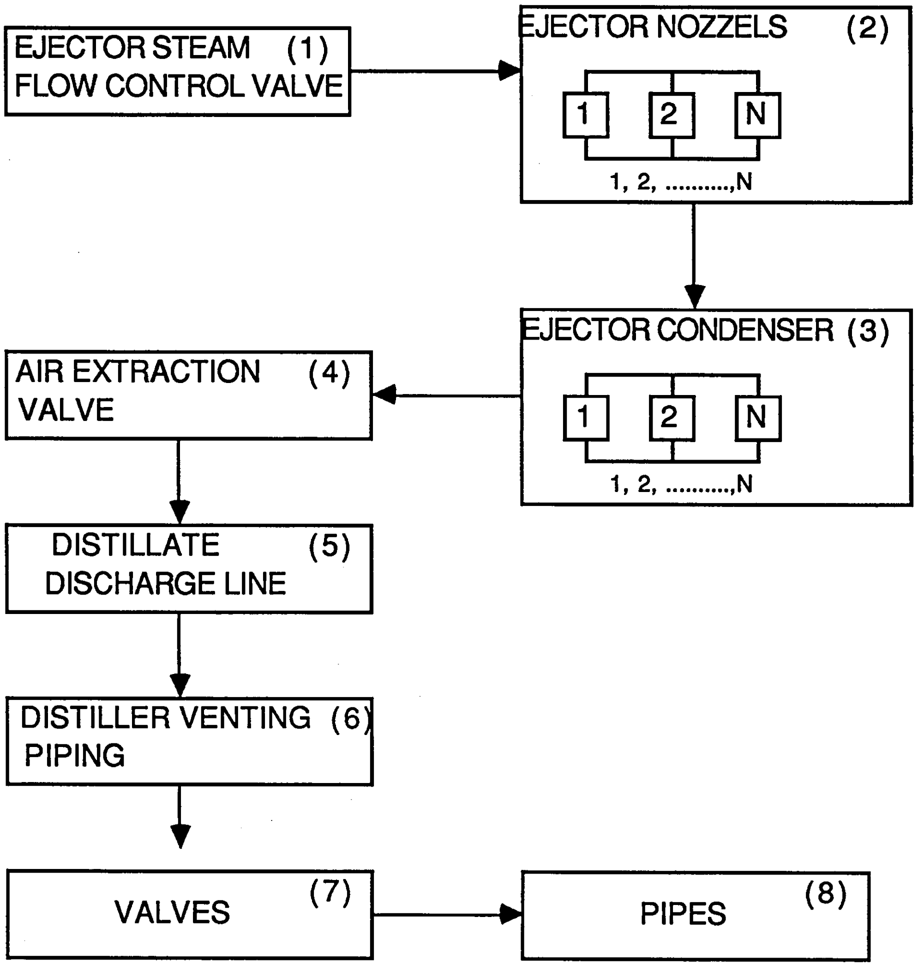
FIGURE NO 111



DISTILLATE DISCHARGE

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 112

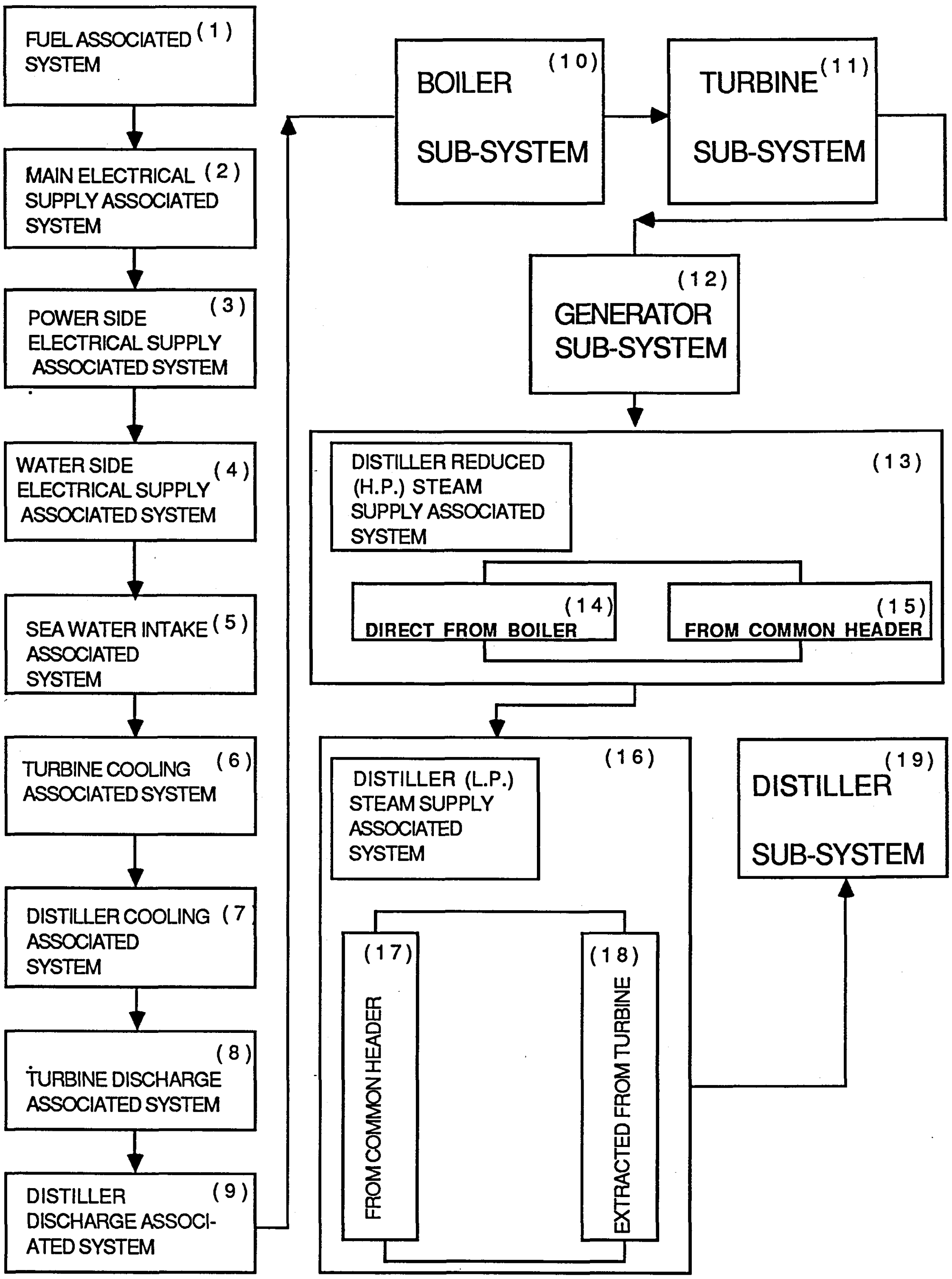


NOTE : THE (N) IN EACH RELIABILITY BLOCK ARE NOT NECESSARILY EQUAL.

DISTILLER EJECTOR

SUB-SUB SYSTEM RELIABILITY BLOCK DIAGRAM

FIGURE NO 113

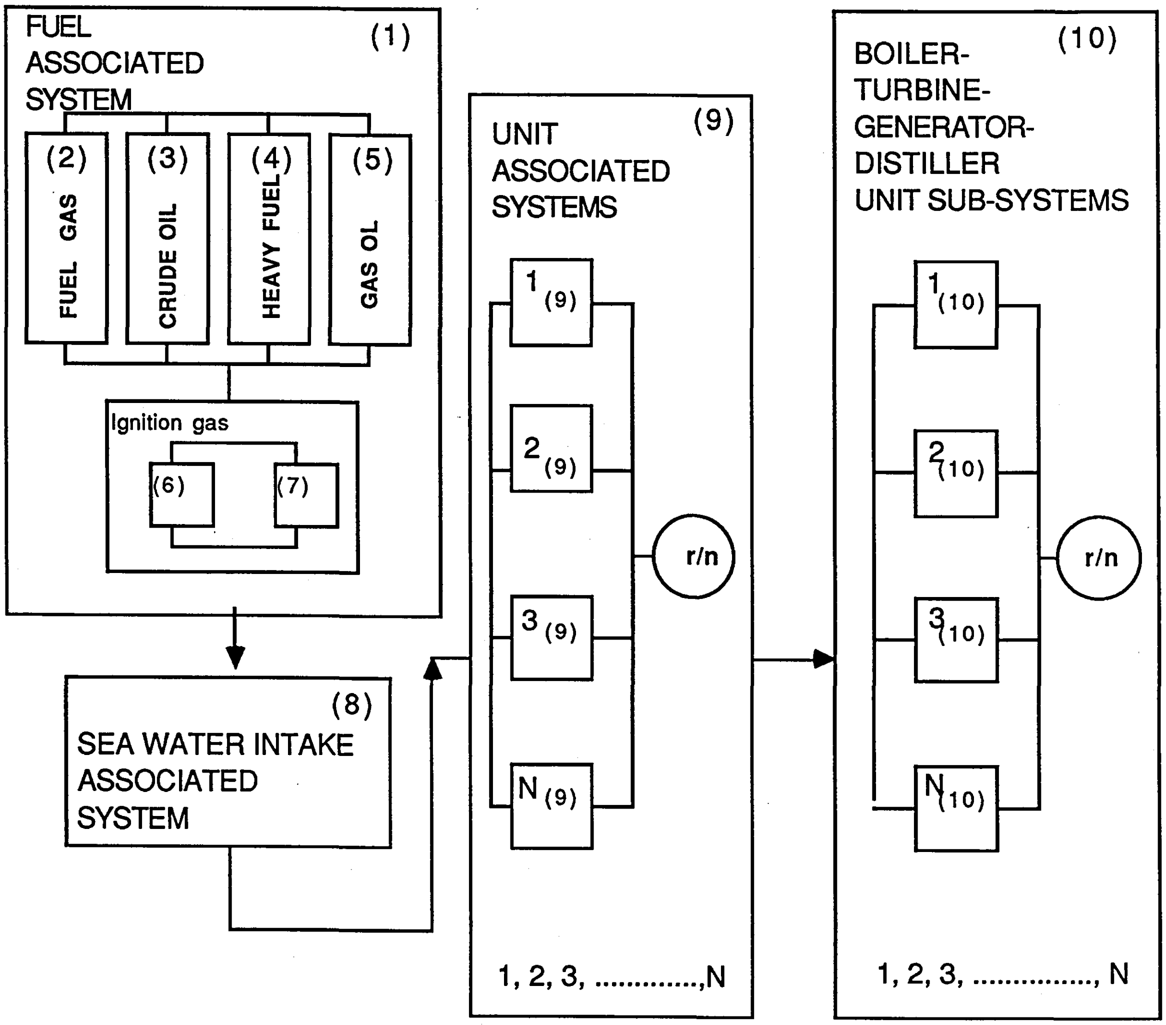


REDUCED

OVERALL DUAL- PURPOSE (POWER & WATER)

COMBINED UNIT RELIABILITY BLOCK DIAGRAM

FIGURE 114



NOTE 1 : THE (r / n) IN EACH RELIABILITY BOLCK ARE EQUAL.

NOTE 2 : THE (N) IN EACH RELIABILITY BLOCK ARE EQUAL.

REDUCED OVERALL

DUAL-PURPOSE(POWER&WATER) STATION RELIABILITY BLOCK DIAGRAM

5.6. Dual - Purpose (Power&Water) Station - Unit Sub - Systems - Unit Associated Systems. - And Their Sub - Sub Systems Reliability Models

In the Following sections the reliability models of the station, production unit, unit sub - systems, unit associated systems, and their sub - sub systems will be developed. It should be noted that the models are based on the reliability block diagrams (figures 62 - 114) of section (5.5) of this chapter, therefore, the reliability model in question should be examined in consultation with its corresponding reliability block diagram. Moreover, in the development of the models, it will be assumed that the failure rates of all equipment are exponentially distributed (constant failure rates). Detailed reliability models will be presented for four different type of the reliability block diagram configurations as was presented in section (5.4.1) of this chapter, in order to illustrate the techniques used to model them. The selected reliability block diagrams from section (5.5) for this purpose are as follows :

1. Fuel associated system (figure 62).

   This will represent a series and fully redundant parallel configuration.

2 Fuel gas sub - sub system (figure 63). This will represent a series configuration.

3. Crude oil sub - sub system (figure 64).

   This will represent a series and identical standby redundant configuration.

4. Reduced main electrical supply associated system (figure 68).

   This will represent a series and "**r**" out "**n**" configuration.

For the remainder of the reliability block diagrams, only the final models will be presented under the corresponding sections. It should be noted that the reliabilities {R (t) }and unreliabilities {Q (t)} in the developed models are time dependent, therefore, the sign (t) will be omitted from the models in order to make them easy to follow.

5.6.1. Fuel Associated System Reliability models

Referring to figure (62) we have the following :

1 Blocks (1) and (6) are connected in series.

2. Block (1) is composed of four fully redundant blocks (2, 3, 4, 5) which are connected in parallel.

3. Block (6) is composed of two fully redundant blocks (7, 8) which are connected in parallel.

Therefore, by applying the techniques presented in section (5.4) of this chapter, the reliability model for the fuel associated system (R_F), will be developed as follows :

From Equation (12), we have :

$$R_F = [R_1] \text{ X } [R_6] \quad \text{-------------------------(48)}$$

From Equation (26), we have :

$$R_1 = \Big[(R_2 + R_3 + R_4 + R_5) - (R_2 \text{X} R_3) - (R_3 \text{X} R_4) - (R_4 \text{X} R_5) - (R_5 \text{X} R_2) + (R_2 \text{ X } R_3 \text{ X } R_4 \text{ X } R_5) \Big]$$

$$R_6 = [R_7 + R_8] - [R_7 \text{ X } R_8]$$

Note that $R_8 = R_2$, substituting R_1 and R_6 in Equation (47), we have :

$$R_F = \Big[(R_2 + R_3 + R_4 + R_5) - (R_2 \text{X} R_3) - (R_3 \text{X} R_4) - (R_4 \text{X} R_5) - (R_5 \text{X} R_2) + (R_2 \text{ X } R_3 \text{ X } R_4 \text{ X } R_5) \Big] \text{ X } \Big[[R_7 + R_2] - [R_7 \text{ X } R_2] \Big]$$

Now substituting the failure rates (λ_ι),we have :

$$R_F = \Big[[(e^{-\lambda_2 t} + e^{-\lambda_3 t} + e^{-\lambda_4 t} + e^{-\lambda_5 t}) - (e^{-t(\lambda_2+\lambda_3)} - e^{-t(\lambda_3+\lambda_4)} - e^{-t(\lambda_4+\lambda_5)} - e^{-t(\lambda_5+\lambda_2)} + (e^{-t(\lambda_2+\lambda_3+\lambda_4+\lambda_5)} \Big] \text{ X } \Big[(e^{-\lambda_7 t} + e^{-\lambda_2 t}) - (e^{-(\lambda_2+\lambda_7)}) \Big] \quad \text{------------------------(49)}$$

The unreliability (Q_F) will be :

$$Q_F = 1 - R_F \quad \text{--------------------(50)}$$

The mean time between failures(MTBT)$_F$ will be :

$$(\text{MTBT})_F = \int_0^\infty R_F \, dt \quad \text{-----------------------------------(51)}$$

5.6.1.1. Fuel Gas Sub - Sub System Reliability Models

Referring to figure (63) we have Blocks (1), (2), (3), (4), and (5) are connected in series.Therefore, by applying the techniques presented in section (5.4) of this chapter, the reliability model for the fuel gas sub - sub system (R_{FG}), will be developed as follows :

From Equation (12), we have,

$$R_{FG} = [R_1] \times [R_2] \times [R_3] \times [R_4] \times [R_5] \quad \text{-----------------(52)}$$

Substituting the failure rates, we have :

$$R_{FG} = [e^{-t(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)}] \quad \text{--------------------------------(53)}$$

The unreliability (Q_{FG}) will be :

$$Q_{FG} = 1 - [e^{-t(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)}] \quad \text{--------------------------(54)}$$

The mean time between failures $(MTBT)_{FG}$ will be :

$$(MTBT)_{FG} = \int_0^{\infty} R_{FG}\, dt \quad \text{------------------------------------(55)}$$

5.6.1.2. Crude Oil Sub - Sub System Reliability Models

Referring to figure (64),we have the following :

1. Blocks (1), (2), (3), (4), (5), and (6) are connected in series.
2. Blocks (3) is composed of (N) identical redundant standby components.
3. Block (5) is composed of (N) identical redundant standby components.
4. The (N) components in blocks (3) and (5) are not necessarily equal.

Therefore, by applying the techniques presented in section (5.4) of this chapter, the reliability model for the crude oil sub - sub system (R_{CO}), will be developed as follows :

From Equation (12), we have,

$$R_{CO} = [R_1] \times [R_2] \times [R_3] \times [R_4] \times [R_5] \times [R_6] \quad \text{-----------(56)}$$

Since block (3) consists of (N_3) identical components, and block (5) consists of (N_5) identical components Now assuming perfect changeover, the the reliability of the each block can be evaluated by the use of the poisson distribution [36], therefore the reliability of block (3) will be as follows, :

From Equation (44), we have,

$$R_3 = \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} \; e^{-(\lambda_3 t)}}{x_3 !}$$

And the reliability of block (5) will be as follow

$$R_5 = \sum_{x_5=0}^{n_5} \frac{(\lambda_5 t)^{x_5} \; e^{-(\lambda_5 t)}}{x_5 !}$$

Now substituting the failure rates in Equation (55) we have :

$$R_{CO} = e^{-t(\lambda_1 + \lambda_2 + \lambda_4 + \lambda_6)} \text{ X } \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} \; e^{-(\lambda_3 \tau)}}{x_3 !} \text{ X } \sum_{x_5=0}^{n_5} \frac{(\lambda_5 t)^{x_5} \; e^{-(\lambda_5 t)}}{x_5 !} \quad \text{---------(57)}$$

The unreliability (QCO) (t) will be as follows :

$$QCO = 1 - R_{CO} \quad \text{---(58)}$$

The mean time between failure $(MTBT)_{CO}$ will be as follows :

$$(MTBF)_{CO} = \int_0^{\infty} R_{CO} \, dt \quad \text{---(59)}$$

5.6.1.3. Heavy Fuel Oil Sub - Sub System Reliability models

Referring to figure (65), the reliability models for the heavy fuel oil sub - sub system (R_{HFO}) will be :

$$R_{HFO} = [R_1] \text{ X } [R_2] \text{ X } [R_3] \text{ X } [R_4] \text{ X } [R_5] \text{ X} [R_6] \text{ X } [R_7]$$

Substituting for $[R_3]$, $[R_5]$, and $[R_6]$ we have :

$$R_3 = \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} \; e^{-(\lambda_3 t)}}{x_3 !}$$

Since the formula for [R_5] and [R_7] are similar to [R_3], therefore the reliability (R_{HFO}) will be :

$$R_{HFO} = e^{-t(\lambda_1+\lambda_2+\lambda_4+\lambda_7)} \times \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} e^{-(\lambda_3 t)}}{x_3 !} \times \sum_{x_5=0}^{n_5} \frac{(\lambda_5 t)^{x_5} e^{-(\lambda_5 t)}}{x_5 !} \times \sum_{x_6=0}^{n_6} \frac{(\lambda_6 t)^{x_6} e^{-(\lambda_6 t)}}{x_6 !} \quad \text{-----------(60)}$$

The unreliability (Q_{HFO}) will be :

$$Q_{HFO} = 1 - R_{HFO} \quad \text{-----------(61)}$$

The mean time between failures $(MTBF)_{HFO}$ will be :

$$(MTBF)_{HFO} = \int_0^{\infty} R_{HFO} \, dt \quad \text{-----------(62)}$$

5.6.1.4 Gas Oil Sub - Sub System Reliability models

Referring ti figure (66), the reliability models for the gas oil sub - sub system $\{R_{GO}(t)\}$ will be :

$$R_{GO} = e^{-t(\lambda_1+\lambda_2+\lambda_4+\lambda_6)} \times \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} e^{-(\lambda_3 \tau)}}{x_3 !} \times \sum_{x_5=0}^{n_5} \frac{(\lambda_5 t)^{x_5} e^{-(\lambda_5 t)}}{x_5 !} \quad \text{-----------(63)}$$

The unreliability (Q_{GO}) will be :

$$Q_{GO} = 1 - R_{GO} \quad \text{-----------(64)}$$

And the mean time between failure $(MTBF)_{GO}$ will be :

$$(MTBF)_{GO} = \int_0^{\infty} R_{GO} \, dt \quad \text{-----------(65)}$$

5.6.2 Sea water Intake Associated System Reliability Models

Referring ti figure (67), the reliability models for the sea water intake associated system (R_{SW}) will be :

$$R_{SW} = [e^{-t(\lambda_1 + \lambda_2 + \lambda_3)}] \quad \text{-----(66)}$$

And the unreliability (Q_{SW}) will be :

$$Q_{SW} = 1 - [e^{-t(\lambda_1 + \lambda_2 + \lambda_3)}] \quad \text{-----(67)}$$

The mean time between failures $(MTBF)_{SW}$ will be :

$$(MTBF)_{SW} = \int_0^\infty R_{SW}\, dt \quad \text{-----(68)}$$

5.6.3. Reduced Main Electrical Supply Associated System Reliability Models

Referring to figure (68), we have the following :

1. Blocks (1) and (2) are connected in series.
2. Block (1) is composed of n - identical unit generator transformers connected in parallel and they are fully redundant.
3. The success condition of block (1) is that "r" unit generator transformers out of "n" unit generator transformers must work.

Therefore, by applying the techniques presented in section (5.4) of this chapter, the reliability models for the reduced main electrical supply associated system (R_{RME}) will be developed as follows:

$$R_{RME} = [R_1] \text{ X } [R_2] \quad \text{-----(69)}$$

Now block (1) is connected in "**r**" out of "**n**" configuration, let,

λ = the average value of the failure rates of [n] generators transformers.

Based on the number of generators transformers that have to be working "r", one can proceed to calculate $[R_1]$. If for example "n" is equal to 7, and "r" is equal to 5 then $[R_1]$ is equal to sum of the first three terms of the binomial expansion. If we substitute the the average value of the failure rates of [n] generators transformers (λ) in binomial expansion then $[R_1]$ will be :

$$[R_1] = e^{-7\lambda t} + 7 \times e^{-6\lambda t} \times (1- e^{-\lambda t}) + 21 \times e^{-5\lambda t} \times (1- e^{-\lambda t})^2$$

Therefore, the reliability (R_{RME}) will be :

$$R_{RME} = [e^{-\lambda_2 t}] \times [e^{-7\lambda t} + 7 \times e^{-6\lambda t} \times (1- e^{-\lambda t}) + 21 \times e^{-5\lambda t} \times (1- e^{-\lambda t})^2]$$

And the unreliability (Q_{RME}) will be :

$$Q_{RME} = 1 - R_{RME} \qquad \text{-------------------------------(71)}$$

The mean time between failures $(MTBF)_{RME}$ will be :

$$(MTBF)_{RME} = \int_0^\infty R_{RME}\, dt \qquad \text{-------------------------------(72)}$$

5.6.4. Unit Power Side Electrical Supply Associated System Reliability Models

Referring to figure (69), the reliability of the unit power side electrical supply associated system (R_{UPSE}) will be :

$$R_{UPSE} = [e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)}] \qquad \text{-------------------------(73)}$$

The unreliability (Q_{UPSE}) will be :

$$Q_{UPSE} = 1 - [e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)}] \qquad \text{----------------------(74)}$$

The mean time between failures $(MTBF)_{UPSE}$ will be :

$$(MTBF)_{UPSE} \int_0^\infty R_{UPSE}\, dt \qquad \text{---(75)}$$

5.6.5 Unit Water Side Electrical supply Associated System Reliability Models

Referring to figure (70), the reliability of the unit water side electrical supply associated system (R_{UWSE}) will be :

$$R_{UWSE} = [e^{-t(\lambda_1 + \lambda_2 + \lambda_3)}] \qquad \text{-----------------------------(76)}$$

And the unreliability (Q_{UWSE}) will be :

$$Q_{UWSE} \quad = \quad 1 - [e^{-t(\lambda_1 + \lambda_2 + \lambda_3)}] \tag{77}$$

The mean time between failures $(MTBF)_{UWSE}$

$$(MTBF)_{UWSE} = \int_0^{\infty} R_{UWSE} \, dt \tag{78}$$

5.6.6 Turbine Cooling Associated System Reliability Models

Referring to figure (71), the turbine cooling associated system reliability model (R_{TC}) will be :

$$R_{TC} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_6)} \times \sum_{x_4 = 0}^{n_4} \frac{(\lambda_4 t)^{x_4} e^{-(\lambda_4 t)}}{x_4 !} \times \sum_{x_5 = 0}^{n_5} \frac{(\lambda_5 t)^{x_5} e^{-(\lambda_5 t)}}{x_5 !}$$

The unreliability (Q_{TC}) will be :

$$Q_{TC} = 1 - R_{TC} \tag{80}$$

The mean time between failures $(MTBF)_{TC}$ will be :

$$(MTBF)_{TC} = \int_0^{\infty} R_{TC} \, dt \tag{81}$$

5.6.7 Distiller Cooling Associated System Reliability Models

Referring to figure (72), the turbine cooling associated system reliability model (R_{DC}) will be :

$$R_{DC} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_6)} \times \sum_{x_4 = 0}^{n_4} \frac{(\lambda_4 t)^{x_4} e^{-(\lambda_4 t)}}{x_4 !} \times \sum_{x_5 = 0}^{n_5} \frac{(\lambda_5 t)^{x_5} e^{-(\lambda_5 t}}{x_5 !}$$

The unreliability (Q_{DC}) will be :

$$Q_{DC} = 1 - R_{DC} \quad \text{--(83)}$$

The mean time between failures $(MTBF)_{DC}$ will be :

$$(MTBF)_{DC} = \int_0^{\infty} R_{DC}\, dt \quad \text{--(84)}$$

5.6.8 Turbine Discharge Associated System Reliability Models

Referring to figure (73), the reliability of the turbine discharge associated system (R_{TD}) will be :

$$R_{TD} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3)} \quad \text{------------------------------(85)}$$

