Refer Ch. 56, Sec 56.21 for India's Power Plans.

India, like other developing Nations is on the verge of perpectual Energy Crisis. The loadgrowth is faster than the growth of power system. The energy resources and status of power sector are covered in Sec. 56. 21. The summary is as follows :

Table 49.1. Growth of Installed Capacity in India

5 year Plan	1	2	3	4	5	6	7	8	9
Span Start	1951	1956	1961	1966	1972	1978	1984	1990	1995
End	1955	1960	1965	1971	1977	1983	1989	1979	2000
Installed Capacity by End Year of plan									
$\times 10^3$ MW	3.4	5.7	10.1	14.7	23	30	42	92	132

Approximate Break-up (1997)

Hydro (Renewable)	30%
Coal Thermal	65%
Nuclear	4%
Gas Turbine and Noconventional	1%

Approximate Contribution of Regional Grids in Installed Capacity 1997

Western	*Nothern*	*Southern*	*Eastern*	*North-Eastern*
30%	*28%*	*25%*	*15%*	*2%*

Landmarks in India's Power Sector

1955 - First 132 kV Transmission Line Commissioned

1961 - First 220 kV Transmission Line Commissioned

1965 - National Grid and regional grids identified

1966 - First nuclear power plant commissioned

1975 - First 400 kV AC transission line commissioned

1978 - First 500 MW Generator Unit Commissioned

1979 - SF_6 and Vacuum Circuit-Breakers introduced

1985 - SF_6 GIS Introduced

1989 - First HVDC Back-to-Back Coupling Station Commissioned (Vindhyachal Back to Back, Northern Grid - Western Grid)

1991 - First Long Distance Bipolar HVDC Link Commissioned Rihand (UP) to Delhi (Dadri)

1992 - First Wind Turbine generator unit commissioned.

SUMMARY

Interconnected power systems have been established all over the world. The interconnection is by 3 phase AC line or by Back to Back HVDC link or by Multi terminal HVDC. National Load Control Centers ensures that : Total power generated = Total load + Losses.

Regional Control Centre controls generation/Load balance in the region plus Import/Export requirement as per instructions of national control centre. Recent Renewable energy power plants either stand alone or grid-connected depending on location.

50

Operation and Control of Interconnected Power Systems, AGC and SCADA

50.1. INTRODUCTION

The role of Master Control Centre, Regional Control Centres, Control Rooms in power stations in the supervision, operation and control of power system has been illustrated in Fig. 46.1. Chapter 46 and also in Sec. 46.22.

The principles of interconnected power systems and tie-line power flow have been described in Chapter 49.

The object of the power supply company is to generate and supply required amount of electrical power at specified voltage and frequency to all the consumers at all times. The extensive growth of interconnected power system has resulted in complex operation and control requirements.

AGC refers to Automatic Generation Control. AGC involves maintaining generation in each area at such a value as to keep the frequency in the area within targetted limits and to keep the net interchange with adjacent interconnected areas within scheduled limits.

SCADA refers to Supervisory Control and Data Aquisition Systems. SCADA systems are essential in the operation of todays large interconnected systems. Basis equipments required in SCADA systems have been mentioned in Sec. 46.3.

Most SCADA equipment operate in scanning mode providing continuous monitoring of several large power stations and substations. SCADA requires two way communication between Master Station (A) and remote outstations (B) which are usually at the sub-station level.

The various aspects of power system operation and the inter-relation between control functions has been reviewed in this chapter.

50.2. MAIN TASKS IN POWER SYSTEM OPERATION

The main tasks in power system operation at different levels are divided into following categories (Table 46.1).

1. Planning of operations
2. Operation control
3. Operation follow-up and accounting.

The functional responsibilities in performing the above tasks are shared by the following (Table 46.1).

1. National Grid Control Centres
2. Regional Load Control Centres
3. Power Station Control Rooms
4. Major Substation Control Rooms.

Tables 46.1 and 46.2 in Sec. 46.1 cover the responsibilities and tasks.

50.2.1. Planning of Operations

Planning refers to formulating and preparing action plan before hand. Planning is done for the next hour, next day, next week, next month, next year and for long range.

Planning tasks include the following :

(A) National Level Planning

1. Load prediction (forecasting) for total grid
2. Generation scheduling for total grid
3. Spinning reserves determination for total grid
4. Generator unit commitment scheduling
5. Planning of reserves
6. Planning of maintenance schedules
7. Energy resource planning
8. Selection of energy sources
9. Hydro-thermal generation co-ordination
10. Planning of interchange between regions
11. Planning of installations and HVDC tie-links

(B) Zonal (Regional) Level Planning

1. Load prediction (for casting) for region
2. Scheduling of generation in the region
3. Planning of overhauls and maintenance of various stations and major sub-stations in the area.
4. Planning of reserves in the area.
5. Selection of load scheduling programmes in the area.

(C) District Control Centres (State Electricity Boards within an area)

1. Short-term planning according to directives of regional control centres.
2. Planning of generation and spinning reserves in the district.
3. Planning of load shedding in the district.

(D) Power Station and Major Sub-station control room

1. Work planning for hourly, daily, weekly, monthly tasks.

The *Load Control Centres* have the following functions :

1. They act as communication centre between various areas generating stations and sub-stations.
2. Analysis of future operating conditions.
3. Co-ordination of emergency procedures and analysis of disturbances.
4. Co-ordination between planning and operation.

50.2.2. Operational Tasks

An electricity supply undertaking generally aims at the following :

— Supply of required electrical power to all consumers continuously at all times.
— Maximum possible coverage of the supply network over the given geographical area.
— Maximum security of supply.
— Shortest possible fault-duration.
— Optimum efficiency of plants and the network.
— Supply of electrical power within targeted frequency limits (say 49.5 Hz and 50.5 Hz).
— Supply of electrical power within specified voltage limits.
— Supply of electrical energy to the consumers at the lowest cost.

As a result of these objectives, there are various tasks which are closely associated with the generation, transmission, distribution and utilization of the electrical energy. These tasks are performed by various manual, semi-automatic and fully automatic devices located in generating stations and sub-stations.

These tasks are accomplished by the teamwork of the following controlling centres :

— National load centre
— Regional load control centre
— District load control centre
— Generating station control rooms
— Transmission divisions and transmission sub-stations
— Distribution sub-stations and feeder sections.

The above control centres are linked by communication system for two way communication of

— Data
— Control signals
— Voice or Teletype information

National Load Control Centre performs the following operational tasks :

1. Supervision of generation, load and frequency of each area and tie-line flow.
2. Power exchange under emergency condition
3. System frequency control and follow-up of network Islanding (Segregation).

Zonal Control Centre performs the following operational tasks :

Supervision of generation, load and frequency in each of the districts, power exchange between districts, reserves.

District Load Control Centres perform the following operational tasks :

1. Supervision and control of generation in the district to match with the load by AGC (Automatic Generation Control).
2. Operation and control of power stations.
3. Operation and Control of transmission system and tie-lines.

Power Station and sub-station Control Rooms perform the following operational tasks :

1. Generation, start, stop function.
2. Automatic restoration functions.
3. Control and protection functions.
4. Supervision of process variables.
5. Maintenance, overhauls.

Transmission Sub-stations perform the following operational functions :

1. Switching operations.
2. Protective functions.
3. Voltage control, reactive power compensation.
4. Data collection and reporting.
5. Load shedding instructions to distribution sub-stations.

Operational Tasks associated with Major sub-stations. The tasks associated with major sub-stations in the transmission and distribution systems include the following :

— Protection of transmission system.
— Controlling the exchange of energy.
— Ensuring steady state and transient stability.
— Load shedding and prevention of loss synchronism. Maintaining the system frequency within targeted limits.
— Voltage control; reducing the reactive power flow by compensation of reactive power, tap-changing.

— Securing the supply by providing adequate line capacity and facility for changing the transmission paths.
— Data transmission via power line carrier/microwave/other channels for the purpose of network monitoring ; control and protection.
— Determining the energy transfer through transmission lines and tie-lines.
— Fault analysis and pin-pointing the cause and subsequent improvements.
— Securing supply by feeding the network at various points.
— Establishing economic load distribution and several associated functions.

These tasks are performed by the team work of load-control centre, control rooms of generating stations and control rooms of sub-stations. The sub-stations perform several important tasks and are integral part of the power system.

The locations of important sub-stations, power stations and the transmission lines are decided while designing the power system by considering the geographical locations of load centres, and energy reserves.

A small power system is generally controlled by direct supervision of generating stations and sub-stations through respective control rooms. A large network having several generating stations, sub-stations and load centres is controlled from central load despatch centre. Digital or voice signals are transmitted over the transmission lines via the sub-stations. The sub-stations are linked with the load control centres via Power Line Carrier System (PLCC) and Microwave Channels. The data collected from major sub-stations and generating stations is transmitted to the load control centre. The instructions from the load control centre are transmitted to the control rooms of generating stations and sub-stations for executing appropriate action. Modern power system is controlled with the help of several automatic, semi-automatic equipment. Digital computers and microprocessor are installed in the control rooms of large sub-stations, generating stations and load control centres for data collection, data monitoring automatic protection and automatic control.

