Chapter 2

Literature Review

2.1 Introduction

One major issue that researchers should consider, is the arrangement of the principles, basic concepts and scientific terms used during discussion. This chapter is to review literature, which has been done and come up with some principles of Distributed Control and Information System (DCIS), basic concepts and definitions of reliability, availability, failure rate (λ), **Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR)** and Fault Tree Analysis. Then, the methods of reliability assessment by using reliability modeling for system prediction, which is proposed by different authors, has been done. The purpose is to assess and select an appropriate method for assessment of the criteria of the Distributed Control and Information System (DCIS) configuration design for thermal power plant, which base on reliability basis.

2.2 Principle of Distributed Control and Information System

The principle of the Distributed Control and Information System (DCIS) has been reviewed from **Power Plant Engineering**, Black and Veatch International [9] and **Continuous Process Control, practical guides for measurement and control**, Instrument Society of America 1996 [14]. This item has an intention to introduce the basic principle of the DCIS. These two textbooks contain a complete information of the basic principle of DCIS. Hence, almost literature reviews for this item will refer to these two textbooks as shown in the following paragraph.

Control System Hardware and Software [9]

When digital computer systems first appeared in power plants in 1960s, they were installed as single central processor type computer systems and the major area of application were data acquisition and supervisory control functions. Since then, as a result of the development of microprocessor technology and rapid technological advances in recent years, the centralized digital system has evolved into a distributed system comprising numerous small computers, each with an assigned control data acquisition function.

Currently, all control hardware found in power plants (or other plants in industry) is known as " distributed " and " microprocessor-based ". This type of hardware has, for all practical purposes, replaced the conventional type devices as the dominant tool to implement the control and monitoring functions as necessary in operating power plant.

2.2.1 Microprocessor-Based Control Systems

The basic components in a microprocessor-based control system are the microprocessor, memory, and input/output modules and peripheral devices.

Microprocessors

A microprocessor-based control system is essentially a computer control system based on the last computer hardware technology. As in any computer, there are four basic elements (show in Figure 2.1) that must be present for the system to function:

- The main memory unit
- The control unit
- The Arithmetic-Logic Unit (ALU), and
- The Input / Output (I/O) unit

The control unit and arithmetic-logic unit constitutes the Central Processing Unit (CPU), which is the " brain " of the computer. The memory unit is used to store programs and data. The program of a digital computer is a serious of instruction that tells the computer how to do its work. The control unit is the conductor of the computer operation. It retrieves programmed instructions from the main memory and collects data (inputs) from the I/O unit for the ALU to do the work. It sends the result of the work done by ALU (outputs) back to the I/O unit. The I/O unit shuttles the input and output data between the computer and the outside world. In the case of a control computer, the I/O unit provides the connection between the computer and the field-mounted process sensors and control drives. A computer system may have more than one I/O unit.

Some I/O units are also known as peripheral devices. Typical peripheral devices include Visual Display Unit (VDU), printers, plotters, keyboards, and auxiliary memory supplements the main memory and is used to store in the main memory or are not frequently used. Auxiliary memory also serves as the permanent offline storage place for all programs in the computer system.

The CPU was once the most expensive item in the computer system. With a structure as shown in Fig. 2.1, each system had only one CPU. The CPU executed the programmed instructions one at a time, generally in a prescribed sequence regardless of the size of the program and the number of programs stored in the system. All mainframe computer and minicomputers operate this way.

The advent of Integrated Circuit (IC) technology, followed by Large - Scale Integration (LSI), and in recent years Very Large Scale Integration (VLSI), has greatly reduced the size of computer components and drastically reduced the hardware costs. This has enabled the manufacturers to put all components of the ALU and the control unit on a single chip. The term microprocessor is used to denote a chip that contains all components of a CPU. A microprocessor should not be confused with computer. For a microprocessor to function as a computer, it requires the addition of one or more memory modules plus one or more interface chips to operate the various I/O devices.

The term micro has been used to denote the small physical size of the components. **The microprocessor technology thus makes it possible for control system manufacturers to put more than one CPU (or microprocessor) in a given system and distribute the system functions thought the various microprocessors in the system, thus giving birth to the term " distributed control system"[9].**

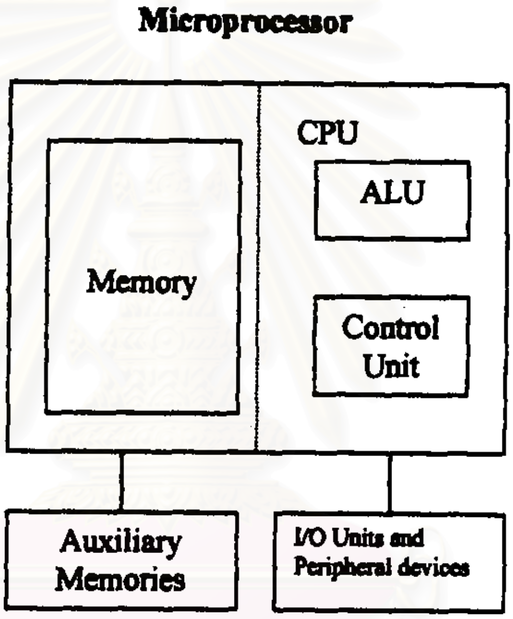


Figure 2.1 Basic Structure of Computer [9]

Memory

Computer systems of the current generation use mostly large-scale integration or very large scale integration solid-state components to build the memories. Memories may be classified into RAM, ROM, PROM, EROM, and EEPROM.

RAM is the acronym for **Random Access Memory** with read/write capabilities. With RAM, the time it takes for the CPU to access any piece of information stored in the memory is always the same regardless of the memory location. This is in contrast to a serial (or sequential) access memory such as a magnetic tape, in which the access time varies with the location of the information to be accessed.

With read/write capabilities, information stored in the RAM can be write capabilities, information stored in the RAM can be altered by writing new information at any memory location over the old information stored at the same spot. RAM is typically used to store program variables and I/O data. For a real-time process control computer, all I/O data that are constantly updated must be stored in the RAM. The solid-state RAM is volatile in that it will lose all stored contents (programs and data) on loss of electric power. Battery backup must be used to maintain the memory comment on loss of power, if required.

ROM, PROM, EPROM, and EEPROM are nonvolatile random access type memories. The information stored in them can be read (retrieved) at will, but information cannot be written into the memory at will. **ROM** is **Read Only Memory**. PROM is **Programmable Read Only Memory**. ROM and PROM share one common characteristic: information can be written into the memory only once. Once it is written. The content can never be altered.

The difference between two lies in the method by which the information is written by a technique known as mask programming, which is done by the chip manufacturers at the time the memory chip is produced. For PROM, the programs are written into the memory through a programming unit know as the PROM burner after the chips are produced.

EPROM (Erasable PROM) differs from the ROM and the PROM in that the content stored in the EPROM can be erased and overwritten with new information. This can be done by ultraviolet radiation or by electric pulses.

EEPROM is variation of PROM (Electronically Erasable PROM). As in EPROM, the information stored in this type of memory can be altered, expect that it can be accomplished without removing the memory from the computer assembly and without removing the memory from the computer assembly and without a separate programming unit.

The forerunner of the solid-state memory is the magnetic core memory. Magnetic core memory is similar to RAM expect that it is slower, larger in physical size, and nonvolatile. Nevertheless, magnetic core memory is no longer popular for the simple reason that it cannot complete from a cost standpoint with the solid-state memories. Among the categories of the solid-state memories, ROMs are the cheapest, RAMs are the most expensive, and the costs of PROMs, EPROMs, and EEPROMs lie in between.