And the unreliability (Q_{TC}) will be :

$$Q_{TD} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3)} \quad \text{----------------------(86)}$$

The mean time between failures $(MTBF)_{TC}$ will be :

$$(MTBF)_{TD} = \int_0^{\infty} R_{TD}\, dt \quad \text{----------------------------------(87)}$$

5.6.9 Distiller Discharge Associated System Reliability Models

Referring to figure (74), the reliability of the distiller discharge associated system (R_{DD}) will be :

$$R_{DD} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3)} \quad \text{------------------------------(88)}$$

And the unreliability (Q_{TC}) will be :

$$Q_{DD} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3)} \quad \text{----------------------(89)}$$

The mean time between failure $(MTBF)_{DD}$ will be :

$$(MTBF)_{DD} = \int_0^{\infty} R_{DD}\, dt \quad \text{--(90)}$$

5.6.10 Boiler Sub - System Reliability Models

Referring to figure (75), the reliability of the boiler sub - system (R_B) will be :

$$R_B = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{-------------(91)}$$

And the unreliability (Q_B) will be :

$$Q_B = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{----------(92)}$$

The mean time between failures $(MTBF)_B$ will be :

$$(MTBF)_B = \int_0^\infty R_B \, dt \quad \text{--(93)}$$

5.6.10.1 Boiler Feed And Make - Up Water Sub - Sub System Reliability Models

Referring to figure (76), the reliability of the boiler feed and make - up water sub - sub system (R_{BFMW}) will be :

$$R_{BFMW} = \Big[[e^{-\lambda_1 t} + e^{-\lambda_2 t}] - [e^{-t(\lambda_1 + \lambda_2)} \Big] \; X$$

$$\Big[e^{-t(\lambda_3 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_9 + \lambda_{10} + \lambda_{11}} \Big] \; X$$

$$\Big[e^{-t(\lambda_{12} + \lambda_{13} + \lambda_{14} + \lambda_{16} + \lambda_{17} + \lambda_{18} + \lambda_{19}} \Big] \; X$$

$$\Big[R_4 \; X \; R_8 \; X \; R_{15} \Big] \quad \text{----------------------------(94)}$$

Now [R_4 X R_8 X R_{15}] is equal to :

$$\sum_{x_4=0}^{n_4} \frac{(\lambda_4 t)^{x_4} e^{-(\lambda_4 t)}}{x_4 !}$$

$$X \sum_{x_8=0}^{n_8} \frac{(\lambda_8 t)^{x_8} e^{-(\lambda_8 t)}}{x_8 !} \quad X \sum_{x_{15}=0}^{n_{15}} \frac{(\lambda_{15} t)^{x_{15}} e^{-(\lambda_{15} t)}}{x_{15} !}$$

The unreliability (Q_{BFMW}) will be :

$$Q_{BFMW} = 1 - R_{BFMW} \quad \text{---------------------------------(95)}$$

The mean time between failures $(MTBF)_{BFMW}$ will be :

$$(MTBF)_{BFMW} = \int_0^\infty R_{BFMW} \, dt \quad \text{--(96)}$$

5.6.10.2. Boiler Heat Recovery Area Sub - Sub System Reliability Models

Referring to figure (77), the reliability of the boiler heat recovery area sub - sub System (R_{BHRA}) will be :

$$R_{BHRA} \quad = \quad e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)} \qquad \text{--------------(97)}$$

And the unreliability (Q_{BHRA}) will be :

$$Q_{BHRA} \quad = \quad 1 \; - \; e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)} \qquad \text{---------------(98)}$$

The mean time between failures $(MTBF)_{BHRA}$ will be :

$$(MTBF)_{BHRA} \quad = \quad \int_0^\infty R_{BHRA} \, dt \qquad \text{-----------------------------------(99)}$$

5.6.10.3. Boiler Drum Sub - Sub System Reliability Models

Referring to figure (78), the reliability of the boiler drum Sub - sub system (R_{BD}) will be :

$$R_{BD} \quad = \quad e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \qquad \text{-------------(100)}$$

The unreliability (Q_{BD}) will be :

$$Q_{BD} \quad = \quad 1 \; - \; e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \qquad \text{--------(101)}$$

The mean time between failures $(MTBF)_{BD}$ will be :

$$(MTBF)_{BD} \quad = \quad \int_0^\infty R_{BD} \, dt \qquad \text{----------------------------------(102)}$$

5.6.10.4. Boiler Furnace Sub - Sub System Reliability Models

Referring to figure (79), the reliability of the boiler furnace sub - sub system (R_{BF}) will be :

$$R_{BF} \quad = \quad e^{-t(\lambda_1 + \lambda_2)} \qquad \text{--------------------------(103)}$$

The unreliability (Q_{BF}) will be :

$$Q_{BF} \quad = \quad 1 \; - \; e^{-t(\lambda_1 + \lambda_2)} \qquad \text{-------------------------(104)}$$

The mean time between failures $(MTBF)_{BF}$ will be :

$$(MTBF)_{BF} \quad = \quad \int_0^\infty R_{BF} \, dt \qquad \text{----------------------------------(105)}$$

5.6.10.5. Combined Boiler Combustion Air And Flue Gases Sub - Sub System Reliability Models

Referring to figure (80), the reliability of the combined boiler combustion air and flue gases sub - sub system (R_{CBCAFG}) will be :

$$R_{CBCAFG} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{----------(106)}$$

And the unreliability (Q_{CBCAFG}) will be :

$$Q_{CBCAFG} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{---------(107)}$$

The mean time between failures $(MTBF)_{CBCAFG}$ will be :

$$(MTBF)_{CBCAFG} = \int_0^\infty R_{CBCAFG}\, dt \quad \text{--------------------------(108)}$$

5.6.11.Turbine Sub - System Reliability Models

Referring to figure (81), the reliability of the turbine sub - system (R_T) will be :

$$R_T = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{-----(109)}$$

The unreliability (Q_T) will be :

$$Q_T = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{---(110)}$$

The mean time between failures $(MTBF)_T$ will be :

$$(MTBF)_T = \int_0^\infty R_T\, dt \quad \text{---------------------------------(111)}$$

5.6.11.1. Main Steam Supply Line Sub - Sub System Reliability Models

Referring to figure (82), the reliability of the main steam supply line sub - sub system (R_{MSSL}) will be :

$$R_{MSSL} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \quad \text{----------------------------(112)}$$

And the unreliability (Q_{MSSL}) will be :

$$Q_{MSSL} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \quad \text{-----------------------(113)}$$

The mean time between failures $(MTBF)_{MSSL}$ will be :

$$(MTBF)_{MSSL} = \int_0^{\infty} R_{MSSL}\, dt \quad \text{--------(114)}$$

5.6.11.2. Auxiliary Steam For Turbine Air Ejector And Gland Seals Sub - Sub System Reliability Models

Referring to figure (83), the reliability of the auxiliary steam for turbine air ejector and gland seals sub - sub System (R_{AE}) will be :

$$R_{AE} = [e^{-t(\lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)}] \times [e^{-\lambda_2 t}(1 + \lambda_2 t)] \quad \text{--------(115)}$$

And the unreliability (Q_{AE}) will be :

$$Q_{AE} = 1 - [e^{-t(\lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)}] \times [e^{-\lambda_2 t}(1 + \lambda_2 t)] \quad \text{------(116)}$$

The mean time between failures $(MTBF)_{AE}$ will be :

$$(MTBF)_{AE} = \int_0^{\infty} R_{AE}\, dt \quad \text{--------(117)}$$

5.6.11.3. Turbine Load Control Sub - Sub System Reliability Models

Referring to figure (84), the reliability of the turbine load control sub - sub system (R_{TLC}) will be :

$$R_{TLC} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{--------(118)}$$

And the unreliability (Q_{TLC}) will be :

$$Q_{TLC} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{--------(119)}$$

The mean time between failure $(MTBF)_{TLC}$ will be :

$$(MTBF)_{TLC} = \int_0^{\infty} R_{TLC}\, dt \quad \text{--------(120)}$$

5.6.11.3. High Pressure (H.P) Turbine Sub - Sub System Reliability Models

Referring to figure (85), the reliability of the high pressure (H.P) turbine sub - sub system (R_{HPT}) will be :

$$R_{HPT} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{----------------(121)}$$

And the unreliability (Q_{HPT}) will be :

$$Q_{HPT} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{---------------(122)}$$

The mean time between failures $(MTBF)_{TLC}$ will be :

$$(MTBF)_{HPT} = \int_0^\infty R_{HPT} \; dt \quad \text{--------------------------------(123)}$$

5.6.11.4. Low Pressure (L.P) Turbine Sub - Sub System Reliability Models

Referring to figure (86), the reliability of the high pressure (H.P) turbine sub - sub system (R_{LPT}) will be :

$$R_{LPT} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)} \quad \text{----------(124)}$$

And the unreliability (Q_{TLC}) will be :

$$Q_{LPT} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7)} \quad \text{---------------(125)}$$

The mean time between failures $(MTBF)_{TLC}$ will be :

$$(MTBF)_{LPT} = \int_0^\infty R_{LPT} \; dt \quad \text{--------------------------------(126}$$

5.6.11.5. Turbine Rotor Sub - Sub System Reliability Models

Referring to figure (87), the reliability of the turbine rotor sub - sub system (R_{TR}) will be :

$$R_{TR} = \left[e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7} \right] X$$

$$\left[e^{-t(\lambda_8 + \lambda_9 + \lambda_{10} + \lambda_{11} + \lambda_{12}} \right] \quad \text{--------------------(127)}$$

The unreliability (Q_{TR}) will be ;

$$Q_{TR} = 1 - \left[[e^{-t(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7}] \text{ X } [e^{-t(\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}] \right] \qquad \text{------(128)}$$

The mean time between failures $(MTBF)_{TR}$ will be :

$$(MTBF)_{TR} = \int_0^{\infty} R_{TR} \; dt \qquad \text{-------------------------------(129}$$

5.6.11.6. Turbine Hydraulic And Lubricating Oil Sub - Sub System Reliability Models

Referring to figure (88), the reliability of the turbine hydraulic and lubricating oil sub - sub system (R_{THLO}) will be :

$$R_{THLO} = [e^{-t(\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9)}] \text{ X } [R_1] \text{ X } [R_2] \text{ X } [R_3]$$

$$\text{-------------------------------(130)}$$

Now $\left[[R_1] \text{ X } [R_2] \text{ X } [R_3] \right]$ is equal to :

$$\sum_{x_1=0}^{n_1} \frac{(\lambda_1 t)^{x_1} e^{-(\lambda_1 t)}}{x_1 !} \text{ X } \sum_{x_2=0}^{n_2} \frac{(\lambda_2 t)^{x_2} e^{-(\lambda_2 t)}}{x_2 !} \text{ X } \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} e^{-(\lambda_3 t)}}{x_3 !}$$

The unreliability (Q_{THLO}) will be :

$$Q_{THLO} = 1 - R_{THLO} \qquad \text{-----------------------------------(131)}$$

The mean time between failures $(MTBF)_{THLO}$ will be :

$$(MTBF)_{THLO} = \int_0^{\infty} R_{THLO} dt \qquad \text{-------------------------------(132)}$$

5.6.11.7. Turbine Condenser Sub - Sub System Reliability Models

Referring ton figure (89), the reliability of the turbine condenser sub - sub system (R_{TCN}) will be :

$$R_{TCN} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \qquad \text{-----(133)}$$

The unreliability (Q_{TCN}) will be :

$$Q_{TCN} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \text{ --(134)}$$

The mean time between failures $(MTBF)_{TCN}$ will be :

$$(MTBF)_{TCN} = \int_0^\infty R_{TCN}\, dt \text{ ---(135)}$$

5.6.11.8. Turbine Condensate Sub - Sub System Reliability Models

Referring to figure (90), the reliability of the turbine condensate sub - sub system (R_{TCON}) will be :

$$R_{TCON} = [e^{-t(\lambda_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)}] \times [e^{-\lambda_3 t} (1 + \lambda_3 t)]$$

--- (136)

The unreliability (Q_{TCON}) will be :

$$Q_{TCON} = 1 - \Big[[e^{-t(\lambda_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)}] \times [e^{-\lambda_3 t} (1 + \lambda_3 t)] \Big]$$

--- (137)

The mean time between failures $(MTBF)_{TCON}$ will be :

$$(MTBF)_{TCON} = \int_0^\infty R_{TCON} dt \text{ ---(138)}$$

5.6.12. Generator Sub - System Reliability Models

Referring to figure (91), the reliability of the generator sub - system (R_G) will be :

$$R_G = [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6 + \lambda 7)}] \text{ ---(139)}$$

And the unreliability (Q_G) will be :

$$Q_G = 1 - [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6 + \lambda 7)}] \text{ ---(140)}$$

The mean time between failures $(MTBF)_G$ will be :

$$(MTBF)_G = \int_0^\infty R_G \, dt \text{ ---(141)}$$

5.6.12.1. Generator Rotor Sub - Sub System Reliability Models

Referring to figure (92), the reliability of the generator rotor sub - sub system (R_{GR}) will be :

$$R_{GR} = \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5)} \right] \text{-----------------------(142)}$$

The unreliability (Q_{GR}) will be :

$$Q_{GR} = 1 - \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5)} \right] \text{------------------(143)}$$

The mean time between failures $(MTBF)_{GR}$ will be :

$$(MTBF)_{GR} = \int_0^\infty R_{GR} \, dt \text{--------------------------------(144)}$$

5.6.12.2. Generator Stator Sub - Sub System Reliability Models

Referring to figure (93), the reliability of the generator stator sub - sub system (R_{GS}) will be :

$$R_{GS} = \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3)} \right] \text{---------------------------------------(145)}$$

The unreliability (Q_{GS}) will be :

$$Q_{GS} = 1 - \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3)} \right] \text{---------------------------------(146)}$$

The mean time between failures $(MTBF)_{GS}$ will be :

$$(MTBF)_{GS} = \int_0^\infty R_{GS} \, dt \text{--------------------------------(147)}$$

5.6.12.3. Generator Hydrogen Cooling Sub - Sub Syste

Reliability Model

Referring to figure (94), the reliability of the generator hydrogen cooling sub - sub system (R_{GHC}) will be :

$$R_{GH} = e^{-t(\lambda_2 + \lambda_4 + \lambda_5 + \lambda_6)} \times \sum_{x_1 = 0}^{n_1} \frac{(\lambda_1 t)^{x_1} e^{-(\lambda_1 t)}}{x_1 !} \times \sum_{x_3 = 0}^{n_3} \frac{(\lambda_3 t)^{x_3} e^{-(\lambda_3 t)}}{x_3 !} \qquad (148)$$

The unreliability (Q_{GHC}) will be :

$$Q_{GHC} = 1 - R_{GHC} \quad \text{-----------------------------------(149)}$$

The mean time between failures $(MTBF)_{GHS}$ will be :

$$(MTBF)_{GHC} = \int_0^{\infty} R_{GHC} \, dt \quad \text{-------------------------------(150)}$$

5.6.12.4. Generator Sealing Oil Sub - Sub System Reliability Models

Referring to figure (95), the reliability of the generator sealing oil sub - sub system (R_{GSO}) will be :

$$R_{GSO} = [e^{-t(\lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)}]$$
$$X\ [(e^{-\lambda_1 t} + e^{-\lambda_2 t}) - (e^{-\lambda_1 t} \ X \ e^{-\lambda_2 t})] \quad \text{----------(151)}$$

The unreliability (Q_{GSO}) will be :

$$Q_{GSO} = 1 - \Big[[e^{-t(\lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)}]$$
$$X\ [(e^{-\lambda_1 t} + e^{-\lambda_2 t}) - (e^{-\lambda_1 t} \ X \ e^{-\lambda_2 t})] \Big] \quad \text{-----(152)}$$

The mean time between failures $(MTBF)_{GSO}$ will be :

$$(MTBF)_{GSO} = \int_0^{\infty} R_{GSO} \, dt \quad \text{-------------------------------(153)}$$

5.6.12.5. Generator Pilot Exciter Sub - Sub System Reliability Models

Referring to figure (96), the reliability of the generator pilot exciter sub - Sub system (R_{GPE}) will be :

$$R_{GPE} = \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3)} \right] \quad \text{--------------------------------------(154)}$$

The unreliability (Q_{GPE}) will be :

$$Q_{GPE} = 1 - \left[e^{-t(\lambda 1 + \lambda 2 + \lambda 3)} \right] \quad \text{--------------------------------(155)}$$

The mean time between failures $(MTBF)_{GPE}$ will be :

$$(MTBF)_{GPE} = \int_0^{\infty} R_{GPE} \, dt \quad \text{-------------------------------(156)}$$

5.6.12.6. Generator Exciter Sub - Sub System Reliability Models

Referring to figure (97), the reliability of the generator exciter sub - sub System (R_{GE}) will be :

$$R_{GE} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_8 + \lambda_9} \times \sum_{x_7=0}^{n_7} \frac{(\lambda_7 t)^{x_7} e^{-\lambda_7 t}}{x_7 !} \quad \text{------------(157)}$$

The unreliability (Q_{GE}) will be :

$$Q_{GE} = 1 - R_{GE} \quad \text{------------(158)}$$

The mean time between failures $(MTBF)_{GE}$ will be :

$$(MTBF)_{GE} = \int_0^{\infty} R_{GE} \, dt \quad \text{------------(159)}$$

5.6.12.7. Generator Voltage Control Sub - Sub System Reliability Models

Referring to figure (98), the reliability of the generator voltage control sub - sub system (R_{GVC}) will be :

$$R_{GVC} = [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5)}] \quad \text{------------(160)}$$

And the unreliability (Q_{GVC}) will be :

$$Q_{GVC} = 1 - [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5)}] \quad \text{------------(161)}$$

The mean time between failures $(MTBF)_{GVC}$ will be :

$$(MTBF)_{GVC} = \int_0^{\infty} R_{GVC} \, dt \quad \text{------------(162)}$$

5.6.13. Distiller High Pressure (H.P) Steam Supply Associated System Reliability Models

Referring to figure (99), we have the following :

1. Block (1) represents the (H.P) steam supply from the boiler.

2. Block (2) represents the (H.P) steam supply from the common header.

3. Blocks (1) and (2) are connected in a parallel standby configuration, and block (1) is the main operating block.

4. We have assumed that there will be a perfect switch from one block to the other.

5. We have assumed that there will not be a failure of block (2) while in the standby mode.of operation.

Now from the above assumptions and operation conditions, we can be sure that the (H.P) steam supply from the common header will always be available if the distiller need such a supply, therefore the reliability of this associated system $\{R_{DHPS}\}$ will be :

$$R_{DHPS} = 1 \qquad \text{------------------------(163)}$$

And the unreliability $\{Q_{DHPS})$ will be :

$$Q_{DHPS} = 0 \qquad \text{------------------------(164)}$$

The mean time between failures $(MTBF)_{DHPS}$ will be :

$$(MTBF)_{DHPS} = \infty \qquad \text{------------------------(165)}$$

5.6.13.1. High Pressure (H.P) Steam Direct From Boiler Sub - Sub System Reliability Models

Referring to figure (100), the reliability of the high pressure (H.P) steam direct from boiler sub - sub system (R_{HPDB}) will be :

$$R_{HPDB} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)} \qquad \text{------------------------(166)}$$

And the unreliability (Q_{TLC}) will be :

$$Q_{HPDB} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)} \qquad \text{------------------------(167)}$$

The mean time between failures $(MTBF)_{HPDB}$ will be :

$(MTBF)_{HPDB}$

$$(MTBF)_{HPDB} = \int_0^\infty R_{HPDB}\, dt \qquad \text{------------------------(168)}$$

5.6.13.2. High Pressure (H.P) Steam Direct From Common Header Sub - Sub System Reliability Models

Referring to figure (101), we have the following :

1. Block (1) is connected in series with blocks (2), (3), and (4).
2. Block (1) is composed of (N) identical high pressure (H.P) steam direct from boiler sub - sub systems. These sub - sub systems are fully redundant.

Therefore the reliability of the high pressure (H.P) steam direct from common header sub - sub system (R_{HPDH}) will be developed as follows :

$$R_{HPDH} = (R_1) \text{ X } (R_2) \text{ X } (R_3) \text{ X } (R_4)$$

From Equation (32) the reliability of block (1) (R_1) is equal to :

$$R_1 = 1 - \prod_{i=1}^{n} [\, 1 - \exp(\lambda_i t) \,]$$

Therefore (R_{HPDH}) will be :

$$R_{HPDH} = e^{-t(\lambda_2 + \lambda_3 + \lambda_4)} \text{ X } \Big[1 - \prod_{i=1}^{n} [\, 1 - \exp(-\lambda_i t) \,] \qquad \text{-------------------(169)}$$

And the unreliability (Q_{HPDH}) will be :

$$Q_{HPDH} = 1 - R_{HPDH} \qquad \text{------------------------------(170)}$$

The mean time between failures $(MTBF)_{HPDH}$ will be :

$$(MTBF)_{HPDH} = \int_0^{\infty} R_{HPDH} \, dt \qquad \text{---------------------------------(171)}$$

5.6.14. Distiller Low Pressure (L.P) Steam Supply Associated System Reliability Models

Referring to figure (102), we have three non - identical standby blocks connected in parallel. Since low pressure (L.P) supply direct from boiler block (1) is very expensive and rarely used in practice, therefore figure (102) will be replaced by figure (103). From figure (103), we have the following :

1. Block (1) represents the (L.P) steam supply from the turbine.
2. Block (2) represents the (L.P) steam supply from the common header.
3. Blocks (1) and (2) are connected in a parallel standby configuration, and block (1) is the main operating block.
4. We have assumed that there will be a perfect switch from one block to the other.
5. We have assumed that there will not be a failure of block (2) while in the standby mode.of operation.

Now from the above assumptions and operation conditions, we can be sure that the (L.P) steam supply from the common header will always be available if the distiller need such a supply, therefore the reliability of this associated system $\{R_{DLPS}\}$ will be :

$$R_{DLPS} = 1 \qquad \text{-----(172)}$$

And the unreliability $\{Q_{DHPS})$ will be :

$$Q_{DLPS} = 0 \qquad \text{-----(173)}$$

The mean time between failures $(MTBF)_{DHPS}$ will be :

$$(MTBF)_{DLPS} = \infty \qquad \text{-----(174)}$$

5.6.14.1. Distiller Low Pressure (L.P) Steam Extracted From Turbine Sub - Sub System Reliability Models

Referring to figure (104), the reliability of the distiller low pressure (L.P) steam extracted from turbine sub - sub system (R_{DLPFT}) will be :

$$R_{DLPFT} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \qquad \text{-----(175)}$$

And the unreliability (Q_{DLPFB}) will be :

$$Q_{DLPFT} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \qquad \text{-----(176)}$$

The mean time between failures $(MTBF)_{DLPFT}$ will be :

$$(MTBF)_{DLPFT} = \int_0^\infty R_{DLPFT}\, dt \qquad \text{-----(177)}$$

5.6.14.2. Distiller Low Pressure (L.P) Steam From Common Header Sub - Sub System Reliability Models

Referring to figure (105), we have the following :

1. Blocks (1), (4), (5), and (6) are connected in series.
2. Block (1) is composed of Blocks (2) and (3) which are non - identical blocks connected in parallel. These blocks are fully redundant.
3. Block (2) is composed of (N) identical low pressure (L.P) steam direct from boiler sub - sub systems. These sub - sub systems are fully redundant.
4. Block (3) is composed of (N) identical low pressure (L.P) steam extracted from turbine sub - sub systems. These sub - sub systems are fully redundant.
5. The (N) in blocks (2) and (3) are equal.

The reliability models for the distiller low pressure (L.P) steam from common header sub - sub system (R_{DLPFH}) will be developed as follows :

$$R_{DLPFH} = (R_1) \text{ X } (R_4) \text{ X } (R_5) \text{ X } (R_6) \quad \text{-----------------(178)}$$

$$R_{DLPFH} = e^{-t(\lambda_4 + \lambda_5 + \lambda_6)} \text{ X } (R_1) \quad \text{-----------------(179)}$$

From Equation (26), (R_1) is equal to :

$$R_1 = R_2 + R_3 - (R_2 \text{ X } R_3)$$

$$R_2 = 1 - \prod_{i=1}^{n} [\, 1 - \exp(\lambda_i t)\,]$$

And

$$R_3 = 1 - \prod_{i=1}^{n} [\, 1 - \exp(\lambda_i t)\,]$$

R_2 and R_3 have to be evaluated separately, then their values should be substituted in Equation (178).