50.2.3. Operating Accounting and Financial Control

The operating accounting deals with the data collection and evaluation and thereafter preparation of financial reports and billing *e.g.* the tasks include :

1. Collection data regarding MWhr produced, MWhr interchanged.
2. Billing on adjacent area for the interchange MWhr.
3. Evaluation of performance of power stations, districts.
4. Evaluation of pricing after the interchange.

Though the costing of interchange power is on the basis of the agreed rates, the participant power system may like to verify the economic gains loss of interchange against the estimated values.

50.3. AUTOMATIC GENERATION CONTROL (AGC)

Automatic Generation Control (AGC) is performed by the team work of Regional Load Control Centre and the Power Station Control Rooms.

The regional control centre receives real time data (Second to Second) of

— Power generation in each power plant (MW)
— Tie-line power flow (MW) through each tie-line.
— System frequency.

This data is received through transmission channels between the generating stations, major sub-stations and the Regional Load Control Centre.

The Regional Load Control Centre evaluates the data, determines the action and sends instructions to each generating station as to how much generation they should increase or decrease.

The operator in Generating Station Control room receives these instructions and takes appropriate action to change turbine governor setting so as to raise or lower the input to turbines and thereby output of the generating units and the generating station.

Automatic Generation Control (AGC) refers to the closed loops control system having three major objectives.

— To hold the system frequency within targetted limits (near 50 Hz).
— To maintain correct value of net power interchange between adjacent systems through the tie lines.
— To maintain generation of each plant within the area at economical value.

Area Control Error (ACE) refers to the shift in generation required to restore the frequency and net interchange to the desired value.

Load frequency control of a unit has been explained in Sec. 46.23 and Fig. 46.14.

AGC is integrated with SCADA.

50.4. SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM

The functions and configuration of Supervisory control and Data Acquisition systems (SCADA) have been described in chapter 46. SCADA systems are indispensable in the operation and control of interconnected power systems.

SCADA equipment are located in *Master Control Centre* National Grid Control Centre) ; Zonal (Regional) Control Centres, District (State Electricity Board) Control Centres, Control Rooms of Generating stations and large sub-station.

SCADA requires two-way communication channels between the *Master Control Centre* and *Remote Control Centre* (Fig. 50.1).

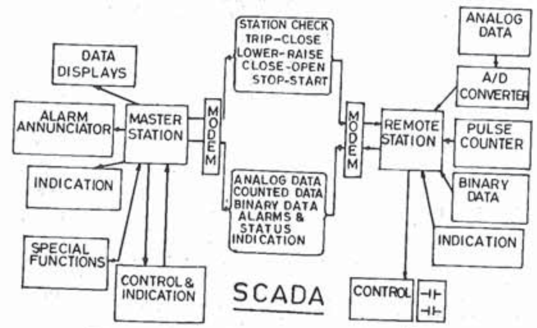

Fig. 50.1. SCADA requires communication between Master Control Station and Remote Control Station.

Traditionally, the SCADA systems were used by the operators in scanning mode, providing data regarding generating stations, Generating units, Transformer Sub-stations etc. (Tables 46.4-46.6) Traditional hard wired SCADA systems were arranged to perform several functions to supplement Automatic Control and Protection Systems.

All the protective relays and most of the control relays and control systems are necessary for automatic control of generating stations and transmission systems even when the supervisory control is used. Only initiating devices may be different or omitted with fully automatic SCADA control. For example, tap changing may be initiated either by the sub-section control room operator or by the automatic voltage control relays connected in the protection panel of the transformer.

With traditional SCADA systems, the function of protection and control were segregated. Controls systems were arranged to keep the values of controlled quantities within target limits. Protection equipments were arranged for sounding alarms and for tripping circuit-breakers. With the recent revolution in microprocessor technology, the size, performance and cost of digital automation

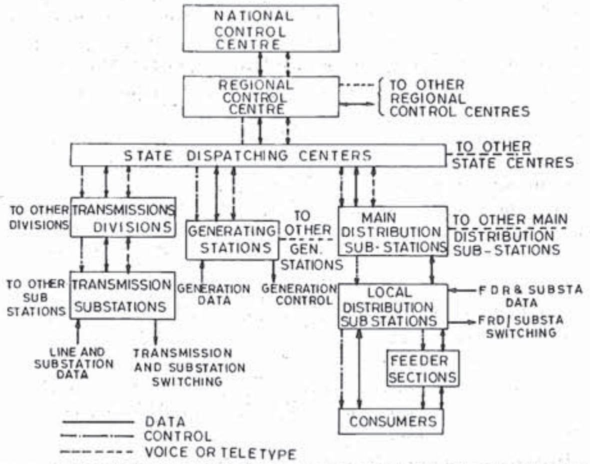

Fig. 50.2. (*a*) Communication between control centres in SCADA system.

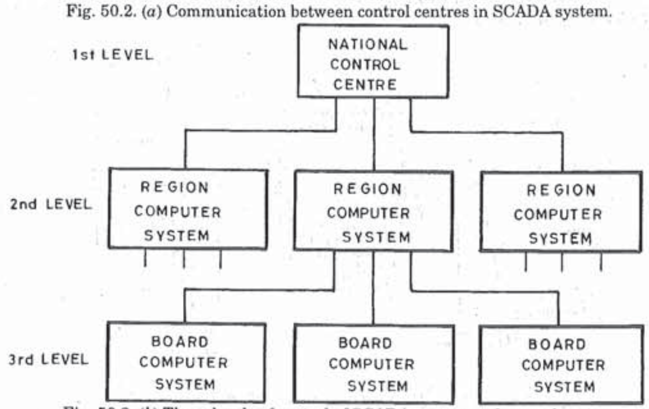

Fig. 50.2. (*b*) Three levels of control of SCADA system and control system.

systems have become acceptable in commercial installation. These automatic SCADA systems provide integrated approach to power system protection, operation control and monitoring, automatically with least intervention of the control room operator.

With the microprocessor based control and automation, the microprocessor are located in the master station, generating stations and sub-stations. The microprocessor in transmission sub-stations and distribution sub-stations provide control and protection decisions locally where the data is located. The action is reported to the operator "by exception". The operator retains the option of taking intervening action of overriding or initiating of his own.

Various types of the microprocessor based SCADA systems are installed for various centres including small centres, small distribution system, small power plants to very large interconnected power systems. The functions and architecture of SCADA system is selected in accordance with the functional requirements and size of the power system. Table 50.1 gives a summary of functions of various alternatives SCADA systems.

Table 50.1
Various types of computer-based Supervisory Control and Data Acquisition Systems (SCADA)

Functions	*System type 1*	*System type 2*	*System type 3*	*System type 4*
Application / functions	*Small Distribution Systems small hydro stations, HVDC Links*	*Medium sized power systems, power stations HVDC links distribution systems*	*Regional control centre, Distribution systems in large Urban areas, several hydropower stations with cascade control*	*National and Regional control centres, distribution systems in large urban areas, several hydro stations, with cascade control*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Interative studies security assessment, Network modeling.	—	—	—	Operators Loadflows (OLF) Training Simulator (TL) Security Assessment calculations Contingency Analysis (CA) State Estimation (SA)
Generation control.			Automatic generation control (AGC)	Automatic generation control (AGC) Economic dispatch calculation (EDC). Load forecasting (LF). Unit commitment (UC)
Calculations	—	—	User-oriented calculation language (CAL) Energy balance. Status calculations.	User-oriented calculation language (CAL). Interchange scheduling and accounting. Status calculations.
Monitoring	Status/indication changes, Control operations. Limit values	Status/Indication changes. Operational commands. Limit values.	Status/indication changes. Control operations. Limit values, 4 limits + gradient limit. Event classification.	Status/indication changes. Control operations. Limit values, 4 limits + gradient limit. Event classification.
Logging	Events. Hard copies or Screen display on printer.	Energy reports max/min reports. Events. Printout copies of screen displays.	Statics, Post-mortem reviews (PMR). Sequential events recording. Event reports. Time tagged date (TTD). Printouts of screen displays.	Statics, Post-mortem reviews (PMR). Sequential events recording. Event reports. Time tagged data (TTD). Printouts of screen displays.
Data acquisition	Status/indications. Measured values. Upto 500 signal points from 16 RTUs and 40 STUs.	Status/indications. Measured values. Energy values, Upto 3000 signal points from 30 RTUs and 100 STUs.	Status/indications. Measured values. Energy values. Up to 7000 signal points from 50 RTUs.	Status/indications. Measured values. Energy value Upto 30000 signal points from 150 RTUs.
Control	ON/OFF commands RAISE/ LOWER regulation.	ON/OFF commands RAISE/ LOWER regulation. Set point values.	OF/OFF commands. RAISE/ LOWER regulation. Set point values. Sequential control.	ON/OFF commands. RAISE/ LOWER regulation Set point values. Sequential control.
Display	Monochromatic display and printer.	Color display and printer.	Color display, mimic diagram and printer.	Color display, minic diagram and printer.

