TECHNICAL AND FINANCIAL EVALUATION OF AUTOMATION OF SHP STATIONS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ALTERNATE HYDRO ENERGY SYSTEMS

By

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Candidate's Declaration

I hereby certify that the work which is being presented in this dissertation, entitled, "**TECHNICAL AND FINANCIAL EVALUATION OF AUTOMATION OF SHP STATIONS** ", in partial fulfillment of the requirement for the award of the degree of **Masters of Technology** in "**Alternate Hydro Energy Systems**", submitted in Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from July 2009 to June 2010 under the supervision of **Dr. Vinod Kumar**, Head, Electrical Engineering Department, Indian Institute of Technology, Roorkee, India and **Dr. Arun Kumar**, Head, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, India.

I have not submitted the matter embodied in this dissertation for award of any other degree.

Dated: June 29, 2010

Place: Roorkee

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Certificate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Abstract

Since the time electricity generation from water has started, plant operators and supervisors have been involved in operation, controlling, monitoring and data acquisition tasks manually. Later, relay logic control systems came into application which assisted the operators in start/ stop sequences of power plant yet monitoring and data acquisition tasks were done manually. During all these years, the accuracy of data acquisition and post-fault-decision was dependent on the experience and judgment of the operators and supervisors.

Computer-based control and data acquisition systems have brought a revolution in every sphere of work and play a key role in hydro power plant operation also. The automation system design and implementation is being done in India for large hydro plants at a wide scale in recent times. But for small hydro power plants, automation system is yet to gain popularity. The main aim of this study is to find reasons attributing to slow adaptation of the automation in Indian small hydro power sector and to report the present status of the automation in small hydro sector.

The present study covers all areas of automation, advantages of its adaptation in terms of higher revenues, longer life of equipment, lesser human interface (interference) and efficiency of the plants. Economic analysis has also been carried out with respect to capital cost, operation and maintenance cost of automation vis-à-vis increased returns. Through consultation with equipment manufacturers and hydro plant personnel, it was found that the problem with the slow adaptation of automation in small hydro power plants is due to mindset of people. Sensitization of end users and consultants need to be done along with training of the operating personnel. Another reason of low adaptability is the installation of non-reliable field instruments becoming bad examples. The full potential of the automation system is not being realized. The cost of implementation of automation system in a small hydro plant is also studied which is about 1- 2% of the total cost.

With the field survey of power plant personnel, it was found that small power plants in South India are more satisfied with the automation system especially on run-of-river plants. Plants on canal falls are less successful especially in North. The operators are less satisfied than managers and engineers. Analyses of the data from the several power plants show that the use of manual system leads to numerous losses which can be reduced by the use of automation.

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Abbreviations

AHEC	Alternate Hydro Energy Centre
CEA	Central Electricity Authority
CRT	Cathode Ray Tube
Cumecs	Cubic meters
DACS	Data Acquisition and Control System
ELC	Electronic Load Controller
E&M	Electromechanical
EWS	Engineer's Work Station
GPS	Global Positioning System
H	Head
HMI	Human Machine Interface (equivalent to MMI)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIT R	Indian Institute of Technology, Roorkee
INR	Indian National Rupees
ISO	International Standards Organization
KPTCL	Karnataka Power Transmission Corporation Limited
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
MHP	Mini Hydro Plant
MMI	Man Machine Interface (equivalent to HMI)

MNRE	Ministry of New and Renewable Energy
MW	Megawatt
O&M	Operation and Maintenance
OSI	Open Systems Interconnection
OWS	Operator's Work Station
PC	Personal Computer
PCB	Printed Circuit Board
PEDA	Punjab Energy Development Agency
PLC	Programmable Logic Controller
PLF	Plant Load Factor
RD	Reduced Distance
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SHP	Small Hydro Plant
UI	User Interface

Nomenclature

E	Energy (kWh)
H	Head (m)
P	Power (kW)
Q	Discharge (cumecs)
η	Efficiency

Chapter 1- Introduction

1.1 General

Energy is one of the key factors that influence the development of a nation by providing economic and social benefits to its people. The different sources of energy are hydro, thermal, nuclear and nonconventional energy resources like wind, solar and biomass. Need of energy is more important in developing countries like India, for economic development. Presently in India the total installed capacity of all the resources is 1, 59,648.49 MW (as on April 30, 2010), of this thermal is 64.6%, hydro 24.7%, nuclear 2.9% and renewable 7.7% [86].

Water resource in India is one of the major energy resources and in fact is a gift of the nature. This is formed by the snowcapped mountains, glaciers and regular monsoons. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation.

Among the different sources of energy, hydropower is recognized as a renewable source of energy, which is economical, non-polluting and environment friendly. The Government of India has announced, in August, 1998, Policy on Hydropower Development. India is blessed with immense amount of hydroelectric potential and only 26% of the hydro potential has been harnessed till now [86].

The conventional large hydropower plants have problems like long gestation period, ecological changes, loss due to long transmission lines, submergence of valuable forest and underground mineral resources. They also require rehabilitation of large population from area to be submerged. Due to all these factors large hydropower plants are unfavorable. On the other hand, Small Hydropower (SHP) projects are free from these aspects. Such installations are environment friendly because they causes negligible or no submergence, minimal deforestation and minimal impact on flora, fauna and biodiversity.

A lot of importance is being given to develop the hydropower potential. Ministry of Power has been entrusted to develop large hydropower resources and Ministry of New and Renewable Energy has been promoting small and mini hydro projects ($\leq$ 25MW) so as to provide energy to remote and hilly areas.

About 70% of the population in India lives in rural areas. The rural energy scenario is characterized by inadequate, poor and unreliable supply of energy services. In such areas, the load density is low and extension of grid system is totally uneconomical, hence the Small Hydropower schemes can provide a solution for the energy problems besides solar photovoltaic, which is not available throughout the day. Realizing the fact promoting small and mini Hydro projects is one of the objectives of the Policy on Hydropower Development in India.

Fortunately, India is blessed with many rivers, natural streams, canal networks and mountains offering tremendous potential of Small Hydropower.

Table 1.1: Hydro Scenario in India [86]

Basin/Rivers	**Probable Installed Capacity(MW)**
Indus basin	33,832
Ganga basin	20,711
Central Indian river system	4,152
Western flowing rivers of southern India	9,430
Eastern flowing rivers of southern India	14,511
Brahmaputra basin	60,065
Total	**1,48,701**

In addition, 56 number of pumped storage projects have also been identified with probable installed capacity of 94,000 MW. In addition to this, hydro-potential from small, mini and micro schemes has been estimated as 15,000 MW. Thus in totality India is endowed with hydro-potential of about 2, 50,000 MW.

1.2 Small Hydro Power

Small hydropower is the development of hydro electric power on a scale serving a small community or industrial plant [86]. Hydro power is obtained from the potential and kinetic energy of water flowing from a height. The energy contained in the water is converted into electricity by using a turbine coupled to a generator. The hydro power potential of a site is dependent on the discharge and head of water. It is estimated by the following equation.

P (power in kW) = $Q \times H \times 9.81 \times \eta$, where

Q = discharge (rate of flow) in cumecs;

H = head in metres; and

η= overall power generating system efficiency. [42]

There is a general tendency all over the world to define Small Hydropower by the power output. Different countries follow different norms, the upper limit ranges between 5 to 50 MW, as given in the Table 1.2.

Table 1.2: Worldwide Definitions of SHP [42]

Country	**Capacity (MW)**
UK	≤ 5
UNIDO	≤ 10
Sweden	≤ 15
Colombia	≤ 20
Australia	≤ 20
India	**≤ 25**
China	≤ 25
Philippines	≤ 50
New Zealand	≤ 50

The present status (as on 31.03.2009) of SHP is given in Table 1.3. In India, SHP schemes are classified by the Central Electricity Authority (CEA) as given in the Table 1.4. Power stations are also classified based on the head available and is given in Table 1.5.

Table 1.3: SHP Status in India [85]

Overall Potential	15,000 MW
Identified Potential	14,305.47 MW (5,415 Sites)
Installed Capacity	2,429.77 MW (674 Projects)
Under Construction	483.23 MW (188 Projects)
Capacity Addition During 2002-2007	1975.59 MW
Target Capacity Addition -11th plan (2007-2012)	1,400 MW

Table 1.4: Classification of SHP Schemes in India [42]

Type	**Station Capacity**	**Unit Rating**
Micro	Upto 100 kW	Upto 100 kW
Mini	101 to 2,000 kW	101 to 1,000 kW
Small	2,001 to 25,000 kW	1,001 to 5,000 kW

Table 1.5: Classification based on Water Head [42]

Type	Range of Head
Ultra Low Head	Below 3 m
Low Head	3 to 30 m
Medium/High Head	30 to 75 m
High Head	75 m and above

1.3 Types of Small Hydropower Schemes

The following are the main types of small hydropower schemes [42]:

a. Run-of-river- in the river bed or by diverting river
b. Existing Canal fall based
c. Storage Dam Toe based
d. Pumped Storage

1.4 Basic Components of SHP

SHP project has the components listed below and shown in Figure 1.1

a. Diversion weir/ barrage/ dam
b. Power channel/ tunnel
c. Desilting devices
d. Fore bay tank/ balancing reservoir
e. Penstock
f. By-pass arrangements/ spillways/ surge tank
g. Powerhouse building
h. Equipment (Turbine, Generator)
i. Power evacuation arrangements

1.4.1 Civil Works Components

The components which are in contact with water and do not have any rotating parts are called as civil works components, examples: Intake weir, Desilting tank, Forebay, Power Channel, Penstock, Power House and Tailrace etc. The purpose of civil work components is to divert the water from stream and conduct towards the power house. In selecting the layout and types of civil components, due consideration should be given to the requirement for reliability.

1.4.2 Electro Mechanical Equipments

Electro Mechanical equipments mainly include hydro turbine, generator, speed increaser, governor, gates and valves and other auxiliaries. The parts which are in contact with water and have rotating parts are called mechanical equipments. The parts which are not in contact with water and have rotating parts are called as electrical equipments as a rule of thumb.