The unreliability (Q_{DLPFH}) will be :

$$Q_{DLPFH} = 1 - R_{DLPFH} \quad \text{--------------------------(180)}$$

The mean time between failures $(MTBF)_{DLPFH}$ will be :

$$(MTBF)_{DLPFH} = \int_0^{\infty} R_{DLPFH}\, dt \quad \text{--------------------------------(181)}$$

5.6.15. Distiller Sub -System Reliability Models

Referring to figure (106), the reliability of the distiller sub system (R_D) will be :

$$R_D = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)} \quad \text{-------------------------------(182)}$$

And the unreliability (Q_D) will be :

$$Q_D = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)} \quad \text{------------------------------(183)}$$

The mean time between failures $(MTBF)_{HPDB}$ will be

$$(MTBF)_D = \int_0^\infty R_D \, dt \quad \text{--------------------------------(184)}$$

5.6.15.1. Distiller Brine Heater Sub -Sub System Reliability Models

Referring to figure (107), the reliability of the distiller brine heater sub - sub system (R_{DBH}) will be :

$$R_{DBH} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{----(185)}$$

The unreliability (Q_{DBH}) will be :

$$Q_{DBH} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{----(186)}$$

The mean time between failures $(MTBF)_{DBH}$ will be :

$$(MTBF)_{DBH} = \int_0^\infty R_{DBH} \, dt \quad \text{--------------------------------(187)}$$

5.6.15.2. Distiller Heat Recovery Section Sub -Sub System Reliability Models

Referring to figure (108), the reliability of the distiller heat recovery section sub - sub system (R_{DHRS}) will be :

$$R_{DHRS} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \quad \text{--------------------------------(188)}$$

λ_2 = sum of the failure rates of the [N-3] stages. The unreliability (Q_{DHRS}) will be :

$$Q_{DHRS} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)} \quad \text{----------------------------(189)}$$

The mean time between failures $(MTBF)_{DHRS}$ will be :

$$(MTBF)_{DHRS} = \int_0^\infty R_{DHRS}\ dt \quad \text{-------------------------------(190)}$$

5.6.15.3. Distiller Heat Recovery Section Stage Sub -Sub System Reliability Models

Referring to figure (109), the reliability of the distiller heat recovery section stage sub -sub System (R_{DHRSG}) will be :

$$R_{DHRSG} = [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6 + \lambda 7)}] \quad \text{----------(191)}$$

And the unreliability (Q_{DHRSG}) will be:

$$Q_{DHRSG} = 1 - [e^{-t(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6 + \lambda 7)}] \quad \text{----(192)}$$

The mean time between failures $(MTBF)_{DHRSG}$ will be :

$$(MTBF)_{DHRSG} = \int_0^\infty R_{DHRSG}\ dt \quad \text{-------------------------------(193)}$$

5.6.15.4. Distiller Heat Rejection Section Sub -Sub System Reliability Model

Referring ti figure (110), the reliability of the distiller heat rejection section sub -sub system (R_{DHRJ}) will be :

$$R_{DHRJ} = e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{-(194)}$$

λ_4 = sum of the failure rates of the [3 stages]. The unreliability (Q_{DHRJ}) will be :

$$Q_{DHRJ} = 1 - e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9)} \quad \text{-(195)}$$

The mean time between failures $(MTBF)_{DHRJ}$ will be :

$$(MTBF)_{DHRJ} = \int_0^\infty R_{DHRJ}\ dt \quad \text{-------------------------------(196)}$$

5.6.15.5. Distillate Discharge Sub -Sub System Reliability Model

Referring to figure (111), the reliability of the distillate discharge sub -sub system (R_{DD}) will be :

$$R_{DD} = e^{-t(\lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)} \; X \sum_{x_1=0}^{n_1} \frac{(\lambda_1 t)^{x_1} \; e^{-(\lambda_1 \tau)}}{x_1 !} \qquad \text{--------------------(197)}$$

And the unreliability (Q_{DD}) will be :

$$Q_{DD} \quad = \quad 1 - R_{DD} \qquad \text{-------------------------------------(198)}$$

The mean time between failures $(MTBF)_{DD}$ will be :

$$(MTBF)_{DD} \quad = \quad \int_0^{\infty} R_{DD} \quad dt \qquad \text{--------------------------------(199)}$$

5.6.15.6. Distiller Ejector Sub -Sub System Reliability Model

Referring to figure (112), the reliability of the distiller ejector sub -sub system (R_{DEJ}) will be :

$$R_{DEJ} \quad = \quad e^{-t(\lambda_1 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)} \; X \sum_{x_2=0}^{n_2} \frac{(\lambda_2 t)^{x_2} \; e^{-\lambda_2 t}}{x_2 !} \; X \sum_{x_3=0}^{n_3} \frac{(\lambda_3 t)^{x_3} \; e^{-\lambda_3 t}}{x_3 !} \qquad \text{-------------------(200)}$$

And the unreliability (Q_{DEJ}) will be :

$$Q_{DEJ} \quad = \quad 1 - R_{DEJ} \qquad \text{---------------------------------------(201)}$$

The mean time between failures $(MTBF)_{DEJ}$ will be :

$$(MTBF)_{DEJ} \quad = \quad \int_0^{\infty} R_{DEJ} \quad dt \qquad \text{-------------------------------(202)}$$

5.6.16. Reduced Overall Dual - Purpose (Power &Water) Combined Unit Reliability Models

Referring to figure (113), the reliability of the reduced overall dual - purpose (power &water) combined unit (R_{ROCN}) will be :

$$R_{ROCN} = \left[e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7} \right] X \left[e^{-t(\lambda_8 + \lambda_9 + \lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{19}} \right] X \left[R_{13} \, X \, R_{16} \right] \quad (203)$$

Now from Equations (162) we have :

$R_{13} \quad = \quad 1$

$R_{16} \quad = \quad 1$

Therefore, (R_{ROCN}) will be :

$$R_{ROCN} = \left[e^{-t(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7} \right] \text{ X}$$

$$\left[e^{-t(\lambda_8 + \lambda_9 + \lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{19}} \right] \qquad (204)$$

And the unreliability (Q_{ROCN}) will be :

$$Q_{ROCN} = 1 - R_{ROCN} \qquad \text{---------------------------(205)}$$

The mean time between failures $(MTBF)_{ROCN}$ will be :

$$(MTBF)_{ROCN} = \int_0^{\infty} R_{ROCN}\, dt \qquad \text{-------------------------------(206)}$$

5.6.17. Reduced Overall Dual - Purpose (Power&Water) Station Reliability Models

Referring to figure (114), we have the following :

1. Blocks (1), (8), (9), and (10) are connected in series.
2. Block (1) is composed of Blocks (2), (3), (4), and (5) which are connected in parallel. These blocks are fully redundant.Also these blocks are connected in series with blocks (6) and (7). Furthermore, blocks (6) and (7) are connected in parallel, and they are fully redundant. Block (1) resemble figure (62).
3. Block (9) is composed of (N) unit associated systems. These (N) unit associated systems are connected in "**r**" out of "**n**" configuration. Also these unit associated systems are fully redundant. Furthermore, each unit associated systems are connected in series.
4. Block (10) is composed of (N) unit sub - systems. These (N) unit sub - systems are connected in "**r**" out of "**n**" configuration. Also these unit sub - systems are fully redundant. Furthermore, each unit sub systems are connected in series.

5. The "**n**" and "**r**" in blocks (9) and (10) are equal.

The reliability models for the reduced overall dual - purpose (power&water) station (R_{ROPS}) will be developed as follows :

$$R_{ROPS} \quad = \quad [R_1] \text{ X } [R_8] \text{ X } [R_9] \text{ X } [R_{10}] \qquad \text{-------------(207)}$$

Referring now to figure (62), and section (5.6.1) of this chapter, we have :

$$\begin{aligned} R_1 = & \Big[[(e^{-\lambda_2 t} + e^{-\lambda_3 t} + e^{-\lambda_4 t} + e^{-\lambda_5 t}) \\ & - (e^{-t(\lambda_2+\lambda_3)} - e^{-t(\lambda_3+\lambda_4)} - e^{-t(\lambda_4+\lambda_5)} - e^{-t(\lambda_5+\lambda_2)} \\ & + (e^{-t(\lambda_2+\lambda_3+\lambda_4+\lambda_5)} \Big] \\ & \text{X } \Big[(e^{-\lambda_7 t} + e^{-\lambda_2 t}) - (e^{-(\lambda_2+\lambda_7)}) \Big] \end{aligned} \qquad \text{---------------(208)}$$

And

$$R_8 = e^{-\lambda_8 t} \qquad \text{----------------(209)}$$

With regards to block (10) we have the following :

Now block $[1_{(9)}]$ in block (9) refers to unit (1) associated systems other than the fuel and sea water intake, block $[2_{(9)}]$ in block (9) refers to unit (2) associated systems and block $[N_{(9)}]$ in block (9) refers to unit (N) associated systems.

Let

The equivalent failure rate of each unit associated systems in block (9) $= \lambda_{e\,(9)}$

The failure rate of block $[1_{(9)}]$ $= \lambda_{[1_{(9)}]}$

The failure rate of block $[2_{(9)}]$ $= \lambda_{[2_{(9)}]}$

The failure rate of block $[N_{(9)}]$ $= \lambda_{[N_{(9)}]}$

$\lambda_{e\,(9)}$ = the average value of $\lambda_{[1_{(9)}]}$, $\lambda_{[2_{(9)}]}$, $\lambda_{[N_{(9)}]}$

Referring to figure (113), we have for unit (1) associated systems :

$$\lambda_{[1_{(9)}]} = (\lambda_2 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9 + \lambda_{13} + \lambda_{16})$$

And for unit (2) associated systems :

$$\lambda_{[2_{(9)}]} = (\lambda_2 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9 + \lambda_{13} + \lambda_{16})$$

And for unit (N) associated systems :

$$\lambda_{[N_{(9)}]} = (\lambda_2 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9\ \lambda_{13} + \lambda_{16})$$

Referring to figure (99) and (103) and sections (5.6.13) and (5.6.14) of this chapter, we heve (λ_{13}) and (λ_{16}) are equal to zero. Now $\lambda[1_{(9)}]$, $\lambda[2_{(9)}]$, $\lambda[N_{(9)}]$ have to be evaluated separately in order to evaluate the equivalent failure rate of each unit associated systems in block (9) $\lambda_{e\ (9)}$

Since block (9) is composed of (N) unit associated systems and these (N) unit associated systems are connected in "**r**" out of "**n**" configuration, therefore, based on the value of "**r**" the calculation can proceed. If for example "**n**" is equal to 7 and "**r**" is equal to 5, then $[R_9]$ is equal to sum of the first three terms of the binomial expansion. If we substitute the equivalent failure rate of each unit associated systems in block (9) $\lambda e_{(9)}$ in the binomial expansion on the reliability of block (9) $[R_9]$ will be :

$$[R_9] \;=\; [\, e^{-7\lambda_{(9)}t} + 7 \text{ X } e^{-6\lambda_{(9)}t} \text{ X } (1 - e^{-\lambda_{(9)}t}) + 21 \text{ X } e^{-5\lambda t} \text{ X } (1 - e^{-\lambda t})^2 \,] \quad \text{-----------(210)}$$

With regards to block (10) we have the following :

Block $[1_{(10)}]$ in block (10) refers to unit (1) sub - systems, block $[2_{(10)}]$ in block (10) refers to unit (2) sub - systems and block $[N_{(10)}]$ in block (10) refers to unit (N) sub - systems.

Let

The equivalent failure rate of each unit - systems in block (10) $= \lambda_{e\ (10)}$

The failure rate of block $[1_{(10)}]$ $=$ $\lambda_{[1_{(10)}]}$

The failure rate of block $[2_{(10)}]$ $=$ $\lambda_{[2_{(10)}]}$

The failure rate of block $[N_{(10)}]$ $=$ $\lambda_{[N_{(10)}]}$

$\lambda_{e\ (10)}$ = the average values of $\lambda_{[1_{(10)}]}$, $\lambda_{[2_{(10)}]}$, $\lambda_{[N_{(10)}]}$

Referring to figure (113), we have for unit (1) sub - systems :

$$\lambda_{[1_{(10)}]} \;=\; (\lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{19})$$

And for unit (2) sub - systems :

$$\lambda_{[2_{(9)}]} \;=\; (\lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{19})$$

And for unit (N) sub - systems :

$$\lambda_{[N_{(9)}]} \;=\; (\lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{19})$$

Now $\lambda[1_{(10)}]$, $\lambda[2_{(10)}]$, $\lambda[N_{(10)}]$ have to be evaluated separately in order to evaluate the equivalent failure rate of each unit associated systems in block (10) $\lambda_{e\ (10)}$

Since block (10) is composed of (N) unit associated systems and these (N) unit associated systems are connected in "**r**" out of "**n**" configuration, therefore, based on the value of "**r**" the calculation can proceed. If for example "**n**" is equal to 7 and "**r**" is equal to 5, then $[R_{10}]$ is equal to the sum of first three terms of the binomial expansion. If we substitute the equivalent failure rate of each unit sub - systems in block (10) $\lambda e_{(10)}$ in the binomial expansion, the reliability of block (10) $[R_{10}]$ will be :

$$[R_{10}] = [e^{-7\lambda(10)t} + 7 X e^{-6\lambda(10)t} X (1- e^{-\lambda(10)t}) + 21 X e^{-5\lambda t} X (1- e^{-\lambda t})^2] \quad \text{-----------(211)}$$

$[R_1]$, $[R_8]$, $[R_9]$, and $[R_{10}]$ have to evaluated separately, then their values should be substituted in Equation (206). The unreliability (Q_{ROPS}) will be :

$$Q_{ROPS} = 1 - R_{ROPS} \quad \text{---------------------------(212)}$$

The mean time between failures $(MTBF)_{ROPS}$ will be :

$$R_{ROPS} = \int_0^\infty R_{ROPS}\, dt \quad \text{---(213)}$$

CHAPTER V I

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION

STATE-SPACE ANALYSIS APPROACH

CHAPTER VI

DUAL - PURPOSE (POWER&WATER) PRODUCTION STATION

STATE - SPACE ANALYSIS APPROACH

6.1. Introduction

In reliability analysis utilizing the state - space technique, a system, sub - system, or associated system is represented by its states and all the possible transition between these states. A system state describes a particular condition where every component is in a specified operating state of its own : it is operating, on forced outage, on planned outage, or in derated state. If a change in the state of any of the components occurs, then the system enters another state. All the possible states of a system make up the state - space. The attractiveness of the state - space approach lies in the fact that in most cases a Makove model can be applied to describe the process of the system travelling through the various possible states. The state - space models that will be produced in this chapter do not include operating consideration such as , operating reserve policy, derated operation conditions, spinning reserve for the power side of the production unit, load cycle shape for the power side of the production unit, effects of start - up delays, outage postponability, and human reliability characteristic. Furthermore, the work of this chapter will be confined to the presentation of the state - space models in a graphical form, and no further analysis will conducted, because such analysis will lead to maintainability concept, and the prime concern of this these is reliability analysis. However, these state - space models are presented here, as a pioneering step for further consideration by later analists.

6.2.Repair rate (μ)

The repair rate is defined as :

$$\mu = \frac{\text{number of failures of a component in the given period of time}}{\text{total period of time the component was being repaired}} \qquad \text{——(214)}$$

6.3. Mean Time To Repair (MTTR)

The mean time to repair is defined as the reciprocal to repair rate. Therefore (MTTR) will be :

$$MTTR = \frac{1}{\mu} \tag{215}$$

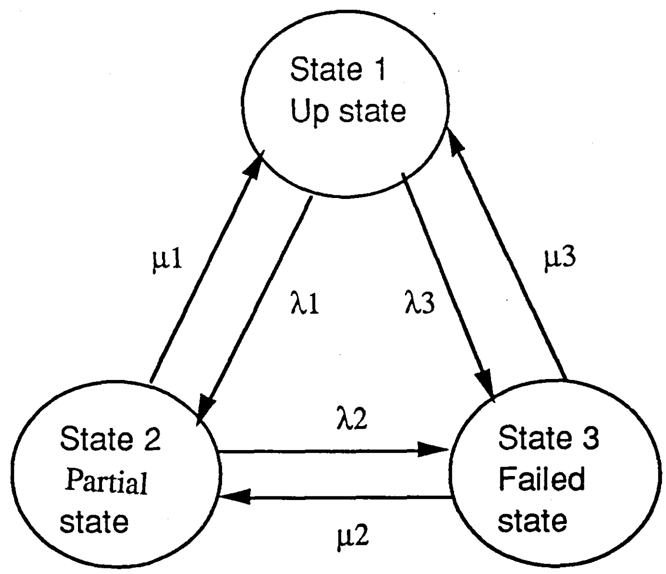
6.4. Markove Model

A markove process is a stochastic process, that is characterized by a lack of memory, that is , the future states of the system are independent of the past states except the immediately proceeding one. This means that the future random behaviour of the system only depends on where it is at present, and not on where it has been in the past or how it arrived at its present position. Furthermore, the Markove process must be homogeneous. The condition of homogeneity "means that the behaviour of the system must be the same at all points of time irrespective of the point of time being considered, i.e., the probability of making a transition from one given state to another is the same (stationary) at all time in the past and future" [36]. The two above mentioned characteristics of the Markove process (lack of memory, and homogeneity) makes it applicable to those systems whose behaviour can be represented by a probability distribution that is characterized by a constant failure, and repair rates, i.e., poisson and exponential distributions. Time and space in Markove models may either be discrete or continuous. Space is normally represented only as a discrete function, whereas, time may be either be discrete or continuous [36].

To solve a markove (discrete or continuous) process, it is required first, to construct an appropriate state - space model which include the relevant transition rates (i.e., failure rate λ, and the repair rate μ)."All the relevant states in which the system can reside should be included in such diagram and all known ways in which transitions between states can occur should be inserted" [36].The state - space model is a translation of the physical and logical operation of the system into a graphical representation. To illustrate the above discussion, let us consider a single repairable component which is assumed to exist in one of the following states :

1. Operating (up state).
2. Operating with partial output (derated state).
3. Failed (down state).

The state - space model for such a component will be as follows :

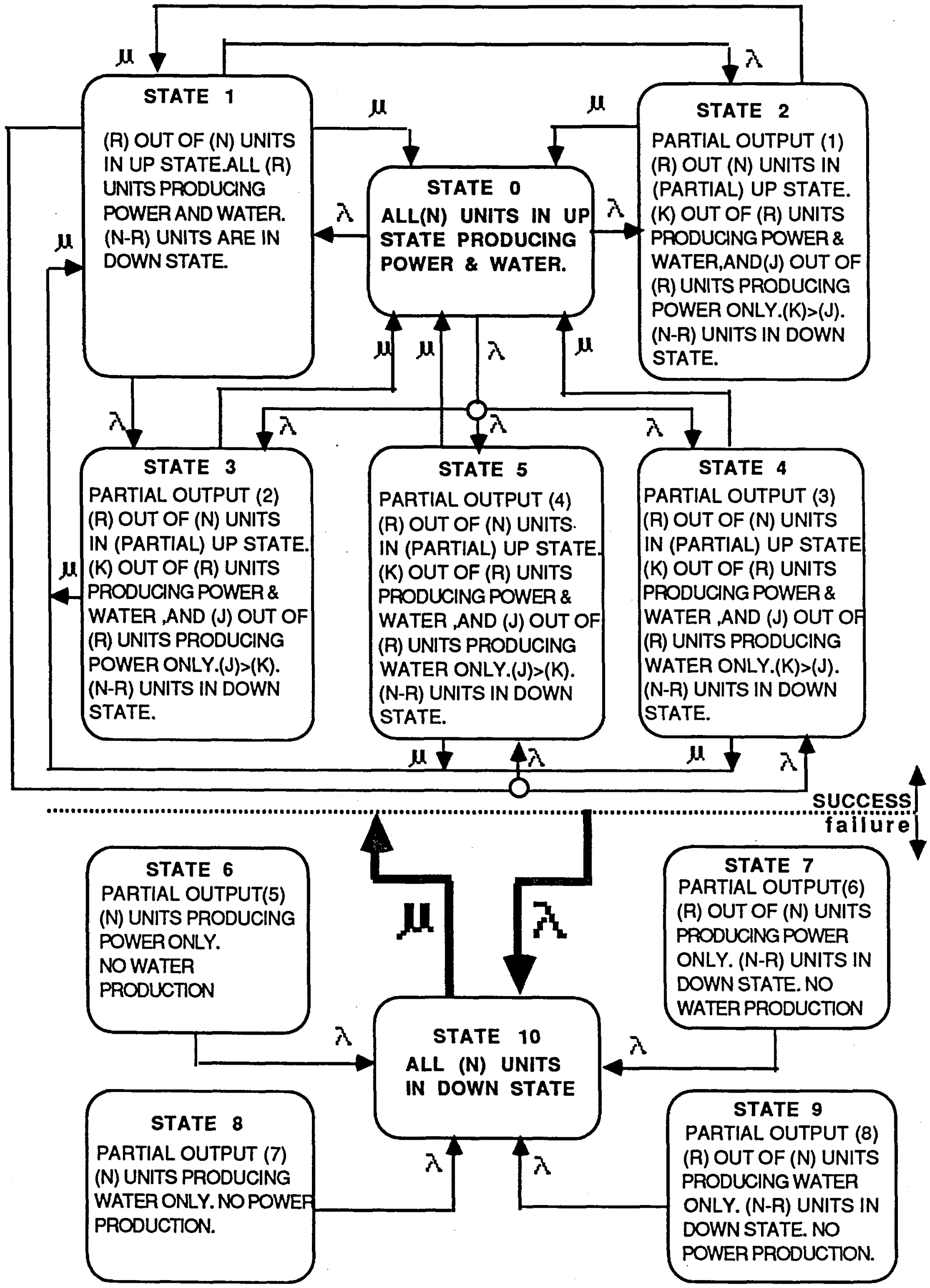


The λ, and μ refer to the failure and repair rates respectively. Furthermore they are assumed constant (exponentially distributed).The above model indicates that the component can reside in state (1) while it is in the up state, and if something goes wrong, then it either goes to state (2), the partial output state or to state (3) the failed state. If it goes to state (2) it then can reside in that state for while until it can be restored and returns to state (1) or fail therefore, it goes to state (3). On the other hand , if it had failed at state (1) it goes directly to state (3), and a repair must be done to restore and it goes back to state (1) or a partial repair is done and it goes to state (2).

6.5. Dual - Purpose (Power&Water) Production Station State - Space Models

In the following models, a partial output, means any operational condition that is different from the ideal operation state, in which all the production units in the station are operating and producing both power and distilled water. Figure (115) represent an overall dual - purpose (power&water) production station generalized state - space model. The model include 11 state that the station can reside in. Furthermore, the model indicate that there are 6 states in which the station can be in a successful operation, and 5 states in which the station will be in a failure operation. The failure conditions is that either all the production units are down or the station is producing power or distilled water only. Figure (116) is a reduced version of figure (115). Figure (117) represents a restricted model of the station. In this model the station can reside in 5 states, and there are 4 states in which the station can be in a successful operation, and 1 state in which the station can be regarded as a failure. Figure (118) represent a dual - purpose (power&water) production unit sub - systems state - space operational model. Figure (119) represent an overall dual - purpose (power&water) production unit state - space model. The model include two derated states. Derated state (1) refers to forced deration and derated state (2) refers to planned deration. The model indicates that there are 9 states in which the production unit can reside in. Figure (120) represent a restricted dual - purpose (power&water) production unit state - space model.

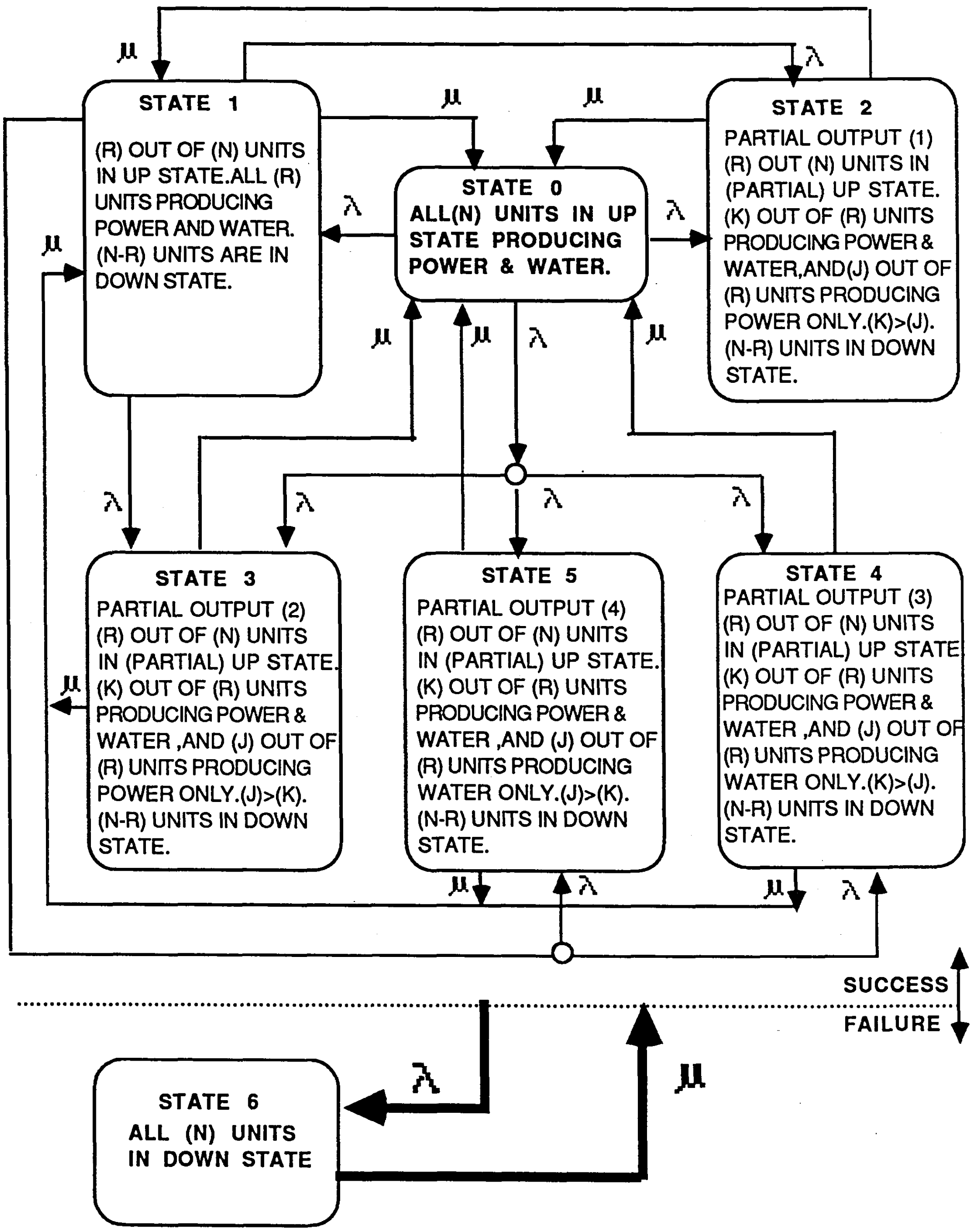
FIGURE NO 115



OVERALL DUAL-PURPOSE(POWER&WATER)

