Chapter 4

POWER PLANT AUTOMATION

Power Plant Automation is the act of controlling the power plant(s) / station(s) via automated processes within computers and intelligent C&I devices using integrated power system. Power system integration is the act of communicating data to, from, or among IEDs in the C&I systems and remote users. Attention is given on automation of generating sections, the final / last stage of fossil-fuel-fired power stations. In this thesis, special emphasis is given on automated 'integrated cooling system' of generating sections as an application area of the work. This part of work is further elaborated in Chapter 5.

4.1 INTRODUCTION

Automated power stations in India were begun around late 1990s, when Direct Digital Control (DDC) system put into operation. Since then, the scope and depth of power station automation has expanded continuously to today's cloud computing and video surveillance integrated with SCADA (supervisory control and data acquisition) system, HMI (human machine interface) using compatible wire / wireless communication links in industrial automation applications. From C&I point of view, the roles of following subjects are important for the control and operation of power plants: process instrumentation, telemetry and remote control, intelligent sensors and networks, and the types of IEDs. Functioning of these topics is elaborated in upcoming sections of the current chapter.

The engineers and designers of process industries have always tried to automate the processes as much as possible, based on available instruments. There has been a continuous development in industrial process which needed the development of better instrumentation and automatic control. It is equally valid from a small factory automation set-up to critical and large units, such as, cooling systems for large generating sections. Conversely, the advancement in 'instrumentation and control' contributes to the development of large and complex processes, bringing numerous approach that establishes the trade-off among the design and control issues, cost, and availability [144], [145].

'Telemetry and Remote Control' systems, and the 'Intelligent Sensors and Networks' act as nerves of the process instrumentation.

4.4 TELEMETRY AND REMOTE CONTROL

When measurand (M) and user (in case of industrial automation, operator / system engineer) are separated in such a way that local measurement methods are unable to measure the measuring quantities, viz., flow, level, pressure, temperature, moisture concentration, etc., due to distance and/or inaccessibility, it needs some method of electrical communication scheme called 'Telemetry'. Temperature of rotor windings, pressure and level inside the close chamber of LH_2 (liquid hydrogen) at generating section are some examples where it requires to apply some method of telemetry. Now a days, digital telemetry schemes have replaced D.C. telemetry systems and A.C. telemetry systems because of (i) error detection and correction capabilities, (ii) measuring large number of physical quantities, and (iii) improved reliability, except some short range applications where A.C. telemetry has proven cheaper. Whereas, pulse modulation schemes such as pulse code modulation (PCM), pulse width modulation (PWM), and pulse position modulation (PPM) are used to implement time-division multiplexing (TDM) / frequency-division multiplexing (FDM) system, by which multiple RTUs can interact with CC (control center). Remote control means control of remote objects not control of variables (pressure, level, humidity, etc.) as in case of telemetry. Reliability is the most important criteria in success of remote control system, and hence, it is used to deal with binary messages. If, both telemetry and remote control merge together, then the system is recognized as SCADA (supervisory control and data acquisition) system.

Therefore, a balanced or unbalanced type communication protocol / link is required to interface the entire automation hierarchy of computer-aided process control, that is, Level-0 (field level) to Level-4 (management information system / MIS). Tasks assigned at each level of operation for C&I of the HCS are as follows [64]:

Level-0 (Field Level): measurement and transmission of field parameters to the control level (Level-1) computer control systems.

Level-1 (Control Level):

- **Control enforcement**: maintaining direct control of the plant units / components (in present case, HCS) under their cognizance, detection of any emergency conditions in these units, for example, safety measures of HCS, and taking appropriate response.
- **System coordination and reporting**: collecting information on unit level, transmitting to the higher level (Level-2), and providing services to the operator's HMI.
- **Reliability of the system**: performing diagnostics of various control equipments of the HCS to help in detecting the faults and keep updating hot-backup (standby) system connected in hierarchy.

Level-2 (Supervisory Level):

- **Control enforcement**: responding to any emergency condition in its region of plant cognizance, and optimization of the process. Further details are discussed in Chapter 8.
- **Plant coordination and operational data reporting**: collection and maintenance of process database. Maintaining communication with the higher and the lower level systems in hierarchy, and providing services to the operator's HMI.
- **Reliability of the system**: performing diagnostics of various control equipments of the HCS to help in detecting the faults and keep updating hot-backup (standby) system connected in hierarchy.