A Distributed Control and Information System (**DCIS**) is composed of a set of processors, input modules, output modules, printers, and workstations that are interconnected by a communication network. A processor consists of a microprocessor-based CPU and memory unit. In the memory unit, EPROM or ROM is typically used to store programs that are closely related to the operation of the processor; RAM is used to store application programs and I/O data, and also to serve as the search pad for the intermediate results of the computer calculations. Since RAM is volatile, its content is lost whenever the power is turned off. To avoid reloading the programs after a power loss, some manufacturers provide auxiliary batteries to serve as a backup power source during power outage.

Some manufacturers do not provide battery backup for the RAM, but simply reload from information permanently stored on auxiliary memories connected to the communication network. Some systems use EEPROM instead of RAM with backup batteries. The drawback to EEPROM is that it does not run as fast as the RAM, PROM and EPROM are seldom used to store application programs because a special programming device is needed and the memory modules must be removed from the computer assembly to make changes to programs.

I/O Modules and Workstation [14]

The input and output modules provide the necessary interface between the DCIS, and the field instrumentation and control device. There are four basic types of I/O devices:

- Digital Inputs
- Digital Outputs
- Analog Inputs, and
- Analog Outputs

Digital input devices sense the presence or absence of an electrical voltage, usually by means of a contact of an electrical switching device such as a pressure switch or a limit switch. The contact state is either open or closed, which is sensed by a voltage imposed on the contact. The voltage level is typically 120 V alternating current (ac) or 125 V direct current (dc) or lower voltage level such as 24- or 48- V dc. The digital input module converts the input voltage signal into a memory bit that is scanned by the processor.

The input module filters signal noise and contact bouncing, and furnishes isolation to guard against voltage spikes external to the system. A digital output from the system is typically a solid-state switching device such as a triac, a power transistor, or solid-state relay that is switched on and off as dictated by the result of the processor calculations. The output contact switches the power, either internal or external, to the controller equipment. In some cases, an interposing relay of the electromechanical type is used to either isolate the output device from the external system or to provide the current carrying-capacity required to handle the load current of the external device.

Analog signals take many forms: millivolt signals from thermocouples, milliampere or low-level voltage signals from transmitters, and signals from **Resistance Temperature Detectors (RTDs)**. The most commonly used analog signal from transmitters is a 4- to 20-milliamperes direct current (mAdc) signal.

Analog input modules contain **Analog-to-Digital (A/D)** converters to digitize the analog signal signals from the field devices for use by the processor. The A/D computer changes the input signal to a digital value that can be stored in the processor's memory. Analog output modules contain **Digital-to-Analog (D/A)** converters to convert the digital values produced by the processor into analog signals usable by the controlled equipment. Like the analog input signals, the most commonly used analog output signal is also 4 to 20 mAdc.

A workstation is an assembly of microprocessors and their peripheral devices. A workstation typically consists of one more VDU monitors, keyboards, pointing devices such as mouses and trackballs, and the associated electronics. The electronics mainly consist of processors with working memory and disk drives (hard drive and floppy disk). Because it is equipped with electronics, the workstation is itself a computer system with data processing and graphic display programs stored in memory or on the hard disk drive to support the VDU monitor.

The workstation is the main interface point between the plant operation, maintenance personnel and the system. When used by plant personnel to monitor and control plant operation, it is called an operation workstation. When used by plant personnel to perform system-programming function, it becomes an engineering workstation. Many manufacturers have specially designed keyboards with keys for specific functions to suit the system for the operator workstation. The keyboard for the engineering workstation can be either the standard typewriter keyboard or a keyboard specifically designed for programming functions, or a combination of both.

2.2.2 Communication Network [9]

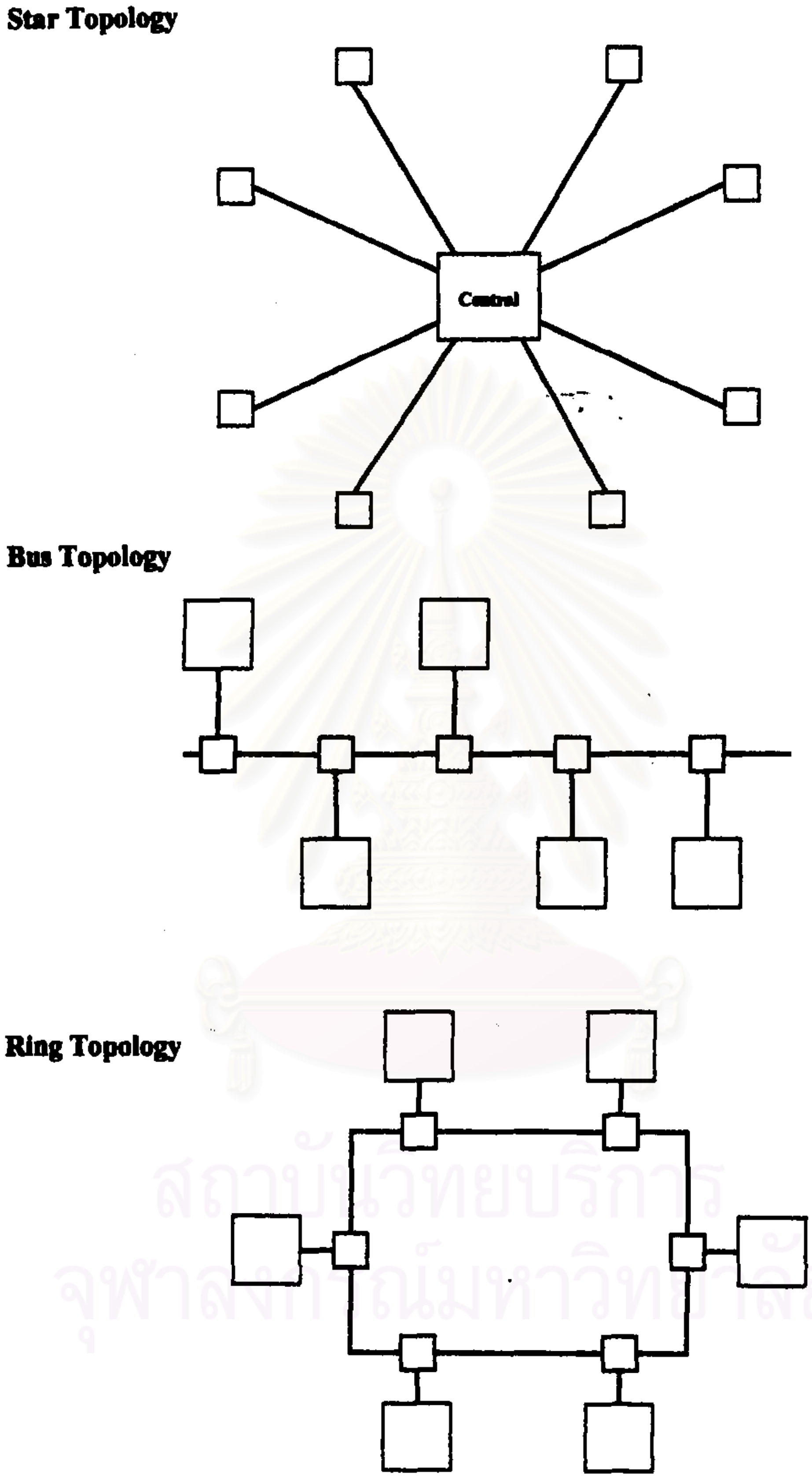
For the various components in a distributed system to perform effectively as an integrated unit, they need to exchange information and share resources (inputs, outputs, or processed data) by communicating with one other. This occurs through a communications line (sometimes know as the data highway) that connects to the components to form a network.

The communications network is similar to the interconnecting wiring between controllers in an analog electronic control system. But, unlike the analog electronic control system, the communication network handles the data in binary form. This makes it possible to scan a group of data signals from any component in the network and transmit them one signal at a time in series though communications lines as simple as two-wire cables.