STATION GENERALIZED STATE SPACE DIAGRAM

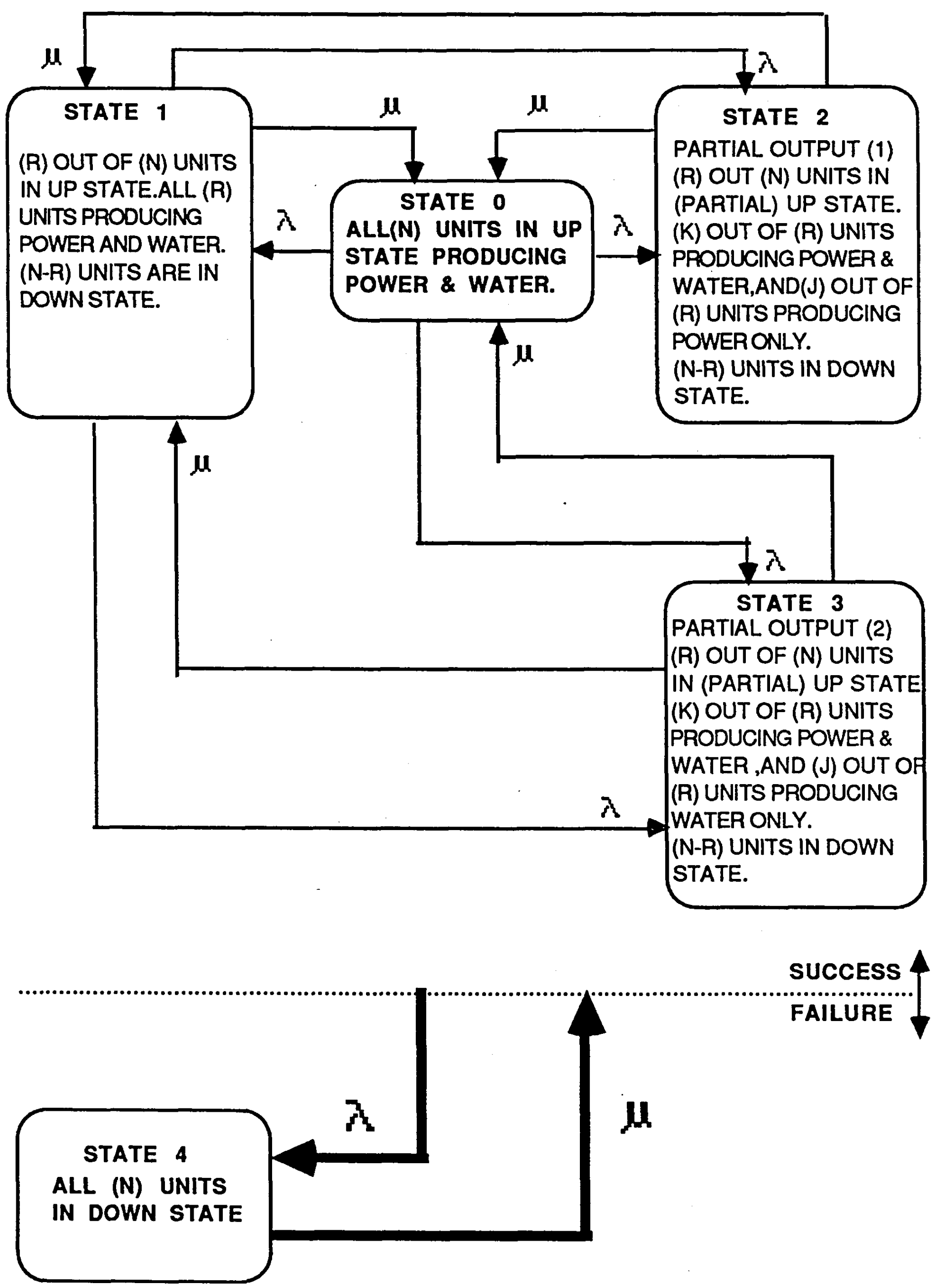
FIGURE NO 116



REDUCED OVERALL

DUAL-PURPOSE(POWER&WATER) STATION STATE SPACE DIAGRAM

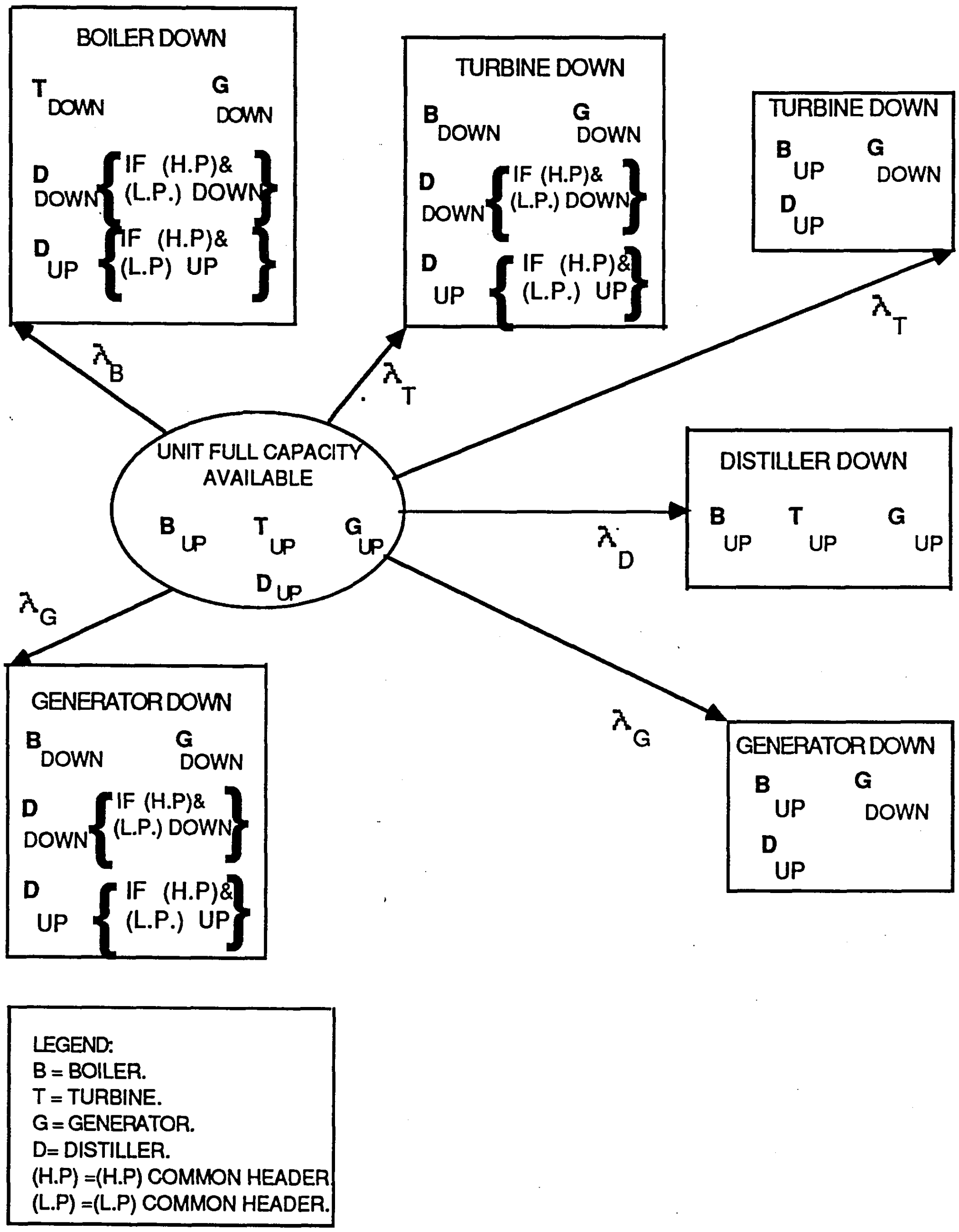
FIGURE NO 117



RESTRICTED

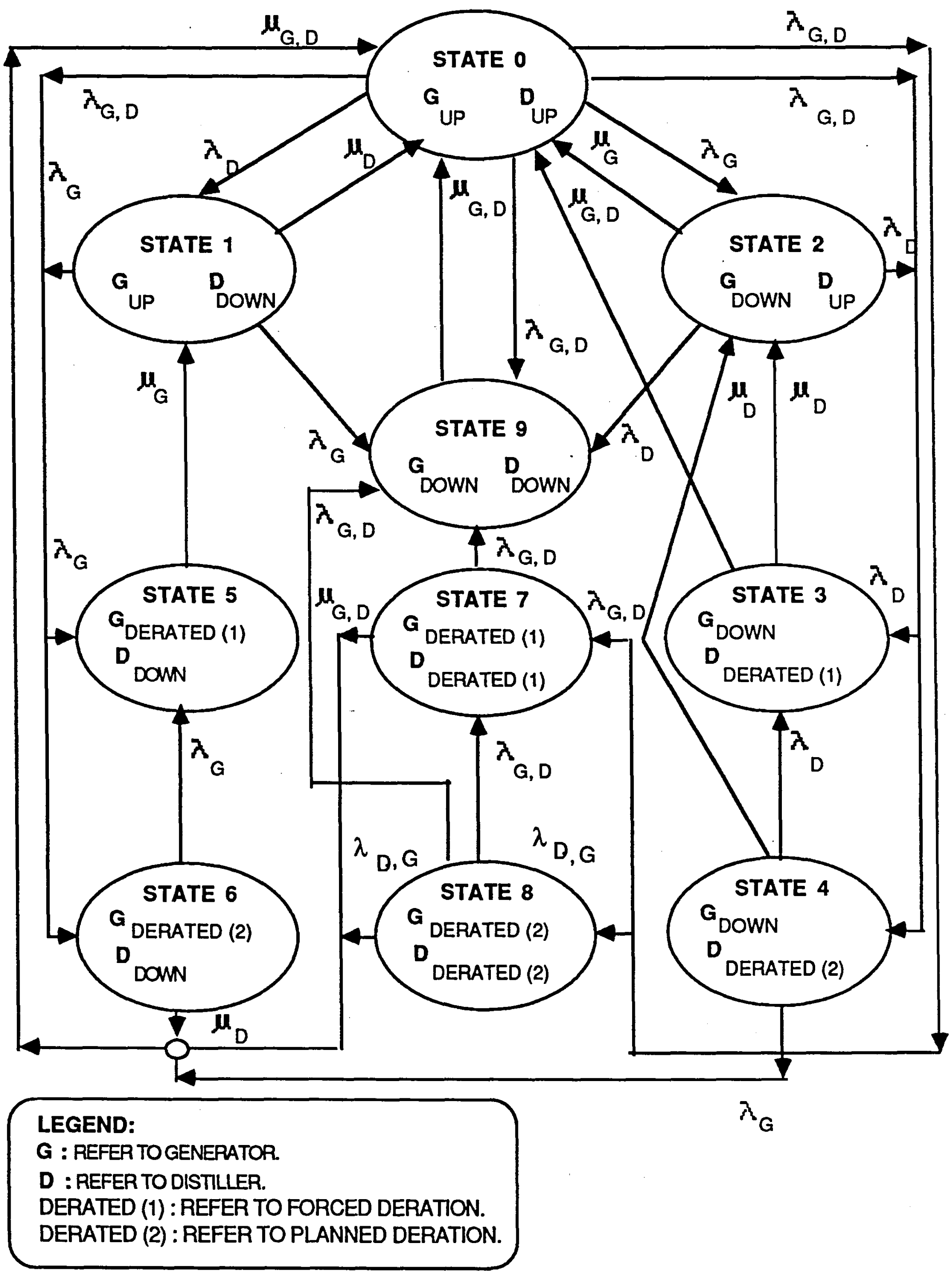
DUAL-PURPOSE(POWER&WATER) SATATION STATE SPACE DIAGRAM

FIGURE NO 118



DUAL-PURPOSE(POWER&WATER) COMBINED UNIT SUB-SYSTEMS OPERATIONAL STATE SPACE DIAGRAM

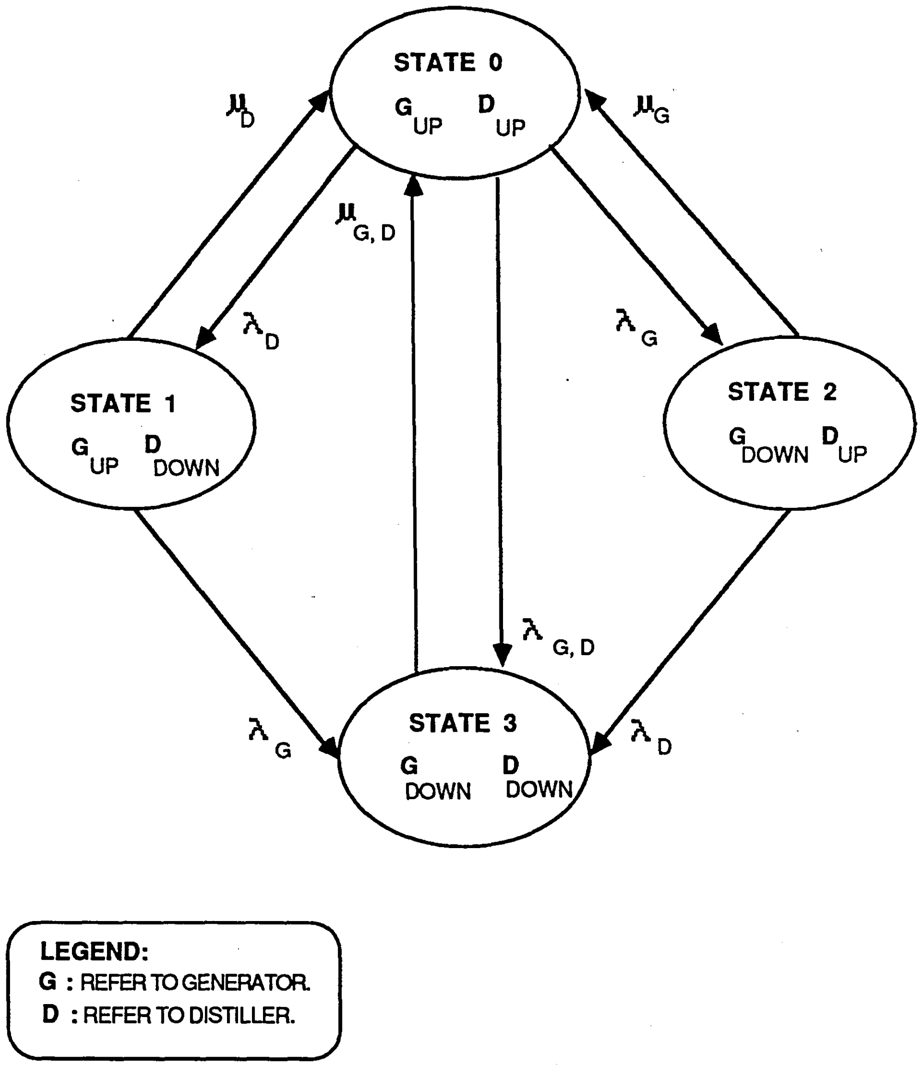
FIGURE 119



OVERALL DUAL-PURPOSE(POWER&WATER)

COMBINED UNIT GENERALIZED STATE SPACE DIAGRAM

FIGURE 120



RESTRICTED

DUAL-PURPOSE(POWER&WATER) COMBINED UNIT STATE SPACE DIAGRAM

CHAPTER V I I

DUAL - PURPOSE (POWER & WATER) PRODUCTION STATION

OUTAGE DATA COLLECTION FORMS

CHAPTER VII

DUAL -PURPOSE (POWER&WATER) PRODUCTION STATION OUTAGE DATA COLLECTION FOREMS

6.1 INTRODUCTION

There are amble justifications for the collection of reliability data in dual - purpose (power&water) production station such as :

1. System availability requirements.
2. Economic criteria.
3. Ascertaining compliance with safety requirements.
4. Facilitating the identification of optimum maintenace and replacement decisions.
5. Logistic and spares provisioning descisions and design decisions.
6. Providing ongoing feedback to the production station.
7. Reliability analysis calculations is based on adequate records of operational performanc (outages).

It is of a vital importance at the stage of designing the outages records to identify clearly the primary purpose of the data collection, because a collection scheme which is ideal in satisfying certain objectives may be less appropriate in satisfying others. There are many ways in which a reliabilility data collection scheme can be designed, however, the most important factor to be considered when designing the various data collection forms is that the collected data can be utilized easily by the reliability analyst. Furthermore, the data collection forms should include data that will enable the analyst to calculate the two most imprtance reliability parameters namely :

1. The failure rate.
2. The average outage duration or repair rate.

Therefore, the collection froms should contain not only the failure duration but also the number of failures in the operation time. As it was mentioned earlier in section (1.4.5) of chapter (I), the work of this chapter is to design and set up appropriate forms for recording the outages of the production units, unit sub - systems, unit associated systems, and their sub - sub systems. These recorded outages will eventually establish a data bank for the station various uses. There are many types of outages that equipment can encounter. Reference [92] contains a list of all possible outages. In the following the two most needed outages will be defined.

1. Planned outage :

   A planned outage is defined as the state in which the production unit is unavailable due to inspection, testing, or overall. A planned outage is normally scheduled well in advance and is of a predetermined duration.

2. Forced outage :

   A forced outage is defined as the state in which the production unit is unavailable but is not in the planned outage state.

The following tables (1 - 49) represents the developed monthly output and outages report for the station, unit sub - systems, unit associated systems, and their sub - sub systems. Each table is a distinctive self explanatory monthly report.

TABLE NO 1

DUAL- PURPOSE(POWER&WATER) STATION MONTHLY OUTPUT REPORT

MONTH OF ________ YEAR ________

TOTAL GENERATION (KWH X 10^6)		
AVERAGE LOAD (MW)		
PEAK LOAD DATA	DAY	
	TIME STARTED (hr.min)	
	TIME ENDED (hr.min)	
	DURATION (hr.min)	
	LOAD VALUE (MW)	
AVERAGE SPINNING RESEVE (MW)		
TOTAL DISTILLED WATER PRODUCTION*		

* = CAN BE QUOTED IN MILLION IMPERIAL GALLONS (M.I.G) OR CUBIC METERS (CU.METERS)

NOTE : THE ABOVE GENERATION DATA SHOULD NOT INCLUDE AUXILIARY POWER SUPPLY (e.g. GAS TURBINES etc).

TABLE NO 2

DUAL- PURPOSE(POWER&WATER) UNIT MONTHLY OUTPUT REPORT

MONTH OF __________ YEAR ________ UNIT NO ______

TOTAL GENERATION (KWH X 10^6)		
AVERAGE LOAD (MW)		
PEAK LOAD DATA	DAY	
	TIME STARTED (hr.min)	
	TIME ENDED (hr.min)	
	DURATION (hr.min)	
	LOAD (MW)	
AVERAGE SPINNING RESEVE (MW)		
GENERATOR DERATION	FORCED (hr.min)	
	PLANNED (hr.min)	
DISTILLER DERATION	FORCED (hr.min)	
	PLANNED (hr.min)	
TOTAL DISTILLED WATER PRODUCTION*		
TIME THAT BOTH THE GENERATOR AND DISTILLER OPERATED TOGETHER (hr. min)		

* = CAN BE QUOTED IN MILLION IMPERIAL GALLONS (M.I.G) OR CUBIC METERS (CU.METERS)

TABLE NO 3

DUAL-PURPOSE (POWER&WATER) UNIT SUB-SYSTEMS AND ASSOCIATED SYSTEMS MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO ______

UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE (hr.min)	FORCED NO	FORCED (hr.min)	PLANNED NO	PLANNED (hr.min)	* AEFAEU (hr.min)	* * ABNO (hr.min)
FUEL								
ELCTRICAL SUPPLY (1)								
ELECTRICAL SUPPLY (2)								
ELECTRICAL SUPPLY (3)								
SEA WATER INTAKE								
TURBNIE COOLING								
DISTILLER COOLING								
TURBINE DISCHARGE								
DISTILLER DISCHARGE								
DISTILLER(H.P) STEAM SUPPLY								
(1) DIRECT FROM BOILER								
(2) FROM COMMON HEADER								
DISTILLER(L.P. STEAM SUPPLY								
(1) DIRECT FROM BOILER								
(2) FROM COMMON HEADER								
(3) EXTRACTED FROM TURBINE								
	BOILER							
	TURBINE							
	GENERATOR							
	DISTILLER							

* AEFAEU = AVAILABLE EXCEPT FOR UNIT SUB-SYSTEMS OR ASSOCIATED SYSTEMS UNAVILABILITY.

* * ABNO = AVAILABLE BUT NOT OPERATED. (STAND BY).

TABLE NO 4

FUEL ASSOCIATED SYSTEM SUB-SYSTEMS MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

FUEL ASSOCIATED SYSTEM SUB- SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES		* ABNO2 hr.min
		NO	hr.min	NO	hr.min	
FUEL GAS (NATURAL GAS)						
CRUDE OIL						
FUEL OIL						
HEAVY FUEL OIL						
IGNITION GAS (NATURAL GAS)						
EMERGENCY IGNETION GAS (PROPANE GAS)						

* ABNO2 = AVAILABLE BUT NOT OPERATED. (STAND BY).

TABLE NO 5

FUEL GAS SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF __________ YEAR __________ UNIT NO ______

FUEL GAS SUB- SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
MAIN ISOLATING VALVE					
PRESSURE REDUCING STATION					
GAS FILTERS					
ISOLATING VALVES					
MAIN HEADER					

TABLE NO 6

CRUDE OIL SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO ______

CRUDE OIL SUB- SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
CRUDE OIL PIPE LINE					
MAIN ISOLATING VALVE					
CRUDE OIL STORAGE TANKS					
FUEL OIL SUPPLY PUMPS					
FUEL OIL PRESSURE CONTROL VALVE					
MAIN HEADER					

TABLE NO 7

HEAVY FUEL OIL SUB-SUB SYSTEM MONTHLY OUTAGES REPOR

MOMTH OF ________ YEAR _______ UNIT NO _____

HEAVY FUEL OIL SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
HEAVY FUEL OIL PIPE LINE					
MAIN ISOLATING VALVE					
HEAVY FUEL OIL STORAGE TANKS					
FUEL OIL SUPPLY PUMPS					
FUEL OIL PRESSURE CONTROL VALVE					
HEAVY FUEL OIL HEATERS					
MAIN HEADER					

TABLE NO 8

GAS OIL SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO ______

GAS OIL SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
GAS OIL PIPE LINE					
MAIN ISOLATING VALVE					
GAS OIL STORAGE TANKS					
FUEL OIL SUPPLY PUMPS					
FUEL OIL PRESSURE CONTROL VALVE MAIN HEADER					

TABLE NO 9

SEA WATER ASOCIATED SYSTEM SUB SYSTEMS MONTHLY
OUTAGES REPORT

MONTH OF __________ YEAR __________ UNIT NO ______

SEA WATER ASSOCIATED SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
SEA WATER					
SEA WATER INTAKE OPEN FOREBAY CHANNEL					
OIL POLLUTION PROTECTION SYSYTEM					

TABLE NO 10

REDUCED MAIN ELECTRICAL SUPPLY ASSOCIATED SYSTEM SUB-SYSTEMS
MONTHLY OUTAGES REPORT

MOMTH OF __________ YEAR __________ UNIT NO ______

MAIN ELECTRICAL SUPLLY ASSOCIATED SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
UNIT GENERATOR TRANSFORMES (15/132)K.V. (STEP UP) (N T RANSFORMERS					
132 K.V MAIN BUS BAR (S.F.6) SWICH GEAR					

TABLE NO 11

UNIT POWER SIDE ELECTRICAL SUPPLY ASSOCIATED SYSTEM SUB - SYSTEMS MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

UNIT POWER SIDE ELECTRICAL SUPPLY ASSOCIATED SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
UNIT TRANSFORMER (15/6.6 K.V) (STEP DOWN)					
132 K.V. MAIN BUSBAR (S.F.6) SWICH GEAR					
UNIT POWER SIDE AUXILIARIES TRANSFORMER (132/6.6 K.V) (STEP DOWN)					
UNIT POWER SIDE AUXILIARIES TRANSFORMER (6.6 K.V/415V) (STEP DOWN)					

TABLE NO 12

UNIT WATER SIDE ELECTRICAL SUPPLY ASSOCIATED SYSTEM SUB SYSTEMS MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

UNIT WATER SIDE ELECTRICAL SUPPLY ASSOCIATED SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
132 K.V. MAIN BUSBAR (S.F.6) SWICH GEAR					
UNIT WATER SIDE AUXILIARIES TRANSFORMER (132/11 K.V) (STEP DOWN)					
UNIT WATER SIDE AUXILIARIES TRANSFORMER (11 K.V/415V) (STEP DOWN)					

TABLE NO13

TURBINE COOLING ASSOCIATED SYSTEM SUB SYSTEMS MONTHLY OUTAGE REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

TURBINE COOLING ASSOCIATED SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
TRASH RACK					
DISINFECTION SYSTEM					
TRAVELLING SCREENS					
TURBINE CONDENSER COOLING WATER PUMPS					
VALVES					
PIPES					

TABLE NO14

DISTILLER COOLING ASSOCIATED SYSTEM SUB SYSTEMS MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO ____

DISTILLER COOLING ASSOCIATED SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
TRASH RACK					
DISINFECTION SYSTEM					
TRAVELLING SCREENS					
DISTILLER COOLING AND MAKE-UP WATER PUMPS					
DISTILLER COOLING AND MAKE-UP WATER HEADER					
VALVES					
PIPES					

TABLE NO15

BOILER SUB-SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

BOILER SUB SYSTEM SUB-SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
BOILER FEED& MAKE-UP WATER					
BOILER HEAT RECOVERY AREA					
BOILER DRUM					
BOILER FURNACE					
BOILER COMBUSTION AIR					
BOILER FLUE GAS					
BOILER MAIN STOP VALVE					

TABLE NO 16

BOILER FEED& MAKE-UP WATER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF __________ YEAR __________ UNIT NO ______

BOILER FEED& MAKE-UP WATER SUB-SUB SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES NO	FORCED OUTAGES (hr.min)	PLANNED OUTAGES NO	PLANNED OUTAGES (hr.min)
SERVICE WATER TANK(S)					
SERVICE WATER PUMPS					
MAKE-UP WATER STORAGE TANKS					
NORMAL MAKE-UP WATER LINE					
EMERGENCY MAKE-UP WATER LINE					
DISTILLER CONDENSATE RETURN HEADER AND LINE					
SPILL OVER RETURN LINE					
MAIN DEAERATOR & FEED WATER TANK					
DEAERATOR (L.P.) STEAM FEEDING LINE					
(H.P.) HEATER STEAM& CONDENSATE RETURN LINE					
FEED WATER TRANSFER PUMPS					
MAIN HEATER					
MAIN HEATER (H.P.) STEAM FEEDING LINE					
CONTROL VALVES& VALVES					
PIPES					