50.4.1. Division of Tasks between various control centres

National Load Control Centre

— To decide generation allocation to various regions and to decide exchange between regions on overall economy and energy policy/reserves.

— Load-frequency control of entire grid by matching total generation with total load.

Regional Load Control Centre

— To decide generation allocation to various generating stations within the region on the basis of equal incremental operating cost considerating line losses are equal.

— Frequency control in the region.

Plant Load Control Room

— To decide allocation of generation of various units in the plant on the basis of equal incremental operating costs of various units.

— To minimize reactive power flow through lines so as to minimise line losses and maintain voltage levels.

— Frequency control in the plant.

Sub-Station Control Room

— To minimise reactive power flow through transmission lines by compensation to minimise line losses and to maintain voltage levels.

— Load shedding as per agreed plan or instructions of load control centre.

— Synchronizing and system restoration.

The primary objectives of the various levels are :

— Load frequency control

— Voltage Control

— Economic load despatch

Large sub-stations perform assigned functions via their control rooms. The basic functions at sub-station level include :

— Maintain the voltage level of sub-station buses within specified limits by tap-changing and reactive power compensation.

— Frequency monitoring and load shedding.

— Network segregation (islanding) during system frequency drop and fluctuations.

— Synchronizing and system restoration.

The load shedding is generally performed at a smaller distribution sub-stations as per the automatic load shedding programme by means of co-ordinated frequency relays or in accordance with instructions from control room of large sub-stations feeding smaller sub-stations.

The 'architecture' of SCADA system at each of the above control centre/control room differs with reference to the required functional tasks.

50.4.2. Functions of SCADA systems

Supervisory control and data acquisition system (SCADA) are arranged to perform one or more of the following functions :

The following functions are common to all types of SCADA systems (type 1 to 4 Table 50.1).

1. Monitoring
2. Alarm
3. Control and Indication of Production Automatic Generation Control (AGC)
4. Data logging
5. Data acquisition
6. Control ON/OFF, RAISE/LOWER
7. Display

The following additional functions are provided with SCADA systems for National Load Control Centres :

— Interactive studies

— Security assessment calculations contingency

— Training simulator

— Network modelling

— Energy Management Systems (EMS)

50.4.3. Common features of all SCADA systems (Fig. 50.3)

The SCADA systems are arranged to perform the following tasks :

— Data Collection (Data Acquisition)

— Data Transmission (Telemetry)

— Scanning, Indication, Monitoring, Logging.

— Execution of operating, commands : ON/OFF, RAISE/LOWER

— Network supervision, alarms and report any uncommon change-of-state.

— Control and indication.

— Ensure sequential events.

— Data presentation, display, reporting.

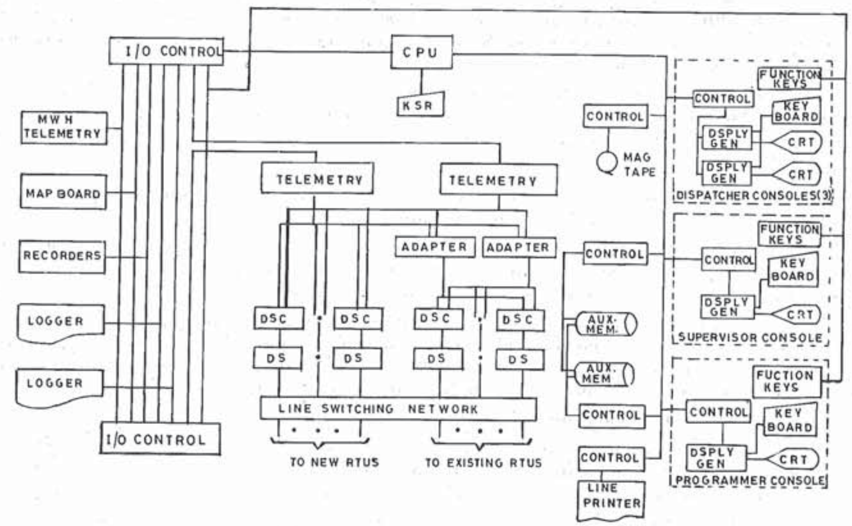

Fig. 50.3. Features of a SCADA system.

Refer Sec. 46.3 regarding SCADA functions. These have been further elaborated in the following paragraphs :

The Data. The data consists of electrical and mechanical variables, on/off states, analogue quantities, digital quantities, change of state, sequence of event, time of occurrence and several other data which the control room operator would like to know.

Data Collection (Acquisition). The data is acquired by means of a CTs VTs, transducers and other forms of collecting information. The process to be supervised has a very large number of electrical and mechanical and other data (information) transducers convert the data into electrical form to enable easy measurement and transmission. Data originates in the main process and is collected at the point of origin. Data may be collected at low level (5 mA) or high level (5 V). The data amplified in signal amplifier and conditioned in data signal conditioner.

Data Transmission. The data is transmitted from the process location to the control room, and from the control room to the control centre. (Refer Sec. 46.5).

Data Processing and Data Logging. The large number of electrical/mechanical/other data are scanned at required interval, recorded and displayed as per the requirements. Some of the data is converted from Analogue to Digital form by A/D convertors (Sec. 31.25).

The *Data Loggers* perform the following functions :

— Input scanning — Signal amplification
— A/D conversion — Recording
— Display — Programming

Fig. 46.2 gives a block-diagram of a programmable data logger.

The input scanner is generally a multiway device which selects input signals at regular periodic intervals in a sequence. (Table 46.3/4/5). The rate of change of input data (*e.g.* 20 seconds, 1 minute, 1 hour etc.). Slow varying quantities are scanned with a longer period of intervals of scanning, fast varying quantities are scanned at shorter intervals of time.

The scanning gives necessary data regarding values of various input variables. The decision regarding follow up actions (e.g. change in input) can be taken according to the program. Automatic control necessitates a series of scans and checks at regular intervals, scanning provides indication has to when appropriate follow action can be initiated.

Output of scanner is given to A/D convertor. Digital signals are given to microprocessor or digital computer. Logic operations are performed rapidly by on-line micro computer.

The electrical signals (A/D) are transmitted (telemetered) to a remote control pannel through control cables.

The analogue or digital signals are received in control room. These are processed for measurement, recording, display, control by the instrumentation system in the control room.

The operator in the control room needs information regarding parameters and network configuration. CRT display (cathode ray tube) provides the operator with these informations whenever he want (when he presses an appropriate button on control desk).

Remote Terminal Units (RTU). A typical modern supervisory control system has remote terminal units (RTUs). The function of RTU is to record and check signals, measured values and meter readings, before transmitting them to control station and in the opposite direction, to transmit commands, set point values and other signals to the switchgear and actuators.

The RTU is capable of following functions :

— Acquisition of information (measured values, signals, alarms, meter readings), including features such as plausibility checks and filtering.
— Output of commands/instructions (binary pulse-type or continuous commands, set points, control variables), including their monitoring (as a function of time, l out of n).
— Recognition of changes in signal input states, plus time data allocation for sequential recording of events by the master control station.
— Processing of information transmitted to and from the telecommunication equipment (data compression, coding and protection).
— Communication with master control stations.

Presentation (CRT Display). CRT is a short form for Cathode Ray Tube. CRT display is made available in the control room. CRT display provides the operator with the information about input

quantities whenever he wants. (When he presses appropriate push button on the control desk). CRT display is located in the control room of Generating Stations, Sub-stations, Control Centre.

Two types of display are available :

— Tabulated values of parameters, measured values and computed characteristics.
— Graphical display representing status of equipment in the form of mimic diagrams.

CRT display include the following :

1. **Alpha-numeric Displays.** These give direct reading of measured parameters. Name of the parameter and numerical value is displayed.

2. **Single Parameter Displays.** For certain parameter several measured numerical data are required in a tabular form. These are displayed.

3. **Mimic diagram display.** In this display, the single line diagram of the circuit with position of C.B's and isolator is displayed. The power flow is indicated.

4. **Displays with threshold blackout.** Threshold means on the border. In threshold blackout display the threshold values of quantity is displayed.

5. **Graphical displays.** This displays graph of quantities.

6. **Histogram displays.** Histogram refers to graphical representation of a distribution of quantity. The quantity can be illustrated vertical lines or horizontal lines representing the parameter values.

7. **Pictorial displays.** Pictorial displays can be used as small mimic diagrams. Line diagram of a plant indicating positions of equipment.

8. **Analogue displays.** These are useful to show continuously varying parameter.

9. **Alarm displays.** These are displayed on control board for attention of the operator.