Level-3 (Plant Level):

- **Production planning and scheduling**: prepare the immediate production schedule in its area of control, and locally optimization of the costs of entire operation.
- **Plant coordination and operational data reporting**: preparing production report of pressurized hydrogen, maintenance of plant inventory about materials and energy usage, maintaining communications between higher and lower level dedicated computers, data collection and off-line analysis for future prediction, and providing services to the operator's HMI.

- **Reliability assurance of the system**: performing diagnostics of various control equipments of the HCS to help in detecting the faults and keep updating hot-backup (standby) system connected in hierarchy.

Level-4 (Corporate Level):

- **Sales and Marketing**: customer order management, order booking, and transferring order information to Plant level (Level-3) computer. Marketing forecasting and marketing intelligence, customer database management, market survey.
- **Finance and Accounting**: logging and monitoring of company's sales and expenditures, annual accounting, profit and loss statements for management information.

In the present work, Ethernet/IP protocol is used to interconnect digital controller(s) and HMI. Though EtherNet/IP is an unbalanced type of communication protocol, it can be used in those automation networks which can tolerate some amount of non-determinism. This is because Ethernet physical media might not have deterministic delays. Typically, it is used to interlink Level-2 to Level-4 components. The Industrial Ethernet Protocol (Ethernet/IP) was originally developed by Rockwell Automation, [195] and is now managed by the Open DeviceNet Vendors Association (ODVA). Ethernet/IP protocol is standardized in the International standard IEC 61158 and Ethernet/IP devices are certified by ODVA for interoperability and conformance. It is an already well established Industrial Ethernet communication system with good Real-Time capabilities. EtherNet/IP is an application layer protocol treating devices on the network as a series of "objects". It is built on the Common Industrial Protocol (CIP), for access to objects from ControlNet and DeviceNet networks. According to nomenclature of the said protocol, it can be easily confused as a simple combination of Ethernet and the Internet Protocol. Instead, it is an industrial application layer protocol used for communication between industrial control systems and their components, such as a PAC (programmable automation controller), PLC (programmable logic controller) or an I/O system. The 'IP' in EtherNet/IP, is not an abbreviation for "Internet Protocol" but instead stands for "Industrial Protocol".

ControlNet protocol is used to interconnect field sensors and actuators / devices, with the digital controller of the C&I of cooling system (HCS) [194]. ControlNet is a balanced type of communication protocol, and therefore, it is preferred to interconnect Level-0 and Level-1 hierarchy of process control. In some cases, it can also be extended to connect with Level-2 objects / components. ControlNet is an open industrial network protocol for industrial automation applications, also known as a Fieldbus. ControlNet was earlier supported by ControlNet International, but in 2008 support and management of ControlNet was transferred to ODVA, which now manages all protocols in the Common Industrial Protocol family. Features which set ControlNet apart from other fieldbuses include the built-in support for fully redundant cables and the fact that communication on ControlNet can be strictly scheduled and highly deterministic. Due to the unique physical layer, common network sniffers such as Wireshark cannot be used to sniff ControlNet packets. Rockwell Automation provides ControlNet Traffic Analyzer software to sniff and analyze ControlNet packets.

4.5 INTELLIGENT SENSORS AND NETWORKS

'Intelligent Sensors and Networks' comprise three subtopics, viz., smart and intelligent sensors, sensor networks, and intelligent instrumentation. It implicitly involves various IEDs (intelligent electronic devices) to establish the network of process C&I of HCS.

A module containing sensor element(s) suitability integrated with necessary electronics such that the output is truly or easily compatible with the intended end-device, and the module usually takes the form of a single IC (integrated circuit) chip is known as 'Smart sensor'. HMI of the HCS needs these smart / intelligent sensors for pre-processing of data by RTUs (remote terminal units), and send only meaningful data to CC (control center) for further actions. There are four levels of integration of a smart sensor.

Level-I: Smart sensor with analog output (± 0 – 5 V / 4 – 20 mA) or quasi-digital output (pulse frequency modulation due to the least chances of distortion). It includes sensing elements, Analog Signal Processing Unit (ASPU) and/or variable frequency control.