TABLE NO17

BOILER HEAT RECOVERY AREA SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

HEAT RECOVERY AREA SUB-SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
			hr.min	NO	hr.min
ECONOMIZER					
PRIMARY SUPERHEATER					
ATTEMPERATOR		NO			
SECONDARY SUPERHEATER					
CONTROL VALVES					
VALVES					
PIPES					

TABLE NO18

BOILER DRUM SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

BOILER DRUM SUB SYSTEM SUB-SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
DRUM INTERNALS					
BOILER FEED CHEMICAL TREATMENT SYSTEM					
BLOW DOWN LINE					
DRUM LEVEL MEASURING SYSTEM					
DRUM SAFETY VALVE					
DRUM VENTING SYSTEM					
DRUM SAMPLING LINE					

TABLE NO 19

BOILER FURNACE SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF __________ YEAR __________ UNIT NO ______

BOILER FURNACE SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
FURNACE WALL TUBES					
DRAIN VALVES					

TABLE NO 20

COMBINED BOILER COMBUSTION AIR & FLUE GAS SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

COMBINED BOILER COMBUSTION & FLUE GAS SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
FORCED DRAFT FANS					
COMBUSTION AIR CONTROL VALVES					
AIR DAMPERS					
STEAM AIR HEATER					
AIR DUCT AND WIND BOX					
FLUE GASES DUCT					
STACK (CHIMNEY)					

TABLE NO 21

TURBINE SUB - SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO ______

TURBINE SUB SYSTEM SUB-SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
MAIN STEAM SUPPLY LINE					
AUXILIARY STEAM LINE FOR MAIN EJECTOR & TURBINE GLAND					
TURBINE LOAD CONTROL					
HIGH PRESSURE TURBINE					
LOW PRESSURE TURBINE					
TURBINE ROTOR					
TURBINE LUBRICATING & HYDRAULIC OIL SYSTEM					
TURBINE CONDENSER SYSTEM					
TURBINE CONDENSATE SYSTEM					

TABLE NO 22

MAIN STEAM SUPPLY SUB-SUB SYSTEM: MONTHLY OUTAGES REPORT

MOMTH OF __________ YEAR __________ UNIT NO ______

MAIN STEAM SUPPLY SUB- SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
MAIN STEAM STOP VALVE LEFT & RIGHT					
MAIN STOP STOP VALVE RIGHT BYPASS VALVE					
VALVES					
PIPES					

TABLE NO 23

AXILIARY STEAM FOR TURBINE AIR EJECTOR & GLAND SEALS SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

AXILIARY STEAM FOR TURBINE AIR EJECTOR & GLAND SEAL SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
AIR EJECTORS					
CONTROL VALVES FOR PRESSURE & LEVEL					
HYDRAUILIC OIL FOR GLANDS STEAM REGULATOR					
VALVES					
PIPES					

TABLE NO 24

TURBINE LOAD CONTROL SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

TURBINE LOAD CONTROL SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
CONTROL VALVES					
CAM AND CAM SHAFT					
SERVOMOTOR					
SPEED GOVERNOR					
GOVERNOR MOTOR					
LOAD LIMITER					
INITIAL PRESSURE REGULATOR					

TABLE NO 25

HIGH PRESSURE TURBINE SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

HIGH PRESSURE TURBINE SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
TURBINE CASING					
FIXED AND MOVING BLADES					
CONTROL VALVES CHEST					
GLAND SEAL					
INTERNAL DIAPHRAM					
VALVES					
PIPES					

TABLE NO 26

LOW PRESSURE TURBINE SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

LOW PRESSURE TURBINE SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
OUTER CASING					
INNER CASING					
FIXED AND MOVING BLADES					
DIAPHRAM RELIEF VALVES					
INTERNAL DIAPHRAM					
GLAND SEAL					
VALVES					
PIPES					

TABLE NO 27

TURBINE ROTOR SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

TURBINE ROTOR SUB-SUB SYSTEM SUB-SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
GOVERNOR DRIVING GEAR					
MAIN OIL PUMP					
HIGH PRESSURE (H.P) ROTOR					
LOW PRESSURE (H.P) ROTOR					
ROTOR COUPLING					
TURNING GEAR					
ROTOR GLAND					
GENERATOR ROTOR					
EXCITER ROTOR					
PILOT EXCITER ROTOR					
TACHOMETER					
BEARING					

TABLE NO 28

TURBINE HYDRAULIC & LUBRICATING OIL SUB-SUB SYSTEM
MONTHLY OUTAGE REPORT

MONTH OF ________ YEAR ________ UNIT NO ______

TURBINE HYDRAULIC AND LUBRICATING OIL SUB-SUB SYSTEM SUB-SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
OIL PUMPS					
OIL COOLERS					
OIL STRAINNER					
CONTROL VALVES					
OIL TANK					
OIL TANK VAPOUR EXTRACTER					
OIL PURIFIER					
VALVES					
PIPES					

TABLE NO 29

TURBINE CONDENSER SUB-SUB SYSTEM : MONTHLY OUTAGE REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

TURBINE CONDENSER SUB-SUB SYSTEM SUB-SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
CONDENSER FRAME AND EXCHANGE TUBES					
WATER BOXES					
CATHODIC PROTECTION SYSTEM					
HOT WELL					
CONTAMINATED CONDENSATE PUMP					
VACUUM BREAKER					
MAKE-UP WATER CONTROL VALVE					
VALVES					
PIPES					

TABLE NO 30

TURBINE CONDENSATE SUB-SUB SYSTEM MONTHLY OUTAGE REPORT

MONTH OF ________ YEAR ________ UNIT NO ______

TURBINE CONDENSATE SUB-SUB SYSTEM SUB-SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
SUCTION STRAINER					
CONDENSATE PUMPS					
MAXIMUM FLOW CONTROL VALVE					
GLAND STEAM CONDENSER					
EJECTOR AND GLAND STEAM LEVEL CONTORL VALVE					
VALVES					
PIPES					

TABLE NO 31

GENERATOR SUB - SYSTEM MONTHLY OUTAGE REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

GENERATOR SUB-SYSTEM SUB-SUB SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
GENERATOR ROTOR					
GENERATOR STATOR					
HYDROGEN COOLING					
SEALING OIL					
PILOT EXCITER					
EXCITER					
VOLTAGE CONTROL					

TABLE NO 32

GENERATOR ROTOR SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO ______

GENERATOR ROTOR SUB- SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
GENERATOR ARMETURE					
COLLECTOR RINGS					
COLLECTOR RINGS COOLER					
BEARINGS					
COUPLINGS					

TABLE NO 33

GENERATOR STARTOR SUB-SUB SYSTEM: MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

GENERATOR STATOR SUB-SUB SYSTEM SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
STARTOR FRAME					
STARTOR WINDING					
DUSBAR DUCT					

TABLE NO 34

GENERATOR HYDROGEN COOLING SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO ____

GENERATOR HYDROGEN COOLING SUB -SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
HYDROGEN CYLINDER RACKS					
HYDROGEN RESSURE REGULATING VALVE					
HYDROGEN COOLERS					
VALVES					
PIPES					

TABLE NO 35

GENERATOR SEALING OIL SUB-SUB SYSTEM MONTHLY OUTAGE REPORT

MONTH OF ________ YEAR ________ UNIT NO ______

GENERATOR SEALING OIL SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE (hr.min)	FORCED OUTAGES		PLANNED OUTAGES	
		NO	(hr.min)	NO	(hr.min)
MAIN SEAL OIL PUMP					
EMERGENCY SEAL OIL PUMP					
VACUUM PUMP					
SEAL OIL PRESSURE CONTROL VALVE					
HYDROGEN DRAINING VALVE					
AIR DRAINING TANK					
SEALING OIL RINGS					
VALVES					
PIPES					

TABLE NO 36

GENERATOR PILOT EXCITER SUB-SUB SYSTEMS MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

GENERATOR PILOT EXCITER SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
PILOT EXCITER RPTOR					
STATOR					
BRUSHES					

TABLE NO 37

GENERATOR EXCITER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF __________ YEAR __________ UNIT NO ______

GENERATOR EXCITER SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
EXCITER ROTOR					
EXCITER STATOR					
SILICON RECTIFIERS					
BRUSHES					
CIRCUIT BREAKERS					
EXCITER COOLOER					
EXCITER CUBICAL COOLING FANS					
VALVES					
BEARINGS					

TABLE NO 38

GENERATOR VOLTAGE CONTROL SUB-SUB SYSTEMS MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO ______

GENERATOR VOLTAGE CONTROL SUB- SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
AUTOMATIC VOLTAGE REGULATOR (AVR)					
INDUCTION VOLTAGE REGULATOR					
AUTOMATIC FOLLOW UP DEVICE					
REACTIVE POWER CONTROLLER					
POWER FACTOR CONTROLLER					

TABLE NO 39

HIGH PRESSURE (H.P) STEAM DIRECT FROM BOILER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

HIGH PRESSURE STEAM DIRECT FROM BOILER SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
HIGH PRESSURE STEAM LINE FROM BOILER					
HIGH PRESSURE STEAM DESUPERHEATER (AT BOILER SIDE)					
REDUCED HIGH PRESSURE STEAM CONTROL VALVE					
VALVES					
PIPES					

TABLE NO 40

HIGH PRESSURE (H.P) STEAM FROM COMMON HEADER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

HIGH PRESSURE STEAM FROM COMMON HEADER SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
HIGH PRESSURE STEAM DIRECT FROM BOILER SUB-SUB SYSTEM (N BOILERS)					
BOILER 1					
BOILER 2					
BOILER (N)					
(H.P) STEAM COMMON HEADER					
VALVES					
PIPES					

TABLE NO 41

LOW PRESSURE (L.P) STEAM EXTRACTED FROM TURBINE SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

LOW PRESSURE STEAM EXTRACTED FROM TURBINE SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
LOW PRESURE STEAM LINE FROM TURBINE					
PRESSURE CONTROL VALVE					
VALVES					
PIPES					

TABLE NO 42

LOW PRESSURE (L.P) STEAM FROM COMMON HEADER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

LOW PRESSURE STEAM FROM COMMON HEADER SUB-SUB SYSTEM SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
HIGH PRESSURE STEAM DIRECT FROM BOILER SUB-SUB SYSTEM (N BOILERS)					
BOILER 1					
BOILER 2					
BOILER (N)					
LOW PRESSURE STEAM EXTRACTED FROM TURBINE SUB-SUB SYSTEM (N TURBINE)					
TURBINE 1					
TURBINE 2					
TURBINE (N)					
(L.P) STEAM COMMON HEADER					
VALVES					
PIPES					

TABLE NO 43

DISTILLER SUB-SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO ____

DISTILLER SUB SYSTEM SUB-SUB SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
MAIN BRINE HEATER					
HEAT RECOVERY SECTION					
HEAT REJECTION SECTION					
DISTILLATE DISCHARGE					
AIR EJECTOR					

TABLE NO 44

DISTILLER BRINE HEATER SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

DISTILLER BRINE HEATER SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
LOW PRESSURE DESUPERHEATER (AT DISTILLER SIDE)					
TEMPERATURE CONTROL VALVE					
HEAT EXCHANGE TUBES					
HEATER SHELL					
HEATER DRAIN PUMP					
LEVEL CONTROL VALVE					
VALVES					
PIPES					

TABLE NO 45

DISTILLER HEAT RECOVERY SECTION SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR ________ UNIT NO _____

DISTILLER HEAT RECOVERY SECTION SUB-SUB SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
BRINE RECIRCULATING PUMP					
STAGES (IN SERIES) (N-3 STAGES)					
VALVES					
PIPES					

TABLE NO 46

DISTILLER HEAT RECOVERY SECTION STAGE SUB-SUB SYSTEM
MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

DISTILLER HEAT RECOVERY SECTION STAGE SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
FLASH CHAMBER					
ORFICE PLATE					
DIMISTER					
HEAT EXCHANGE TUBES					
WATER BOXES					
DISTILLATE TROUGH					
VENTING ORFICE					

TABLE NO 47

DISTILLER HEAT REJECTION SECTION SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF __________ YEAR __________ UNIT NO ______

DISTILLER HEAT REJECTION SECTION SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
SEA WATER MAKE-UP BLEED OFF LINE					
SEA WATER RECIRCULATING PUMP (ONLY FOR WINTER OPERATION					
CHEMICAL INJECTION SYSTEM					
STAGES IN SERIES (3 STAGES)					
LAST STAGE LEVEL CONTROL SYSTEM					
BLOW DOWN PUMP					
DEAERATOR (INTERNAL OR EXTERNAL)					
VALVES					
PIPES					

TABLE NO 48

DISTILLER DISCHARGE SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MONTH OF ________ YEAR ________ UNIT NO _____

DISTILLER DISCHARGE SUB-SUB SYSTEM SUB- SYSTEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
DISTILLATE PUMP					
DISTILLATE LEVEL CONTROL SYSTEM					
DISTILLATE CONDUCTIVITY CONTROL SYSTEM					
VALVES					
PIPES					

TABLE NO 49

DISTILLER EJECTOR SUB-SUB SYSTEM MONTHLY OUTAGES REPORT

MOMTH OF ________ YEAR _______ UNIT NO _____

DISTILLER EJECTOR SUB-SUB SYSTEM SUB-SYSYEMS	IN SERVICE hr.min	FORCED OUTAGES		PLANNED OUTAGES	
		NO	hr.min	NO	hr.min
EJECTOR STEAM FLOW CONTROL VALVE					
EJECTOR NOZZELS					
EJECTOR CONDENSER					
AIR EXTRACTION VALVE					
DISTILLER VENTING PIPING					
VALVES					
PIPES					

CHAPTER VIII

REFERENCE STATION OUTAGE DATA ANALYSIS -CONCLUSIONS AND RECOMMENDATIONS

CHAPTER V III

REFERENCE STATION OUTAGE DATA ANALYSIS -CONCLUSIONS AND RECOMMENDATIONS

8.1. Introduction

As it was mentioned earlier in sections (1.4.6) and (1.4.7) of chapter (**I**), that the work of this chapter is to perform reliability calculations based upon the collected outage data from Doha East power&water production station in the state of Kuwait. Furthermore, it will contain the conclusions and recommendations.

8.2. Reference station characteristics

The selected reference station is Doha East (power&water) production station of the state of Kuwait. This station is composed of seven identical (power&water) production units. The power side sub - systems and associated systems of the seven units were commissioned over the period (1977 - 1979). The power production of each unit is 150 (MW) of electrical power. Therefore the total installed production capacity of the station is 1050 (MW) of electrical power. The boiler efficiency is 88.13 % and its capacity is 650 tons/hour. The turbine exhaust pressure is 1.16 lb /sq in (Absolute pressure). The percentage of steam employed in the power side of the production unit is 79 %. of the boiler capacity.

The water production sub - system (the distiller) and the related associated systems of the seven units were commissioned over the period (1978 - 1979). The water production of each unit is 27270 (cubic meters) (6 million imperial gallons per day) of distilled water. Therefore the total installed production capacity of the station is 191 X 10^3 ((cubic meters) (42 million imperial gallons per day). The distiller performance ratio (P.R) is 8. The percentage of low pressure (L.P) steam extracted from the turbine for distillation purposes is 20 %. of the boiler capacity. The electrical energy needed for the distiller is 5 (MW). At the time of the reference station commissioning, it was considered the world's largest (power&water) production station.

8.3. Reference station original outages data

The reference station operation department collects a monthly outages data in a form that is not meant for reliability assessment but, for the station personnel and the Ministry of Electricity and Water of the state of Kuwait reference and various uses. The outages data are collected separately for power generation side and the distilled water production side. For the purpose of the reliability calculations of the reference station, the monthly outages data for all the seven production units were collected over the period of five years (1982 - 1986). The choice for this particular period is due to the fact that the reference station is in it's useful life (i.e. passed it's de-bugging phase of life and not in it's wear out phase of life). Tables (50 - 54) represent random samples of five months for the generation side outages (pages 321-325). These months are January 1982, June 1983, January 1984, April 1985, and December 1986 respectively. It should be noted that the abbreviation (N.N.C) in these tables refers to the national control centre of the Ministry of Electricity and Water of the state of Kuwait. Tables (55 - 59) represents a random samples of five months for the distilled water production side outages (pages 326-330). These months are January 1982, June 1983, January 1984, April 1985, and December 1986 respectively. It should be noted that the abbreviation (W.C.C) in these tables refers to the water control centre of the water department of the Ministry of Electricity and Water of the state of Kuwait. The reason the thesis does not include the original (raw) reference station collected data is that the thesis will become a three volume thesis. However these original collected data are available on demand. It is obvious from the above mentioned tables that these tables contains only a small amount of information on the definitive failure mode and failed part description. The sample forms will be found at the end of the text of this chapter.

8.4. Reference station processed outages data

The original reference station data as in it's raw form were not suitable for reliability calculations. Furthermore, there are two monthly forms, one for the generation side and the other for the water production side. Moreover, each form include the monthly outages for all the seven production units. Therefore, a new form was designed to enable us to input in it the monthly outages data of each production unit alone. The new form contains the monthly outages data for all the production unit associated systems and sub - systems. In order to fill in the new forms the original data was studied and all the queries regarding the outages data were verified. To accomplish the verification of the queries I, have made six trips to the state of Kuwait over the period of the research study, and held extensive discussions with the reference station operation personnel. Tables (60 - 64) represents a random samples of five months for production unit (A - 1) outages data (gages 331-337). These months are January 1982, June 1983, January 1984, April 1985, and December 1986 respectively. The selected months are the same as the ones for the original data. The outages data in the new forms are referred to as the processed data. The processed data for all the seven production units over the five years period are presented in appendix (1) and found in volume (**II**) of the theses.The sample forms will be found at the end of text of this chapter.

8.5. Discussion of the results

All the processed data for the seven production units were entered in a computer spread sheet program, and the various reliability calculations were performed on them. The following sub - sections contains the various results. It should be noted that the reliability calculations in the following sections are mainly related to the major parts of the production units sub - systems (i. e. boiler, turbine, generator, distiller) and the station.

8.5.1. Five years statistics for unit sub - systems

Figure (121-A-B-C) represents a cumulative five year statistics for the production unit sub - systems (page 338). Figure (121-A) represent the total number of failures for boiler, turbine, generator, and distiller. From this figure, the number of forced failures encountered by the boiler was 102, the turbine was 29, the generator was 46, and the distiller was 72. It is obvious from the statistics that the boiler is the most vulnerable sub - system to forced outages.

Figure (121-B) represents the mean time to repair (MTTR) for the various unit sub - systems. From this figure, the mean time to repair for the boiler is approximately 64 hours, for the turbine is approximately 108 hours, for the generator is approximately 55 hours, and for the distiller is approximately 45 hours. These results shows that eventhough, boiler is the most vulnerable sub - system to forced outages, however, it's mean time to repair is reasonable in comparison with the turbine. The mean time to repair for generator and distiller are not far from each other. The mean time to repair for the turbine is the most lengthy in comparison to the other production unit sub - systems.

Figure (121-C) represents the total outages over the five years period for the various unit sub - systems. From this figure, the total outages for the boiler was (6539) hours, for the turbine was 3132 hours, for the generator 2511 hours, and for the distiller was 3220 hours. Furthermore, this figure shows the percentage of time the various production unit sub - systems were out of service over the five years period. The percentage of time the boiler was out of service was 2.1 %, the turbine was 1 %, the generator was 0.82 %, and the distiller was 1 %. These percentages indicates that the production unit sub - systems outages are fairly reasonable and acceptable, provided the maintenance work is kept at a high level.

8.5.2. Average failure rates over the five years

Table (65) represents the average failure rates (λ) for the production unit associated systems, and the unit sub - systems for the years (1982), (1983), (1984), (1985), and (1986) as well as the overall average (page 339). Furthermore, it contains the production unit reliability over a year, a month, a week, and a day. Moreover, it contains the unit availability. From the table it is clear that the failure rate (λ) for the main electrical supply (electrical supply 1) associated system, and the sea water intake associated system is zero. Furthermore, the table shows that the distiller failure rate is the highest among the production unit sub - systems, and the distiller cooling associated system failure rate is the highest among the unit associated systems. The average production unit reliability per year is 1.36 $X10^{-4}$, per month is 0.27, per week is 0.71, and per day is 0.95. The average production unit availability is 49 % . It should be noted that these values refers the production unit when it is producing both power and distilled water at the same time. These values illustrates that the production unit is maintenance intensive, and requires constant repairs. Furthermore, with such a low reliability and availability the station should have a substantial reserves units in to order meet the demands.

8.5.3. Average failure rates for the boiler sub - system

Figure (122) represents the average failure rates for the boiler sub - system for each boiler of the seven production units (page 340). From this figure, values of the failure rates for the different boilers are close.

8.5.4. Average failure rates for the turbine sub - system

Figure (123) represents the average failure rates for the turbine sub - system for each turbine of the seven production units (page 341). From this figure, values of the failure rates for the different turbine are very close, and can be regarded as constant.

8.5.5. Average failure rates for the generator sub - system

Figure (124) represents the average failure rates for the generator sub - system for each generator of the seven production units (page 342). From this figure, values of the failure rates for the different generator are very close, and can be regarded as almost constant.

8.5.6. Average failure rates for the distiller sub - system

Figure (125) represents the average failure rates for the distiller sub - system for each distiller of the seven production units (page 343). From this figure, values of the failure rates for the different distiller are close except for unit (A - 7), because the brine pump of this unit was on a forced outage for almost one and half years.

8.5.7. Average failure rates for all unit sub - systems

Figure (126) represents the average failure rates for all the production unit sub - systems (page 344). The dotted line in the figure refers to the distiller average failure rate without unit (A - 7) outages included in the calculations. The confidence that can be placed in theses calculated average values is dependent upon the amount of in service time and the number of failures that occur. In order to establish the confidence limits in these average values, the chi - square distribution method of calculating the upper and lower limits was used.

8.5.8. Chi - Square Distribution Estimate

The chi square distribution estimate of the 95 % confidence limits of the calculated average failure rates for the boiler, turbine, generator, and distiller were computed using the chi - square tables. The lower limit of the chi - square distribution is as follows [94] :

$$\text{Lower limit} = \frac{\chi^2 \; 1 - \frac{p}{2} \, , 2\,\nu}{2\,t} \qquad \text{-----------------------------------(214)}$$

Where :

$$p = 1 - 0.95 = 0.05$$

ν = number of failures

$2 \times \nu$ = degree of freedom

t = in service time (hours)

And the upper limits is as follows ;

$$\text{Upper limit} = \frac{\chi^2 \; \frac{p}{2} \, , 2\,\nu + 2}{2\,t} \qquad \text{-----------------------------------(215)}$$

The lower and upper limits values of the χ^2 are found by looking into a cumulative chi - square distribution tables using the ordinate (P/2) or (1 - P/2) and the abscissa of (2 ν) or (2 ν + 2). The tabulated values are divided (2 X t) and expressed in hours to obtains the 95 % confidence limits for the mean failure rate. Figure (127) represents the chi - squrare upper and lower confidence limits for the boiler, turbine, generator, and distiller for, 1982, 1983, 1984, 1985, and 1986 respectively (page 345). From the figure, it is clear that the values of the calculated average failure rates for all the production unit sub - systems lies between the upper and the lower limits of the estimated chi - square values. This indicates that the assumption that the failure rates is constant, which was made in developing the reliability models in chapter (V) is consistent with these calculations.

8.5.9. Average failure rates for Unit (A - 1) Sub - Systems

Figure (128) represents average failure rates for unit (A - 1) sub - systems. The figure is presented for comparison purpose (page 346). It is clear from the figure that the failure rates of the various sub. systems are scattered.

8.5.10. Production Unit Sub - Systems Mean Time Between Failures (MTBF)

Figure (129) represent the production unit sub - systems mean time between failures (MTBT) (page 347). From the figure, The (MTBF) for the boiler is approximately 2250 hours, for the turbine is approximately 7750 hours, for the generator is approximately 5000 hours, and for the distiller is approximately (1500 hours). It is clear from these values that the distiller (MTBT) is the shortest and the (MTBT) for the turbine is the longest. It should be noted that these values should be compared with values of the mean time to repair (MTTR) in figure (121). Figure (129) and (121) form part of the station maintainability analysis. It is recommended that this analysis should be performed by future interested analysts.

8.5.11. Dual - purpose (power&water) station reliability

Figure (130) (page 348) represents the reliability of the station based on the "**r**" out of "**n**" configuration reliability model developed in chapter (V) of the thesis..The figure shows the probability of no failures within a month encountered by the seven production units versus the number of units operational to be considered a successful operation of the station. From the figure it is clear that the number of units that can be operated successfully out of the seven in a month time is 3 units with a probability of success of 40 %.

8.6. Conclusions

From the work of the previous chapters, and the results of this chapter, the following conclusions can be made :

1. The reliability models for the production station, unit associated systems, unit sub - systems, and their sub - sub systems which were presented in chapter (V) of the thesis are fairly representative and adequate for reliability calculations of the dual - purpose (power&water) production station and production unit.
2. The assumption that the failure rates is constant, which was made in developing the reliability models in chapter (V) is consistent with reliability calculations. Hence it reasonable to make such an assumption for future reliability calculations.
3. The results of the reliability calculations indicates that the dual purpose (power&water) production units are highly maintenance intensive. Therefore, in order to meet the demands, a highly skilled maintenance team should be available, and adequate spare parts should available at all time.
4 The results of the reliability calculations indicates that the boiler is the most vulnerable sub - system to forced outages.
5. The results of the reliability calculations indicates that the turbine mean time to repair is very long. Therefore, this factor should be considered when setting - up turbine specifications.