The type of signal transmission does not require a cable for each signal or a point to point connection between component in the system. A communications network can handle a large volume of data at a very high speed and saves a tremendous amount of field wiring. For this reason, the communications network has become indispensable to the distributed system. Such as a network installed in a power plant is essentially a local area network that is commonly employed to facilitate data transmission between computers in office building.

Network Topology

In a communications network, the point at which a component is connected to the network is generally know as a node, and component is often referred to as a drop. Network topology refers to the pattern in which the drops are connected to one another within the network. There are basic types of network topology: star network, bus network, and ring network (Fig. 2.2).



Star Topology

Bus Topology

Ring Topology

Figure 2.2 Network Topology [9]

In the star network topology, each component in the system is connected to a central computer by a point-to-point line. Any information exchange between two components is routed through the central computer. In such a scheme, the central computer serves as a traffic director and the communication channels are simple and structured. However, the network is very much dependent on the integrity of the central computer to keep the communications lines open. If the central device fails, all communications are lost.

The bus network topology is basically a single cable for transporting information between devices that are connected to the highway. Because this topology has only one transmission path for all system components, it requires a method for all components on the bus to share the use of the transmission line.

The ring network topology links system components in a continuous loop. Information is passed from drop to drop on the ring until it reaches its destination. The movement of information in the ring is usually unidirectional. It can be made bi-directional, but to do so requires more sophisticated software.

Signaling Method

Data signals between drops in the network are transmitted through cables that make up the data highway. In general, there are two basic signaling methods: baseband transmission and broadband transmission. The two methods refer to the way signals are imposed on the cable.

The baseband method send voltage pulses representing the binary bits (ones and zeros) through the cable. Sending signals by the broadband method is like radio or television broadcasting. The transmission has a wide bandwidth that is divided into channels of separate ranges of bandwidth with different frequencies. With this method, more than one signal can be sent simultaneously through the medium at different frequencies within the separate sections of the bandwidth simultaneously.

The baseband method has one transmission channel and can transmit data signals only one at a time. The equipment associated with this method is relatively inexpensive. The boardband method, because of its multiple channels, has a higher transmission capacity and can handle data, voice, and video signals on the same medium. However, the cost for equipment required for broadband transmission is relatively higher. It also requires the use of a modem (modulator demodulator).

For data transmission, a modem converts the data signals from the binary from into signals that fall in the frequency band and propagate along the transmission lines (the medium) as electromagnetic waves. Another modem at the receiving end then converts the electromagnetic waves back to the original binary form. Both methods are used in the power plant application.

Transmission Media

Three types of transmission media are most often used for the communications network: twisted-pair wire, coaxial cable, and optical fiber.

The basic twisted-pair wire has two insulated copper conductors twisted together and sheathed with Polyvinyl Chloride (PVC). A large number of wire pairs can be encased in one sheath and made into cables. Twisted-pair wire is inexpensive, but it is susceptible to electromagnetic interference and noise from the environment. The signal attenuation of twisted wire pairs and the amount of cross-talk between adjacent pairs rise sharply with increasing frequency. Thus, its usage is confined to single-baseband applications.

The coaxial cable has a copper conductor in the core surrounded by insulation material (foam or plastic) that is covered by a semi-rigid metal conductor and encased in an outer shielding of PVC or Teflon. This type of cable reduces the interference from the environment and reduced the signal attenuation characteristics of the cable. Coaxial cables can be used for both baseband and broadband signal transmission without any limitation on the bandwidth. Coaxial cable costs more than the twisted-pair wire. In general, extra care is required to install the coaxial cables.

Optical fiber conductors are made of small-diameter glass fibers. Light signals can travel long distances without losing their signal strength. A fiber conductor has very precise light-propagation qualities. Optical fiber conductors have many advantages. They have large bandwidth and can be used for both baseband and broadband signal transmission. They are also immune to electromagnetic interference and corrosive agents. However, optical fiber conductors are the most expensive to use. They are difficult to install and, once installed, cannot be easily modified. However, they are gaining acceptance in the industry, and it is only a matter of time before they become well used in power plant.

Transmission Protocols

Protocols are sets of rules that govern the flow of data in a network. Their purpose is to ensure that data are correctly transmitted from point to point with procedures for automatic error detection and correction.

The data highway that form the network is shared by all drops collected to the network. All drops must have access to the data highway before they can communicate with each other. The access method is the protocol used to coordinate the data transmission activities among the drops and to avoid any conflict that may arise when two or more drops are attempting to access the medium at the same time. The access method, in general, can be classified into the contention and non-contention methods.

In the contention method, the drops in the network complete with one another for access to the medium. One of the most commonly used contention systems is **CSMA/CD**. **CSMA/CD** is the abbreviation for Carrier Sense Multiple Access with Collision Detection. In this method, each drop in the system "listens" to the traffic on the highway. If the drop has data to transmit to another drop, it " listen" and sends the data only if it senses no traffic. If more than one drop in the system is listening and transmitting information at exactly the same moment, a data collision occurs on the highway.

The immediate result is that all data on the highway are garbled. This method permits the drops to recognize a data collision, and the drops involved back off immediately. Each drop then waits for a random period and tries again. The length of random period is different for each drop. This ensures that no collision happens on the second try.

This method is also called the non-deterministic access method because the drops do not have a definite turn in which to transmit signals, and the time it takes for a signal to reach its destination is not predictable because of the potential for data collision and the retry. CSMA/CD is predominantly used in the bus topology. One of the most well known users of CSMA/CD is **Ethernet**, which was developed by the Xerox Corporation.

In the non-contention method, the drops share the medium according to some predetermined schedule to avoid conflicts. One of the widely used non-contention methods is the token passing method. This method can be used for either the ring or bus topology.

The token ring was developed by IBM. In this method, a token is passed along the data highway from drop to drop. A token is a prescribed pattern of bits. Only the drop having possession of the token has the right to transmit data to any other drop on the highway. The receiving drop, on receipt of the data, sends the token back to the originating drop, which then passes the token to the next downstream drop on the ring.

Token passing on a bus is similar to the procedure used for the token passing ring, except that the token passing sequence is prearranged with no regard to the physical arrangement of the drops on the bus. After the data are transmitted, the drop passes the token to the next drop in the sequence. The Manufacturing Automation Protocol (MAP) that is frequently used in factories was developed on the basis of a token bus.

The token passing technique allows predictable data transmission among the drops and potentially saves transmission time because a drop does not have to listen before transmission. On the other hand, the token may be damaged while passing through a drop and cause an interruption to the process. This system needs a monitor to oversee the transmission process and the monitor will step in whenever the token is lost. In this method, adding a drop to the highway has an impact on all drops in the system and requires changes in the communication software.

Another access method of the non-contention type is the polling method. The polling method requires a host station to the system that controls the information exchange activities, asking if it has any information to transmit. If the answer is positive, the drop is given permission to send the information. The central controller then proceeds to the next drop and continues to make rounds. This method is most often used in the star topology.

IEEE 802 committee is dedicated to development of communications network standards. The committee has established the following standards for the access methods:

- 802.3 CSMA/CD Bus Standard,
- 802.4 Token Bus Standard, and
- 802.5 Token Ring Standard.

These standards are followed by manufacturers who supply bus and ring networks, with some variation to suit the particulars of their systems.

RS232C Interface

In a discussion on communications network, mention must be made of the RS232C interface because, in the digital world, the RS232C interface is well known and the most widely used standard for direct point-to-point serial data transmission between two pieces of digital equipment (for example, a workstation and a printer). What is not well known is that this standard was originally developed to specify the interface between a computer and a modem.

RS232C is the recommended standard (RS) of the Electronics Industry Association (EIA), No. 232. The letter C refers to the revision level of the standard. The full name of RS232C is " Interface Between Data Terminal Equipment (DTE) and Data Communication Equipment (DCE) Employing Serial Binary Exchange." The standard specifies the interconnection and signal exchange between the DTE and the DCE (Fig. 2.3).