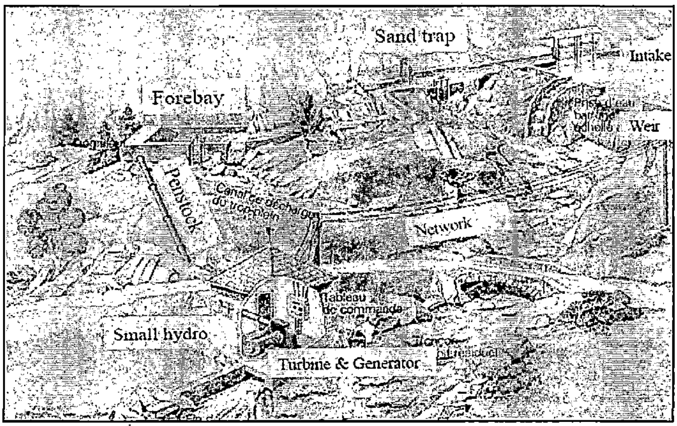

Figure 1.1: Basic Components of SHP [87]

1.5 Advantages of Small Hydropower

a) Hydro power involves a clean process of power generation.

b) A fast way to increase rural electrification, improved living standards and simulation of rural industries.

c) Flexibility of installation and operation in an isolated mode and also in a localized or regional grid system.

d) Relatively small investments required as compared to large hydro.

e) Low operational cost with cheap and simple maintenance.

f) Standard indigenous technologies and maintenance base available which require only minor adaptation to specific site condition.

g) Compatible with use of water for other purposes such as irrigation, drinking etc.

h) Long life of 60 and above years.

i) Perennial source of income generation.

j) Environment friendly due to negligible or no submergence, least deforestation.

k) It is the most cost effective option for power supply because it does not suffer from the limitation on account of fuel consumption.

l) Most small hydro projects in Himalayan region are being developed in remote and backward areas where substantial support for economic development is actually needed.

m) Small hydro power contributes in solving the low voltage problem in the remote hilly areas and helps in reducing the losses in transmission and distribution.

n) In certain cases projects are helpful in providing drinking water and irrigation facilities.

o) It helps in promoting the local industries in remote areas.

p) The development of small hydro projects requires minimum rehabilitation and resettlement as well as environmental problems.

q) Small hydro projects help in generating self employment in remote areas of the state.

r) Small hydro power projects help in providing stable electricity supply at remote areas where such facility by other source shall be much costlier and unreliable.

1.6 Meaning of Automation

Automation means AUTOM(ATIC OPER)ATION. The origin of the term dates back to 1945-50. According to [84], automation (noun) means

a) The technique, method, or system of operating or controlling a process by highly automatic means, as by electronic devices, reducing human intervention to a minimum

b) A mechanical device operated electronically, that functions automatically, without continuous input from an operator.

c) Act or process of automating.

d) The state of being automated.

Automation [87] is the use of control systems (such as numerical control, programmable logic control, and other industrial control systems), in concert with other applications of information technology (such as computer-aided technologies [CAD, CAM, CAx]), to control industrial machinery and processes, reducing the need for human intervention. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the muscular requirements of work, automation greatly reduces the need for human sensory and mental requirements as well. Processes and systems can also be automated.

Human-machine interfaces (HMI) are usually employed to communicate with PLCs and other computers, such as entering and monitoring temperatures or pressures for further automated control or emergency response.

1.7 Automation for Small Hydropower Station

Before the existence of the automation, qualified personnel operated the equipment manually. This was called Manual System, The qualified personnel, to operate manually the equipment, must first take into account the situation of the equipment. Next, depending on the situation, the operator can undertake certain correction to modify on the situation that they have recognized as deficient on the equipment. This approach requests full time supervision by the operators.

The same applies to the automatic system. The automatic system also reads the information on the equipment status operation, and then activates commands or controls to optimize the output production. However, this type of system will need specialized personnel. The operator of the automatic system will still have to make the necessary changes to the commands or controls, based on the needs or production demands from time to time. This approach does not request full time supervision by an operator. [75]

1.7.1 Need of Automation for SHP [26, 75]

Although sophisticated control equipment is being used for the control and protection of large hydropower plants, the same does not apply to SHP due to the following:-

a. Hydro units are started and stopped more frequently

b. Hydroelectric units also provide flexibility of changing the mode of operation, for example, kW control, level control, etc.

c. Hydro power plants are usually situated in remote areas with difficult access, because of which there is a need to reduce the number of operating personnel stationed in these plants by resorting to increased automation.

d. While in the case of large plants, the cost of control and protection systems, compared with the total investment, is not so significant; its share is much higher with small hydro plants. Thus comparatively cheaper system which can still provide adequate control and protection requirements are necessary.

e. SHPs are usually situated in remote areas and are manned by operators without adequate skills. This often leads to a number of problems caused by operational mistake, or remedial action not taken in time, etc.

f. Maintenance and repair of equipment become difficult as spare parts, tools, and skilled personnel are usually difficult to obtain in remote places. The system should be reliable and maintenance-free as far as practicable.

g. The cost of operation has to be kept low in SHP. Hence the system must be designed to operate with minimum staff. Automatic/semi-automatic control may save operational costs.

1.8 SWOT Analysis of Automation of Small Hydro Power station

1.8.1 Strength

Automation of the control system of a small hydro power station provides the ability to integrate plant control functions in one hardware system. It provides flexibility of changing the mode of operation for example, kW Control, Level Control. The complete power plant information is available at any time online. Automation helps in raising the efficiency of power plant to almost the practical highest value by ensuring optimized operation of each generation unit and optimal load sharing between units. Else, it may guide operator to optimize generation by running units at best efficiency. Automation provides security against wrong operations by the operator. It helps in efficient utilization of manpower. Automatic starting and stopping of machine sets are faster than manual starting and stopping. It improves performance and carries out operation reliably.

Automation of control system reduces wire and interconnection. Also the panel space reduces. It has made remote operation possible and introduced networking capability. Capital cost involved in the automation of Small Hydro Power stations is almost 1 or 2 % of the total project cost. It reduces cost of operation.

1.8.2 Weakness

The quality of field instruments being used as data acquisition devices is low. Skilled operators are not easily available. Consultants and plant owners are not sensitized towards the "use" of automation. Testing is not given proper time during commissioning.

1.8.3 Opportunities

India has loads of untapped hydro power potential. With the promotion of private players in hydro development scenario through country policies, a lot of development is soon to be undertaken.

1.8.4 Threats

Operators are more comfortable to operate power plant manually. It has been observed that if any problem creeps in the automation system, it is not dealt properly at the place where manual control is implemented as a backup. Slackness of management of the power plant in the maintenance of the system once it is installed is a big threat to the use of the automation system.

1.9 Objective

According to the literature available and reviewed, it was seen that there has been a lot of new control system implementations, complete automation system for hydro power plants and examples of Programmable Logic Controller (PLC) based and Supervisory Control And Data Acquisition (SCADA) based automation. Literature covers implemented and proposed models for control schemes, remote controlling, and remote monitoring for large as well as small hydro power plants across the world. There have been instances reporting the implementation and status of automation at various power plants abroad. The actual status of automation in India has not been stated and evaluated for small hydro power plants.

It was seen that throughout the world, the automation of small hydro power plants is in full swing. Unmanned projects with advanced security controls have come up for very small capacity power houses abroad. But, in India, the speed of adopting automation is very slow for small hydro projects. The reason for this slow adaptation has to be found out in this study.

The technology of developing the automation system is available in India and is being used widely for large hydro. But the adaptation of the same automation system is very slow in the small hydro sector in spite of the advantages. Thus it was seen that there is a gap between the technology and its implementation in small hydro sector. To find reason behind this gap is the main objective of this study.

The detailed objectives of this study are mentioned below:

a) To evaluate technically the present status of automation of small hydro power stations.

b) Find out the parameters to be monitored and corresponding field devices to be used to get an idea of the things dealt by operators.

c) To find out the changes those are introduced when a plant is automated.

d) Study of control configurations and recommending the same for the small hydro power plants.

e) To consult and get feedback of equipment manufacturers on the status of automation. Find out their operational experience, problems, recommendations and cost involved.

f) To visit automated power plants and get feedback of various personnel (owner, manager, engineer, supervisor and operator) on the status of automation. Find out their operational experience, problems, recommendations and cost involved.

g) To conduct a survey about "Feasibility of Automation in Small Hydro Power Plants" from end user's perspective (owner, manager, engineer, supervisor and operator)

h) To quantify the benefits of automation financially.

The automation referred to in the thesis means computer based automation as is explained in [36]. It should not be confused with the mechanical relay based automation prevalent earlier. Only exception is Rajwakti SHP simulated in the AHEC Real-time digital simulator laboratory which is has a relay based control system.

Chapter 2 – Literature Review

2.1 Control Systems

An integrated, economical and effective control system design specifically for small-scale plants, incorporating all the functions commonly required for these plants, and maintaining a high level of quality has been proposed by Arnaiz *et al.*[2]. They have kept in mind the reduced engineering, flexibility, operation and standard of quality while designing.

A compact and versatile system by the name of Direct Turbine Control (DTC) Vario controller for mini hydro plant has been proposed by Buser *et al.* [8]. DTC involves the use of full system integration, a few auxiliary components and no compromise of the flexibility of the system.

A method to show how the behavior of an existing controller is reconstituted on a simulation platform has been discussed by Libaux *et al.* [48] using software with rapid development. They combined the leading-edge commercial products with products developed in house to develop an advanced simulation methodology having many advantages. This was done to shorten the commissioning phase by copying the new version of the modified and tested program into the plant controller. Example of two complex run-of-river hydro plants, Campan and Riouperoux, with a capacity of roughly 25 MW each was discussed.

2.2 Complete Automation System for Hydro Power Plants

The basis and concept of the automation of a hydroelectric power station have been presented by Erschler *et al.* [16]. The purpose of this automation was to maximize the active power supplied by the station. The general principles of variable structure control systems are presented and a procedure is given for the control law synthesis when the control action is restricted. Some experimental results of an automation system based on the developed algorithms are also presented.

Programmable run-of-river (ROR) controllers were developed by Havrilla *et al.* [29] of New York State Electric and Gas Corporation to achieve complete automatic operation of their small hydroelectric stations along with maximizing their energy generation. The benefit/cost ratio of various projects was anticipated to be from 1.15 to 4.35.

The supervisory control concepts, elements of a typical system, testing activities, project management, and the procurement process have been explained by Sierzant [76]. He discussed the modes of control systems with examples.

The latest versions (1989) of the ABB control system Hydro Power Control (HPC) were described by Isakon [37] along with an emphasis on the MMC (Man Machine Communication) system. HPC systems developed are of three types, HPC 100, HPC 200, and HPC 300. HPC 100 is intended to be used for mini hydro power projects. HPC 200 is a single-computer system designed for stations with few generating units/ gates. HPC 300 is developed for large hydro power stations.