8.7. Recommendations

Based on the research studies, the following recommendations are presented :

1. A maintainability analysis should be initiated to complement the reliability works of this thesis
2. The maintainability analysis should address it's self not only to forced outages, but also to the planned outages and the stand by outages.
2. A state space reliability assessments of the (power &water) production station and the production unit should be conducted in order to establish the static production capacity planning for future stations, production capacity reserve, and operating reserve.
3. A detailed criticality analysis should be performed in order to identify the critical components of the production unit associated systems and sub - systems.and their

sub - systems.

4. A computerized information system for reliability and maintainability works based on the suggested monthly outages report of chapter (**VII**) of thesis should be developed and implemented.

5. An interconnected production stations reliability analysis should be initiated, in order to establish an overall reliability models for future planning of the production of power and distilled water for the country as a whole.

TABLE NO 50

DOHA POWER & WATER PRODUCTION STATION.

GENERATING UNITS OUTAGES REPORT FOR THE MONTH OF JANUARY 1982.

UNIT	RUNNING HOURS	STANDBY HOURS	OUTAGES EMERGENCY HOURS	OUTAGES PLANNED HOURS	Availability % Including standby	TOTAL GENERATION KWH X 10^6	AVERAGE LOAD MW	REASONS & REMARKS.
1	223-02	—	—	520-58	30	15.02	20	Unit started after annual overhaul on 21/1/82. Shutdown for N.C.C. work also
2	533-27	—	—	210-33	72	48.970	66	Shutdown for Gen. Exciter Cooler leakage and for Air furnace tubes Support modifications.
3	743-28	—	—	0-32	99.9	70.840	95	Taken off bar for N.C.C. Work
4	478-22	—	—	265-38	64	45.580	61	Unit Shutdown for annual overhaul from 20/1/82 -
5	273-48	36-55	—	433-17	37	21.870	29	Unit was under annual Overhaul upto 19/1/82
6	741-34	—	—	2-26	99.6	67.810	91	Unit taken off bar for N.C.C. Work
7	741-58	—	—	2-02	99.6	67.620	91	Unit taken off bar for N.C.C. work
	TOTAL					337.710	453.00	

OPERATION ENGINEER

TABLE NO 51

DOHA EAST POWER & WATER PRODUCTION STATION

GENERATING UNITS OUTAGES REPORT FOR THE MONTH OF JUNE 1983.

UNIT	RUNNING HOURS	STANDBY HOURS	OUTAGES		Availability % including standby.	TOTAL GENERATION KWH X 10^6	AVERAGE LOAD MW	REASONS & REMARKS
			EMERGENCY HOURS	PLANNED HOURS				
1	717-24	-	-	2-36	99	68.940	96	Unit taken off bar to change fuel ratio logic card.
2	660-59	-	-	59-01	92	62.670	87	Unit taken off bar to attend F.W.low range control v/v,110V D.C. earth fault & other minor defects.
3	712-46	-	-	7-14	99	72.220	100	Unit shut down to attend H.P.heater B Condenenser to deareator line puncture.
4	679-05	-	-	40-55	94	65.530	91	Unit shut down for C.W. Condenser outlet culvert inspection work.
5	714-24	-	5-36	-	99	69.520	97	Unit tripped as blr tripped on "Critical flame out".
6	720.00	-	-	-	100	70.810	98	No outage.
7	720.00	-	-	-	100	70.430	98	No outage.
				TOTAL :		480.120	667	

SUPERINTENDENT OPERATION ENGINEER

TABLE NO 52

DOHA EAST POWER & WATER PRODUCTION STATION

GENERATING UNITS OUTAGES REPORT FOR THE MONTH OF JANUARY 1984.

UNIT	RUNNING HOURS	STANDBY HOURS	OUTAGES EMERGENCY HOURS	OUTAGES PLANNED HOURS	Availability % including standby.	TOTAL GENERATION KWH X 10^6	AVERAGE LOAD MW	REASONS & REMARKS
1	668-50	2-09	-	73-01	90	60.880	81.827	Unit tripped due to fuel gas preparation switch made off by mistake, and shut down to check steam leakage at primary S/H area, and 110V, DC earth fault.
2	269-10	-	-	474-50	36	25.550	34.341	Unit shut down to attend main steam sample line leakage.
3	737-25	1-34	-	5-01	99	70.220	94.382	Unit tripped due to turbine thrust brg. metal temp high switch actuated by mistake and shut down to check unit aux. autothrow over.
4	352-06	-	-	391-51	47	30.080	40.430	Unit was under overhaul upto 7/1/84. Shut-down to remove turbine MSV fine mesh strainer
5	430-23	-	-	313-37	58	39.550	53.159	Unit shut down for annual maintenance on 19/1/84.
6	744-00	-	-	-	100	68.520	92.097	No outage.
7	744-00	-	-	-	100	64.210	86.304	No outage.
			TOTAL :			359.010	479.540	

0.227

SUPERINTENDENT. 359,237 90,458

OPERATION ENGINEER.

TABLE NO 53

DOHA EAST POWER & WATER PRODUCTION STATION

GENERATING UNITS OUTAGES REPORT FOR THE MONTH OF APRIL 1985

UNIT	RUNNING HOURS	STANDBY HOURS	OUTAGES EMERGENCY HOURS	OUTAGES PLANNED HOURS	AVAILABILITY % INCLUDING STANDBY	TOTAL GENERATION KWH X 10^6	AVERAGE LOAD M.W.	REASONS & REMARKS
1	696-44	—	—	23-16	97	52.260	75.007	Unit shutdown for inspection of Rotary airheater and to check 110V. D.C. earth-fault.
2	555-37	—	0-50	163-33	77	40.380	72.676	Unit tripped due to Gen. ground relay action. Unit shut down to check 110V D.C. e/f. & attend F.W. low range control valve
3		Shut down		720-00				Unit remain under annual maintenance from 19/3/85 to 8/5/85.
4		Shut down		720-00				Unit remain under annual maintenance from 23/3 to 1/5/85.
5	720-00	—	—	—	100	53.910	74.875	No outage.
6	634-39	—	1-08	84-13	88	48.170	75.900	Unit was under annual maintenance to 3/4/85. Unit shut down for cooling of burners on oil firing.
7	720-00	—	—	—	100	54.480	75.666	No outage.
				TOTAL :		249.200	—	

DIRECTOR. 8/5

OPERATION ENGINEER. 7/5

TABLE NO 54

DOHA EAST POWER & WATER PRODUCTION STATION

GENERATING UNITS OUTAGES REPORT FOR THE MONTH OF December 1986.

UNIT	RUNNING HOURS	STANDBY HOURS	OUTAGES		AVAILABILITY % INCLUDING STANDBY	TOTAL GENERATION KWH X 10^6	AVERAGE LOAD M.W.	REASONS & REMARKS
			EMERGENCY HOURS	PLANNED HOURS				
1	704-12	-	-	39-48	95	53.430	75.873	Shut down for annual maintenance on 30/12/1986.
2	62-56	65-04	-	616-00	17	4.580	72.776	Shut down for annual maintenance on 3/12/1986.
3	744-00	-	-	-	100	58.970	79.261	No outage.
4	720-55	-	-	23-05	97	57.910	80.328	Shutdown to attend blow down line leak near blow down tank.
5	55-19	35-44	-	652-57	12	3.940	71.226	Under annual maintenance upto 27/12/86. Taken off bar to carryout turbine no load tests
6		Shut down		744-00				Under annual maintenance from 19/10/1986 to 15/1/1987.
7	556-05	3-49	-	184-06	75	41.350	74,359	Under annual maintenance upto 8/12/1986. Taken off bar to carry out turbine no load test
					TOTAL :	220.180	-	

/rkm/

DIRECTOR.

OPERATION ENGINEER.

TABLE NO 55

DOHA POWER & WATER PRODUCTION STATIO

DISTILLATION PLANTS OUTAGES REPORT FOR THE MONTH OF JANUARY 1982.

UNIT	RUNNING HOURS	STAND BY HOURS	OUTAGES		Availability % including stand by	TOTAL PRODUCTION M.I.G.	AVERAGE PRODUCTION I.G. PER HOUR	REASONS & REMARKS.
			EMERGENCY HOURS	PLANNED HOURS				
A1	—	—	—	744.00	—	—	—	Shut down for overhaul & sea water culvert inspection
A2	—	—	—	744.00	—	—	—	——do——
A3	—	—	—	744.00	—	—	—	Sea water culvert inspection.
A4	744.00	-	-	-	100	179.436	241,177	No outage.
A5	744.00	-	-	-	100	188.334	253,137	No outage.
A6	688.45	55.15	-	-	100	171.979	231,155	Shut down and kept as standby as requested by W.C.C.
A7	704.00	40.00	-	-	100	174.926	235,116	Standby as per w.c.c.
TOTAL						714.675	960,585	

SUPERINTENDENT

OPERATION ENGINEER.

Badr

TABLE NO 56

DOHA PO[illegible]ER & WATER PRODUCTION STATI[illegible]

DISTILLATION PLANTS OUTAGES REPORT FOR THE MONTH OF JUNE 1983

UNIT	RUNNING HOURS	STAND BY HOURS	OUTAGES		Availability % including stand by	TOTAL PRODUCTION M.I.G.	AVERAGE PRODUCTION I.G. PER HOUR	REASONS & REMARKS.
			EMERGENCY HOURS	PLANNED HOURS				
A1	118-45	—	—	601-15	16	28·630	39,764	Unit was under annual overhaul from 3/6/83 to 28/6/83
A2	694-30	—	—	25-30	96	167.003	244,449	Unit was under annual overhaul & started on 2/6/83
A3	720-00	—	—	—	100	174.470	242,319	No Outage.
A4	712-30	—	—	7-30	99	174.962	242,953	Unit Shut down to Check Distillate Pump.
A5	720-00	—	—	—	100	179·624	249,478	No outage.
A6	720-00	—	—	—	100	173·469	240,929	No outage
A7	—	—	—	720-00	—	—	—	Unit Shutdown for maintenance of Pumps since 11/8/82.
TOTAL						898·158	1,259,892	

SUPERINTENDENT

OPERATION ENGINEER.

TABLE NO 57

DOHA EAST POWER & WATER PRODUCTION STATION

DISTILLATION PLANTS OUTAGES REPORT FOR THE MONTH OF JANUARY 1984.

UNIT	RUNNING HOURS	STAND BY HOURS	OUTAGES		Availability % including stand by	TOTAL PRODUCTION M.I.G.	AVERAGE PRODUCTION I.G. PER HOUR	REASONS & REMARKS.
			EMERGENCY HOURS	PLANNED HOURS				
A1	483-00	-	-	261-00	65	118.395	159,133	Unit was under annual overhaul till 10/1/84.
A2	520-45	223-15	-	-	100	121.426	163,207	Shut down to check the reason of high conductivity. Unit was standby as per W.C.C.
A3	744-00	-	-	-	100	181.170	243,508	No outage.
A4	______	Shut	Down ______	744-00	______	______	______	Unit under annual maintenance from 28/12/83 to 11/2/84.
A5	574-30	169-30	-	-	100	142.593	191,657	Shut down and was standby.
A6	485-30	186-30	-	72-00	90	117.437	157,846	Shut-down to attend seawater to inlet waterbox leakage. Unit was standby as per W.C.C.
A7	223-15	59-55	-	460-50	38	61.238	82,309	Shut down for annual maintenance on 14/1/84.
TOTAL						742.259	997,660	

SUPERINTENDENT

OPERATION ENGINEER.

TABLE NO 58

DOHA EAST POWER & WATER PRODUCTION STATION
DISTILLATION PLANTS OUTAGES REPORT FOR THE MONTH OF APRIL 1985.

UNIT	RUNNING HOURS	STAND-BY HOURS	OUTAGES		Availability % including stand-by	TOTAL PRODUCTION M.I.G	AVERAGE PRODUCTION I.G. PER HOUR	REASONS & REMARKS
			EMERGENCY HOURS	PLANNED HOURS				
A1	608-00	105-35	-	6.25	99	148.038	243,484	Unit shut-down for heat rejection section inspection.
A2	279-60	440-30	-	-	100	67.719	242,286	Unit shut-down and kept as stand by as per w.c.c.
A3	———	shut	Down——	720-00	———	———	———	Unit remain under maintenance from 23/2/85 to 20/5/'85
A4	676-00	20-00	-	24-00	96	166.317	246,031	Unit S/D for the inspection of heat rejection section and to check distillate pump alignment.
A5	663-00	52.00	-	5-00	99	163.925		Unit shut-down for heat rejection section inspection.
A6	———	319-00	——— shut down	401-00	44	———	———	Unit Shut Down. and was stand-by as per w.c.c. A/M from 14.4.85
A7	5-00	51-15	-	663-45	8	1.124	224,800	Unit was under annual maintenance from 10/3/85 to 28/4/'85.
A8	555-45	-	-	164-15	77	23.724	42,688	Unit was not available upto 7/4/85 due to inspection of primary ejectors gaskets.
				TOTAL:		570.847		

DIRECTOR

TABLE NO 59

DOHA EAST POWER & WATER PRODUCTION STATION

DISTILLATION PLANTS OUTAGES REPORT FOR THE MONTH OF December 1986.

UNIT	RUNNING HOURS	STAND-BY HOURS	OUTAGES		Availability % including stand-by	TOTAL PRODUCTION M.I.G	AVERAGE PRODUCTION I.G. PER HOUR	REASONS & REMARKS
			EMERGENCY HOURS	PLANNED HOURS				
A1	345-00	119-00	-	280-00	62	86.688	251,270	Shut down as per w.c.c. under annual maintenance since 20/12/1986.
A2	165-15	58-45	-	520-00	30	39.027	236,169	Unit under annual maintenance since 10/12/1986.
A3	744-00	-	-	-	100	184.623	248,149	No outage.
A4	553-45	165-15	-	25-00	97	136.220	245,995	Shut down for acid cleaning.
A5	25-00	705-15	-	13-45	98	6.424	256,960	Shut down and kept as standby.
A6	254-25	63-00	-	426-35	43	62.032	243,821	Unit was under annual maintenance upto 18/12/1986. Shut down & standby as per W.C.C.
A7	68-15	399-15	-	276-30	63	17.470	255,971	Under annual maintenance upto 10/12/1986. N/A for repairs of brine heater steam inlet expansion joint.
A8	366-20	302-30	-	75-10	90	15.278	41,705	Shut down due to heater drain p/p suction was checked. Not available due to non-availability of both air blowers of decarbonator.
TOTAL:								

/rkm/ DIRECTOR OPERATION ENGINEER.

TABLE NO 60

DUAL-PURPOSE(POWER & WATER) STATION UNIT MONTHLY OUTAGES REPORT (Refrence Station Processed Data)						
MONTH OF : JANUARY		YEAR : 1982			UNIT NO : A 1	
UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGE hr.min	PLANNED OUTAGE hr.min	* AEFAEU 1 hr.min	** ABNO 2 hr.min
FUEL		223.02			520.58	
ELECTRICAL SUPPLY (1)		744.00				
ELECTRICAL SUPPLY (2)		223.02			520.58	
ELECTRICAL SUPPLY (3)					744.00	
SEA WATER INTAKE		744.00				
TURBINE COOLING		223.02			520.58	
DISTILLER COOLING				744.00		
TURBINE DISCHARGE		223.02			520.58	
DISTILLER DISCHARGE					744.00	
DISTILLER H.P STEAM SUPPLY						
(1) DIRECT FROM BOILER					744.00	
(2) FROM COMMON HEADER						744.00
DISTILLER L.P. STEAM SUPPLY						
(1) DIRECT FROM BOILER						
(2) FROM COMMON HEADER						744.00
(3) EXTRACTED FROM TURBINE					744.00	
	BOILER	223.02		520.58		
	TURBINE	223.02		520.58		
	GENERATOR	223.02		520.58		
	DISTILLER			744.00		

* AEFAEU 1 = Available except for unit sub-systems or associated systems unavailability.

** ABNO 2 = Available but not operated, (stand by).

TABLE NO 61

DUAL-PURPOSE(POWER & WATER) STATION UNIT MONTHLY OUTAGES REPORT (Refrence Station Processed Data)						
MONTH OF :	JUNE	YEAR :	1983		UNIT NO :	A 1
UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGE hr.min	PLANNED OUTAGE hr.min	* AEFAEU 1 hr.min	** ABNO 2 hr.min
FUEL		717.24	2.36			
ELECTRICAL SUPPLY (1)		720.00				
ELECTRICAL SUPPLY (2)		717.24			2.36	
ELECTRICAL SUPPLY (3)		118.45			601.15	
SEA WATER INTAKE		720.00				
TURBINE COOLING		717.24			2.36	
DISTILLER COOLING		118.45			601.15	
TURBINE DISCHARGE		717.24			2.36	
DISTILLER DISCHARGE		118.45			601.15	
DISTILLER H.P STEAM SUPPLY						
(1) DIRECT FROM BOILER		118.45			601.15	
(2) FROM COMMON HEADER						720.00
DISTILLER L.P. STEAM SUPPLY						
(1) DIRECT FROM BOILER						
(2) FROM COMMON HEADER						720.00
(3) EXTRACTED FROM TURBINE		118.45			601.15	
	BOILER	717.24			2.36	
	TURBINE	717.24			2.36	
	GENERATOR	717.24			2.36	
	DISTILLER	118.45		601.15		

* AEFAEU 1 = Available except for unit sub-systems or associated systems unavailability.

** ABNO 2 = Available but not operated, (stand by).

TABLE NO 62

DUAL-PURPOSE(POWER & WATER) STATION UNIT MONTHLY OUTAGES REPORT (Refrence Station Processed Data)						
MONTH OF :	JANUARY	YEAR :	1984		UNIT NO :	A 1
UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGE hr.min	PLANNED OUTAGE hr.min	* AEFAEU 1 hr.min	** ABNO 2 hr.min
FUEL		668.50			73.01	
ELECTRICAL SUPPLY (1)		744.00				
ELECTRICAL SUPPLY (2)		668.50	73.01			
ELECTRICAL SUPPLY (3)		483.00			261.00	
SEA WATER INTAKE		744.00				
TURBINE COOLING		668.50			73.01	
DISTILLER COOLING		483.00			261.00	
TURBINE DISCHARGE		668.50			73.01	
DISTILLER DISCHARGE		483.00			261.00	
DISTILLER H.P STEAM SUPPLY						
(1) DIRECT FROM BOILER		483.00			261.00	
(2) FROM COMMON HEADER						744.00
DISTILLER L.P. STEAM SUPPLY						
(1) DIRECT FROM BOILER						
(2) FROM COMMON HEADER						744.00
(3) EXTRACTED FROM TURBINE		483.00			261.00	
	BOILER	668.50			73.01	2.09
	TURBINE	668.50			73.01	2.09
	GENERATOR	668.50			73.01	2.09
	DISTILLER	483.00		261.00		

* AEFAEU 1 = Available except for unit sub-systems or associated systems unavailability.

** ABNO 2 = Available but not operated, (stand by).

TABLE NO 63

DUAL-PURPOSE(POWER & WATER) STATION UNIT MONTHLY OUTAGES REPORT (Refrence Station Processed Data)						
MONTH OF :	APRIL	YEAR :	1985		UNIT NO :	A 1
UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGE hr.min	PLANNED OUTAGE hr.min	* AEFAEU 1 hr.min	** ABNO 2 hr.min
FUEL		696.44			23.16	
ELECTRICAL SUPPLY (1)		720.00				
ELECTRICAL SUPPLY (2)		696.44	23.16			
ELECTRICAL SUPPLY (3)		608.00			6.25	105.35
SEA WATER INTAKE		720.00				
TURBINE COOLING		696.44			23.16	
DISTILLER COOLING		608.00			6.25	105.35
TURBINE DISCHARGE		696.44			23.16	
DISTILLER DISCHARGE		608.00			6.25	105.35
DISTILLER H.P STEAM SUPPLY						
(1) DIRECT FROM BOILER		608.00			112.00	
(2) FROM COMMON HEADER						720.00
DISTILLER L.P. STEAM SUPPLY						
(1) DIRECT FROM BOILER						
(2) FROM COMMON HEADER						720.00
(3) EXTRACTED FROM TURBINE		608.00			112.00	
	BOILER	696.44	23.16			
	TURBINE	696.44			23.16	
	GENERATOR	696.44			23.16	
	DISTILLER	608.00	6.25			105.35

* AEFAEU 1 = Available except for unit sub-systems or associated systems unavailability.

** ABNO 2 = Available but not operated, (stand by).

TABLE NO 64

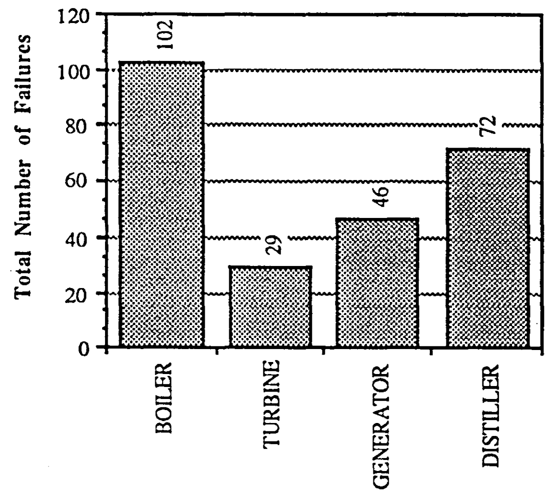
DUAL-PURPOSE(POWER & WATER) STATION UNIT MONTHLY OUTAGES REPORT (Refrence Station Processed Data)						
MONTH OF :	DECEMBER	YEAR :	1986		UNIT NO :	A 1
UNIT ASSOCIATED SYSTEMS	UNIT SUB-SYSTEMS	IN SERVICE hr.min	FORCED OUTAGE hr.min	PLANNED OUTAGE hr.min	* AEFAEU 1 hr.min	** ABNO 2 hr.min
FUEL		704.12			39.48	
ELECTRICAL SUPPLY (1)		720.00				
ELECTRICAL SUPPLY (2)		704.12			39.48	
ELECTRICAL SUPPLY (3)		345.00			280.00	119.00
SEA WATER INTAKE		720.00				
TURBINE COOLING		704.12			39.48	
DISTILLER COOLING		345.00			280.00	119.00
TURBINE DISCHARGE		704.12			39.48	
DISTILLER DISCHARGE		345.00			280.00	119.00
DISTILLER H.P STEAM SUPPLY						
(1) DIRECT FROM BOILER		345.00			119.00	
(2) FROM COMMON HEADER						720.00
DISTILLER L.P. STEAM SUPPLY						
(1) DIRECT FROM BOILER						
(2) FROM COMMON HEADER						720.00
(3) EXTRACTED FROM TURBINE		345.00			119.00	
	BOILER	704.12		39.48		
	TURBINE	704.12		39.48		
	GENERATOR	704.12		39.48		
	DISTILLER	345.00		280.00		119.00

* AEFAEU 1 = Available except for unit sub-systems or associated systems unavailability.