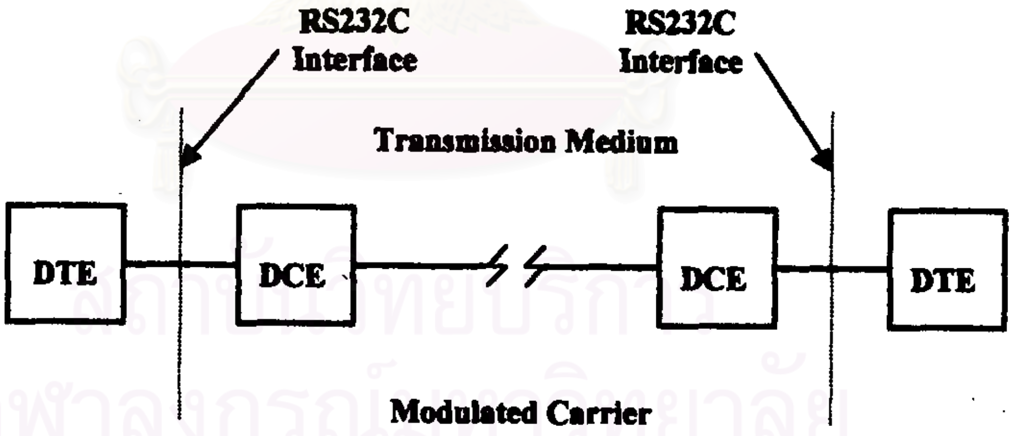


Figure 2.3 RS232C Interface [9]

The DTE can be a computer, VDU, printer, or any digital equipment that sends or receives binary data in serial form, to and from another DTE at a separate location. The DCE is a modem that transforms the binary bit steam from the DTE into electromagnetic waves or vice versa. The standard is intended for serial data transmission, using pulses at a rate of up to about 20,000 bits per second over a distance of no more than 50 feet. The interface uses a 25-pin connector at both the DTE end and the DCE end for a maximum of 25 signal lines, with the function of each line defined for both the DTE and the DCE. Not all of the 25 lines need to be used to complete a transmission. In some cases, as few as three lines are sufficient to complete the interface and, for this reason, some manufactures use a nine-pin connector for their equipment.

Since the 1970s, the computer industry has borrowed this standard and used it to facilitate serial data transmission between computers. It is commonplace to find an RS232C port on a computer or its peripherals. However, this standard was meant only for defining the interface between DTEs and DCEs. If it used for data transmission between parties other than a DTE and a DCE (such as an interface between a workstation and printer or between two microprocessors), one party must play the role of the DTE and the other must play the role of the DCE, and how the pins are connected between the two ends depends on the roles of the two parties. This point sometimes causes confusion between the user and the computer manufacturer because equipment designed with a provision for an RS232C interface is not always identified clearly as DTE or DCE.

There are other standards similar to the RS232C for serial data transmission, such as RS442A and RS423A. The differences lie in the electrical and/or mechanical aspects of the signals and connections to allow for transmission at a higher rate and longer distance. By far, the RS232C is still the most popular standard in the computer industry.

2.2.3 Distributed Control and Information System [9,14]

Strictly from technical standpoint and in the broadest sense, any microprocessor-based control system can be made into a distributed control and information system as long as the control programs are stored in more than one processor. However, in the power industry, the term **Distributed Control and Information System (DCIS)** is generally applied to the system that implement boiler control and data acquisition functions of the power plant.

The DCIS, when it first appeared on the market, was applied to the boiler controls which, until the late 1970s, were mostly of the analog electronic type. The data acquisition systems at that time were predominantly centralized computer systems. Since the early 1980s, with the advent of operator workstations and increasing power of microprocessors, DCIS manufacturers have expanded the functions performed by the DCIS into the data acquisition area, and today, they have completely replaced the centralized computer system.

Thus, the DCIS has in effect become a power plant control and information management system. This is why the DCIS is frequently referred to as a **DCDAS** (**D**istributed **C**ontrol and **D**ata **A**cquisition **S**ystem) or by similar description and abbreviation.

2.2.4 Configuration [9,14]

As previously mentioned, a state-of-the-art DCIS typically is composed of modularized microprocessor-based processing units, input modules, output modules, operator workstations, engineer workstations, printers, and other types of peripheral devices, all connected through a multiple level communications network. DCIS manufacturers have standard modules for different functions. They generally fall into categories: control modules and data processing modules.

The control modules are structured to perform a variety of control and computing tasks such as **PID (Proportional plus Integral plus Derivative)** control, binary logic, and arithmetic functions. Some manufacturers have separate modules for modulating and on-off control functions and others have combined the two into one module. For some manufacturers, each module is available in varying sizes to suit a user's needs.

The data processing modules manipulate data, performing such functions as data table, graphic display, variable trending, report generation, and long-term data storage and retrieval. Module structure is dependent largely on the particular manufacturer's design and, as a rule, auxiliary memory units such as hard drives are required if the processing function involves a large amount of data storage. For long-term data storage, magnetic tapes are medium typically used. However, optical disks are also gaining acceptance.

Input and Output modules are similar to those used in Programmable Logic Controller (PLC) applications including analog, digital, and pulse type inputs and outputs. Analog input modules accept signals from thermocouple, resistance temperature detectors, and pressure, flow, and level transmitters. Analog output signals are wired to the modulating control loops final control elements such as control valves and control dampers. The standard transmitter and analog output signals are 4 to 20 mA dc. Digital inputs and outputs are the same as those for PLC applications.

I/O modules can be either dumb or intelligent. A dumb module merely digitizes the input signals and sends them to the processors. An intelligent module is equipped with a microprocessor and has the capability of further processing the digitized signals such as conversion to engineering units, square root extraction, and alarm limit checking. Some manufacturers even use their digital I/O modules to perform ladder control logic functions, thus further decentralizing the functions of the DCIS.

As with the PLC I/O modules, the DCIS I/O modules can also be housed in environmentally hardened cabinets located near the controlled equipment to shorten the field I/O wiring. Experience in recent design has demonstrated that considerable savings in wiring costs can be realized if the I/O cabinets are geographically distributed in such a manner.

System configuration for a DCS varies from manufacturer to manufacturer. At the lowest level are I/O modules. The I/O modules associated with a particular control loop or related loops may be grouped together. The I/O signals are bussed to a control module or a group of control modules. Some manufacturers designate control and I/O modules grouped in this way as a processing unit dedicated to a particular process system in a plant area.

When applied to a power plant or given boiler-turbine-generator unit in the plant, the DCIS may comprise a number of processing units, each connected to a plant-wide communications network. In addition, the data processing modules, operator and engineer workstations, and other peripheral devices are connected to the plant communication networks. Figure 2.4 shows the system configuration of DCIS systems from one famous manufacturer.

2.2.5 Programming Language [9]

Control functions can be programmed in any computer language as long as the language can be operated in a real-time environment (running the program using live data from the I/O modules). Examples of the languages that can be adopted for this purpose are C, APL, FORTRAN, and BASIC. These are all high-level languages. The engineers who use them need to have some knowledge of computer programming.