The Hydro Control System (HCS) has been described by Cook *et al.* in [11]. It measures on-line turbine generator performance and provides optimized plant operation by properly allocating required generation among units. A test of the Tactical Planner (a key element of the system) was performed at the School Street Hydroelectric plant (total capacity 38 MW).

The developments in hydro plant control systems due to the increased integration of functions in the computer systems have been described by Soerensen [78]. More efficient control systems are thus formed in terms of flexibility, performance and space requirements. Reliability and availability is also increased. ABB's computer-based control system (HPC) is based on the philosophy of implementing software modules in common computers, to give a higher degree of integration.

The integration of two systems Automatic Control System (ACS) and WaterView is discussed by Adams *et al.* [1] of TVA. This integration causes the automated control of hydro system to provide a near real-time scheduling. ACS is a control system designed to operate hydro units for producing power and WaterView is a monitoring and decision support system. The paper summarizes issues in the ACS- WaterView integration, like communications, scheduling, unit and plant limits, power versus discharge relationships, preferential loading and unloading for units, and testing issues.

A system of automatic design and database development for small hydro power plants which allows evaluating the main parameters for a single SHP as well as their complex has been proposed by Grigoryan *et al.* in [25]. The system is developed on the basis of definition methods of SHP optimum parameters, statistical data of SHP, supplier's equipment data and the local tax regulations.

One of the first integrated hydro power plant automation system NEPTUN, provided by VATECH SAT GmbH&Co, has been described by Päutz [68]. It uses one overall concept for all subsystems based on standardized communication, common engineering tool and unique hardware and is said to have many advantages. The subsystems of hydro power plant automation are: turbine governor, excitation, synchronizing, protection, automation & control, monitoring & diagnosis and power plant management. An integrated process control system designed to decrease the capital and operational expenditures has been described by Päutz [67]. It includes the automation and control, turbine governor and power plant management in NEPTUN, an integrated hydro plant automation system.

An ideal automatic system for Small Hydropower Plants from the perspective of a developing country (China) has been discussed by Xialei *et al.* [82]. Authors say that the design for SHP automation should be simple, reliable and practicable and describe a design by Hangzhou Regional (Asia-Pacific) Center for Small Hydropower (HRC) which fulfills the above criteria. The implementation of the above mentioned design was done at Andi Cascade 1 Hydropower Station (capacity 6 MW) and economic benefit was found due to the increase in the efficiency of the units. In addition to this, the implementation of SHP automation improved the operational conditions and working environment, reducing the working staff and operational cost and increasing the reliability and safety of the plant.

The issues related to the automatic operation of trashrack cleaners are discussed by Radhuber [69], giving examples of hydroelectric plants on the river Mur. In [61] the principles of creation of automated control system for small HPP are considered since modern conditions and features of operation of small HPP in energy market require increasing of automation level of the processes associated with electricity production. It describes a stage-by-stage development and realization of automated control system to create the system maximum adapted to the structure and parameters of small HPP. The three-level hierarchy of ACS of HPP provides high reliability and system effectiveness and, at the same time, allows reducing essentially capital expenditures for elaboration and introduction of ACS.

2.3 PLC Based Automation for Hydro Power Plants

PLC and Embedded control systems were overviewed by Grandmaitre [24] and their role within a small hydro setting was discussed and it was found that both systems are capable of controlling hydroelectric generation facilities. It was said that to decide which system is right for a particular application, the user must properly assess the technical ability of the operators, the available support for the chosen system, as well as the size and location of the site.

A schematic of controls and control functions for SHP plants on irrigation canal drops was discussed by Rangnekar *et al.* [71]. With the help of a block diagram of a suitable control system using smart sensors, programmable logic controls and main controller for several units it was concluded that a remote control system of canal drops based small hydropower plants using wireless communication of signals and commands, smart sensors and distributed controls provides a robust, compact and user friendly control solution.

The use of Programmable Logic Controller (PLC) for control and automation of SHP station, its advantages and cost effectiveness has been explained by Gupta *et al.* [26]. Stressing the advantages of digital control and automation, it suggests the use of a simple PLC scheme with manual back-up control system for a SHP station with a single unit and minimal auxiliaries and the use of a personal computer interfaced with PLC for monitoring and data logging of a remotely operated plant.

2.4 SCADA Based Automation for Hydro Power Plants

A detail of supervisory control capabilities of the PLC along with the use of operator information screens, automatic printer operation, data logging, alarm message and event recording is provided by Lamb [44]. The performance characteristics of the PLC based governor are discussed and communication system and SCADA based remote control is described.

The use of PC to design a control and protection unit for hydro generating unit described Foss *et al.* [18]. The design involved a set of micro-controllers covering control and sequencing, protection, human-computer interface, synchronization and water level measurement, all linked via data buses. Equipment development, factory-based system testing and on-site commissioning were optimized through the creation and use of these cost-effective tools. The successful application of this technology to the control and protection of a 2 MVA hydro generating unit is described.

2.5 Remote Control, Monitoring and Communication

A new model for depicting the dynamic behavior of reservoirs is proposed by Frick [20]. Its usefulness in the design of automatic controllers for small hydroelectric plants is demonstrated. For plants equipped with propeller type turbines a flow rate bandwidth concept is defined and is used to show that the propeller blade pitch angle performs the major flow control function in such installations.

The potential, control requirements and cost constraints for mini and micro hydropower is discussed by Hagen [27] and concluded that using adaptive control and self diagnostics would make remote installation of microprocessor controls practical.

The basic monitoring and diagnosis system for the assessment of the thermal and mechanical condition of hydro equipment is described by Müller *et al.* [58]. Monitoring and diagnosis system is different from control system as the previous provides a diagnosis and/ or condition assessment, and does not list process data. These systems provide an important link between the control systems (process control level) and the operational management systems (operational control level).

Particular trends in control technology, such as self-diagnosis, redundant systems and component reduction which improves the plant availability dramatically are discussed by Kehoe *et al.* [38]. The use of microprocessor based control equipment has led to the use of high level of supervisory system as monitoring and diagnosis tool.

A logical software DAVID for control of small hydroelectric power stations made by HIDROGES (a hydroelectric power station operator) and LOGICAL SOFTWARE S.A is described by Leclerc [46]. DAVID is a command and control cubicle designed for small hydroelectric power stations based on standard, parameterisable computer components.

A PC-Controlled Optimization for SHP is developed by Mitterfelner *et al.* [56]. The hardware, software and interface were made in order to create a practicable solution for the improvement of new and existing small hydro power plants with different heads, different types of turbines and various configurations.

Control, protection and monitoring of a micro hydro generating set is described by Henderson *et al.* [31]. The turbine speed control, generator voltage control, conditions initiating shutdown, protection circuit operation, transient voltage protection, protection system development and PC-based generator monitoring system are discussed.

Systems were developed for the hydro power plant monitoring and control according to their size and capacity by Loibl *et al.* [50]. The classification of the hydro power plant is done on the basis of a correlation that exists between the scope of data involved and the machine output and number of machines. It makes use of a flexible, modular approach for optimization.

The value of pre-defined solutions for hydro control systems as opposed to traditional, custom designed "one of a kind" systems is highlighted by Nicoson [64]. The paper explains what a pre-defined solution is, discuss the evolution of a control system to a pre-defined product, present the benefits to the customer (quality, delivery, cost and service), and show a case study of a controls upgrade utilizing a pre-defined control package for a 25 MW and a 22 MW plant. One of the major advantages is improved service after installation. Since in "one of a kind" system, supplier might forget the system when some problem occurs. With a pre-defined solution there is a larger installed base, so after sales support people have greater familiarity, and are able to be of greater assistance.

Advantages, communication aspects, definition and discussion of the issues that are fundamental to the development of architecture for a geographically centralized site control center are stated by Kumar *et al.* in [43]. Recommendations for hydro power stations based on techno-economical aspects in respect of scheduling, monitoring, control and communication requirements are provided.

The use of Model Based Control without process feedback variable in PID control is advocated by Schade *et al.* [74]. The model is built based upon knowledge of the process dynamics (torque, deadtime, time constants, etc.). This model is then used to forecast outcome of the "controlled" process/system. The model uses direct or indirect process feedback to optimize the accuracy of the forecasts. Model Based Control allows the user to control a process variable that can't be directly measured, or to remove a feedback device from a system that was traditionally required. The essence of this advanced control algorithm is an optimized model of the process behavior.

A new control structure called Vertical Interlaced Hierarchical Control (VIHC) with its benefits in technological and economical sense is presented by Šikovc *et al.* [77]. Individual levels are discussed in detail and possibilities for interfacing to external systems are considered.

A Remote Control system is presented in [73] for small hydro energy power stations to provide an integral operability of the tele-controlled installation from a remote Central Control Position sited into the electric company's operation offices. The system has been designed as a storage system of the fundamental information from each power station defined inside the system. The stored data can be processed and analyzed by the remote operation's central position. In the same way, this Remote Control System provides a full operation to the Power Stations by means of the corresponding commands or set-points dispatching.

The increased speed by tailored algorithms enabled the capability for multifunctional protection using a low-cost state-of-the-art microcomputer facility according to Foss *et al.* [19]. Excel with Visual Basic for applications on an everyday PC was found to be an effective low-cost environment for the development and testing of small hydro protection and control algorithms.

A novel flow control based model for the automatic control of small hydro power plants is proposed by Goyal *et al.* [23]. In the proposed model, a servomotor is used to control the flow of water by controlling the rotational motion of the spear valve. The spear valve causes a 'continuous' control of the flow of water. State space representation is used to mathematically model the proposed model. Extensive simulations are performed to analyze the behavior of the proposed model. Parameter optimization is performed using Artificial Neural Networks.

Some of the technologies involved in remote monitoring of hydroelectric facilities and pumping stations are discussed by Friedman [21]. A surveillance system that can monitor gradual changes in machine health is focused upon. These systems will provide specific information about the fault the machine has such that spare parts can be ordered and repairs planned long before the machines actually fails.

The already developed control solutions (PI with feed forward, Fuzzy Logic and Volume Balance) are summarized by Libaux *et al.* [47] together with their advantages. Parameter adjustment methods are also presented and other techniques such as robust multivariable control for hydro automation are proposed.

A review on the technology status and ongoing research work in the area of hydropower plant is presented in [40]. It was observed that a number of contributions exist for simple linearized first-order model of the plant. Different control approaches have been tested and implemented to study the behavior of the plant and thus its performance under different conditions. On the other hand, the non-linear models' controller tuning and long-term dynamics have not been yet comprehensively studied. The majority of control designs do not account for compressible effect of water column experienced in long penstock layout of the plant. In the last one-decade some contributions have been made to seek the advantages of artificial intelligence in modeling and control of the plant.