** ABNO 2 = Available but not operated, (stand by).

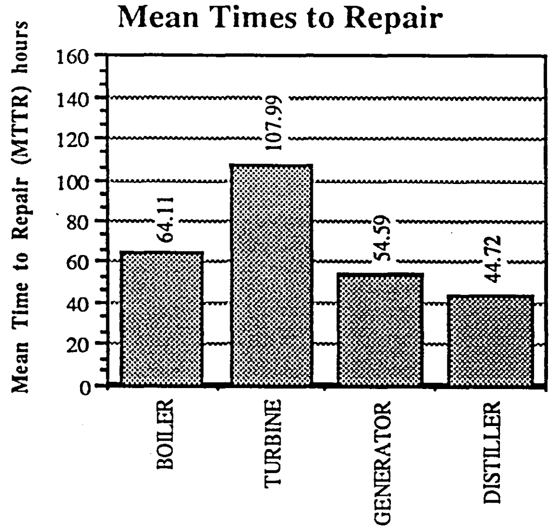
FIGURE NO 121
Five Year Statistics for Unit Sub-systems

Total Number of Failures



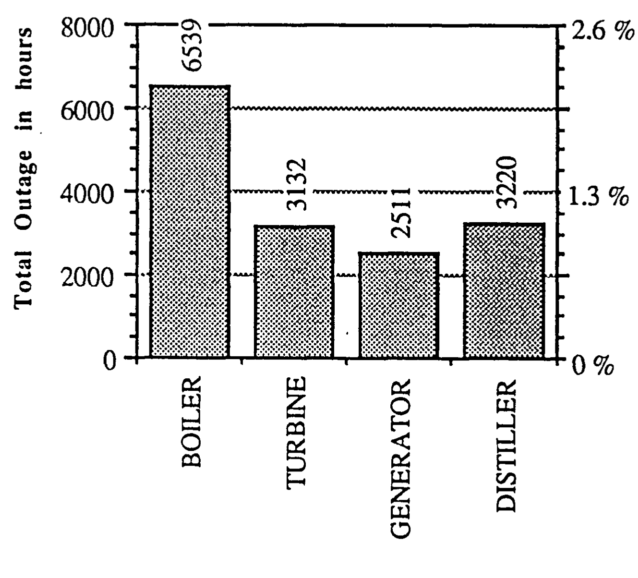
121 - A

Mean Times to Repair



121 - B

Total Outages



121 - C

TABLE NO 65

Average Failure Rate over 5 Years

	1982	1983	1984	1985	1986	
UNIT ASSOCIATED	Av. Fail Rate	Av. Fail Rate	Av. Fail Rate	Av. Fail Rate	Av. Fail Rate	Av. Fail Rate
SYSTEMS	/hour (Lambda)	/hour (Lambda)	/hour (Lambda)	/hour (Lambda)	/hour (Lambda)	/hour (Lambda)
FUEL	0.00E+00	9.81E-05	0.00E+00	1.18E-04	1.83E-04	7.98E-05
ELECTRICAL SUPPLY (1)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ELECTRICAL SUPPLY (2)	1.79E-04	1.81E-04	1.21E-04	8.29E-05	1.76E-05	1.16E-04
ELECTRICAL SUPPLY (3)	1.70E-04	8.01E-05	2.33E-04	7.86E-05	4.75E-05	1.22E-04
SEA WATER INTAKE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TURBINE COOLING	0.00E+00	1.78E-05	2.15E-05	0.00E+00	2.46E-05	1.28E-05
DISTILLER COOLING	2.40E-04	0.00E+00	1.30E-04	5.15E-04	1.13E-04	2.00E-04
TURBINE DISCHARGE	0.00E+00	6.96E-05	0.00E+00	0.00E+00	0.00E+00	1.39E-05
DISTILLER DISCHARGE	6.74E-05	0.00E+00	6.28E-05	4.36E-04	0.00E+00	1.13E-04
UNIT SUB-SYSTEMS	.					
BOILER	4.62E-04	4.51E-04	4.31E-04	4.79E-04	4.26E-04	4.50E-04
TURBINE	9.67E-05	1.41E-04	1.19E-04	1.33E-04	1.51E-04	1.28E-04
GENERATOR	1.85E-04	3.39E-04	1.77E-04	2.20E-05	2.61E-04	1.97E-04
DISTILLER	9.09E-04	1.03E-03	6.19E-04	4.96E-04	4.21E-04	6.96E-04
RELIABILITY OF						
UNIT /year	4.98E-04	3.16E-06	7.57E-07	1.15E-04	6.27E-05	1.36E-04
/month	0.31	0.23	0.26	0.24	0.33	0.27
/week	0.71	0.68	0.72	0.68	0.76	0.71
/day	0.95	0.94	0.95	0.94	0.96	0.95
Availability	67%	57%	43%	31%	45%	49%

FIGURE NO 122

Average Failure Rates for Boiler Sub-system

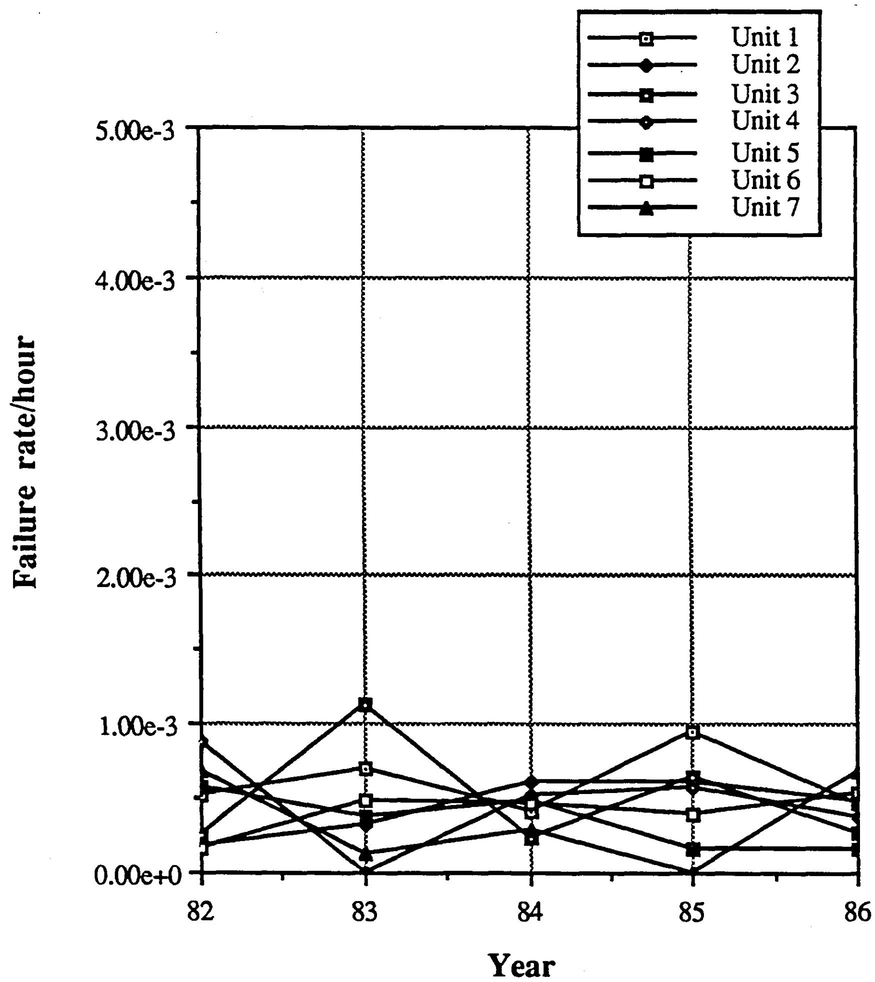


FIGURE NO 123
Average Failure Rates For Turbine
Sub-system

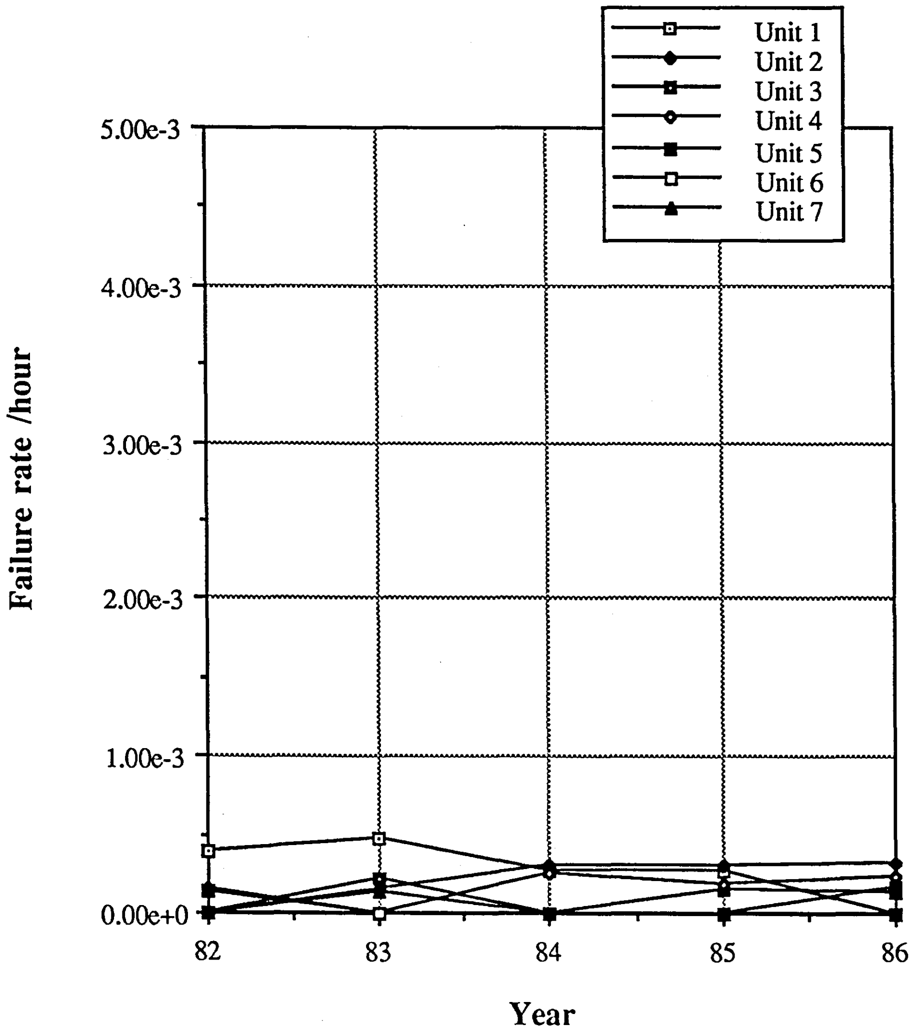


FIGURE NO 124
Average Failure Rates For Generator
Sub-syatem

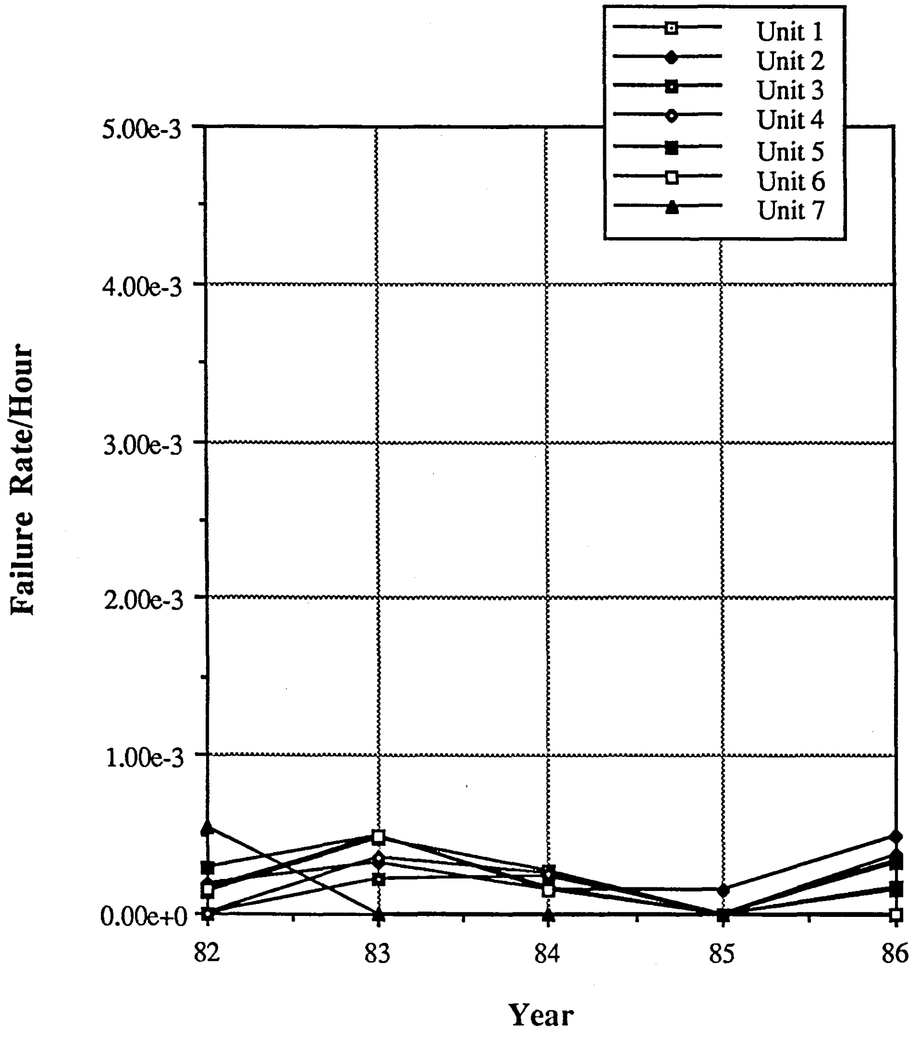


FIGURE NO 125
Average Failure Rates For Distiller Sub-system

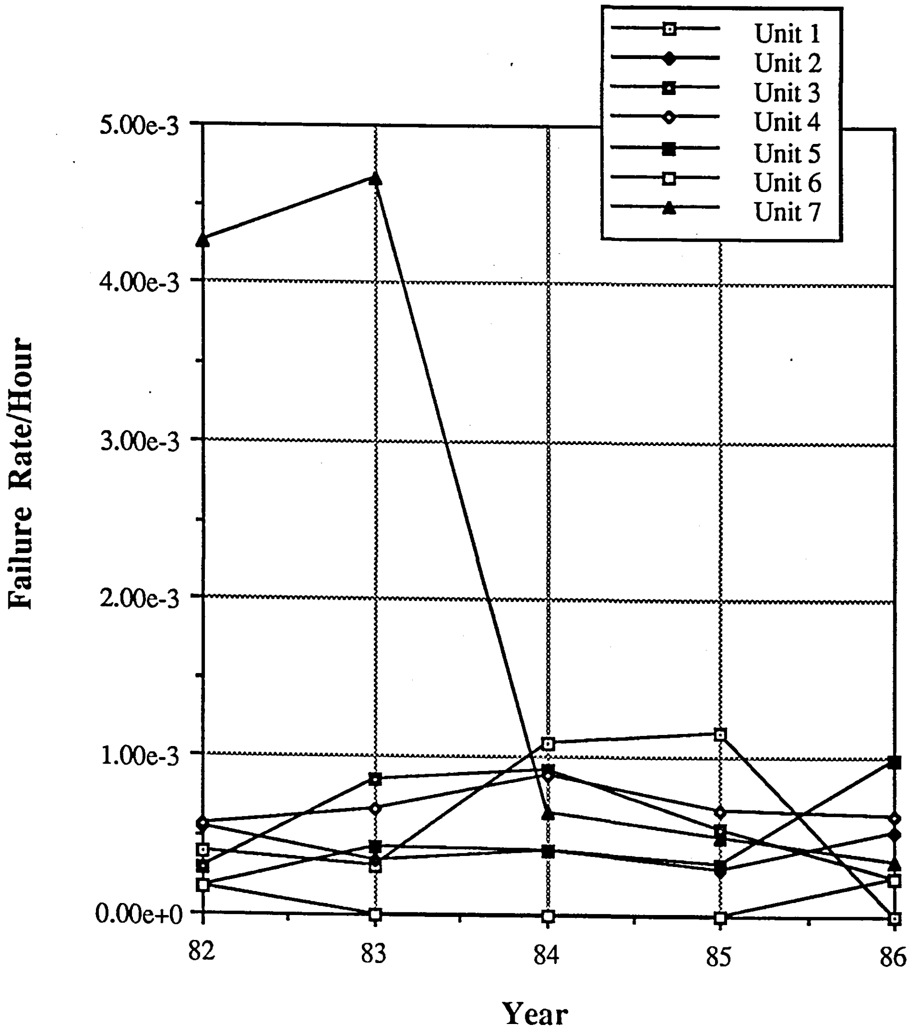
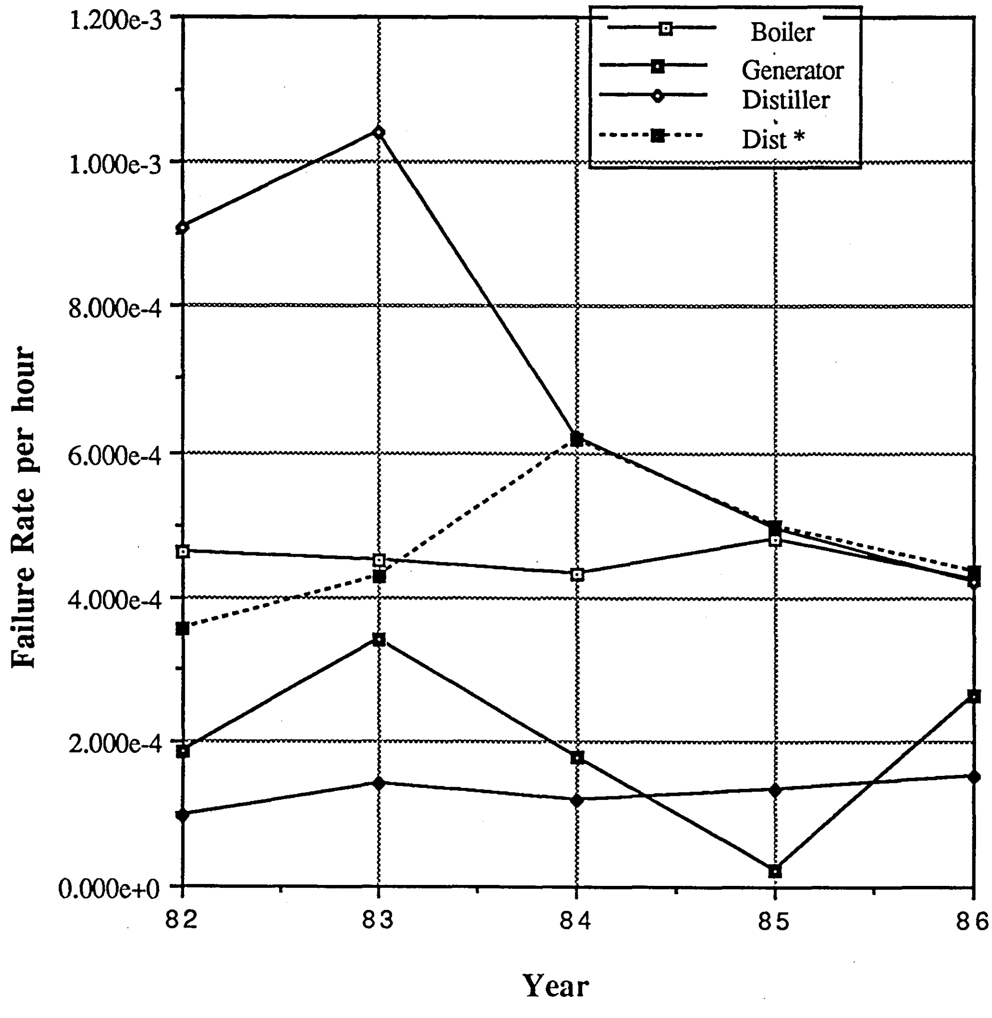


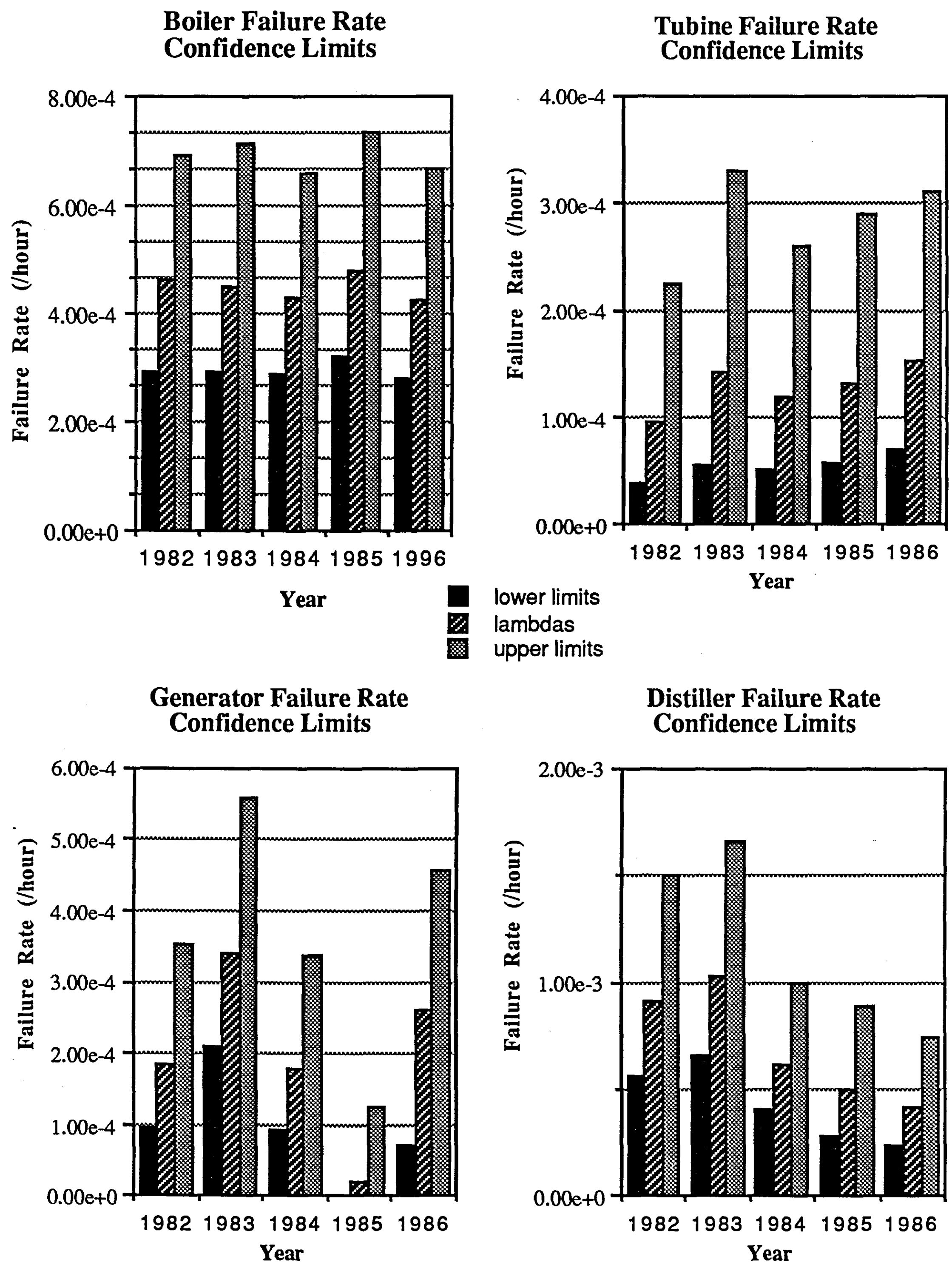
FIGURE NO 126
Average Failure Rates for all Unit Sub-systems



* Distiller without unit 7

FIGURE NO 127

Average Failure Rates Chi - Square Distribution Estimate



FIGUR NO 128
Average Failure Rates for Unit-1 Sub-systems

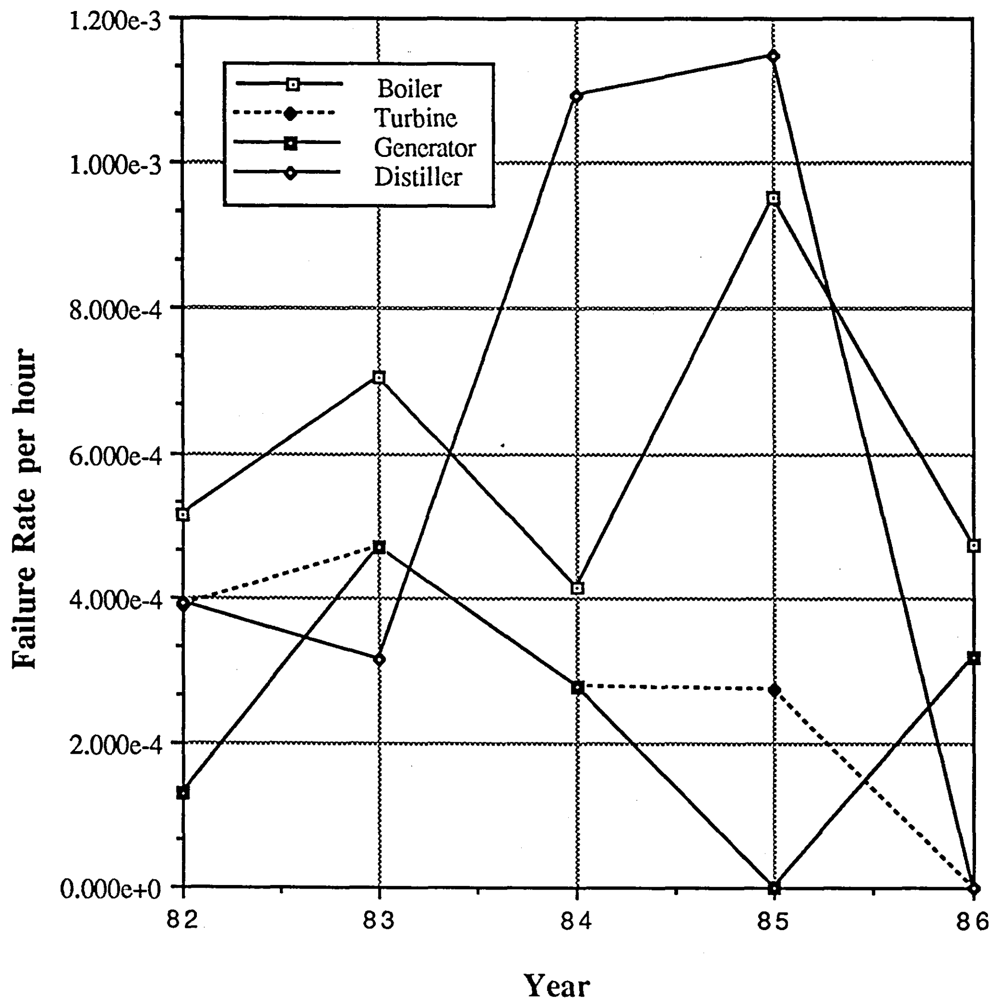


FIGURE NO 129

UNIT Sub - systems Mean Time Between Failures

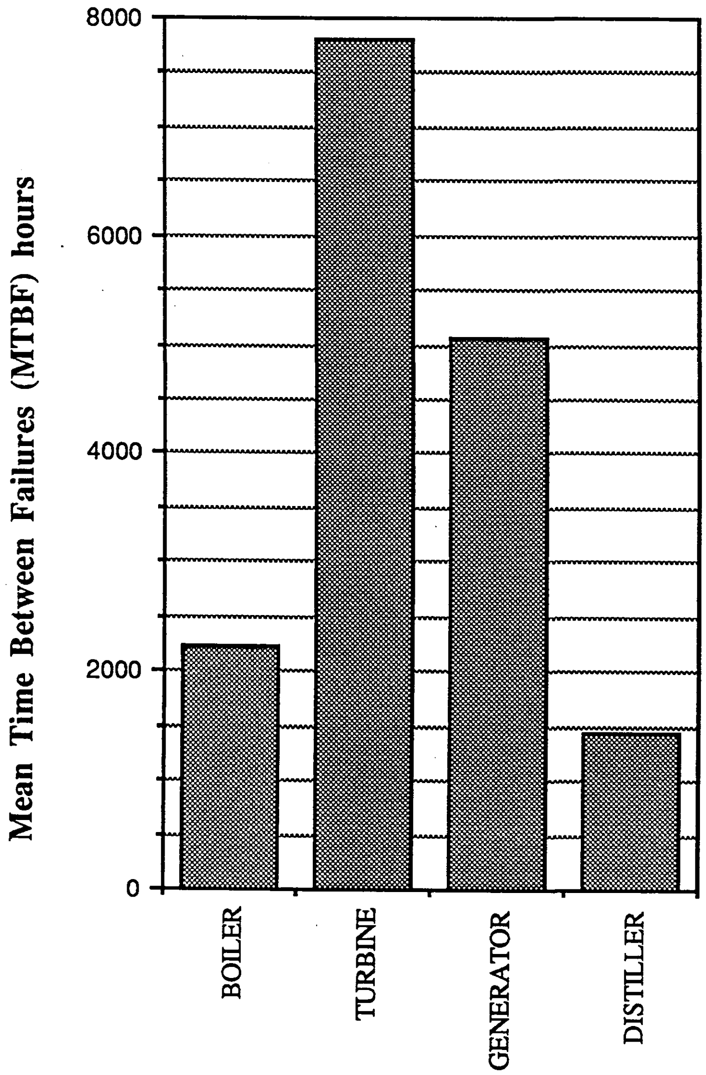
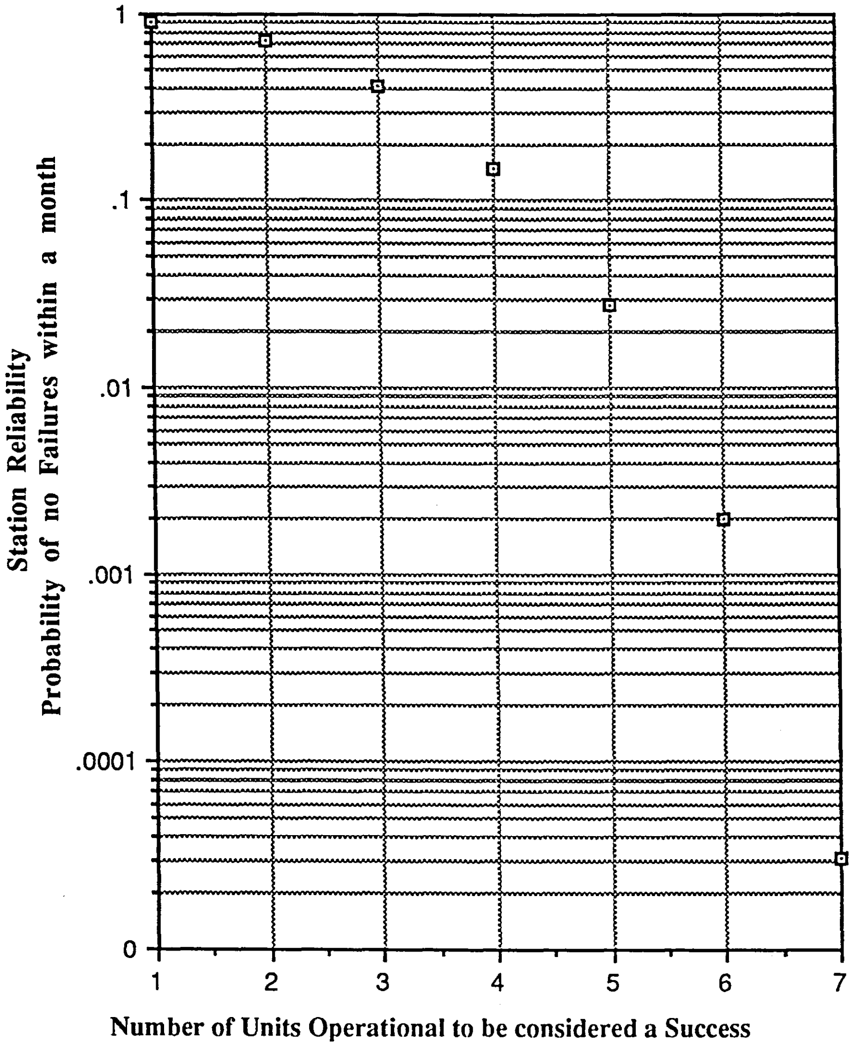