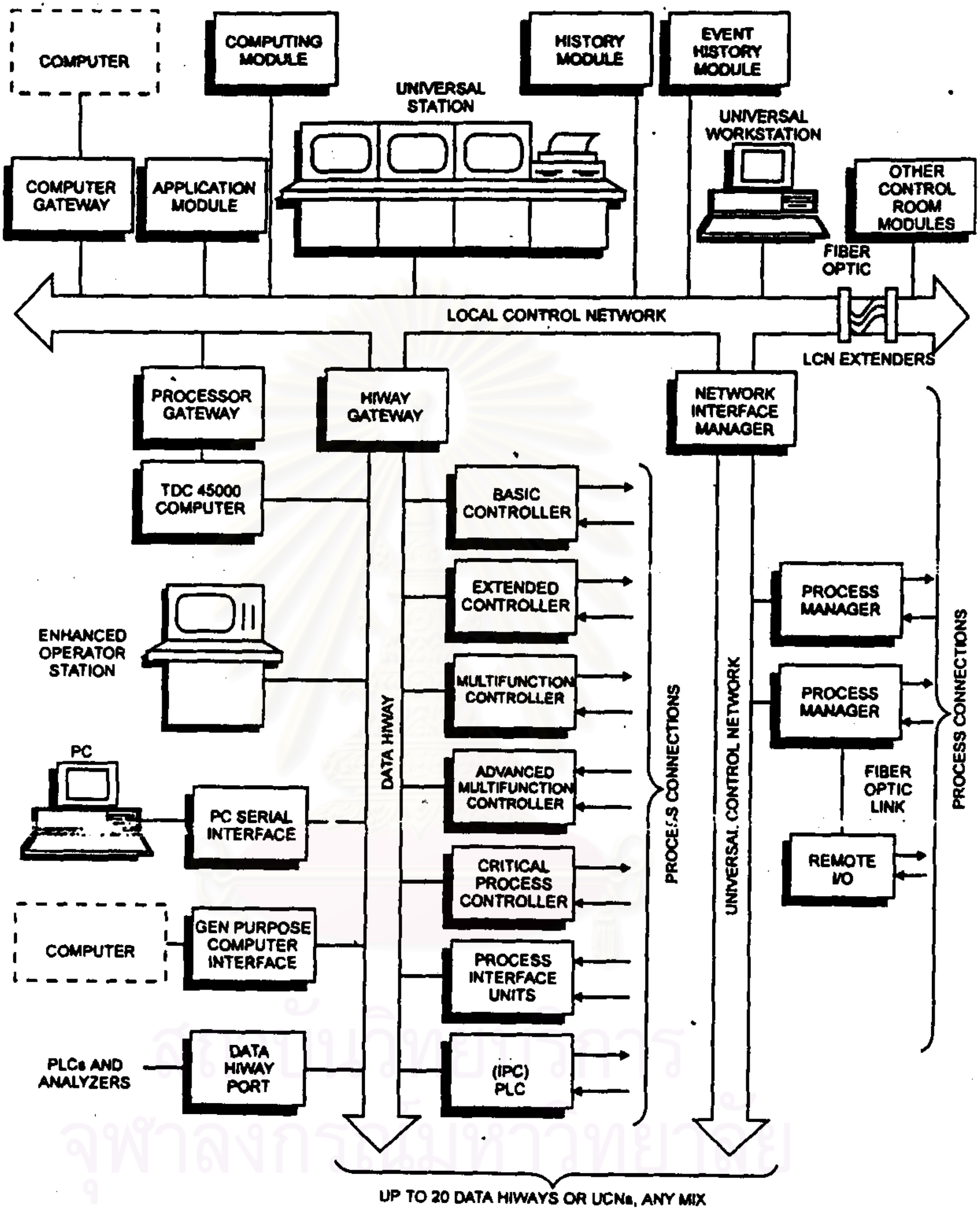


Figure 2.4 The system configuration of DCIS systems from one famous manufacturer [14].

However, the programming format that DCIS manufacturers use most is what is known as " function blocks". A function block is like a subroutine consisting of a set of algorithms designed to execute a specific control or data manipulating function such as a PID control function or a high/low signal selecting function is expected to be used repetitively in a control program. When developing a control program, the engineer selects the blocks required to fit the control strategy and strings the blocks together to form a control loop. The attributes of each block are then placed into program through a fill-in-the-blank type data entry form. The manufacturers have a standard repertoire of function blocks typically constructed from control functions listed in the Instrument Society of America (ISA) standard.

A control program composed of function blocks can be used for both modulating and on-off control loops. The manufacturers also generally provide ladder diagram programs because of their popularity among technicians in power plants. The ladder logic can be accommodated in a DCIS in many ways. Some manufacturers use a separate PLC-like control module, some use modules that are suitable for both function blocks and ladder diagrams, and some put the ladder logic into the I/O modules. Because the on-off control logic is essentially Boolean algebra, it can also be readily programmed in Boolean statements. Most of the control processors available have made provisions for programming the logic in this fashion.

In addition to the control functions, DCIS needs programs to implement all operator interface, report generation, and data storage and retrieval functions. The manufacturers generally divide these functions into separate packages, each with a specially structured program that serves as a platform for the user to develop graphic displays, other forms of data presentation, and format operating logs. In general, the programming functions are user friendly and menu-driven so that they can be a programming tool that is easily understood by the user's personnel.

Even though the programming packages are designed for use by technical personnel who have little knowledge of computer programming, it is not practical for the user to assume that this personnel can become proficient in developing DCIS programs with absolutely no training.

Programming functions are conducted from the engineer workstation, usually with a full complement of VDU screen, keyboard, auxiliary memory, and floppy disks. The workstation is normally connected to the DCIS communications network, and the programs developed from the workstation can be directly downloaded to the individual processor modules in the system.

2.2.6 DCIS Applications in Power Plants

DCIS application in power plants typically covers the following areas:

- Boiler controls, including the combustion (firing rate), furnace draft, steam temperature, and feed water control loops;
- Burner control and pulverizer control;
- Control loops in the plant auxiliary systems that need to be monitored and/or operated from the central control room;
- Alarm annunciation and recording functions;
- Monitoring functions for other separate stand-alone controllers or control system;
- Remote indication and recording of the plant operating parameters;
- Periodic reports and event logs; and
- Historical data storage and retrieval functions.

In nearly all power plants built in recent years, the monitoring and data processing tasks that the DCIS is capable of handling have largely replaced the conventional mimic panels, annunciator light boxes, indicators, and recorders in the power plant control rooms. It should also be mentioned that DCIS application in power plants has been expanding into motor controls for the balance-of-plant equipment (pumps, fans, etc.) which was once predominately an area for PLC applications. At the present time, the choice between PLC and DCIS for this application is largely a matter of cost and users' preference.

2.3 Basic Concepts and Definitions of System Reliability

The other important part of the literature review is an introduction of the basic concepts of reliability and necessary definitions on the reliability basis, which need for this thesis research.

Because the system and equipment which are used in power plant, are so complicate, difficult to maintain and costly.. Moreover, it must be operated for a long period of time without a series failure and must have a total long life. So the power plant need a reliable operation to generate the electricity. The reliability is a key to monitor that how well each system in power plant can achieve the maintaining the power plant operation. The great incentive for achieving high reliability is the safety requirements of the power plant. Moreover high reliability help the operating of the power plant avoid from unnecessary down time which waste a lot of money.

To achieve the reliable system for power plant operation requires **careful planning followed by a well-executed program with engineering tasks that start when design concepts emerges and continue through development, plant construction and operation. Reliability must be treated as a basic design parameter on a par with the performance and cost [3].**

It is necessary to show some basic definitions those are the reliability, availability, failure rate (λ), **Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR)**, fault tree analysis, reliability modeling for system prediction and its usefulness before further more presentation of in this thesis research as follow:

2.3.1 Reliability

The word reliability plays important role in any industrials. It is a major factor to control a quality of a product from any industrials, even an electricity generation industrial. Reliability has many definitions, which was defined by many authors. The reliability definitions are collected from many textbooks, reliability research document and reliability journals as follow:

Kurpis and Booth gave a definition of the reliability that it is **"the ability of an item to perform a required function under stated conditions for a stated period of time, the probability that a device will function without failure over a specified time period or amount of usage"**[15].

Keyes, Dziubakowski and Lukas gave a definition of the reliability that it is **"the dependability or the probability that the system will perform satisfactory for at least a given period of time when used under stated conditions"**[1].