The main criterion of CRT display system is the number of independent displays required for some simultaneous viewing.

Display selector switches are provided for following duties :

1. Display unit selection2. Clear tube

Common display requirements of sub-station control room, generating station, control room, control entire control room are markedly different.

Typical display in a *Generating Station Control* room includes :

— Tabulated values of various process parameters (Refer Table 46.3 and 46.4)
— Mimic diagram indicating the position of ON/OFF of circuit breakers, isolators, earthing switches and stations of operating units, tap position of tap-changers.

Typical display in sub-station control room includes :

— Tabulated values (*e.g.* Table 46.5)
— Electrical layout indicating ON/OFF condition of circuit breakers, tap position.

Typical display in Regional Control Centre, Control Room includes the following :

— Configuration of the system in the form of Mimic Diagram
— Alarm and logging
— State of system : Normal, Alert, Emergency
— Tabulated Data (Table 50.2)
— Transmission system status.

Table 50.2. Data in Regional Load Control Centre

System Data	*Unit*	*Input Interval and or Check Interval*
1. Generating station status	MW	15 min
2. Spinning reserves	MW	15 min
3. Tie line status	MW	30 min
4. Frequency	f	20 sec
Rate of change	df/dt	20 sec
5. Transmission system status		
— Voltages	kV	1 min
— Active Power	MW	1 min
— Reactive power	MVAr	1 min
6. Emergency condition Data		20 sec.

50.4.4. Alarm Functions (Ref. Sec. 46.4, 25.1)

The operator in control room receives on alarm in the form of Audio Visual indication. The alarm indicates dangerous condition calling for supervisors immediate attention and intervention, if necessary.

The alarms are arranged for electrical/mechanical/other parameters and are included in the configuration of Data Logger (Fig. 46.2 – Alarm and Annunciation Block in the output portion). The variables and scanned at regular intervals. When scanned value exceeds certain limit, and alarm is sounded.

50.4.5. Integration of Measurement Control and Protection Functions by SCADA Systems

With recent revolution in the static relays, microelectronics, microprocessor and digital computers, several functions of measurement instrumentation, data logging, supervision, monitoring alarm control, protection and automation are integrated with the help of SCADA systems. The total system becomes compact, economical and versatile.

Instrumentation deals with measurements, recording, display and infeed to control and protection systems, data acquisition, data transmission, data monitoring, data logging etc.

Control deals with sensing the controlled quantity, comparing with reference quantity to bring the controlled quantity with in targeted limits. In a open loop control system, the input influences output directly the output is not fed back to input.

Protection deals with protecting the system and its sub-systems from harmful effects of abnormal quantities, such as over-current, undervoltage, temperature rise, etc.

Monitoring means checking the performance by measuring at regular intervals.

Closed loop control systems have a provision of comparing output and changing the input to achieve the necessary corrections. Adaptive control systems are able to tune themselves to the changing environment.

On line control deals with real time (second to second) control of the system variables.

The above tasks are dealt by SCADA systems. The SCADA system supplements the control system and protection system to form an integrated system.

50.5. AUTOMATIC SUB-STATION CONTROL

The electrical energy is transferred from large generating stations to distant load centres via various sub-stations. In every sub-station certain supervision, control and protection functions are necessary. Every sub-station has a control room. The relay and protection panels and control panels are installed in the control room. The various circuit breakers, tap changers and other devices are controlled by corresponding control-relay panels. In a small independent sub-station, the super-

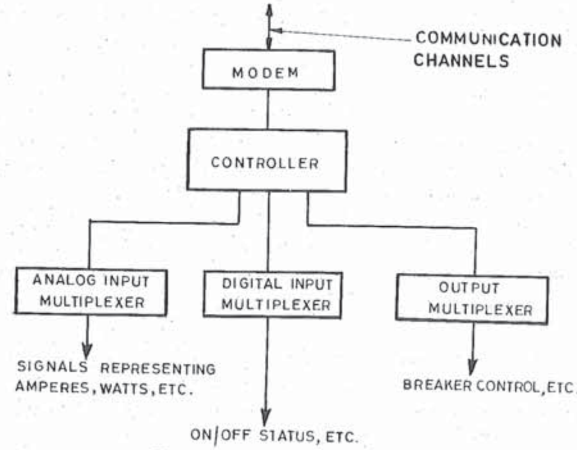

Fig. 50.4. SCADA system in sub-station.

vision and operation for normal service can be carried out by the operator with the aid of analogue and digital control systems in the plant. The breakers can be operated by remote control from the control room. During faults and abnormal conditions, the breakers are operated by protective relays automatically. Thus, the primary control in sub-station is of two categories.

1. Normal routine operation by operators command.
2. Automatic operation by action of protective relays and control systems.

Two Sub-systems in Sub-stations. The control equipment in a sub-station are to be treated as two sub-systems :

1. Control System 2. Protective System.

For many reasons, it is desirable to have two separate systems as above.

The relay protection system should acquire the data independently, process it, evaluate it and take action to perform protective tasks (tripping).

The different event are reported to the control system as well as protective system. Both the systems must, therefore, co-operate closely with one another.

In modern sub-station, these functions are realised with relays, static processing devices and micro-computers.

The tasks of protective systems include sensing abnormal condition, annunciation of abnormal condition alarm, automatic tripping, back-up protection, protective signalling etc.

The tasks of control systems in sub-station include data collection, scanning, event reporting and recording ; voltage control, power control, frequency control, other automatic and semi-automatic controls etc. The two systems work in close-co-operation.

Two Hierarchical Levels in a sub-station. The control equipment are generally arranged it two hierarchical levels. From the higher (sub-station) level, the entire sub-station is controlled and supervised. From the lower (unit) level, the lines, transformers etc. are controlled and supervised. The equipment on unit level is divided into a number of independent 'units'. This division improves the operating reliability and simplifies future extensions such as additional lines.

Inter-level Communication. Information is transferred between the two control levels primarily via a series bus, where the sub-station level computer controls the traffic by cyclic scanning the other units connected to the bus.

Sub-station level. The following main functions are arranged on sub-station level :

— Ordinary man-machine communication system of the sub-station.

— Remote control inter-face.
— Disconnector inter-locking
— Fault annunciation
— Automatic switching sequences
— Voltage control
— Disturbance reconditioning/recording
— Synchronising
— Busbar Protection (Relay Protection) System
— Automatic network restoration
— Load shedding/Load re-connection
— Compiling of energy and other reports
— Sequential events recording.

Most of these functions are integrated as softwares in the substation level computer. This software is of modular design, which facilitates addition of new functions.

The man-machine communication system of a sub-station consists of the following :

(*i*) Video Display Unit (VDU)
(*ii*) Functional key-board
(*iii*) Typewriter
(*iv*) Indication pannel.

These units replays the control board of conventional control system. The VDU is used to display indication and events that have occurred in the power system.

The function of key board is to enable the operator to operate high voltage apparatus and automation systems. The typewriter is used to present events as they occur.

Unit level. The entire sub-station is divided into certain 'units' (Similar to protective zones). Each unit includes one or two major equipment such as line, bus-bar section, transformer, etc.

The function relating to particular unit include the following :

— Line Protection, Breaker Failure Protection etc.
— Auto-reclosing
— Synchronising check
— Energy metering
— Acquisition and time tagging of events
— Acquisition of position indication and measured values
— Execution of commands from sub-station-level computer
— Back-up control.

Sub-station Control Functions arranged through SCADA systems. These include the following :

1. **Alarm Functions**

To sound alarm/annunciation regarding dangerous, uncommon events such as abnormal values of process parameters, fire, illegal entry in premises, over temperatures, low voltage of auxiliary supply, unusual happening etc. Alarms are obtained from data logger and are for alerting the operator in the control room.

2. **Control and Indication**

2.1. Control of two position devices such as circuit-breakers, isolators, earthing-switches, starters.
Indication of ON/OFF state of the devices on control board/mimic diagrams.

2.2. Control of position of devices having positions (closed, middle open) *e.g.* values, input settings, indication of position on control panels.

2.3. Control positions of multi-position device *e.g.* tap changer, indication of position on control panels.

2.4. Indication without control.

2.5. Control without indication : *e.g.* raise or lower control of generator load by automatic load frequency control.

2.6. Set-point control to provide set point to a controller located at remote sub-station.

3. Data collection, recording, display.

4. Sequential operation of devices with predetermined time and conditions for operation of various devices *e.g.*

1. Auto-reclosing of circuit-breakers operation O-CO-Time-CO
2. Operation of circuit-breaker, isolator and earthing switch in a particular sequence during opening of circuit and another sequence during closing of circuit.

By means of SCADA system, the operator in control centre can cause operations in a remote sub-station. The possible remote operations include :

— Opening and closing of switching devices
— Tap-changing of transformers (voltage control)
— Switching of capacitor banks (voltage control)
— Load shedding (load frequency control)

Some of the remote operations are made automatic by one-line computer based system without human intervention *e.g.* Net work islanding, Backup protection. The automatic control function are segregated into :

1. Interconnection functions
2. Transmission line automatic function (Table 50.3)
3. Distribution system automatic functions (Table 50.4).