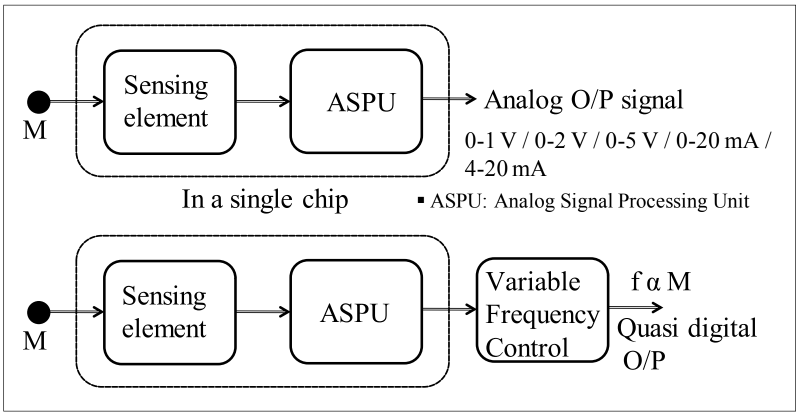

Figure 4.3: Schematics representing Level-I types of sensor.

Level-II: Smart sensor with digital output (typically, 12 bit output).

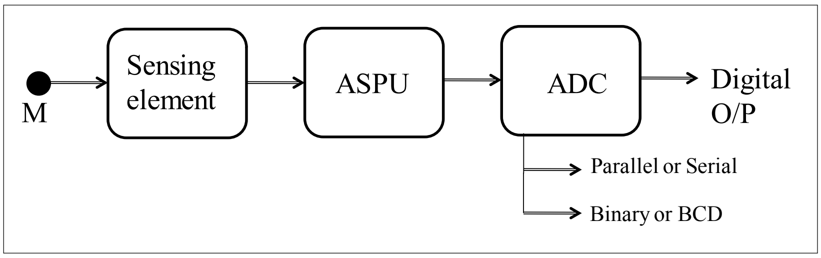

Figure 4.4: Schematic diagram representing Level-II type of sensor.

Level-III, Intelligent sensor: A sensor which has been integrated 'Level-II' with Digital Processing Unit (DPU), is recognized as intelligent sensors. A DPU can be a type of (i) microprocessor, (ii) microcontroller, or (iii) digital signal processor including required memory and I/O devices.

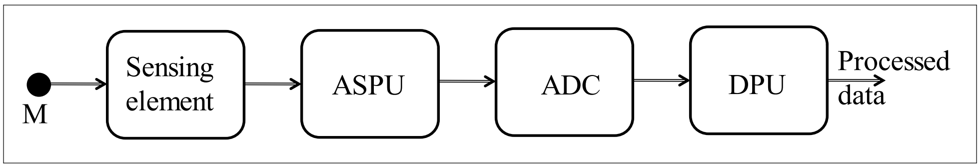

Figure 4.5: Schematic showing Level-III type of sensor.

Level-IV, Network processors / sensor: If, a 'Level-III' type of sensor also includes compatible communication interface and network port, then such a sensor is defined as Network sensor. Network port allows connecting to network without any further processing.

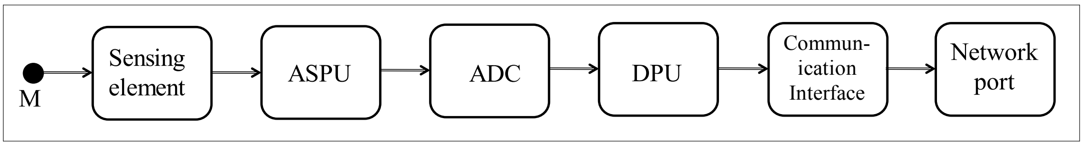

Figure 4.6: Schematic showing Level-IV type of sensor.

Presently, 'Level-III' and 'Level-IV' are two most preferred types of sensors in APC (advanced process control) application, such as HCS. Sensor networks have major contributions to draw the system architecture of HCS, which is further discussed in sub-section 5.3.4. They may consist of following things:

- Servers, PCs and work stations: in offices.
- Control terminals: located in control room (PCs) [72].
- Industrial controller: located either in CC or on plant floor (invariably placed on PLC).
- Field devices: comprises of sensors and actuators are located on plant floor.

The aforementioned schemes of sensors networking are compatible with wired / wireless protocols, as discussed in Section 3.3 to the respective stages of the presented HCS. Both balanced (Ethernet/IP) and un-balanced (ControlNet) type of communication links / protocols are referred in system architecture of HCS [194], [195].