Paul Kales gave a definition of the reliability that it is **" the probability that the item will perform a specified function under specified operational and environment conditions, at and throughout a specified time"**[2].

Armand A. Lakner and Ronald T. Anderson gave a definition of the reliability that it is **" the probability that an item will perform satisfactory for specified period of time under a stated set of use conditions"**[3].

Roy Billinton and Ronald N. Allan gave a definition of the reliability that it is " **the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered** "[4].

Charles E. Ebeling gave a definition of the reliability that it is " **the probability that a component or system will perform a required function for a given period of time when used stated operating conditions**" [5].

E. E. Lewis gave a definition of the reliability that it is "**the probability that a system will perform its intended function for a specified period of time under a given set of conditions**" [6].

From the definition of reliability by many authors, we can categorize the meaning of reliability into four major parts as follow:

- Probability
- Adequate performance
- Time
- Operating conditions

2.3.2 Availability

The other important definition, which is so important for this research, is a definition of availability. Availability and reliability is so close relation between each other. Many authors also gave the definition of the availability as follow:

Kurpis and Booth gave a definition of the availability that it is **" the long-term average fraction of time that a component or system is in service satisfactorily performing its intended function, the steady-state probability that a component or system is in service and the ratio of uptime and uptime plus downtime. Where downtime includes corrective maintenance, preventive maintenance, and system expansion downtimes if such times compromise the user's ability to operate apparatus normally controlled by the equipment being expanded"** [15].

MacDiarmid and Bart gave a definition of the availability that it **is the ability of a product (or service) to be ready for use when the customer wants to use it** [16]. They also define the availability as an equation of the operated time and total hours that the customer owns the product, uptime and downtime as follow:

$$\text{Availability} = \frac{\text{Hour that Product is in Customer's Procession and Works}}{\text{Total Hours that the Customer Owns the Product}} \quad [16]$$

$$\text{Availability} = \frac{\text{Uptime}}{\text{Uptime + Downtime}} \quad [16]$$

Ebeling gave a definition of the availability that it **is a probability that a component or system is performing its required function at a given point in time when used under stated operation conditions** [5].

Lakner and Anderson gave a definition of the availability that it is **" a property of an equipment or system, which provides a single combined measure of its reliable operation and its ability to be efficiently maintained "** [3].

Keyes and Dziuabakowski and Lukas gave a definition of the availability that it is **the device (or devices) will be operational at any given instant of time or " the probability that the system is operating satisfactorily at any point in time when used under stated conditions, where the total time considered generally includes operating time and active repair time, and in some cases administration time and logistic time** [1].

The definition of availability differs from reliability in that it is the probability that the component is currently in a non failure state even though it may have previously failed and been restored to its normal operating conditions. Availability may be the preferred measure when the system or component can be restored it accounts for both failures (reliability) and repairs (maintainability) [5].

2.3.3 Failure rate (λ)

Failure rate is a fraction representing number of failures per hour of components or systems, which have operated past their " burn-in " period (Total number of failures/ Total operating time {typical failure rate per hour}). The failure rate of components or systems typically follows a bathtub curve (shown on figure 2.5), with a relatively high failure rate initially during " burn-in", a stable period (to which the typical failure rate applies) then a period of increasing failures as the system " wears out".

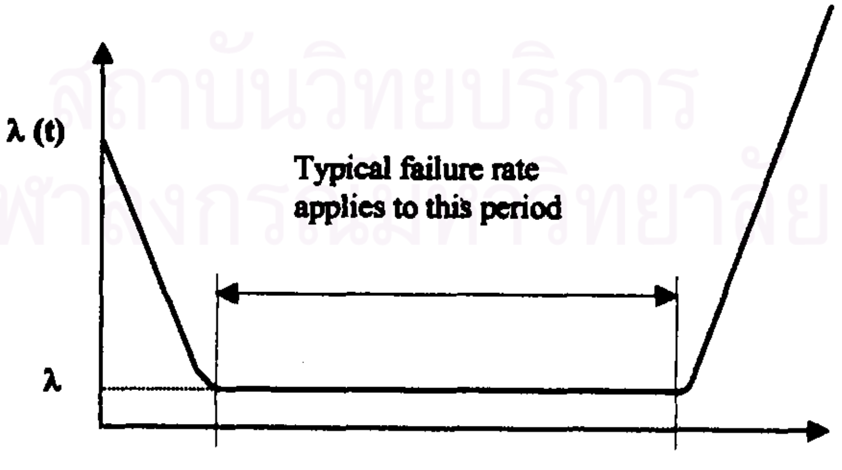


Figure 2.5 Bathtub Curve

2.3.4 Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR)

Paul Kales gave a definition of the **Mean Time Between Failure (MTBF)** that it is the average frequency of (preventive or corrective) maintenance actions upon the item, whether or not the machine actions impose or are in response to an outage [2].

Paul Kales gave a definition of the **Mean Time To Repair (MTTR)** that it is the average time taken up by maintenance activities, whether or not the item is inoperable during the maintenance activities [2].

These mean times are very important to use in this thesis research in order to calculate the reliability of the case study, which is the configuration of the Distributed Control and Information System (DCIS). The objective of this calculation is to find the fitted criteria of the DCIS configuration design (consider only on the controller of DCIS) which based on the reliability basis.

2.3.5 Fault Tree Analysis

Fault tree diagram was first developed as a means of qualitatively assessing the failure processes of a complex system and the consequences of failure on system behavior. Fault trees use a logic that is essential the reverse of that used in event trees. In this method, a particular failure condition, known as the top event, is considered and a tree is constructed that identified the various combinations and sequences of other failures that lead to the failure being considered.

The process starts by first identifying a specific mode of system failure to be assessed. The causes of this system failure are broken down into an increasing number of hierarchical levels until a level is reached at which the behavior or effects of failure of the basic system components can be identified.

This evaluation method is frequency used as a qualitative tool in order to assist the designer, planner or operator in deciding how a system or subsystem may fail as a result individual component behavior. This method can also be used for quantitative evaluation, in which case the reliability data for the individual components are inserted into the tree at the lowest hierarchical level and combined together using the logic of the tree to give the reliability assessment of the complete system being study.

2.3.6 Reliability Modeling for System Predictions

Reliability is an assessment of the likelihood of manufactured product or service to perform for its user when the user demands it. Hence, if we can predict the reliability of each of our product or service, it will be very useful to eliminate the down time which cause an unnecessary waste cost.

The reliability prediction technique used considers our reliability of any product or service is called Reliability Modeling for System Prediction. System composes of a piece of hardware component, software component or procedural steps of a service process. The Reliability Modeling for System prediction is a math model. It is a mathematical description of how all the components behave within their system. By using the reliability math model, we can apply component-failure and component restoration rates, determined to estimate a system reliability or availability. Further more, the reliability math model can also be used to evaluate cost-effective ways of improving performance. The reliability math model can be categorized into two systems, which are series and parallel systems.

- **Series System**

A series system is composed of a series of elements, components, product or service. The failure of any of which will result in a system failure. Reliability of the series system can be calculated as follow:

$$R_{system}(t) = R_1(t) * R_2(t) * R_3(t) * \ldots . * R_n(t)$$ [5]

R is reliability of each component in series system. It is much clearer to see how series system is performed in figure 2.6.

Figure 2.6 Reliability block diagram for components in series [5]

- **Parallel System**

A parallel system is composed of a group of elements, the failure of all of, which is necessary for a system failure. Hence, a parallel system is a particular type of redundant system. The redundant system is the identical elements, components product or service, which work properly in parallel at the same function and time fame. The redundant system does not fail unless all of its redundant elements, components, product or service fail.