Table 50.3

Automatic Function in Transmission Sub-station with SCADA System	
Protective Functions	
— Sequential events — Auto-reclosing — Bus protection — Fault distance reporting — Backup protection	— Line protection — Transformer protection — Reactor protection — Synchronising checks
Control and Monitoring Functions	
— Voltage control VAr flow control — Automatic bus sectionalising — Synchronising checks — Sub-stations transformer load monitoring — Data collection, monitoring alarm, display, logging.	— Load frequency control, load shedding, islanding — Sequential events — Monitoring — Power flow monitoring

Table 50.4

Automatic Function in Distribution Sub-station with SCADA Systems	
Protective Functions	
— Underfrequency protection — Conductor fail protection — Transformer protection — Bus bar protection	— Earthfault protection — Feeder protection and autoreclosing — Breaker failure protection — Backup protection
Control and Monitoring Functions	
— Feeder Sectionalizing — Voltage control, VAV control	— Feeder deployment switching — Data collection, monitoring status, loading, display.

50.6. SCADA CONFIGURATIONS

Fig. 50.5 (*a*) represents the simplest SCADA configuration employing a single computer.

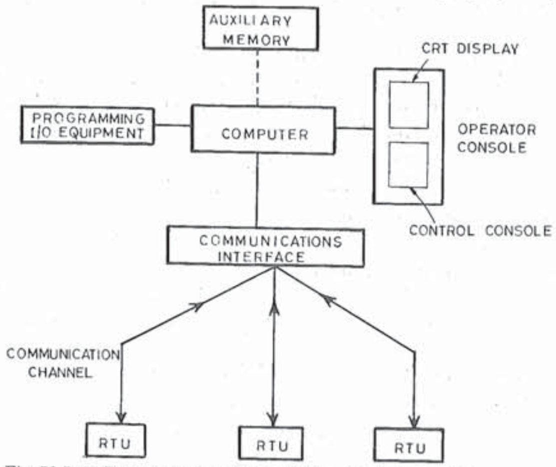

Fig. 50.5. (*a*) Remote Terminal Units RTU and interfaces with computer. Simple SCADA system with single computer.

Computer receives data from RTUs via the communication interface.

Operators control base one or more CRT terminals for display. With this terminal it is possible to execute supervisory control commands and request the display of data in alpha numerical formats arranged by geographical location and/of type.

The programming input/output is used for modifying the supervisory software. In the basic SCADA system, all the programmes and the data is stored in the main memory. The more sophisticated version of SCADA has additional auxiliary memories in the form of magnetic disc units.

Redundant SCADA System. For more important applications, to satisfy the reliability criteria the SCADA systems may have built in redundancy. Main computer, auxiliary memory, communication interface may be duplicated. In the event of a failure of one of the elements, the SCADA function is carried out by its duplicate elements.

The system is designed to continuously monitor its own operation. In the event of malfunctioning, the change-over to the duplicate system automatically.

Fig. 50.5(*b*) illustrates a more sophisticated system which has two computers one failures can be sustained without interruptions.

50.7. ENERGY MANAGEMENT SYSTEMS (EMS)

The Energy Management System (EMS) for a large inter-connected system have following hierarchical levels :

1. System control centre
2. Area control centre
3. Remote Terminal Units (RTU's)

Many energy management systems are similar to the structure shown in Fig. 50.2 (*a*) in which

— System control centre controls and co-ordinates a transmission system. The generated power is injected into the transmission system and the centre is also a charge of generation control and co-ordination.

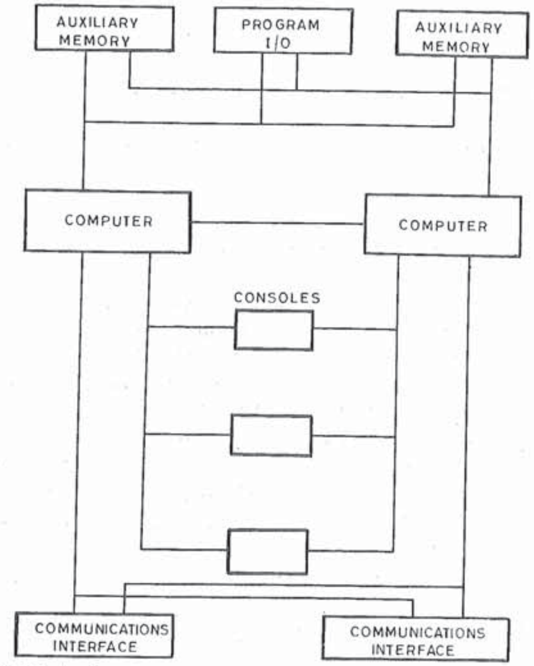

Fig. 50.5. (*b*) Redundant (Duplicate) Computer system, sophisticated SCADA system.

— Area control centres monitor and the transmission equipment and the supply points to the distribution systems in their areas. These centres are also responsible for performing the controls that area issued by the system control centre. If necessary these centres may issue controls directly.

— Remote terminal units which primarily acts as the data acquisition units for telemetry and provide the means of executing the instructions received from the control centres.

In such an arrangement, the typical objectives of the *system control centre* include :

— Building and maintaining a model of the steady state situations of the power system. This model will be used for control, optimization and operational planning.

— Providing means of reacting to power system events in an optimum and secure manner so that the system frequency and interchange are maintained at specified values.

— Providing means of maintaining voltage levels with optimum allocation of reactive power in systems with a centralized voltage control policy.

— Examining the effect of possible power system faults on the current operating state of the system in real time. Monitoring the produced fault levels and checking for availability of adequate circuit beaker capacity. Monitoring the post fault situation and checking for any violations in the system steady state.

— Supporting the operator by providing him with (*a*) The tools to extract the most critical information about the operating state of the system. (*b*) The tools to examine the effects of his commands in an accurate and fast way before actually issuing them. (*c*) The analytical tools to calculate the optimum states and schedules under a given situation.

Tools for integration

The job of managing and integrating an Energy Management (EM) system is large and complex. Fig. 50.3 illustrates the software functions of EMS.

To achieve it within reasonable time scales and budget require a good software support tools. Essential tools are :

— Database management
— Display compiler
— Source of control
— Database query programme
— Task manager

While these tools should be adequate for the system development and integration needs, they should not compromise the requirements of the on-line operation of the system control centre.

Database Systems

An EM system has three major sources of data; telemetered data, network parameters and generation parameters. This data is organized and managed by a common database system which has many of the features of structured and relational database.

The facilities of the database system are used as tools for defining as well as accessing the data structures required by SCADA, generation and network applications.

The structure and discipline imposed by the database system allows various tools to be developed to manage this data, one of the most important being a display compiler.

The features that have aided development and integration phases are :

— Ease of scheme modification to cater for specific contract requirements.
— Ease of re-dimensioning.
— Capability to dump and re-load into a newer version where the scheme has been modified.
— The capability of the database to provide means of grouping together the data which have the same characteristics, (*e.g.* same purpose of use, same life time).

Integration

The system database is divided into the major areas of the SCADA database, the network database and the generation data base. These database are built using the facilities of the database manager and the database compilers which are specific to individual application areas.

The defined databases each form a logical independent description, from which any application may draw the required data. For example the network database describes the power network and supports all the network applications. The correspondence between the different databases is built in an off-line mode but updated in real time, if necessary.

In the energy management task organization of Fig. 50.6 each solid box is a task. Each broken box includes a set of tasks that operate on the same database and is referred to as an application.

The applications normally divide into the two areas of real time and study. The real time set runs automatically on a cyclic basis or on a power system event.

A typical network sequence is ; topology processing, state estimation and contingency analysis. Some systems also include short circuit analysis. The generation applications form a second on-line sequence of tasks.

Fig. 50.6 shows the data communications between the applications. Inter-application communication falls into three groups.

— From real time to study applications or between study applications.
— Between real time applications in the same analysis sequence (*e.g.* estimator to short circuit analysis).
— Between real time applications with different database structure (*e.g.* SCADA to estimator).