2.6 Others

Automation of existing hydroelectric power stations for their reliable and economic operation is insisted upon by Beyrich *et al.* [5]. The extent of automation, the replacement of existing governors and the work and cost involved for the necessary modifications is discussed.

The control system design considerations for small hydro projects are explained by Bogert [7]. The role of control systems in the context of a small hydro plant is highlighted and the previous and present design approaches are specified emphasizing the impact of shift in the design approach.

The need to clearly understand the functions microprocessors can perform and to appreciate the limits is explained by Beck [4]. The hazards that might be caused if the automation scheme is not engineered and implemented properly are mentioned. The use of protective relays and control switches is stressed upon and a way to bypass the PLC for some protective functions lest it should fail is insisted upon.

Maintenance strategies and condition monitoring techniques are reviewed by Henderson *et al.* [30] and two projects based on PC based generator monitoring system and fault prediction program are described.

The experience in hydroelectric automation from a consultant's perspective has been shared by Zadeh [83]. The development of automation guide which could be used throughout the organization and in various hydroelectric facilities, to ensure consistency and optimized/

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economical approach, has been stressed. This guide is drafted in planning stage and is reviewed, revised and produced in the integration phase. Ergonomics (human factors issues) also form a necessary consideration.

The mechanical design features required for hydro plant automation have been discussed by Keith *et al.* [39]. The systems discussed are shear pin alarm system, wicket gate latching mechanisms, automatic back-flushing strainers and raw water flow transmitters.

A life cycle program is designed by Marshall [51] to keep the new hydroelectric installations abreast of technology development. The program provides smooth continuity of software and hardware upgrades that will keep the control systems in service, without significant service disruptions, for approximately three decades. The program, Generic DACS software was written to perform the tasks that all DACS systems do, but without prior knowledge of the powerhouse layout. In order to allow generic functions, the GDACS architecture had to include scalable hardware. The GDACS life cycle plan attempts to predict failure and/or obsolescence of equipment, allowing the replacement to be designed, funded and done while the equipment is still functioning.

The issues involved in making the decision on how to improve the existing governing and unit control systems for hydroelectric generating plants are discussed by Kornegay [41]. Case studies of actual installations are presented to illustrate the decision-related issues discussed in this paper.

2.7 Implementation in Practice

The automatic hydroelectric generating station of the Iowa Railway and Light Company at Cedar Rapids, Iowa is explained in [14]. Each of the three 400 kW units have individual control panel consisting of the necessary consisting of the necessary contactors and relays to connect it to the bus at the proper time. This is one of the earliest reported instance of automation in hydropower plant and the paper is dated 1918.

The old mechanical governors at Belleville hydro station, France were absolutely incapable of supplying a group of isolated users. Thus the renovation work of speed governors was undertaken [3] by Neyrpic which provided a DIGIPID 1000-based solution. The differences in construction costs are generally not significant, in relation to the overall costs involved in upgrading.

Automation of Osage Plant starting from the automation decision to the automated equipments description is described by Duxbury *et al.* [15]. The automation system included the use of a new digital control system, PLC-based digital governor system, automatic voltage regulators, automatic synchronizing equipment, automated gate lock system and a SCADA system for overall control of the units.

Three case studies of Germany were described by Müller *et al.* [59] to highlight the need of individual tailor-made control systems for each of the hydroelectric plants as their characteristics vary so greatly. A distributed monitoring and control system of Siemens was used for this.

The case of control automation of NIPSCO hydroelectric plants was discussed [10] from the view point of the plant holder. The procedures followed in planning, designing and testing of the circuits of the automation system are elaborated. The problems faced are specified and the solutions are obtained through the experience during the work.

The automation of control of a 13 MW Stewart Mountain Plant and 3 MW Crosscut Plant of Arizona is discussed [32]. Both of the SHP stations made optimum use of all the available resources so as to minimize the cost of automating the plants. This was made possible by clearly stating the automation objectives and by making economic considerations govern the operational decisions. The cost benefit analysis reveals that the considerable benefits of automated facilities have resulted in a reasonable payback period.

Cost savings seen after the automation of one Large and one small generating unit in western North Carolina, U.S.A. are shared in [61]. Reduction on the number of moving parts caused improved unit reliability and thus decreased maintenance costs.

The design and individual features of the 3200 MW Yacyretá project are discussed by Gässler *et al.* [22]. The power house, power lines and spillway gates are controlled by the Prokon –LSX control system. It also controls the active power, voltage and frequency using the Automatic Generation Control. A design structure consisting of small modules and distributed over multiple devices can keep local failures from influencing the overall system. The probability of failure of individual devices can be reduced by redundant hardware.

The experience of automation of Rocky Reach Hydroelectric Project is shared by Mettler [53]. It uses a Windows NT based plant control system with PLC's controlling the unit auxiliary systems. This system used off-the-shelf software and hardware to create an inexpensive yet versatile system. A control Ethernet network connects the primary and backup serves to the HMI's and the plant controller. The control Ethernet also provides a link to the Automatic Generation Control (AGC). The system developed to optimize the control and monitoring of the World's largest pumped-storage plant, Guangzhou, China is explained by Müller [59].

The upgrading of the SCADA control system at the M'Bei Valley plants is described by Mertens [52] and the result were optimized management of water resources and more efficient control of the power plants and substations. Remote auto-operation of Sobla SHP is described in [13]. The report was prepared so as to train the personnel working at 6 MW Sobla hydro electric power plant.

PC based Control Systems for four US Army Corps hydroelectric projects in the Northwest United States: McNary, The Dalles, John Day and Bonneville is explained by Miska *et al.* [55]. The Data Acquisition and Control System include the design, installation, and maintenance of new powerhouse automation equipment. The generic design developed can be used for future installations.

Two examples of low-cost, personalized systems have been installed by Idaho Power Company [81] namely, an advanced warning system at Swan Falls power plant and capacity optimization at Brownlee power plant. After the discussion of technical aspects, system costs, implementation strategy, and financial benefits, it was concluded that owner supplied monitoring systems are particularly applicable for single purpose applications where budget constraints may preclude the use of other monitoring technologies.

Advanced control system developed by one of the Brazil's major utilities is described by Lamy *et al.* [45]. Generation Operation Centre (GOC) is an advanced control room responsible for coordinating power plant operation to maximize operational availability, reliability and safety indices. The information exchange is through optical ring to help a SCADA system. The system also performs some pre-operation and after operation activities.

The design and configuration of the SCADA system installed at Awash II and III hydro plants, together with a summary of its advantages has been described by Mirjanič *et al.* [54].

The modernization included installation of a new turbine governor, protection devices, a control system with visualization and a SCADA system.

The modernization of control system involving the use of a common control cabinet, unit automation system, digital governor, optimization module for blade/gate relationship, mechanical adaptations and interface with remote control centre is described by Hanke *et al.* [28].

The upgradation system at the 200 MW Kidatu hydro plant in Tanzania is described by Roset [72]. It consists of a state-of-the-art automation system based on Simantic PLCs and a PC-based Man-Machine-Interface. The generating units, auxiliary systems and the switchyard hall have autonomous Unit Controllers (UC). Backup systems enable the generating units to be operated without he MMI and UCs in service.

The monitoring and control of three hydro stations (capacity from 0.8 to 5.0 MW) of Rapid-Eau Technologies using the Internet has been described in [57]. The use of the Internet evolved from a radiophone system that was the source of numerous communications problems.

Case studies to show examples where on-line monitoring of air gap data and other generator parameters has helped the power producers to better manage their generating assets has been shared in [16].

Falaki *et al.* [17] describe the modernization program of an underground hydroelectric, pumping-generating plant- Hyatt power plant (Capacity 645 MW). The Hyatt power plant performance has been enhanced through modernization of unit design and fabrication. The feasibility study, modernization program, special technical features, quality control and unexpected problems are specified and the benefits of the modernization program are stated by specifying the results of post-refurbishment testing.

The replacement of the mechanical governors of Tyee Lake Hydroelectric plant (2 × 11.25 MW), Alaska with a digital-hydraulic governor which allowed flexible operation of the system, providing needle sequencing, automatic under frequency detection, water waste mode capability and integrated automatic synchronization is explained by Williams *et al.* [80].

The architecture and characteristics of the Generation Integrated Operating System (GIOS), which is able to integrate and operate scattered hydro power plants around Korea are studied and discussed by Paik *et al.* [66].

The automation of Guri hydroelectric plant (Capacity 10,000 MW) in Venezuela is explained by Llort *et al.* [49]. The plant specific logic and applications development, and interfaces with existing equipment was done by holding workshops with plant staff. The automation system follows the OSI/ISO model and the control system was designed in three hierarchical levels. Using a structured process assisted in defining the situation at the plant, the new functionality requirements and selection of the right technology.

The modernization of three projects of Truckee Meadows Water Authority (TMWA), originally built around the turn of the 20th century and each in the 2-3 MW range of output is described by Claybrook *et al.* [9]. The plants underwent complete controls and excitation upgrade. The benefits are realized in the form of efficiency improvement.

The guidelines underlying the hydraulic concept and the internal architecture of the automated forebay water level regulation system called Master-Controller as well as its integration architecture in the global scheme of the system of the Chute-Allard (62 MW) and Rapides-des-Coeurs(76MW) power installations is presented by Nzakimuena *et al.* [65]. This automated regulation system analyses the forebay and tailrace water-level data and translates them into retaining or evacuating flow requests to regulate forebay water-level. Also in spring at Rapides-des-Coeurs facility, the Master-Controller modulates a minimal ecological flow, required to maintain adequate conditions for the fish spawning grounds.

2.8 Conclusion

Several control systems like Hydro Power Control, Hydro Control System, NEPTUN, etc. have been implemented. Each has some specific requirements and working conditions. These controllers use a microcontroller or PLC which is programmed to do control of operation. Comparison of PLC and embedded system revealed that the choice of system is done after assessing the technical ability of the operators, the available support for the chosen system, as well as the size and location of the site. The introduction of a SCADA system or a PC for supervision and monitoring purposes is explained. PLC (or any other controller) forms an integral part of the SCADA system. Since SCADA is a supervisory software which needs to be mounted on a hardware.

Due to different types of layout/ configuration of hydropower plants, a number of models are developed to suit the requirements of study in each case. Majorly modeling the dynamic behavior of reservoirs, use of adaptive control, basic monitoring, self diagnostics and redundant systems is said to have improved the plant availability. Use of pre-defined control system and custom designed control systems is compared. Various new control systems have been proposed and implemented.