Sometime the series and parallel system of reliability math model make the electrical engineers confuse about the meaning of series and parallel because the sense meaning of series and parallel in reliability and electrical system are not exactly the same sense of meaning. It is quite possible for two components to be electrically parallel but in series in the reliability sense. A reliability math model is generally accompanied by a reliability block diagram such as those are following to illustrate the series and parallel system. Reliability of the parallel system can be calculated as follow:

$$R_{system}(t) = 1-(1-R_1(t))*(1-R_2(t))*(1-R_3(t))*\ldots*(1-R_n(t))$$ [5]

R is reliability of each component in parallel system. It is much clearer to see how parallel system is performed in figure 2.7.

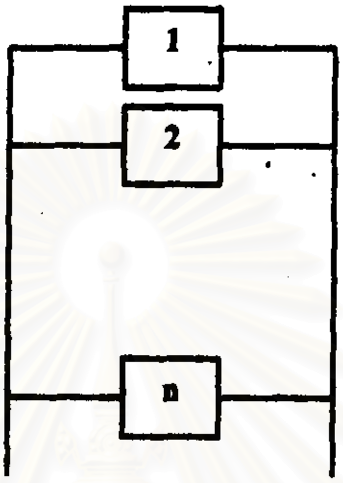


Figure 2.7 Reliability block diagram for components in parallel [5]

- **K-OUT-OF-N Redundancy**

Redundancy is similar to parallel system. K-OUT-OF-N redundancy is so similar to parallel system. The K-OUT-OF-N redundancy system is composed of N identical elements, all active, of which any K must be successful for system success. The reliability block diagram is shown in figure 2.8. The maximum allowable number of failures is F = N-K. The probability of success of any of the elements is R. The parallel system which was explained in the above paragraph is one case of the K-OUT-OF-N redundant system, where K = N and the maximum number of failure is F = 0. Reliability of K-OUT-OF-N system can be calculate as follow:

$$\text{If } K \leq (N/2) \quad R_{sys}(t) = \sum_{X=K}^{N} \left(\frac{N}{X!\,(N-X)!}\right) * \{R(t)\}^{X} * \{1-R(t)\}^{N-X} \qquad [5]$$

$$\text{If } K > (N/2) \quad R_{sys}(t) = 1 - \sum_{X=0}^{K-1} \left(\frac{N}{X!\,(N-X)!}\right) \{R(t)\}^{X} * \{1-R(t)\}^{N-X} \qquad [5]$$

R is a reliability of each component in K-OUT-OF-N system. It is much clearer to see how K-OUT-OF-N system is performed in figure 2.8. From the above formula, there are two opportunities to calculate the K-OUT-OF-N system reliability. The result from each method is the same. We will use each method because in each case will generate fewer computations.

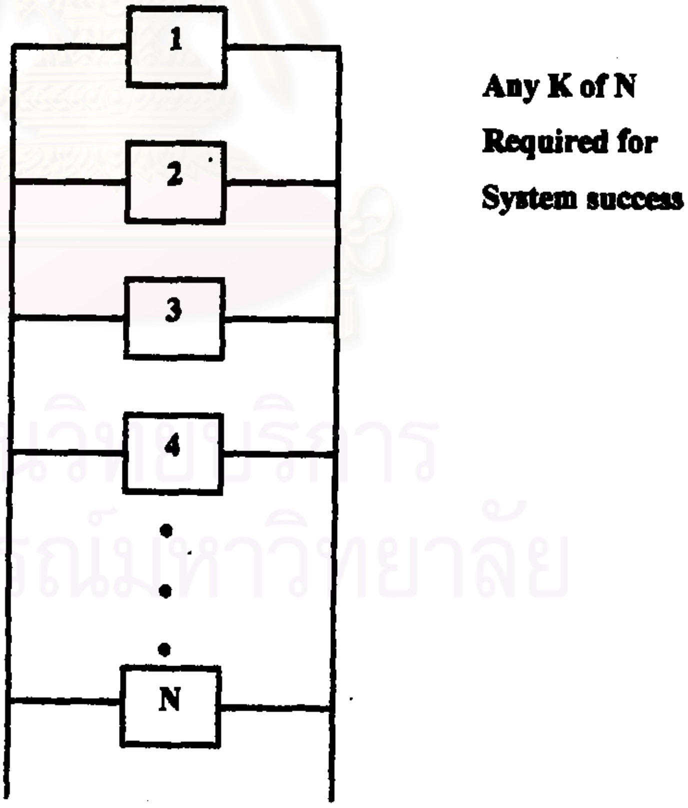


Figure 2.8 Reliability block diagram for K-OUT-OF-N redundancy [5]

- **Standby Redundancy**

Standby redundancy is similar to K-OUT-OF-N redundancy system but standby redundancy system is composed of N identical elements, of which K must be successful for system success and the remaining n = N-K are in standby at the start of the mission. Figure 2.9 shows a reliability block diagram for the standby redundancy system. If, at any time during the mission, one of the K active elements should fail, the system is required to detect that failure and to switch on one of the standby elements.

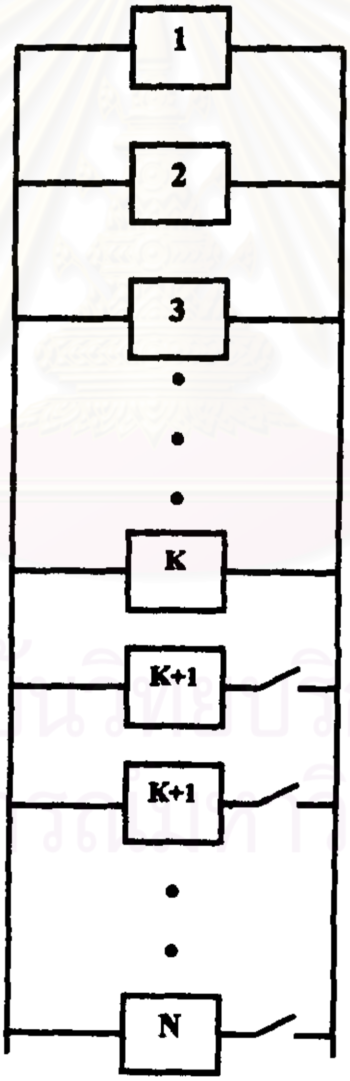


Figure 2.9 Reliability block diagram for a system with standby redundancy [5]

2.3.6 Usefulness of Failure Rate (λ), MTBF, MTTR and Reliability

Failure rate, MTBF, MTTR and reliability have a usefulness to calculate the system reliability. The system reliability is so important to reliability analysis of any systems. We can evaluate and do the improvement of the system reliability by using the result from the reliability calculation as a guideline to monitor in each configuration of any systems. The relation between failure rate (λ), MTBF, MTTR and reliability which will be used to calculate the system reliability are as follow:

$$\text{MTBF} = \frac{1}{\text{System Failure Rate}} = \frac{1}{\sum_{i=1}^{n} \lambda_i}$$

The reliability for specified mission time is

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

2.4 The literatures review which are reviewed to perform this thesis research

The basic concepts, definition of system reliability, fault tree analysis and reliability modeling for system prediction has been reviewed from many text books which were written by many authors as follow:

2.4.1 Book1 Reliability Objective, Book2 Measuring and Evaluating Reliability of Paul Kales, " <u>Reliability Technology Engineering and Management</u> ", Prentice-Hall Inc. 1998. This book includes solutions of system reliability, availability and MTBF. It also suggests opportunities for using reliability engineering practices for non-engineering applications and for service as well as manufacturing industry [2].

2.4.2 Armand A. Lakner and Ronald T. Anderson, " **Reliability Engineering for Nuclear and Other High Technology Systems a Practical Guide** ", Elsevier Applied Science Publishers London and New York. This book presents a much needed practical methodology of reliability techniques applied in high technology industries. The methodology developed in this book has the total integrated reliability program approach in the design, procurement, manufacturing, test, installation and operational phases of an equipment of an life cycle. From Chapter1 to 3 of this book has been reviewed to do the literature review in this Chapter. The details in chapter 1 to 3 of this book are about basic reliability concepts, basic maintainability concepts, availability analysis & improvement, and reliability analysis techniques.