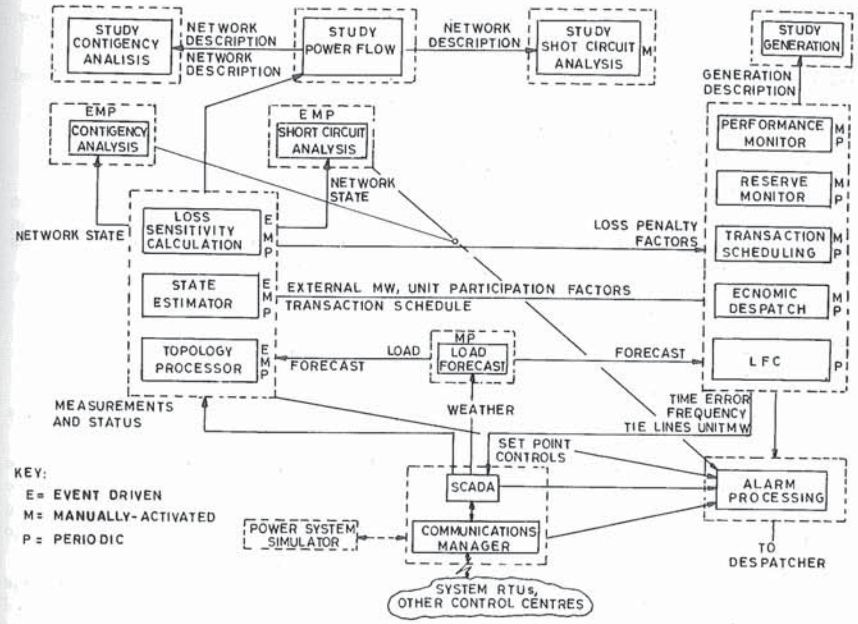

Fig. 50.6. Software in energy management system (EMS).

The facilities of the database and task management system are used interfacing the EM applications. These interfaces are capable of

— Transferring the data to the receiving application in time, without causing any deadlocks.
— Transferring enough information so that the receiving application can carry out its analysis.
— Supporting an inter-machine application interface.

50.8. SYSTEM OPERATING STATES

For the purpose of analysis and for achieving appropriate on line control actions, the operating states of power system are classified into the following categories (Fig. 50.7).

— Normal state (Secure State)
— Emergency state
— Restoration state.
— Alert state (Insecure state)
— In Extremis state (Islanding)

50.8.1. Normal State (Secure State)

The power system is in the normal (secure) state when frequency, currents voltages are of normal value and no likely contingency would cause on emergency condition to exist.

50.8.2. Alert State (Insecure State)

The power system is in the alert (Insecure) state when one or more like contingencies would cause an emergency condition. The border line between the Normal and Alert States depends upon what contingencies are considered likely. Generally all single contingencies are used as a basis for security analysis and a condition for Alert State.

Outage of a large unit; outage of a transmission path etc. are examples of single contingencies.

50.8.3. Emergency State

The power system is in the emergency state when critical operating constraints being violated and thereby the integrity of the system is adversely effected.

Examples of such critical operating constraints include :

— Thermal loading limits of transmission lines, transformers
— Line loading based on transient stability limit or voltage collapse limit
— Voltage limits of sub-station buses.

In emergency state the above constraints are being violated but the integrity of the system is still continuing and the system is supplying power to the consumers.

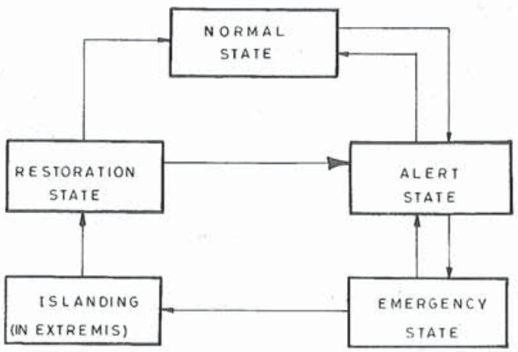

Fig. 50.7. Transition of operating states in a power system.

50.8.4. Islanding (In Extermis) State

This is an emergency state in which the system integrity is lost either by load shedding or by network islanding. In islanding condition, the inbalance between generating and load exists within each island resulting in frequency excursions, further load scheduling and tripping of generators. Thus islanding state is associated with black-out of some portion of the interconnected system.

50.8.5. Restoration State

By bringing the Islanding state under control, the system is brought in Restoration State. The generating units are restarted, the loads are reconnected, the interconnection are established.

Overall operation for reliability means to operate the system is Normal State. This means to generate enough power to meet area load and area net interchange demand, no overloading or machines/apparatus/lines, and the effect of contingencies are minimum. If the power system departs from the above conditions for any reason, the attempts should be to restore the above conditions in minimum time.

50.9. SYSTEM SECURITY (Refer Ch. 55)

Power system security may be defined as ability of the power system to operate in the normal state even with occurrence of specified contingencies. The system shall remain in normal state by means of fast acting automatic control systems following a contingency without allowing the system to pass to emergency state.

For steady state security analysis the following contingencies are generally considered :

1. Loss of one generating unit
2. Sudden tripping of a large load
3. Sudden change of tie-line power flow
4. Sudden outage of a major transmission line
5. Outage of one large transformer
6. Outage of one shunt reactor or one shunt capacitor bank.

50.9.1. Security Control (Refer Ch. 55)

The system state is continuously monitored by means of one line computer system. The data acquisition is through SCADA system. Fast computations of the security status are made. Command signals are sent to remote terminals regarding corrective actions to be taken.

Continuous monitoring of security and appropriate corrective actions for improving security is called security control.

System security function is generally broken down into following three major functions :

1. System monitoring 2. Contingency analysis 3. Corrective action analysis

System monitoring provides up-to-data information about conditions in the power system.

State Estimation based on system monitoring data produces best estimate of latest power system condition (state).

Contingency Analysis allows the system to be operated defensively. Many of the problems which occur in the power system can cause serious trouble within a very short time that the operator could not take any fast action. Therefore, modern computers are equipped with contingency analysis programmes, which model the power system and are used to study outage events and alert the operators of potential overloads or over voltages.

The third major function of the security is *Corrective Actions.* It allows the operator to take appropriate corrective action in the event of a contingency such as certain outage or certain overload. A simple form of corrective action involves shifting generation from one station to another station. Such a shift causes flow to change and this can bring about change in the loading overloaded lines.

Modern power systems have evolved the following guide lines :

— To operate the power system such that the power is delivered reliability.
— Within constraints of reliability, the system shall be operated economically.

50.10. STATE ESTIMATION

The state estimation is the process of estimating the 'state' of the power system.

It is based on statistical approach. The process involves acquiring data about system variables based on imperfect measurements and estimating the system state based on statistical criteria.

In a power system, the state variables are ; the voltage magnitudes and relative phase angles of system nodes. Measurements are required in order to estimate the power system performance and real time for the following :

— System security control — Constraints on economic despatch.

The inputs to an estimator are selected. These include imperfect power system measurements of the following for the various modes :

— Voltage — Power flow
— VAR flow

The estimator is designed to produce the best estimate of the system voltages and phase angles with understanding that there are errors in measured quantities and there is redundant data.

The output data of state estimates is used by system control centres for implementing :

— System security control — Constraints on economic load despatch.

50.11. EXPERT SYSTEMS USING ARTIFICIAL INTELLIGENCE FOR POWER SYSTEM OPERATION

Consider an emergency situation in a *large interconnected power system* during a cascade tripping of breakers accompanied by a large scale black-out. The load despatcher starts getting several alarms, the indications, print-outs etc. from the control panel does not know what to do. He finds himself in a helpless situation. In such situations digital computer aided artificial intelligence systems called 'expert systems' come to his rescue. The expert system tells him within seconds the probable location of the line fault and suggests steps to be taken for restoring the system.

Consider a complex thermal plant having many units and auxiliaries, several parameters are being scanned periodically. Some are within safe limits and some trouble is likely to develop. What are the actions to be taken in advance to overcome the trouble and to avoid tripping of a unit? An Expert System can give the possible solutions quickly and suggests actions which may be taken. Such *Expert Systems* are now beginning to emerge as practical tool for helping the operation and maintenance personnel to deal with increasingly complex power systems. The Expert Systems enable to acquire and preserve the knowledge of its best experts and keeps it always readily available. By encoding critical domains of human expertise for computer manipulation, an expert system can quickly sort through enormous amount of data to provide a system despatch/power plant operator/maintenance engineer/testing engineer with provisional diagnosis of problems and printout a list of possible corrective actions to be taken.

Expert Systems are not designed to calculate exact solutions to specific mathematical problem or technical problem, in the manner of conventional computer programs. The Expert Systems imitate human logic by applying a series of 'If-then' rules based on past experience.

50.11.1. What is an Expert System?

Expert Systems (like robotics, spoken language interpretation, visual object recognition) is a major branch of Artificial Intelligence (AI), a branch of computer science that enable the machines to perform like human beings in limited ways.

50.11.2. Components of Expert System

Each Expert System has three essential components :

1. **Knowledge Base.** This contains specific *facts* about application and the rules that apply under various situations.
2. **Interface Engine.** This controls the problem of solving by selecting and *executing the rules* and determining when the solution has been found.
3. **User Interface.** This provides a convenient format for entering additional data and for describing possible *solutions* or *scenarios.*

50.11.3. Example of an Expert System's Working

Suppose the on line data coming from a turbo-generator unit shows the temperature of a critical component to be 320°C. The *knowledge base* contains the information indicating that the safe temperature is 280°C. One rule coded in the *Interface engine* might be. "If the temperature exceeds 300°C then sound an alarm". After executing this rule, the *user interface* might provide a message saying "70% probability that hydrogen cooler is blocked. Suggest check the hydrogen cooler before shutting down the unit". The operator gets this message on control panel VDU and takes necessary corrective action.