Various topics regarding automation of small hydro power plants have been discussed like need of automation of existing hydroelectric power stations, need to fully understand the automation system, maintenance strategies, condition monitoring techniques, mechanical design features, life cycle program, automation from a consultant's perspective, improving existing unit control systems, etc.

Implementation in Practice showed the wide range of implementation of automation control system. This included replacement of the mechanical governors, renovation work of speed governors, automation of control system for new power plants, upgrading of the SCADA system, PC based Control Systems, low-cost, personalized systems, modernization of existing control system, forebay water level regulation system. This shows the wide acceptance of automation system for small hydro power plants across the world. But, in India, the speed of adopting automation is very slow for small hydro projects.

Chapter 3 - Real-Time Digital Simulator Training

3.1 Real time Digital Simulator Laboratory

Considering the fact that apart from design and erection deficiencies, incorrect plant operation and maintenance is a major cause of the failure of any power plant, the Real-Time Digital Simulator at Alternate Hydro Energy Centre (AHEC), Indian Institute of Technology, Roorkee (IITR) has been installed for training of operating personnel to be engaged by the SHP developers, manufactures as well as those already operating plant for improvement in operation practices of SHP. The simulator provides realistic simulation of small hydropower plant, its control room environment, hardwired panels and soft panels.

The objectives of this study for personnel working in the control room covers event diagnoses, plant monitoring, operating skill, communication capabilities, use of resources & knowledge and over all operating approach.

The SHP simulator comprises a training simulator with similar hard panels of the control rooms for two SHP plants: Narangwal and Rajwakti. Out of the two set of hard panels in the digital simulator laboratory, one set of hard panels correspond to Narangwal small hydropower plant based in Punjab, the other to Rajwakti small hydropower plant based in Uttarakhand.

The simulator can also be operated through a high fidelity screen-operated human-machine interface (HMI), including a replica of the SCADA system in operation at Narangwal. The Control Room model is an almost exact replica of the control room of these plants.

Rajwakti (2x1800 kW) is medium head, Run-of-the-River plant with horizontal axis Francis turbine and Synchronous generator having a design discharge = 10 cumec, Head = 52 m. Narangwal (2x750 kW) is Low Head canal based SCADA operated plant with vertical-axis Semi-KAPLAN turbine and Induction generator with siphon intake having a design discharge = 28.4 cumecs and head = 2.82 m.

3.2 Use of SHP Simulator for Operator Training

The training simulator is based on the ALICES software product. It provides extensive functions at the Instructor Station, drives the Operator Station (MMI) and hard panels connected to the simulator. The training simulator allows instructor/trainee teamwork with comprehensive instructor functions. The trainee benefits from a visual, representation of the hydro power plant and of the control centre interfaces with its hard panels and screens. The instructor prepares a training session, selects an initial state and launches a simulation, he can inject failures or malfunctions and he can record the operator response.

3.3 Aim of Study at Real-Time Digital Simulator

In the first year of M. Tech., a thorough study of the various layouts of a small hydro power station, its different components and its operation was done in the course work. But for an explicit understanding of the operation of the power station and control of station (with and without automation), a training in the Real-Time Digital Simulator Laboratory of Alternate Hydro Energy Centre (AHEC) was undergone.

3.4 Work Done

Starting of the turbine and generator and its connection to the grid was performed. During this time an understanding of the functional units was developed. The start/ stop sequence clarified the use and importance of the various auxiliaries. The manual control operation of the power plant included the monitoring of the various parameters. Thus the various parameters monitored and the corresponding field devices were familiarized with. This understanding of the functional units led to the development of Chapter 4.

An understanding of working of automated plant, start stop sequence, synchronization, control scheme of the plant, SCADA working, mimics, malfunctions and protection was developed.

The automated operation of machines was done which led to an improved understanding of the control scheme. The various literatures referred and the practical hands-on training at simulator laboratory led to things compiled in Chapter 5.

3.5 Experiment with Startup Time of Power Plant

There are two power houses simulated in the real time digital simulator laboratory of AHEC, namely Rajwakti SHP and Narangwal SHP. Rajwakti is a relay logic based system having an auto/manual start up sequence and a manual synchronization in both the cases. Narangwal has auto/manual start. Synchronization does not come into picture since it uses induction generator. The outcome of this study at simulator lab is shown in the table below:

Table 3.1: Start up time in manual and automation mode

Start up time (min)				
	Rajwakti SHP		Narangwal SHP	
	Manual	Automation	Manual	Automation
Start sequence	5	3	10	5
Synchronization	3	NA	NA	

3.6 Start/ Stop Sequence of Operation of Power Plant

The start up and shut down sequence of the plant having automated operation of power plant along with a manual back up is given in Figure 3.1 and Figure 3.2. This sequence defines the control action steps to be followed at the time of starting or stopping of the power plant. These steps would vary according to the type of control chosen.

3.7 Recommendations prepared for the Guideline

AHEC is preparing guidelines/ manuals for various topics related to small hydro power plants. One such guideline named "Guidelines for monitoring, control, protection and automation of small hydropower stations" is in draft stage. Some recommendations for the control system to be used in small hydro power plants were prepared under the guidance of Mr. S. K. Tyagi for this guideline. These have been included in Chapter 5.

Legends for Figure 3.1 and 3.2

AC	Alternating Current
AVR	Automatic Voltage Regulator
BFV	Butter Fly Valve
CW	Cooling Water
CWP	Cooling Water Pump
DC	Direct Current
DT	Draft Tube
Gen	Generator
GLOP	Generator Lubricating Oil Pump
GV	Guide Vane
HPU	High Pressure Unit
M/C	Machine
MIV	Main Inlet Valve
Sync	Synchronization

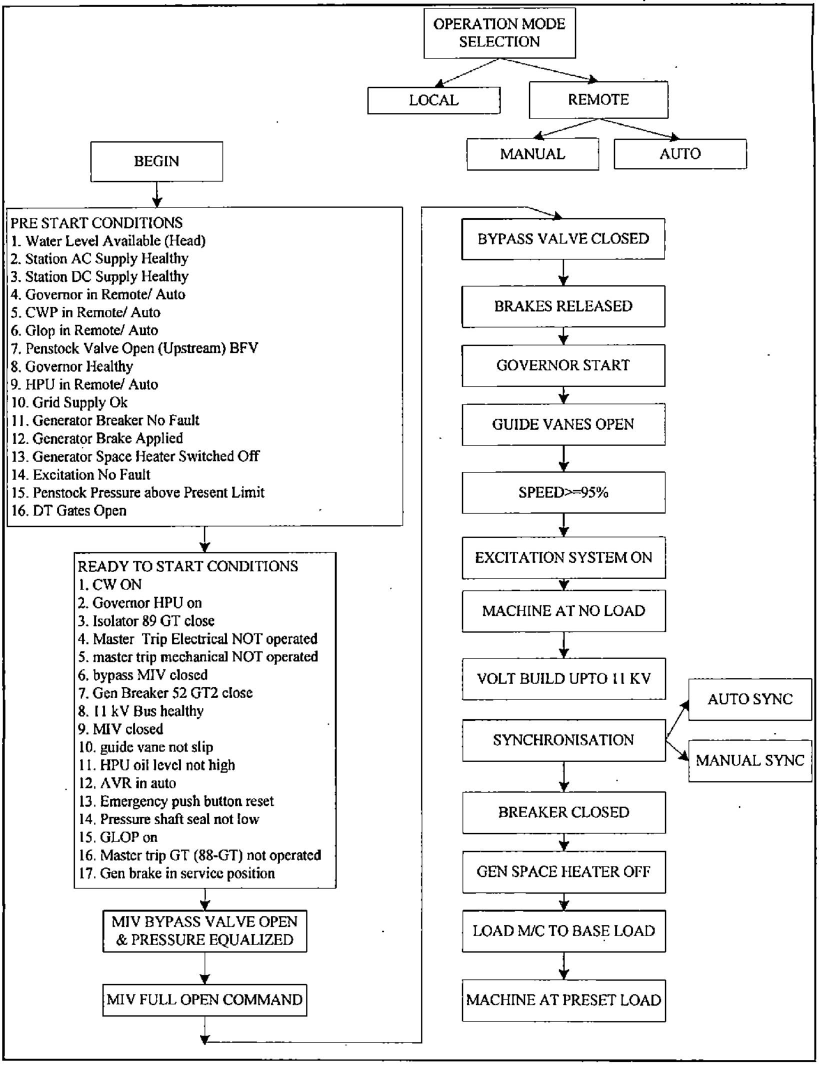

Figure 3.1: Start Sequence of a power plant (Courtesy: Voith Hydro, Noida)

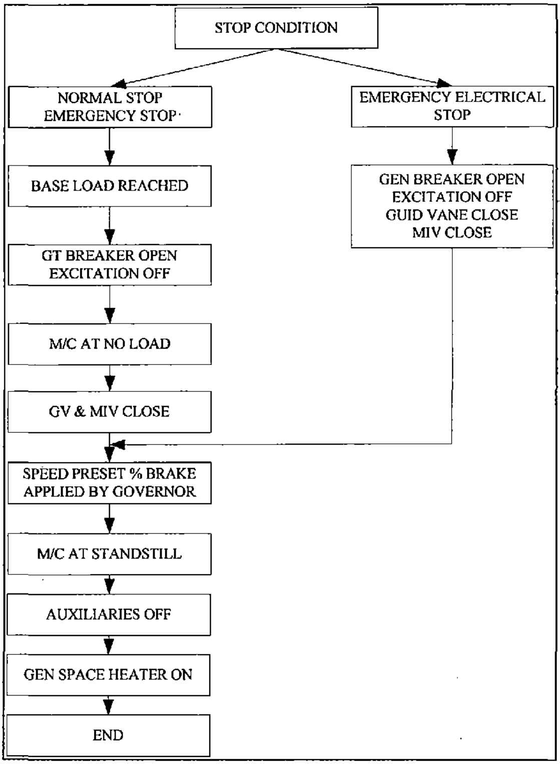

Figure 3.2: Stop Sequence of a Power Plant (Courtesy: Voith Hydro, Noida)

Chapter 4 - Division Of Automation In SHP Station

4.1 Introduction

After developing an understanding of the control and operation of small hydro power house, all the elements of the power station were divided into functional units. These functional units are water conductor system, turbine, generator, evacuation and amenities. The auxiliaries of the power house, the parameters to be monitored and a few possible malfunctions from the perspective of individual control unit are specified. An attempt is made to highlight the difference in the control scheme when the plant operated manually and when it is run in automated mode. For this, a few parameters and/or controls are taken from each functional unit of power station and a comparison of the changes in the two operation modes is done.