At this stage role of intelligent instrumentation comes into existence. Intelligent instrumentation is the instrument which process data both logical and arithmetic operations, and can reach to a decision. Therefore, Intelligent Instrumentation must have a data processor. Data processors are of two types, depending on the mode in which microprocessor / microcontroller / DSP, is used in intelligent instrumentation. It can be either of 'Computer-Host / Host-Computer' mode or of 'Embedded system' mode. The architecture of HCS (hydrogen cooling system) falls in the category of 'Host-Computer' mode. In this mode, a standard computer is used as a host and the computer is not embedded into application, that is, applications can be kept on changing. It is well illustrated in Figure 4.7.

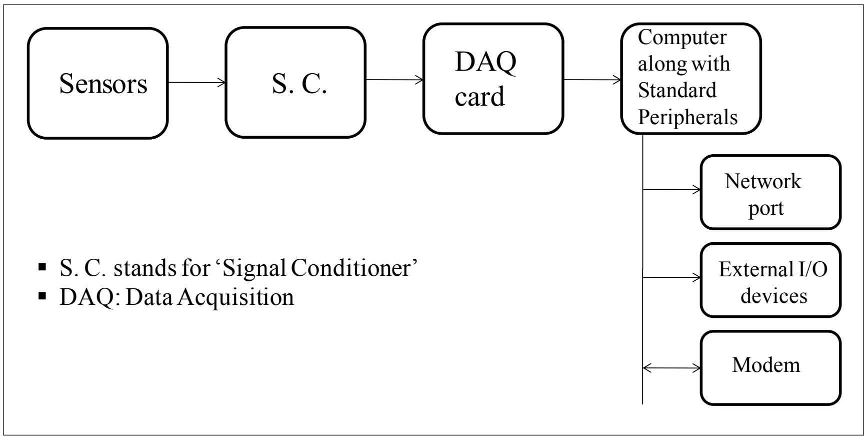

Figure 4.7: Schematic representing architecture of the Host-Computer Instrumentation System.

4.6 INTELLIGENT ELECTRONIC DEVICES

Any electronic device that possess or have some type of local intelligence can be known as IEDs (intelligent electronic devices). IEDs are used for control and monitoring of remote operations of power plants as substitutes of hard-wired electro-mechanical devices. A typical IED can contain around 5 – 12 protection functions, 5 – 8 control functions controlling separate devices, an auto-reclose function, self monitoring function, communication functions, etc. Hence, they are aptly named as Intelligent Electronic Devices. Some recent IEDs are designed to support the IEC 61850 standard for substation automation, which provides interoperability and advanced communications capabilities. An IED, as it relates to the protection and power system automation industry, is a device that performs electrical protection functions, advanced local control intelligence, has the ability to monitor processes and can communicate directly to a SCADA system [69], [76], [104], [105]. It can be a type valve or a complex digital controller. However, the ability of an IED to perform all the functions of protection, control, monitoring, and upper level communications independently, without the aid of other devices like an RTU or communications processor (not including interface modules) is the identifying feature of an IED.

4.6.1 Types of IEDs

Control valves, HMI, RTUs, and even PLCs, PACs, DCS, SCADA system are some popular examples of IEDs.

Control valves are valves used to control conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing in response to signals received from controllers that compare a 'set-point / SP' to a 'process variable / PV' whose value is provided by sensors that monitor changes in such conditions. The opening or closing of control valves is usually done automatically by electrical, hydraulic or pneumatic actuators. Selection of actuators depends on the type of application. Positioners are used to control the opening or closing of the actuator based on electric / pneumatic signals. These control signals, traditionally based on 3 – 15 psi (0.2 – 1.0 bar), more common now are 4 – 20 mA signals for industry [71], 0 – 10 V for HVAC systems, and the introduction of 'Smart' systems, wire / wireless HART, Fieldbus, and Profibus being the more common protocols.

A **RTU** (remote terminal unit) is a microprocessor-controlled electronic device that interfaces objects in the physical world to a DCS or SCADA by transmitting telemetry data to the system, and by using messages from the supervisory system to control connected objects. An RTU monitors the field digital and analog parameters and transmits data to the Central Monitoring Station. An RTU can be interfaced with the CC with different communication media, usually serial RS232, RS485, Profinet [70] or Ethernet. RTU can support standard protocols, Modbus, DNP3, IEC 61850, etc. to interface any third party software. An RTU can monitor analog inputs of different types including 4 – 20 mA [71], 0 – 10 V., −2.5 to 2.5 V, 1 – 5 V, etc.; the RTU or host system then translates this raw data into the appropriate units such as gallons of liquid hydrogen left or temperature before presenting the data to the user via the HMI. **HMI** is discussed in forthcoming subsection 4.7.2, which is also a part of focus area of research work for the process control of HCS. RTUs differ from PLCs in that RTUs are more suitable for wide geographical telemetry, often using wireless communications, while PLCs are more suitable for local area control (plants, production lines, etc.) where the system utilizes physical media for control. The IEC 61131-3 programming tool is more popular for use with PLCs, while RTUs often use proprietary programming tools.