The expert system have different approach than conventional computer programme solution in following respects.

1. Expert Systems use Artificial Intelligence (AI) language which makes it easier to encode "If—, them—" rules.

2. The programming time of AI language is lesser.
3. New rules and facts can be incorporated without the need of complete reprogramming.
4. The problem solving by Expert System is mainly probabilistic and intutive approach. The vast experience of experts, research studies, earlier case histories, probability theory etc. is used effectively.

In the above example the expert system has told the operator on the basis of past experience that blocked hydrogen cooler is the most likely cause of the abnormal temperature rise in the generator. Conventional computer would do several lengthy and irrelevant calculations to solve such a problem.

The importance of Expert Systems comes from their ability to imitate human reasoning process in specific ways, providing answers to problems that may be less precise than those calculated by conventional computer programs but which are more relevant and easy to understand. The search of solution is based on 'thumb rules' which can be updated with further experience.

Structurally, the process permits separation of rules, data, system control, user interface into different modules as shown in Fig. 50.8.

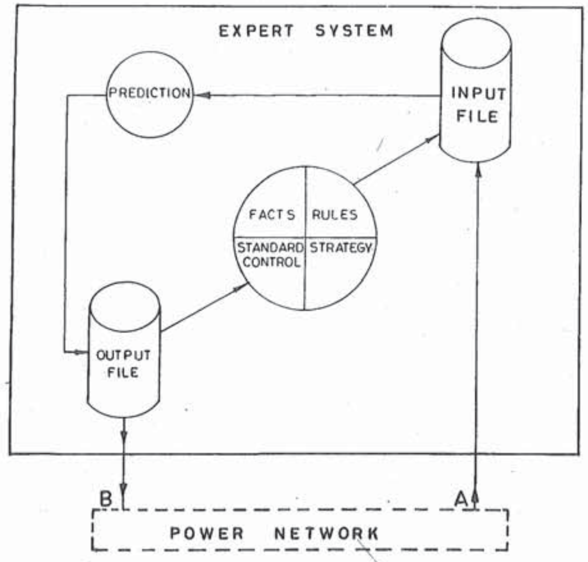

Fig. 50.8. Principle of Expert System applied for Network Restoration. [Customer Restoration and Fault Testing (CRAFT)].

50.11.4. Applications in Power Systems

Expert Systems have opened new era in power systems by integrating the following :

— Protection — Controls

— Diagnostics — Computers

— Accumulated human knowledge, etc.

Commercial applications of AI based on-line or off-line Expert System are being introduced by Electrical Power Research Institute (EPRI), USA.

Westinghouse, USA and other Electrical Manufacturing/Research/Power Supply companies in several areas of power systems. Following Expert Systems are now commercially available (1989).

1. **Generator Expert Monitoring System (GEMS).** It is a diagnostic tool for improving the generator's operation, reliability and availability on the basis of available monitoring information. GEMS can be installed with any generator unit by means of installation advisor module.

2. **Customer Restoration and Fault Testing (CRAFT).** CRAFT identifies and isolates faulted section in multi-tapped transmission lines. It is an effective means available at the Load Control Centre of a large interconnected AC system.

3. **On-line Diagnostic System for Emergency Diesel Generators.** It is a microcomputer based system to help the plant engineer in identifying operating trends and problem areas before complete failure of emergency power supply system.

4. **Plant Systems Inspection (PSI).** It is an expert system for maintenance engineer for inspection of the plant. The PSI inspects the plant periodically and performs predictive and preventive maintenance.

5. **On-line Monitoring System (OMS).** Such a systems collects and interprets data and advises operator about possible failures and advises corrective actions.

Many more Expert Systems are under development. Expert Systems are becoming an essential complement to switchgear protection, control, maintenance, testing, trouble-shooting etc.

In traditional protective systems the protection is not actuated until the abnormal condition (such as a fault) develops. The conventional protective system does not prevent a fault. Conventional protective system does not assist the operator in finding solution regarding actions to be taken. These limitations are overcome by the Expert Systems.

50.12. CENTRALISED DIAGNOSTIC EXPERT SYSTEM USING ARTIFICIAL INTELLIGENCE

Courtesy : Westinghouse, USA.

As the data can be transmitted from the plant to its control room, the data from several control rooms can be transmitted to the Central Master Controller. Thereby several plants can be watched from the Central Control. One example of such a system is described here.

Westinghouse, USA has installed (1988) On-line Expert System in Centralized Turbine-Generator Monitoring located in the load control centre at Orlando, Florida USA. The remote power plants are being monitored from the centralized system.

Commercial application of artificial intelligence (AI)-based, on-line diagnostics puts the combined diagnostic knowledge of turbine/generator experts in the hands of utility personnel so they can have a better continuous understanding of the health of their equipment.

From a central diagnostic centre, it is possible to monitor any power plant in the on-line, around the clock-and diagnose turbine generator conditions as they develop. The centralized diagnostic centre is connected to power plant data centres through telephone lines and packet switching network to transmit digital data.

The data centres receive data signals from hundreds of sensors located on the turbine/generator being diagnosed. This data is stored in the data centre's computer, then transmitted to the diagnostic centre. There, the data is analysed, and the resulting diagnosis is sent to power plant and displayed for use of operating personnel.

This is one of the few practical commercial applications of artificial intelligence. In particular, this is an application on the one branch of AI called Expert Systems.

Process diagnosis system. The process diagnosis system (PDS) is an Artificial Intelligence tool. It can be used for the *on-line* diagnosis of a wide variety of complex equipment, not just turbine generators.

PDS is a forward-chaining, rule-based system. It is an "empty" expert system ; that is, it defines a generic set of concept such as *sensors, rules and hypotheses for representing expert knowledge.* The knowledge engineer uses these concepts to create a rule base which contains the expert knowledge for diagnosing a specific process.

Once a rule base is defined, the PDS *inference-engine software* will use the rule base and the sensor inputs to compute the actual *diagnosis.* The representatives and propagation of belief are similar to that found in MYCIN, a medical expert diagnostic system.

For each rule, there are schemata describing each constituent part of the rule's antecendent (or evidence) a schema describing the rule's consequent (or hypothesis), and a schema describing relationship between the rule's evidence and hypothesis.

In most applications, it is just as important for the expert system to question the "truthfulness" of the data it receives as it is to perform a diagnosis on the equipment itself.

The correct diagnosis of any equipment condition requires knowledge of the condition and accuracy of the sensors themselves. If a sensor is known to be completely failed (*e.g.* an open circuit thermocouple), its reading should be ignored. Or a sensor may be slowly deteriorating so that its reading is still useful, but to a reduced extent (*e.g.*, a drifting sodium monitor).

PDS provides a method for handling both situations. The knowledge engineer can write rules which will determine a sensor's present condition. These rules can be based on redundant sensing, physical or logical tests, or on expert knowledge of the behaviour of a failed or failing sensor.

These are called sensor diagnosis rules and are executed before the set of rules perform the actual equipment diagnosis.

Another special class of rules exists, called *Parameter alternation rules*, that will dynamically alter the equipment diagnosis rules according to the results of the sensor diagnosis.

System Configuration of On-line Diagnostic System

Fig. 50.9 shows the system configuration. It comprises of :

1. **Diagnostic Centre.** The expert system computer is located at the *diagnostic centre* and not at individual power plant sites. The centralized approach allows the expert system to improve its knowledge based on experience gained from all power plants using the system.

The diagnostic centre consists of three functional areas :

Two artificial intelligence laboratories are used to facilitate the transfer of knowledge from experts to the knowledge engineer who is putting the knowledge into the computer.

The system takes advantage of the synergy of using multiple experts to create the knowledge base. The knowledge is put into the computer and then the experts are called back to verify that the diagnosis is in agreement with their judgement and experience.

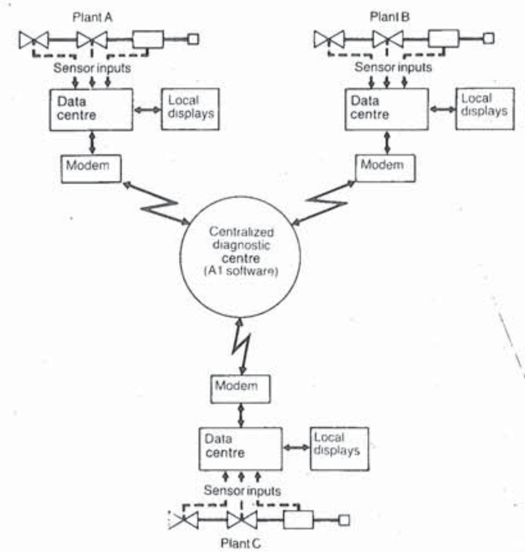

Fig. 50.9. Configuration of On-line Diagnostic System (*Courtesy* : Westinghouse, USA).