Figure 4.1 depicts the generation of electricity from water. The kinetic energy of water is taken through a water conductor system to the turbine in the power house. The turbine in the power house is the prime mover which converts the energy of water (potential/ kinetic) into mechanical energy by rotating shaft. This turbine shaft is coupled to the generator shaft. The rotation of turbine shaft causes the rotation of generator shaft thus producing electrical energy. The electrical energy thus produced is stepped up through a transformer and sent for

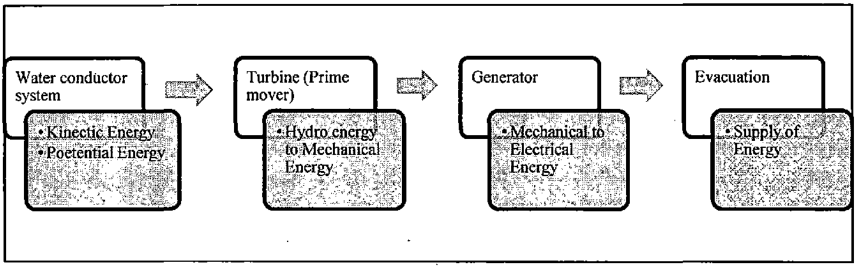

Figure 4.1: Generation of Hydroelectricity

transmission and distribution to the user. This basic flow diagram of generation of electricity forms the basis of division of the power plant into functional divisions.

Figure 4.2 depicts the above mentioned division of the power plant into functional units. The functional units of the power station are comprised of several apparatus at different levels. Water conductor system (for a typical run-of-river scheme) consists of intake channel, desilting tank, power channel, forebay tank, spillway and penstock. The electrical generator is the device that produces electricity, but the excitation system controls the voltage and reactive power. The prime mover for the generator is the hydraulic turbine that is controlled by the hydraulic governor. Thus under the functional units their components and/or parameters to be monitored are mentioned. The last division in Figure 4.2 i.e. Amenities consists of the station auxiliaries along with the extra facilities that can be incorporated in the system in conjunction with the automation of control system.

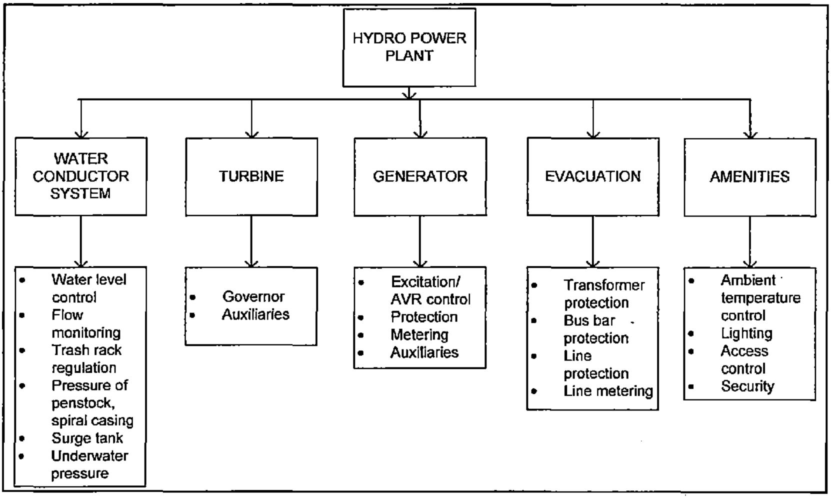

Figure 4.2: Functional units of automation in a SHP Station

In the next few sections, the details of the parameters monitored, field devices used and possible malfunctions are mentioned for each of the functional units to give an idea of the magnitude of things to be handled during the operation of power plant. When the control system of the power plant is operated through computer based automation, the working principle of the system remains the same. The principle is: the sensor or data acquisition system senses the data, sends it for comparison, the appropriate decision is taken and thus action is performed. Automation causes difference in the type of sensor, type of data communication, decision making device (human or relay logic or computer based), actuator, etc.

4.2 Water Conductor System

Water conductor system of a power plant forms the first functional unit of the system. Here the water conductor system is being considered for a typical run-of-river type of layout. It consists of weir, intake, feeder channel, desilting tank, power channel, forebay tank and penstock.

4.2.1 Parameters for Monitoring in Water Conductor System

The following parameters are to be monitored in the water conductor system:

a) Storage level at dam / barrage / weir
b) River discharge
c) Head race channel discharge
d) Discharge at outlet of desilting basin
e) Fore bay level
f) Discharge of spillway
g) Penstock pressure
h) Tail water level

4.2.2 Field Devices used in Water Conductor System

The field devices being used in the water conductor system are water level sensor, position switches, flow meters, level switches (operating a valve after a particular level of silt is deposited), differential pressure switch for trash control, pressure transducers, etc.

4.2.3 Troubles Possible in Water Passage System

Possible malfunctions in a water passage are:

a) Failure of head gate or inlet valve
b) Head gate inoperative
c) Free fall of head gate
d) Trash rack blockage
e) Water level control malfunction

4.2.4 Difference in Manual and Automated control system for Water Conductor System

There are several parameters like gate operation, trash rack cleaning (differential pressure switch), silt deposition (opening of a valve after a particular amount i.e. level of silt deposition), spill operation (spillway gate to open above a particular water level), etc. which could be monitored and automated. Table 4.1 consists of a few parameters which are compared in manual and automated mode of operation.

Table 4.1: Comparison of manual and automated mode of operation in water conductor system

S. No.	Manual mode of operation	Automated mode of operation
1.	Communication of level, flow and pressure valves is through hardwires	Communication of level, flow and pressure valves may be either by hard or soft communication
2.	Gate can be opened manually or by pushing the button of the motor by a person.	Gate would be opened by a motor whose start button is operated using a contact from the PLC

4.3 Turbine Control

In turbine, control is required for maintaining a constant speed before synchronization to grid and to maintain a constant level or desired load after the synchronization. This action may be due to a constant discharge or to cater to a load. Thus the turbine control system regulates gate position, blade angles, or nozzles, depending on the applied turbine type for its working.

Figure 4.3 shows the different ways of controlling the turbine. The control system can be flow control or load control. In flow control, the output of the turbine is decided according to the incoming flow of water to the turbine runner while in load control the output of the turbine is decided according to the demand.

The load control can be done with the help of an Electronic Load Controller (ELC). The flow control can be done by maintaining speed of turbine or the water level upstream or the output. This is done through the use of needle, guide vane, wicket gate, by pass jet deflector, etc. depending on the type of turbine.

The control action is performed through an actuator or a hydraulic power unit, which converts the external control signals (speed increase/ decrease signal, water control mechanism position, etc.) to mechanical movement of the corresponding water control mechanism (gate, valve, wicket gates, blades, or nozzles). This hydraulic power unit includes an oil pump, pressure tank, actuating valve and servomotor and is called Governor.

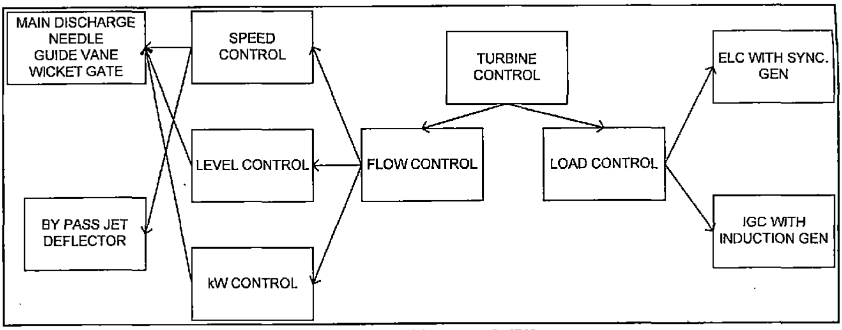

Figure 4.3: Various turbine controls [79]

There are three main components of a governor:

a) Speed sensing element which senses the turbine speed & provides an output proportional to speed

b) Control element compares the turbine speed with the desired set point & produces suitable controlling signal

c) Power amplification element produces mechanical force to position the water-flow controlling device (wicket-gates, blades etc) in response to output of control element

Electronic governor senses the speed electrically and produces a signal for control and governor uses this signal to position the gate servomotors. Digital governor consists of a dedicated PLC designed specifically for turbine control.

4.3.1 Parameters to be Monitored for Turbine and Accessories

The parameters to be monitored under turbine and its accessories are:

a) Speed
b) Pressure and levels in oil pressure system
c) Bearing temperatures (oil & pads)
d) Oil level in bearing sumps (if provided)
e) Cooling water pressure and temperatures
f) Clean water pressure for shaft gland
g) Vibration in shaft for large machines (optional)
h) Status of inlet and other valves.
i) Guide vane opening & limits (percent)

j) Runner blade opening in Kaplan Turbine (percent)
k) Nozzle opening in impulse turbine (percent)

4.3.2 Field Devices used in Turbine Control

The field devices used to monitor the above mentioned parameters in turbine system are speed transducer, pressure transducer, level switch, temperature transducer, vibration detector, pressure switch, etc.

4.3.3 Turbine Auxiliaries

Turbine has the following auxiliaries associated with it:

a) Governor
b) Servomotor
c) Oil pressure unit (running hours of pumps, level in pressure accumulators, pressure of oil)
d) Cooling system (common)
e) Lubricating oil system
f) Filter unit

4.3.4 Possible Malfunctions in Turbines and its Auxiliaries

The malfunctions that may creep in turbine system are mentioned in the following points:

a) Excessive vibration
b) Bearing problems
c) Over speed
d) Insufficient water flow
e) Shear pin failure
f) Grease system failure
g) Low accumulator oil level
h) Low accumulator pressure
i) Electrical, electronic or hydraulic malfunctions within the governing or gate positioning system

4.3.5 Difference in Operation in Automated & Manual Mode: Speed control

Figure 4.4 shows the difference in sensing feedback and action taken regarding speed. It is clear that in manual operation of power plant (considering mechanical speed control), the speed is sensed mechanically (say by a flyball) while in computer based automation the speed sensor is electrical, Hall effect or electromagnetic effect based. In manual mode, Flyball system is directly connected to the piston of servomotor which in turn is connected to the water control mechanism. Thus any change in the speed is sensed by the fly ball mechanism and is reflected in the appropriate movement of the flow regulating mechanism. While in automated operation mode, the speed is sensed and converted to a 4-20 mA signal. This information is passed to the specific DI in PLC. The signal is compared in PLC and the soft output is sent to the I/O module. This signal is sent to the relay which actuates a feeder which in turn moves the servomotor piston to cause the appropriate movement of the flow regulating mechanism.