A **PLC** (programmable logic controller) is a digital computer used for automation of industrial processes, such as control of machinery on factory assembly lines. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real-time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result [105]. PLC has following specific features suited to industrial control.

- PLC is rugged and noise immune equipment.
- PLC have modular plug in construction, allowing easy replacement / editing of input-output units.
- Standard low-level and high-level programming is possible.
- Ease of programming and reprogramming (both in Run and/or Edit mode).
- Communication port for interfacing with other PLCs and PCs [72].
- Ease of maintenance.
- Greater life and reliability.
- Energy saving.
- Shorter project time.
- Easier storage archiving and documentation.

PLCs may need to interact with people for the purpose of configuration, alarm reporting or everyday control. A HMI (human-machine interface) is employed for this purpose. HMI's are also referred to as MMI's (man-machine interface) and GUI (graphical user interface).

A **DCS** (distributed control system) refers to a control system usually of a process or any kind of dynamic system, in which the controller elements are not central in location (like the human brain) but are distributed throughout the system with each component sub-system being controlled by one or more controllers. The entire system of controllers is connected by networks for communication and monitoring. DCS is a system having the controller, HMI integrated with control / supervision capability, the network integration, and usually many choices of Asset Management and Historian software, often with ERP integration. Some DCSs use PLCs as their controllers, such as ControlLogix / FlexLogix / ProcessLogix, etc. from Rockwell, and PCS7 from

Siemens. Today, all DCS vendors have incorporated PLCs into their systems to satisfy the demands of discrete control requirements.

The term **SCADA** usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (on the scale of kilometers or miles). Most site control is performed automatically by RTUs / PLCs / PACs. Host control functions are usually restricted to basic site overriding or supervisory level intervention [69], [76]. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow of cooling water, and enable alarm conditions.

4.7 SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM

The direct control of large industrial operations, such as all the operations of generating sections of a power plant is impractical. Better approach is to place closed loop controller and supervisor from the central locations called control room or CC (control center). It requires:

- First, mathematical model of the system, that is plant, and
- Second, complete data of the plant, that is, control positions of plant. It can also be recognized as input of the plant so that output can be generated and at the same time, plant can be controlled in real-time.

The entire aforesaid process in one idiom is recognized as SCADA system. SCADA is useful for controlling from a small hydro power station to large and complex power grid. In other words, SCADA system is established by exchanging data between CC and RTUs of the respective sections. Jobs assigned to RTU and CC is as follows:

RTU:

- Acquire the data from plant,
- Execute the control command, and
- Carry out the automatic control on the basis of the SP (set-point) received from control center.

Control Center:

- Receive the data from RTU,

- Analyze the system,
- Decide the commands to be sent,
- Decide the SP to be sent, and
- Transmit the messages.

The major functions of SCADA are:

- Data acquisition,
- Monitoring,
- Control,
- Data collection and storage, Calculations, and
- Report generation.

Further, types of items in controlled plant and their functions are as follows:

Table 4.1

Types of functions of a SCADA system

S. No.	Function type		Data acquisition
1.	Controlled variables	:	Acquire the analog values
2.	Uncontrolled variables	:	Acquire the analog values
3.	Remotely controlled objects	:	Acquire the status information / discrete values
4.	Locally controlled objects	:	Acquire the status information / discrete values

4.7.1 SCADA versus DCS

The DCS system is one, which has several micro-computers physically spread all over and each assigned with a special task, and further all are manually linked through a data highway / Shielded Twisted Pair (STP) cable / co-axial cables / fiber optics. Where, each of these computers can perform its own task concurrently and independent to the micro-computers in the system. On the other hand, SCADA is a recognized as a system, which is typically a combination of telemetry and data acquisition. It consist of collecting information, transferring it back to a central site (ERP / CMS – Central Monitoring System), carrying out necessary analysis and control, and then displaying data on one / number of operators screens as per requirement. It can help a small utility with just a single operator as well as a large utility with operators managing the process around the clock. As illustrated in Table 2.1, Chapter 2, differences between SCADA system and DCS are as follows:

Features	DCS	SCADA
Identity	The system is useful for Level-0 to Level-2	A system may spread over multiple hierarchy
Area	Confined	Large geographical
Close loop(s)	Significant amount	Least priorities
Executions	Is delayed in DCS	Can be faster in some cases at plant floor level
Control and Monitoring	More control and less monitoring	Primarily for monitoring with less control actions
Communication links	High speed network	Telemetry (wired or wireless)

4.7.2 Human Machine Interface

The HMI is a user friendly link between plant operator and the automation system which finally controls the plant or process. The purpose of HMI is to help plant personnel monitor and control their industrial automation systems more effectively [103] – [105], [193]. The objectives of HMI are well depicted in Figure 4.8. Highlights of the objectives are as follows:

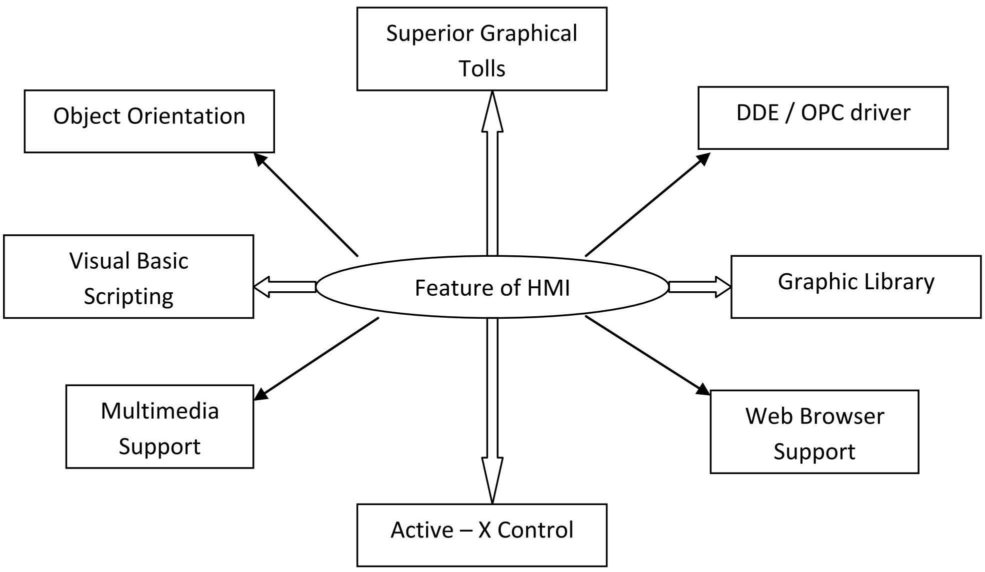

Figure 4.8: Different features of the Human-Machine Interface.

- Viewing graphical representations of plant devices and processes.
- Monitoring and controlling real time data.
- Receiving notification of alarm conditions.
- Trends of real-time / historical process values.
- Limiting access to critical processes by implementing security measures.

The HMI is very important interface between the users (such as plant / unit operators, computer specialists, C&I engineers, communication engineers, etc.) and the computer control system. HMI permits users to observe, monitor, log, diagnose, optimize, and control the current state of the plant system. It also provides historical review, trending storage of process conditions, and maintenance / updating of any control elements, viz., instrumentation hardware and software systems, communication systems, etc. It is therefore chosen as area of research from process instrumentation point of view, focused on HCS.

4.8 CONCLUDING REMARKS

❖ The need to improve performance and safety of a power plant and its complex processes has led to increased use of automation. In addition, the ongoing revolution in computing and information system technology is leading plant designers, through economic and performance incentives, to continually increase the extent of automation. At the same time, worldwide experience confirms that societies are demanding higher standards from designers and operators. More automation, as such, is not necessarily the total solution to these problems. A major objective of the thesis is to promote increased availability by assisting the designer to improve the process of assigning functions to humans and to automation. Emphasis is given on discussing back ground work of designing an efficient HCS and key components associated with generating sections.

❖ Telemetry is a technology that allows measurements to be made at a distance, via radio wave (RF) or IP network transmission and reception of the information. Also, it has been observed that the role of intelligent sensor networks has been growing rapidly over the past years. New sensor devices are equipped with processors capable of running the complex machine or play