FIGURE NO 130
REFERENCE STATION RELIABILITY



REFRENCES

References

1. Munasinghe, M., The Economics of Power System Reliability and Planning. John Hopkins University Press, Baltimore, M.D., 1985.
2. Goodman, A. S., Principles of Water Resources Planning. Perntice-Hall, Englewood Cliffs, New Jersey., 1985.
3. Billinton, R. and Allan, R. N., Reliability Evaluation of Power Systems. Plenum Press, New York, NY., 1984.
4. El-Saie, M. H., "History And Economics of the Water Production In Kuwait". Inter-Regional Seminar on the Economic Application of Water Desalination, United Nation, New York, NY, 22 September - 2 October, 1965.
5. Silver, R. S., "Multistage Flash Distillation - The First 10 Years".Desalination, Vol. 9, pp. 3-7, 1971.
6. Khan, A. K., Desalination Processes and Multistage Flash Distillation Practice. Elsevier, Amsterdam, Holland., 1986.
7. Abu Eid, Z. H., and Fakhoury, A. G. A., "Inter-connection Between Electrical Power Generation and Distillate Water Production". First Arabian Power Conference, Abu-Dhabi, United Arab Emigrates., 1979.
8. Bou-Hasan, A.H., "The Inter-connection Between Electricity Generation and Sea Water Desalination". Second Arabian Power Conference, Doha, Qatar, 6-11 March 1982. (Original in Arabic, English Translation Available).
9. Rogers, A. N., "Work Potential : An Objective Basis for the Comparison of Desalination Processes". 10th Annual Conference and Trade Fair of the Water Supply Improvement Association, Honolulu, Hawaii., Vol. 1., pp. 1-20., 25-29 July 1982.
10. Wagnic, K., "Desalting Plant Inventory", Report No.8, February. 1985.International Desalination Association, Topsfield, Mass, U.S.A. 1985.

11. Catalytic Construction Company, "A Study of Desalting Plant (15-150 MGD) and Nuclear Power Plant (200-1500 M.W.) for Combined Water and Power Production", U.S. Department of the Interior, Office of Saline Water, R & D Report No. 124, November 1964.

12. Barba, D., Germana, A., and Tagliaferri, G., "Analysis of very Large Desalination Plants". Desalination, Vol 33, pp.1-10, 1979.

13. Awerbuch, I., "Future Developments in Desalination Distillation processes". Desalination, Vol 50, pp. 61-70, 1984.

14. Al-Zubaidi, A. A. J., "Sea Water Desalination in Kuwait - A Report on 33 Years Experience". Symposium on Reverse Osmosis Sea Water Desalination Technology, Kuwait , 22-24 November, 1986.

15. Al-Golaikah, A., "Desalination by the Saline Water Conversion Corporation of Saudi Arabia". Desalination, Vol 50, pp. 83-86, 1984.

16. Private communications with various Stations Owners personnel.

17. Evans, R. H., and Mulford, S. F., "Operating Experience with Land-Based Distillation Plants". Third International Symposium on Fresh Water from the Sea, Dubrovnick, Yugoslavia, 13-17 September, 1970.

18. Bailie, R. E., Hornburg, C. D., Morin, O. J., and Suratt, W. B., "Commercial Desalting Plants- Data & Analysis", U. S. Department of the Interior, Washington. D. C., Office of Saline Water, R & D Report No. 906, DSS Engineers, Inc., February. 1973.

19. Reside, J., Editor., "The Government of Kuwait Sea Water Desalination Plants- A Report on 20 Years Experience", Water Resources Development Center Report No R/18, Ministry of Electricity and Water, Kuwait, 1973.

20. Al-Adsani, A. M. S., "The Progress of Desalting Technology in Kuwait", The First World Congress on Water Resources, Chicago, Illinois, U.S.A., 24-28 September, 1973.

21. Steinbrchel, A. B., "Review Of Desalination Plant Operating Experience",

First Desalination Congress of the American Continent, Mexico City, Mexico, 24-29 October, 1976.

22. Brikett, J. D., and Newton, E. H., "Survey of Service Behavior of Large Evaporative Desalting Plants", A Report of A. D. Little, Inc., April, 1981.
23. Kutbi, I. I., Sabri, Z. A., and Husseiny, A.A., "Performance Evaluation of MSF Plants, the Case of Jeddah plants", 10th International Desalination and Environmental Association (IDEA) Anniversary Congress on Desalination and Water Reuse, Manama, Bahrain, November 29- December 3, 1981.
24. Black, D. W., and Morris, R. M., "Experience in Commissioning Large Desalination Plants in the Middle East", Desalination, Vol 39, pp 229-239, 1981.
25. Billinton, R., "Bibliography on the Application of Probability Methods In Power System Reliability Evaluation". IEEE Transactions on Power Apparatus and Systems, Vol. 91, pp. 469-660, April 1972.
26. Arendt, J. S., and Fussell, J. B., "System Reliability Engineering Methodology for Industrial Application", Loss prevention vol 14, 14th AIChE loss prevention Symposium, at 88th National meeting, Philadelphia, Pa, U.S.A. June 8-12 1980. Published by AIChE (CEP Tech Man) New York, NY, U.S.A., 1981.
27. Barlow, R. E , "Mathematical Theory of Reliability : A Historical Perspective". IEEE Transactions on Reliability, Vol R-33, No 1, pp. 15-20, April 1984.
28. Lotka, A. J. , "A Contribution to the Theory of Self-Renewing Aggregates with Special Reference to Industrial Replacement". Ann. Math. Statist., Vol 10, pp. 1-25, 1939.
29. Shooman, M. L , Probabilistic Reliability, An Engineering Approach. McGraw-Hill., New York, NY., 1968.
30. Coppola, A., "Reliability Engineering of Electronic Equipment : A Historical Perceptive" IEEE Transactions on Reliability, Vol R-33, No 1, pp 29-35,

April 1984.

31. Gnedenko, B.V., Belyayev, Yu. K., and Solovyev, A. D., Mathematical Methods of Reliability Theory. Academic Press., New York, NY., 1969.

32. Fussel, J. B., "Fault Tree Analysis -Concepts and Techniques". Proc. NATO Advanced Study Institute on Generic techniques of System Reliability Assessment, Liverpool, July 1973.

33. Fussel, J. B., "Nuclear Power System Reliability : A Historical Perspective". IEEE Transactions on Reliability, Vol 33, No 1, pp 41-47, April 1984.

34. Lee, W. S., Grosh, D. L., Tillman, F. A., and Lie, C. H., "Fault Tree Analysis, Methods, and Applications-A Review". IEEE Transactions on Reliability , Vol R-34, No 3, pp 194-203, August 1985.

35. Endrenyi, J., Reliability Modeling in Electric POwer Systems. John Wiely & Sons., New York, NY., 1978.

36. Billinton, R., Allan, R. N., Reliability Evaluation of Engineering systems : Concepts and Techniques.Pitman Books Limited., London, U.K., 1983.

37. Shooman, M. L., "Software Reliability : A Historical Perspective". IEEE Transactions on Reliability, Vol R-33, No 1, pp 48-55, April 1984.

38. Hwang, C.L., Tillman, F. A., and Lee, M.H., "System-Reliability Evaluation Techniques for Complex / Large Systems - A Review". IEEE Transaction on Reliability, Vol R-30, No 5, pp 416-423, December 1981.

39. Windebank, E.,"Monte Carlo Simulation Method Versus a General Analytical Method for Determining Reliability Measures of Repairable Systems". Reliability Engineering, Vol 5, No 2, pp 73-81, 1983.

40. Lyman, W. J., "Fundamental Consideration in Preparing Master System Plan".Electrical World,New York, NY., Vol 101, No 24, pp 788-792,june,1933.

41. Simth, S. A.Jr., "Spare Capacity Fixed by Probabilities of outage". Electrical World, New York, NY., Vol 103, pp 222-225, Feb 1934.

42. Simth, S. A.Jr., "Service Reliability Measured by Probabilities of outage". Electrical World, New York, NY., Vol 103, pp 371-374, March 1934.

43. Calabrese, G.,"Generating Reserve Capability Determined by the Probability method". AIEE Transactions, vol 66, pp 1439-1450, 1947.

44 Lyman, W. J., "Calculating Probability of Generating Capacity Outages". AIEE Transactions, Vol 66, pp 1471-1477, 1947.

45. Seelye, H. P., "Outage Expectancy as a Basis for Generator Reserve". AIEE Transactions, Vol 66, pp 1483-1488, 1949.

46. AIEE Sub-Committee , "Outage Rate of Steam Turbine and Boilers and of Hydro Units". AIEE Committee Report, AIEE Transactions, Vol 68, part 1, pp 450-457, 1949.

47. AIEE Sub-Committee , "Forced outage Rates of High-Pressure Steam Turbines and Boilers". AIEE Committee Report, AIEE Transactions, (Power Apparatus and System), Vol 73, Part III-B, pp 1438-1439, December 1954.

48. AIEE Sub-Committee, "Forced outage Rates of High-Pressure Steam Turbines and Boilers". AIEE Joint Sub-Committee Report, AIEE Transactions, (Power Apparatus and System), Vol 76, pp 338-343, June 1957

49. Watchorn, C. W., "Power and Energy Production". AIEE Transactions, Vol 73, part III-B, pp 901-908, August 1954.

50. Kirchmayer, L. K., Mellor, A. G., O'Mara, J. F., and Stevenson, J. R., "An Investigation of the Economic Size of Steam-Electric Generating Units". AIEE Transactions.(Power Apparatus and System),Vol 74, part III, pp 600-614, August 1955.

51. Miller, A., "Details of Outage Probability Calculations". AIEE Transactions (Power Apparatus and System), Vol 77, part III, pp 551-557, August 1958.

52. Halperin, H., and Adler, H. A., "Determination of Reserve - Generating Capability". AIEE Transactions (Power Apparatus and System), Vol 77, part III, pp 530-544.August 1958.

53. Kist, C., and Thomas, G. J., "Probability Calculation for System Generation Reserves" , AIEE Transactions (Power Apparatus and System), Vol 77, part III, pp 515-520, August 1958.

54. Baldwin, C. J., Gaver, D. P., and Hoffman, C. H., "Mathematical Models for Use in the Simulation of Power Generation Outages : 1 - Fundamental Considerations". AIEE Transactions (Power Apparatus and System), Vol 78, part III, pp 1251-1258, December 1959.

55. Baldwin,C. J, Billings, J. E., Gaver, D. P., and Hoffman, C. H., "Mathematical Models for Use in the Simulation of Power Generation Outages : II - Power System Forced outage Distributions". AIEE Transactions (Power Apparatus and System), Vol 78, part III, pp 1258-1272, December 1959.

56. AIEE Sub-Committee, Manual for Reporting the Performance of Generating Equipment.. AIEE Subcommittee on Application of Probability Methods,1960.

57. AIEE Sub-Committee, "Proposed Definition of Terms for Reporting and Analyzing Outages of Generating Equipment".IEEE Committee Report, IEEE Transactions, (Power Apparatus and System), Vol 85, No 4, pp 390-393, April 1966.

58. AIEE Sub-Committee, "Application of Probability Methods to Generating Capacity Problems". AIEE Sub-Committee Report, AIEE Transactions, part III (Power Apparatus and System), Vol 79, pp 1165-1182, February 1960, (February 1961 section).

59. Hall, J. D, Ringlee, R. J, and Wood, A. J, "Frequency and Duration Methods for power System Reliability Calculations- Part I - Generation System Model". IEEE Transactions, (Power Apparatus and System), Vol 87, No 9, pp 1787-1796, September 1968.

60. Ringlee, R. J, and Wood, A. J, "Frequency and Duration Methods for power System Reliability Calculations- Part II -Demand Model and Capacity Reserve Model". IEEE Transactions, (Power Apparatus and System), Vol 88, No 4, pp 375-388,April 1969.

61. Galloway, C. D., Garver, L. L., Ringlee, R. J, and Wood, A. J, "Frequency and Duration Methods for power System Reliability Calculations- Part III -Generation System Planning". IEEE Transactions, (Power Apparatus and System), Vol 88, No 8, pp 1216-1223,August 1969.

62. Cook, V. M, Ringlee, R. J, and Wood, A. J, "Frequency and Duration Methods for power System Reliability Calculations- Part IV -Models for Multiple Boilers-Turbine and for Partial Outages States". IEEE Transactions, (Power Apparatus and System), Vol 88, No 8, pp 1224-1232,August 1969.

63. Billinton, R, and Jain, A. V, "Unit Derating Levels in Spinning Reserve Studies". IEEE Transactions, (Power Apparatus and System), Vol 90, No 4, pp 1677-1687, July./ August. 1971.

64. Billinton, R, Jain, A. V, and MacGowan, C, "Effect of Partial Outage Representation in Generation System Planning Studies". IEEE Transactions, (Power Apparatus and System), Vol 93, pp 1252-1259, Sept. / Oct. 1974.

65. Marco, Attilio, "A Semi - Markov Model of a Three - State Generating Unit". IEEE Transactions, (Power Apparatus and System), Vol 91, No 2, pp 2154-2160, 1972.

66. Day, J. T, Shortley, P. B, and Skooglund, J.W, "Expected Value of Generation Deficit : A Supplemental Measure of Power System Reliability". IEEE Transactions, (Power Apparatus and System), Vol 91, No 2, pp 2213-2223, 1972.

67. Singh, C, Billinton, R, and Lee, S.Y, "Reliability Modelling using the Device of Stages". Proceeding of 1973 Power Industry Computer Application Conference pp 22-30, 1973.

68. Ayoub, A.K, and Patton, A.D, "A Frequency and Duration Method for Generating system Reliability Evaluation". IEEE Transactions, (Power Apparatus and System), Vol 95, No 6, pp 1929-1933, Nov/Dec 1976.

69. Patton, A.D, Singh, C, and Sahinglu, "Operating Consideration in Generation Reliability Modeling - An Analytical Approach". IEEE Transactions, (Power Apparatus and System), Vol 100, No 5, pp 2656-2663, May 1981.

70. Hittman Associates, Inc, "Evaluation of the Reliability and Maintainability of Desalting plants". U.S. Department of the Interior, Office of Saline Water, Report No INT-OSW-RDPR-73-859, 1972.

71. Unione, A, Burns, E, and Husseiny, A, "Reliability Analysis of Desalination Equipment". Desalination Vol. 32, pp. 225-237, 1980.

72. Unione, A, Burns, E, and Husseiny, A, "MSF Desalination Plants. Availability, Reliability and Safety Analysis". Desalination Vol. 33, pp. 49-84, 1980.

73. Kutbi, Ibrahiim. I, Sabri, Zeinab A, and Husseiny, A, "Reliability of MSF Processes based on Operation History". Desalination Vol. 41, pp. 81-113, 1982

74. Bailie, Robert E, "Reliability Assurance Survey - An Initial Step Towards Increasing Operating Reliability at Existing Desalination Facilities". Desalination Vol. 45, pp. 185-194, 1983.

75. Thies, K, Rohlfs, U, and Schulze, H.D, "Enhancement of the Availability of Desalination Plants By Means of In - Service Inspections". Proceeding of the Second World Congress on Desalination and Water Re - Use, Bermuda, November 17 - 22, 1985, Vol 2, pp 387-396.

76. Glueck, A.R, and Bradshaw, R.W, " A Mathematical Model For A MultiStage Flash Distillation Plant". Proceeding of the Third International Symposium on Fresh Water from the Sea, Dubrovnik, september, 1970, Vol 1, pp 95-108.

77. Goldsmith, K, and Lewin, D.A, "Some Aspects of Combined Water and Power Production". Proceeding of the 6th International Symposium on Fresh Water from the Sea, Las Palmas, Spain, september 17-22, 1978, Vol 1, pp 357-367

78. Buros, O.K, "An Overview and Brief Description of Desalination Processes". Proceeding of the 12th Annual Conference of the Water Supply Improvement Association (WSIA), Orlando, Florida, May 13-18, 1984,Vol II, pp 1-13.

79. Lindemuth, T.E, and Awerbuch, L, "A New Look AT Dual - Purpose Plant Design". Desalination Vol. 17, pp. 75-86, 1975.

80. Hanbury, W.T., Cunningham, J., Galbrith, R.A., and Hodgkiess, T., "Course in Desalination Technology, Parts 1 - 5,". University of Glasgow, Scotland, 1983 / 1984.

81. Hittman Associates, Inc, "Multistage Flash Distillation Desalting State - of - the - Art (1968)". U.S. Department of the Interior, Office of Saline Water, Research and Development Progress Report No 490, October 1969.

82. Veenman, A.W, "A Review of New Developments In Desalination By Distillation Processes". Desalination Vol. 27, pp. 21-39, 1978.

83. Barba, D, Bogazzi, D, Germana, A, and Tagliferri, G, "Design and Operation Experience with Long - Tube Acid - Dosed and Cross - Tube Polyphosphate Feed MSF Plants". Desalination Vol. 19, pp. 15-24, 1976.

84. Hill, K, "The MSF Desalination Process : A Comparison of Acid and Polyphosphate Treatment Plants". Desalination Vol. 25, pp. 111-122, 1978.

85. Toyama, shigeki, "Report on the High Flow Rate Long.- Tube Designed Multistage Flash Evaporator Test Module". Desalination Vol. 22, pp. 21-30, 1977.

86. Moen, D.L, and Cane, D, "An Improved MSF Evaporator Configuration". Desalination Vol. 45, pp. 25-34, 1983

87. Wade, N.M, "A Review of Scale Control Methods". Desalination Vol. 31, pp. 309-320, 1979.

88. Silver, R.S, "The Development of Multistage Flash Distillation". Transactions of the Institution of Engineers and Shipbuilder in Scotland (Glasgow), Vol 124, Paper No 1436, pp 51-64, 1981.

89. Mawer, P.A, "The Economics of Multi - Stage Flash Distillation in Relation to Conventional Water Supply". Desalination Vol. 2, pp. 99-108, 1967.

90. Itahara, Seije, and Stiel, Leonard.L, "The optimal Design of Multi - Stage Flash Evaporator By Dynamic Programming". Desalination Vol. 4, pp. 248-257, 1968.

91. Tadros, sameer.K, "A New Look at Cogeneration Systems for the Production of Power and Desalinated Water Economy and Design Features". Proceeding of the 9th Annual Conference and International Trade Fair of the National Water Supply Improvement Association (NWSIA), Washington D.C., U.S.A., May 31-June 4, 1981,Vol I, pp 1-25.

92. Power System Engineering Committee of the IEEE Power Engineering Society, "IEEE Trial - Use Standard Definition for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity". ANSI / IEEE Std 762, IEEE, December 1980.

93. Chang, N. E, "Application of Availability Analysis Techniques to Improve Power Plant Productivity". IEEE Transactions, (Power Apparatus and System), Vol 102, No 6, pp 1521-1529, june, 1983.

94. Ostle, Bernard, and Mensing, Richard, Statistic in Research, The Iowa State University Press, Ames Iowa, USA, 1975.

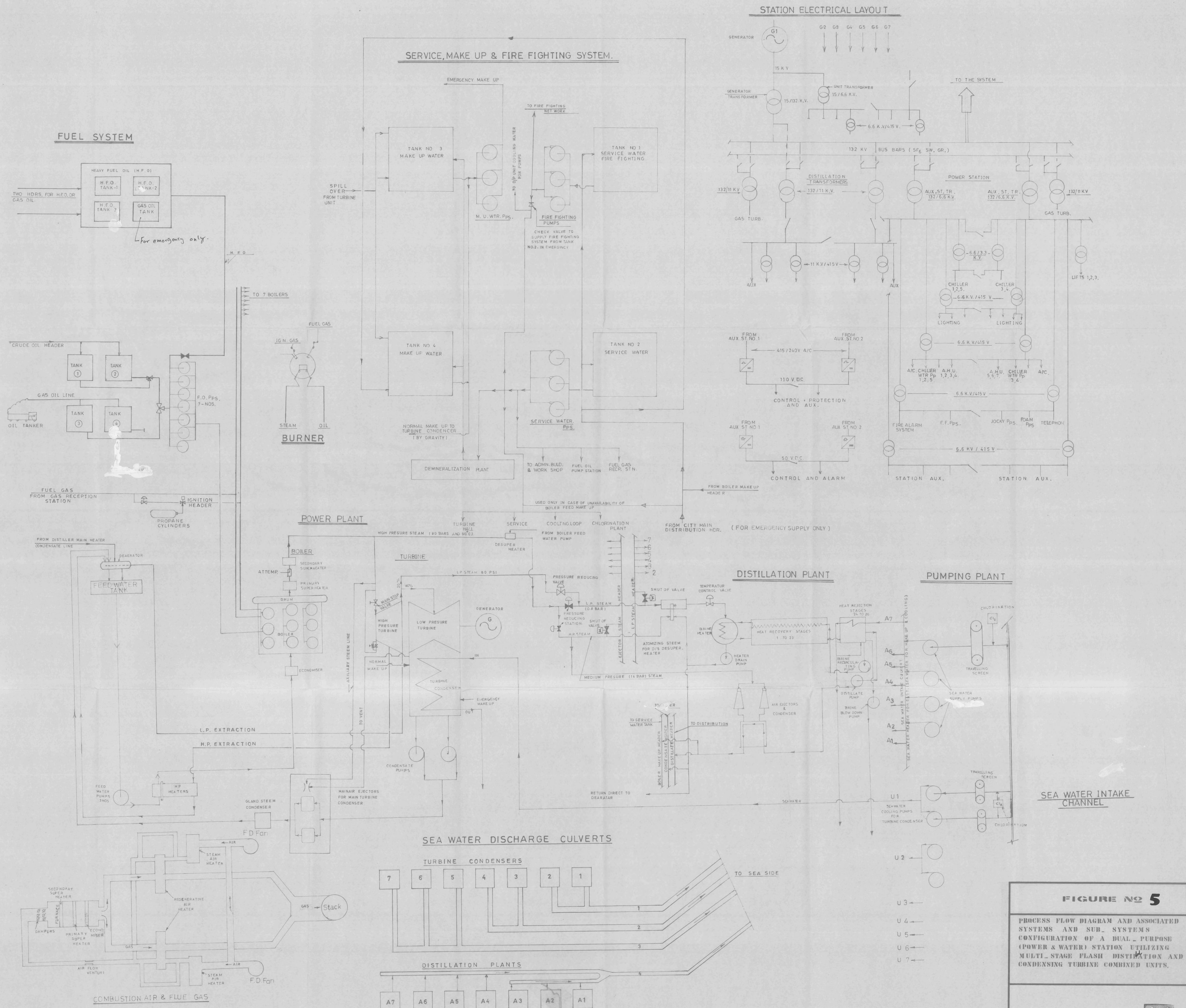


FIGURE No 5

PROCESS FLOW DIAGRAM AND ASSOCIATED SYSTEMS AND SUB_ SYSTEMS CONFIGURATION OF A DUAL_ PURPOSE (POWER & WATER) STATION UTILIZING MULTI_ STAGE FLASH DISTILLATION AND CONDENSING TURBINE COMBINED UNITS.