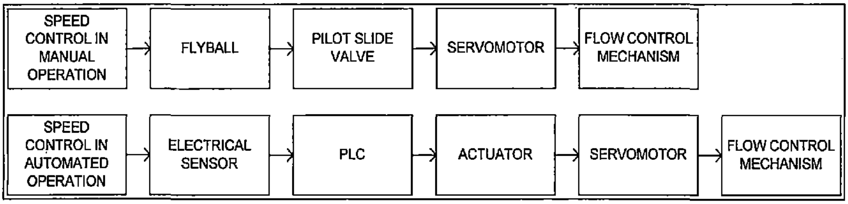

Figure 4.4: Speed control in manual operation vs. automated operation

4.4 Generator Control

Generator control consists of the excitation control of synchronous generator as shown in Figure 4.5. Excitation is an integral part of synchronous generator which is used to regulate operation of generator. The main functions of excitation system of a synchronous generator are:

a) Voltage control in case of isolated operation and synchronizing
b) Reactive power or power factor controls in case of inter connected operation.

For induction generator, the speed needs to be maintained at super synchronous speed till the time of synchronization with the grid, after which load control takes over.

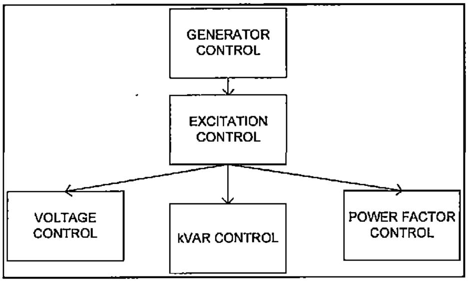

Figure 4.5: Generator control [79]

4.4.1 Parameters to be Monitored for Generator & Auxiliaries

The parameters that need to be monitored for the proper working of the power plant are:

a) Stator winding temperature
b) DE/NDE end bearing temperatures
c) Cooling water and air temperatures
d) Governor actuator balance current (Amp)
e) Generated power (kW or MW)
f) Generated units (kWh)
g) Kilovolt ampere (kVA)
h) Kilovolt ampere reactive (kVAR)
i) Power factor (PF)
j) Frequency (Hz)
k) Excitation voltage (Volts)
l) Excitation current (Amp)
m) Recorder for kW, Hz, kWh etc.

4.4.2 Field Devices to be used for Generator control

Field devices used for the monitoring of the above mentioned parameters are temperature sensor, ammeter, voltmeter, energy meter, power factor meter, frequency sensor, etc.

4.4.3 Auxiliaries associated with Generator

Auxiliaries associated with generator are:

a) Lubricating oil system
b) Cooling system

4.4.4 Possible Malfunctions in Generator and its Auxiliaries

The possible malfunctions that can come in generator section of the power house are:

a) Abnormal electrical conditions
b) Stator winding high temperature
c) Low frequency
d) Bearing problems
e) Motoring
f) Fire
g) Excessive vibration
h) Cooling failure
i) Over speed

4.4.5 Difference in Auto and Manual mode Operation for Synchronization of Unit

Synchronization is one aspect of power plant operation which comes only through experience. The matching of parameters may become quite difficult some cases. Even the most practiced operators have problem in closing the breaker for grid synchronization. The matched parameters for a small time may be missed by human error but the precision and

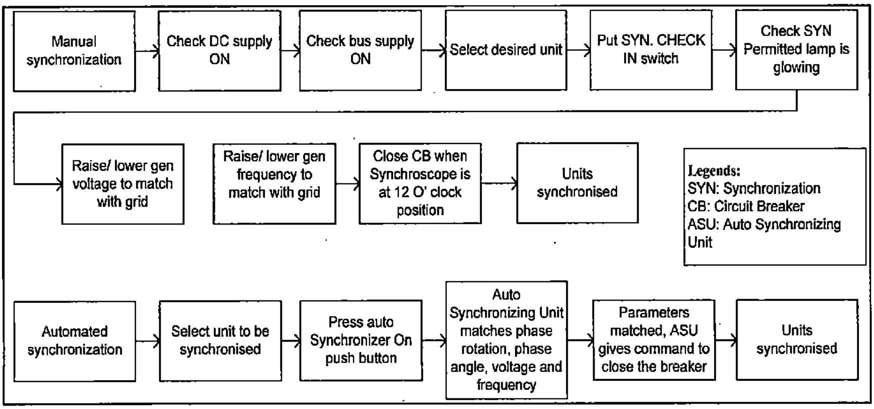

Figure 4.6: Synchronization in manual mode vs. Synchronization in automatic mode

timing of an auto synchronizer is much better.

The difference on automated and manual synchronization is depicted in Figure. 4.6

4.5 Evacuation

Small hydroelectric power plants are mostly located far away from load centers. It becomes, therefore, necessary to step up generation voltage through step up transformers in switchyard located near power plant and connect the same to grid substation through transmission line at a suitable point.

4.5.1 Parameters to be Monitored for Power Evacuation

The parameters to be monitored in a power evacuation sub system are mentioned as follows:

a) Transformer and auxiliaries

1. Winding temperature
2. Oil temperature
3. Oil level
4. Cooling water temperature and pressures
5. Tap position
6. HV/LV current
7. Primary/ secondary voltage

b) Grid system & transmission line

1. Grid voltage
2. Grid frequency
3. Power export / import (kW)
4. Current (Amp)
5. Kilowatt hour (kWh) export / import

4.5.2 Field Devices used for Power Evacuation

The field devices used in the measurement of the various parameters are temperature sensor, level sensor, pressure sensor and switch, ammeter, voltmeter, etc.

4.5.3 Possible malfunctions in Power Evacuation System

The malfunctions that may come in the power evacuation system are:

a) Main Transformer

1. Insulation failure
2. High temperature

3. Abnormal oil level
4. Fire

b) Generator Switchgear and Bus
   1. Electrical fault
   2. Mechanical failure
   3. Loss of control power

c) Utility
   1. Ground or phase faults
   2. Single phasing
   3. Abnormal voltage
   4. System separation (islanding)

4.5.4 Difference in Protection in Manual Mode of Operation and Automatic Mode

As shown in Table 4.2, the protection system in manual mode of operation of operation uses separate electromechanical relays for each protection while in computer based automation, separate digital relays for each protection or a single numerical relay can be used for many protections.

Table 4.2: Protection in manual mode vs. Protection in automatic mode

Manual Operation	Automated operation
Uses separate Electromechanical relays for each protection	Uses separate Digital relays or a single numerical relay or multifunction relay

4.6 Amenities

Under amenities we cover all the facilities equipped in the station, including the station auxiliaries. Computer based automation of small hydro power stations has enabled tasks other than the control, monitoring and data acquisition of energy generation. Thus this section points out the services which can be automated in a power plant.

4.6.1 Parameter to be Monitored for Station Auxiliaries

The station parameters that need to be monitored are as follows:

a) Voltage, current and units (kWh) on LTAC system
b) Diesel generator running hour, kWh & other parameters
c) Drainage & dewatering system (Running hours of pumps, Water level in sump)

d) Fire extinguisher

e) Battery set- Regular monitoring as per manufacturers recommendations

f) Battery chargers & distribution boards – voltage current etc.

g) Air compressors – HP /LP pressures and running hours

Following are the services which can be automated in a power plant,

a) Ambient temperature control: During operation of the generator, due to the heat produced, the ambient temperature rises. So to maintain the ambient temperature, natural/ forced ventilation can be provided. In case of horizontal turbine, automatic opening/ closing of windows can also be done.

b) Lighting: Auto switching on of lights during dusk and night.

c) Access control: Entry in the power house can be made through cards which are read electronically.

d) Security: Surveillance cameras may be employed.

4.6.2 Field Devices used for Station Auxiliaries

Field devices used for station auxiliaries are voltmeter, ammeter, energy meters, pressure switches, etc.

4.6.3 Possible Malfunctions in Station Auxiliaries

The malfunctions that may come in the station services are as under:

a) Transformer failure

b) Unbalanced current

c) DC System Trouble

d) Station Air System Trouble

e) Service Water System Trouble

f) Flooding

g) Fire

h) Unauthorized Entry

i) Protection or Control Logic System Malfunction

j) Water level Monitoring System Malfunction

4.7 Conclusion

In this chapter functional units of the power plant are discussed along with the various parameters to be monitored, field instruments to be used and possible malfunctions. This shows the quantum of work to be handled by operator. Manual error is quite possible if the operator has to take care of such an extensive work. Also in case of manual operation, the efficiency of the system depends on the skills of the operator. Thus to do away with the dependency of the system on "human factors", we are introducing computer based automated control of hydro power plant. On comparison of operation by automated control system with the corresponding manual operation, it has been found out that fundamentally the control action remains the same. The changes are observed in the field instruments, mode of communication and the decision making (earlier decisions were made by operator which has been replaced by a controller).

Chapter 5 -Control Configuration and Automation System for a Hydro Power Station

5.1 Introduction

Computer based control and data acquisition has changed the way operation of the power house was done manually by plant supervisors earlier. There are a lot of new avenues opened up to ensure a more cost effective, efficient and safe operation of the power plant.

In the previous chapter we saw the major changes caused by automation in the data flow and working of the individual functional system of hydroelectric power plant. In this chapter we combine all the functional system and observe the controlling of the station as a whole. The chapter deals with different possible control hierarchy in automation. Also it sees an overview of the system architecture, communications and databases of the automation system. This chapter contains many of details of the IEEE standard 1249-1996 and 1020-1988.

5.2 Programmable Logic Controller (PLC)

A programmable logic controller (PLC) [88] or programmable controller is a digital computer used for automation of electromechanical processes. As seen in Chapter 4, there are many field devices to be interfaced with the control system, a large quantum of parameters to be monitored, a wide operating range to be catered to. Also the system should be robust and immune to electrical noise, vibration and impact. The general-purpose computers do not fulfill all the criteria so PLC is used. PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact.

Programs to control machine operation are typically stored in battery-backed or non-volatile memory. PLCs are used to synchronize the flow of inputs from (physical) sensors and events with the flow of outputs to actuators and events. This leads to precisely controlled actions that permit a tight control of all the parameters and field devices in the hydro power plant. A PLC in a hydro power plant works in a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result.

A PLC is a heart of automation system. As we would see further in this chapter and forthcoming chapters that PLC consists of the programmed actions or sequence-of-events which should be followed to ensure an automated operation of power plants. A control system may have a dedicated or proprietary controller. PLC is clubbed with a Human Machine Interface (HMI) like touch screen to "interact" with humans regarding the operation and status of the control system. Another way of interaction with humans on a higher level is done through the use of Supervisory Control And Data Acquisition (SCADA).