The knowledge to allow the computer to supply confidence factor values is obtained from the experts in the form of necessity and sufficiency functions. Thus if the human experts who provided the knowledge were given the same data as the computer, they should diagnose the same conditions with approximately the same confidence factors.

The rules can be tested using internal functions that allow the manual entry of sensor values and the setting of specific contexts in lieu of actual data. An edit function allows the study of the effects of small modifications in sensor values on the *propagation-of-belief* process.

2. **Monitors and data centres.** At the user end of the system are the monitors and data centre located within the power plant. Monitors contain the primary means of variable measurement. Typical monitors are the generator condition monitor for detection of particulation from overhead coils, radio frequency monitor for identifying arcing, and the fibre optics generator end turn vibration monitor. The fibre optics vibration monitor is interesting because of its ability to measure the magnitude of vibration of the end turns of the stator winding in the presence of high magnetic and electrostatic fields. High amplitude vibration is indicative of future problems with the stator winding and its detection allows operational changes which can extend the life of the windings.

50.13. SCADA SYSTEMS FOR POWER SYSTEM

The basic job of a SCADA (Supervisory Control And Data Acquisition) system is to supervise the working of various processes and to provide to the operator, the requisite information & the facility and means to control the working of the system and the outputs of the process.

Hardware. There is a main server computer (often with an identical twin, to provide redundancy), which runs the basic software of the SCADA system. There may be other associated servers to undertake specific functions. The main job of this system is to acquire the process data, and present it to the operator in suitable formats to enable him to take decisions as well as recognize any maloperations. The operator works via the HMI (Human Machine Interface). There is at least one HMI acting as a client to the server. For every small application, the HMI may be operative on the main-server.

While it is usual in a hydro power station to interface the PLC system to the SCADA system for data acquisition purposes, in some other application, this work may be entrusted to a Remote Terminal Unit (RTU) system. A block diagram of the digital control system for a hydro power plant is given in Fig. 50.10.

Software. The software enables reading in of the process information. Thereafter, the information is stored, transformed and displayed for supervision by the operator. In case the operator so decides, his instruction is forwarded to the process for execution. The resultant changes in the process are again displayed to the operator so that he may check out the effects of his command.

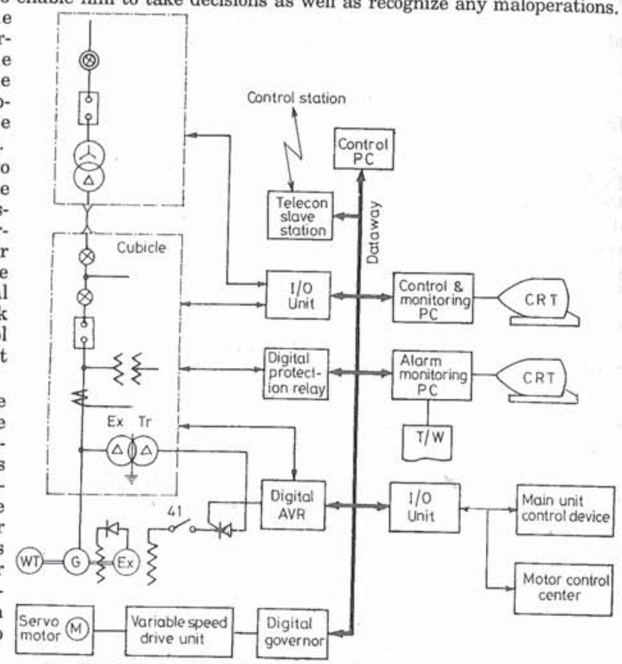

Fig. 50.10. Typical Block diagram of the digital control SCADA system for a Hydro Power Plant.

There are many sub-functional modules in the software. Each module has a specific function. The following are the common functions of the software :

— Analog value processing
Converting the binary coded value into a standard value

— Binary value processing
Getting the status of the represented element, checking its plausibility.

— Counted value processing
Converting the counts into numeric value of (energy).

— 1-of-n value processing
Locating which option has been selected.

— Time stamp processing
Converting time to normal representation, storing the variable as per the given time.

— Data base operations
Storing information in a suitable detabase and retrieving the correct information on query.

— Events logging
Keeping and retrieving the events in the given chronological order, printing them on the logging device.

— Alarms logging and acknowledgement
Similar to events. But the operator acknowledgement has to be applied on the stored alarms.

— Station diagrams
Display Single Line Diagrams of individual locations with all the relevant data filled in.

— Reports display
Create the desired report using the correct template and the right variables, for display on the screen.

— Reports printing
Same as above, however, the output is added to the print queue.

— Events/alarms based actions (reports, storage of information)
On occurrence of the defined event/alarm, initiate the predefined action.

— Trends/bar charts
Take the initial data from the database and create the desired graph. Update it on receiving fresh information.

— Limits processing
The analog values and the counted values may be subject checking for limits. The limits are operator defined. Crossing of limits leads to alarm.

— 'Rate of change' processing
Here the limit is set on the first derivative of the value.

— Status evaluation
Checking the current status of any variable. The processing of the variable could change depending on its current status. e.g. if a value is not being received from the process, there is no point in checking the value for limits.

— Plausibility check
Any value, when received, is checked for being what it represents. Wrong or invalid entries are to be discarded.

— Command outputs
Check the validity of the command for authorization, background status, correct state, etc.

— Manual inputs

If the operator doubts the current value of the variable, he may decide to replace it with his estimate.

— Valid/invalid check

Any value declared invalid shall not be used for further functions.

— System configuration

All system modules (Hardware & Software) are monitored for proper functioning. Any significant deviation leads to a change in the system to enable uninterrupted but correct operation.

— Hot-standby function (Dual servers)

Duplication of hardware is done to increase system availability. Duplication also enables a fully functional identical server, which shadows the main server and, hence can ensure continuation without interruption, in case of a switchover. It is also useful in case of any significant changes in the system, which are tested on the standby system first.

— Switch-over

The various supervisory functions within the SCADA system at Hardware and Software level will signal a switchover to the back up or standby system, in case any serious fault or error is observed.

— Archive

A very important part of the SCADA system is its storage of process related data. As an extension there to it stores data pertaining to some past time-points as well. This enables a proper comparison of any status or value. It also permits trending of data for later analysis. The same data can also be used by other systems, such as, the Higher-level functions.

— Database access for other programs

This is the gateway to enable other interested systems to use the stored data for their specific function. The same gateway may be used to transfer the data to any other site.

The software has many built-in functions to check the validity of the data received. This prevents misinterpretation of data.

HMI (Human Machine Interface)

There may be one or more HMI logically connected to the main server. The operator gets the process data as visualization on the screen of the HMI. The functionality of the HMI is capable of drawing operator's attention towards any mishap in the system. The operator issues his command over the HMI and the system, in turn, informs him of the validity of his action and later, the result of his action.

Together, the HMI's and the servers constantly keep check on the health of the SCADA system. If any error is detected, the whole system reconfigures itself in the most logical way, to continue operation.

Video screens are provide to display an overview of the process i.e., the Network diagram or combined SLDs. Typically the screen has space to display an interconnecting diagram of all the important stations along with space for additional information, e.g., alarms. Such a screen is a big help for the operator. A change would be depicted by switching on or by blinking of the corresponding lamp. The operator's attention is drawn to this change and he may now check up details on the monitor of the HMI.

A video screen device is very similar to a video projector. Technically, it is similar in working to a monitor of a computer (HMI). Hence, the symbols and other graphics look the same as any other diagram on the HMI screen. Any graphic constructed for display on normal monitor can also be displayed on the Board. With the use of 'windows', we can project many pages on the Board at the same time. Hence the looks and feel of the Board is very similar to the computer monitor, making it simple to configure and operate. To construct a large board, we can combine a number of devices vertically and horizontally. In this case, a special electronic unit is required, which splits

the original diagram in to a number of part diagrams, each of which is displayed on to the corresponding unit. So the combined face of the units reproduces the original diagram. Making a change is as simple as editing the diagram and using the changed diagram thereafter. No hardware change in required.

Add-on functions

Since the SCADA system stores a whole lot of process information, the same is available to carry out other useful functions. The more important among these are :

— Load-Frequency Control — Generation Scheduling
— Load Forecasting — Machine Parking
— Condition Monitoring based maintenance scheduling
— Asset Management — Spinning Reserve
— Multi Tariff Billing — Power System Modelling
— Water Inflow Prediction — ABT Reporting

Expert Systems incorporating Artificial Intelligence are being introduced to assist the control room operator/plant engineer/testing engineer/maintenance engineer, etc. An Expert System incorporates computer programs based on AI-language and 'If..then..' rules. Expert System provides quick possible clues regarding problem and likely solution.