2.4.3 Roy Billinton and Ronald N. Allan, " **Reliability Evaluation of Engineering Systems** ", Plenum Press New York and London Second Edition 1992. This book has a background in concepts and basic techniques for evaluating the reliability of engineering systems. Chapter 1, 5, 7 and 11 of this book has been reviewed to do the literature review in this Chapter. The details of chapter 1, 5 and 7 of this book are reliability definitions & concepts, reliability evaluation techniques, reliability improvements, modeling & evaluation concepts, fault tree analysis and system reliability evaluation.

2.4.4 Charles E. Ebeling, " **an Introduction to Reliability and Maintainability Engineering** ", McGraw-Hill International Editions 1997. This book has a practical coverage of reliability and maintainability. The fundamental concepts, models, and analysis techniques necessary to perform reliability and maintainability engineering. Chapter1, 2 and 5 of this book has been reviewed to do the literature review in this Chapter. The details of chapter 1, 2 and 5 are reliability concepts, reliability terms, reliability definitions, basic reliability models, reliability of systems, availability concepts & definitions and system availability.

2.4.5 E. E. Lewis, " **Introduction to Reliability Engineering** ", John Wiley & Sons, Inc. 1996. This book has an elementary and reasonably self-contained overview of reliability engineering. Chapter 1, 6 and 9 of this book has been reviewed this Chapter. The details of Chapter 1, 6 and 9 are about reliability defines, performance, cost, reliability, basic definitions, the bathtub curve and redundancy.

2.4.6 N. E. "Bill" Battikha, " **Developing Guidelines for Instrumentation and Control, Implementing Standards and Verifying Work Performed** ", the International Society for Measurement and Control, Instrument Society of America 1995. This book's primary purpose is to provide guidelines for developing standard and/or corporate control engineering functions. This book is directed towards engineering and maintenance personnel in plants, consulting firms and central engineering offices.

This book describes how to develop a corporate standard and discusses the points that are typically included in a corporate standard. Chapter 1 and 2 which are introduction of philosophy, engineering, installation and maintenance has been reviewed to used as a fundamental background knowledge to create the design criteria in this thesis research.

2.4.7 **Distributed Control and Information System Specification and Catalogues of ABB power plant control**, ABB Power 1998. This specification and catalogues have a huge documentation. The details inside this document have reviewed to study the structure of K DCIS. From the reading of this document let us understand about the DCIS structure and give us the necessary information to do the reliability analysis for the case study in this thesis research.

2.4.8 Black & Veatch International, Inc. by Lawrence F. Drbal, Patricia G. Boston, Kayla L. Westra and R. Bruce Erickson, " **Power Plant Engineering** ", Chapman & Hall, an International Thomson Publishing Company. The principle of DCIS in this chapter has been reviewed by using the information from this book. This book contains all engineering technology for the power plant engineering.

Chapter 18 of this book, which is plant control system, has been reviewed to do the principle of DCIS in this chapter together with the book in the next item. In chapter 18, it shows the basic control function, on-off control function, modulating control function, and control system hardware and software.

Moreover, the other Chapter of this book can explain about the basic principle of the over all power plant process. (the details of fossil fuels, combustion processes, steam generators, steam cycle heat exchangers, fans, pumps, circulating water system, cycle performance impact, power plant atmosphere emission control, water treatment, liquid & solid waste treatment & disposal, and electrical system)

2.4.9 P.G. Friedmann and T.P. Stoltenberg, " **Continuous Process Control, Practical Guides for Measurement and Control** ", Instrument Society of America 1996. This book is practical guides for measurement and control by Instrument Society of America (ISA). The principle of DCIS in this chapter has been reviewed by using this book together with the book in item 8. This book contains the practical experience of the writers in the area of the field of measurement and controls that bridge the gap between theory and actual industrial practice. Chapter 11 of this book, is the control system architectures. Chapter 11 has been reviewed together with the textbook in item 8 to create the principles of DCIS in this chapter.

2.4.10 M. M. El-Wakil, " **Power Plant Technology** ", McGraw-Hill, Inc. International Edition 1984. This book is the out growth of the lecture notes used in a course on power plant technology and engineering and given to a class of senior graduate students over several years. It contains almost technology and engineering of power processes, which are fossil-fuel steam generators, fuel & combustion, turbines, the condensate-feedwater system, the circulating-water system and environment aspects of power plant generation. This book gives a deep understanding to the power plant generation process.

2.4.11 Dale E. Seborg, Thomas F. Edgar, Duncan A. Mellichamp, " **Process Dynamics and Control** ", John Wiley & Sons, Inc. 1989. This book has a purpose usage for chemical engineer. Anyway, the material which contains in this book, concern to the advanced control techniques. In part 5 to 7 of this book, it shows advance control strategies, digital computer control and the art of process control. From reading through this book, we can understand about the basic principle of DCIS, which is implemented to do the automatic control of the plant. The knowledge from reading this book can help to write the principles of DCIS in this chapter.

2.4.12 Prester R. MacDiarmid and John J. Bart, " **Reliability Toolkit: Commercial Practices Edition (a practical guild for commercial products and military systems under acquisition reform)**", Reliability Analysis Center. This book contains the framework and methodologies, which has been used for thirty years of the military standard and handbooks. The reliability concepts and definitions have been reviewed to use in the literature review in this Chapter 2.

In section 1 and section 2 of this book, it contains the definition of reliability, availability, maintainability, bathtub curve and life cycle. In section 6, it contains the reliability analysis methodologies, which are reliability modeling, reliability prediction methods, and fault tree analysis. Hence, this book contains so many useful basic principles of reliability, which is useful of the literature review in this Chapter 2.

2.5 Literatures, which relate to the research study

2.5.1 **Technical Information, Reliability Manual Centum CS, Yokokawa Electric Corporation 1995.**

This technical information of Yokokawa contains the process to approve their product reliability. They use the reliability modeling for system prediction to show the reliability of the specific area, which they consider. The information, which contains inside this document, is only for the case of Yokokawa DCIS model Centim CS. The reliability evaluation technique which is used in this technical information give an idea to apply the using of reliability modeling for system prediction to ensure the DCIS configuration in the case study of this thesis research.

2.5.2 Technical Paper of Bailey Control Systems " **Design of Batch Control Systems** ", Bailey Control Company 1991.

This technical paper contains the design philosophy of the DCIS of Elsag Bailey. The details inside this technical paper are about the reliability and availability evaluation techniques for the DCIS controller for design of batch control systems. The MTBF and MTTR of the DCIS controller are used to do the reliability and availability evaluation of their DCIS controller. Hence, this technical paper gives an idea for the using of MTBF and MTTR of the DCIS controller to evaluate the system reliability in this thesis research.

2.5.3 M. A. Keyes IV, D. J. Dziubakowski, M. P. Lukas, " **Technical Paper Control System Design and Diagnostic Techniques for Improving Total System Availability** ", Bailey Controls Company 1989.

This technical paper contains the control system design and diagnostic techniques for improving total system availability. Inside this technical paper, the design of high reliability control system is introduced. The using of MTBF and MTTR to calculate the system reliability and availability has been used. Anyway, the details of the calculation method do not show in this technical paper. Only the methodology and the result of the reliability of each DCIS configuration has shown and discussed.

Some part of this technical paper explained about the partitioning for advanced control. The preventive and predictive maintenance techniques were explained. This technical paper give an initiate idea to used the reliability modeling for system prediction to evaluate the system reliability of the DCIS configuration. Moreover, the reliability modeling for system prediction can be used to solve the problem of the DCIS partitioning concept, which is the core problem of this thesis research.