5.3 Supervisory Control And Data Acquisition (SCADA)

SCADA [88] stands for *Supervisory Control And Data Acquisition*. It generally refers to an industrial control system: a computer system monitoring and controlling a process.

The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas. Most control actions are performed automatically by PLCs. Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through various parts of plant, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow, to be displayed and recorded. The feedback control loop passes through the PLC, while the SCADA system monitors the overall performance of the loop. Daneels, *et al.* [12] describes SCADA systems in terms of their architecture, their interface to the process hardware, the functionality and application development facilities they provide.

Data acquisition begins at the PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal PLC controls. Data may also be fed to a Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing.

5.4 Human Machine Interface

A Human-Machine Interface or HMI is the apparatus which presents process data to a human operator, and through which the human operator controls the process. It is also refrred to as Man Machine Interface (MMI).

HMI referred to in this thesis is touch screen. The operator can enter the set points from the touch screen. The operation and monitoring of the system can be done from the screen. The values of the parameters, alarms, annunciations, etc appear on the screen. Thus the system can be monitored from the screen.

5.5 Control Hierarchy

Figure 5.1 shows a typical scheme illustrating a vertical array controlling a powerhouse. The figure is not defined at component level but is a functional diagram showing the control flow. Almost all apparatus are connected with the plant's control system to allow operation in either manual or automatic mode.

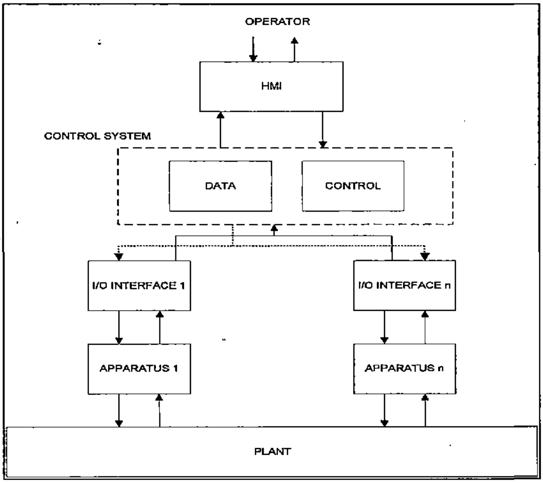

Figure 5.1 A typical control system arrangement [34]

The following functions are common to all hydroelectric control systems:

a) Gathering of process information

b) Controlling the process

c) Protecting and supervising the process

d) Monitoring of process information

The control hierarchy in a hydroelectric power plant may be divided in accordance with Table 5.1.

Table 5.1: Summary of control hierarchy for hydroelectric power plants [36]

Control category	Subcategory	Remarks
Location	Local	Control is local at the controlled equipment or within sight of the equipment.
	Centralized	Control is remote from the controlled equipment, but within the plant.
	Offsite	Control location is remote from the project.
Mode	Manual	Each operation needs a separate and discrete initiation; could be applicable to any of the three locations.
	Automatic	Several operations are precipitated by a single initiation; could be applicable to any of the three locations.
Operation (Supervision)	Attended	Operator is available at all times to initiate control action.
	Unattended	Operation staff is not normally available at the project site.

The Table 5.1 describes the various divisions of the control category. The control of a power house may be from the location of the equipment or from the control room or from a location away from the power house. The mode of operation of the power house may be manual or automatic. Also the operation of the power house may be attended or unattended on the basis of availability of manpower at the power house.

Any plant having automated control implemented may or may not have a manual control. Manual controls are used during testing, maintenance, and as a backup to the automatic control equipment. As we would see in Chapter 7 and 8, all the power plants (except one) studied for the thesis has a manual control implemented as a backup.

Figure 5.2 illustrates the arrangement of control locations, typical functions at each location, and typical interchange of control and operating information. It is seen that at local level, the control has some specific functions to perform. The centralized control, in addition to supervising the tasks done at local level, does the overall plant monitoring and control functions. Also at the off-site control, all the control can be replicated and all the functions can be performed but since it causes unnecessary duplication and leads to complexity of the control system so the replication of the entire system is not done generally. Instead the offsite control follows generation control and power plow control.

Local control, centralized control and offsite control mentioned in Figure 5.2 are explained in the following sections.

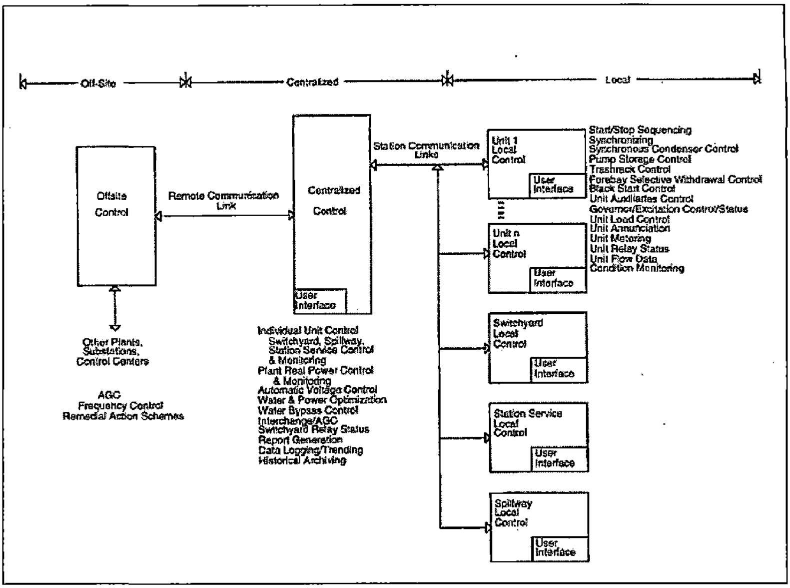

Figure 5.2: Relationship of local, centralized and offsite control [36]

5.5.1 Local control

Local control is the control provided by equipment located near the generating unit itself. The local unit computer/PLC is part of this equipment and backup manual control may be implemented depending on the operator's design philosophy. Where there are multiple units in a plant, one PLC is typically allocated to each unit. This is observed during the study of the power plants and is mentioned in Chapter 7. The local unit controller (e.g. PLC) interfaces to higher level plant or offsite computers (say SCADA) for exchanging control signals and data without the need for additional wiring.

Local control includes sequential operation like startup, excitation control, synchronization, loading unit under specified conditions, normal shutdown, emergency shutdown etc. The operation of turbine operation optimization is also covered in the local control. In practice the turbine operation optimization is not included in the control philosophy by any manufacturer and was not followed at any of the power house. The mode of control may be manual or automatic and may be controlled locally or from remote location. Plant control usually includes monitoring and display of plant conditions.

5.5.2 Central control

Centralized control refers to a common control location from which plant functions can be initiated and plant operating information can be collected and displayed. The purpose of centralized control is to consolidate control and monitoring at a common location in order to facilitate efficient plant operation and to carry out control functions best handled at the plant level. An important example of efficiency derived from centralized control is the economy of minimizing the number of operating staff required during attended operation of the facility. Centralized control also provides a link between the offsite control facilities and the in-plant facilities.

5.5.3 Offsite control

Offsite control refers to plant control activity from one or more control centers remotely located from the hydroelectric plant. Plant operations performed from such centers are usually integrated power dispatch and system operation strategy. Personnel at the offsite control location are normally responsible for operating several power plants and substations, and will probably interface with other control centers (regional, power distribution system, or other power producers).

Centralized control can also be implemented for the ease of operation in case sufficient trained manpower is not available. This was seen in the case of Shahapur power plant in Chapter 7.

5.6 Data Acquisition Capabilities

The availability and flexibility of modern computer input hardware and data acquisition software make the collection and manipulation of large amounts of plant data possible. Data can be acquired directly from plant devices such as transducers and contacts, but given the communication capabilities of computer-based equipment such as dataloggers, sequence-of-events recorders, and digital fault recorders, the plant computer can, if a common protocol is available, acquire data directly from these intermediate data collection systems. This data can be displayed for operator's use, used in the computer control logic, uploaded to higher level control computers, or stored for future report generation.

5.7 Alarm Processing and Diagnostics

Power plant control system is designed to provide status and alarm indication of virtually all electrical and electrical/ mechanical systems in the plant. When major plant problems occur, multiple alarms are inevitable. Knowledge-based programs can filter alarms for the operator and even interpret alarm groupings to identify the probable event that generated them. Expert system programming can assist plant operations and maintenance personnel in the location and solution of problems.

5.8 Report Generation

Raw data collected by the computer system is necessary for the generation of reports that are used for operations and maintenance decisions. Computer database management and document preparation capabilities are becoming powerful tools for increasing plant efficiency. The multi-tasking capabilities of the computer provide report generation capability while accomplishing real-time control and monitoring of plant functions. However, in practice, the reports generated are not being used for making maintenance decisions.

5.9 System Architecture

System architecture defines the structures and relationships among the components of the hydro power plant automation system, including its interface with the operational environment. It includes hardware components, software components, configurations, networks, performance, reliability concepts, and maintainability of the automation system. System architecture for a hydroelectric power plant is designed after considering factors such as the number, size, and types of turbines and generators in the plant; the plant's auxiliary systems, and whether or not the plant is designed for attended or unattended operation, etc.

The system architectures employed in hydroelectric plant automation systems may be either closed or open. The closed system consists of proprietary hardware and software which has little or no provision for interoperation with other hardware and software while the open system uses an integrated system involving a common hardware and software interconnected by common data communication devices. The trend, these days, is towards open systems. Open system architectures offer the advantages of ease of expansion, ability to accommodate changing technologies, and immunity to premature obsolescence.

5.9.1 System architecture Characteristics

A data communication system is an important characteristic of system architectures for hydroelectric automation systems. The communication system can also be classified as closed or open. Open Systems Interconnection (OSI) model of International Standards Organization (ISO) is used to alleviate the problem of connectivity. This model provides a tool for describing, designing, implementing, standardizing, and using communication networks. Some examples of connection standard are Small Computer System Interface (SCSI), RS232, RS422 and RS485 (industry standards).

5.9.2 Communications and Network Layer Considerations

Availability and successful operation of the data communication network is essential to the reliability of a hydroelectric automation system. The design of communication data network for a hydroelectric power plant data acquisition and control system must consider many factor such as serial/parallel data links, adherence to industry standards, maximum availability, error detection, data transmission speed, etc.

5.9.3 Diagnostics

The data communications network should include diagnostic software for both online and offline functions. Monitored online functions include data network performance and alarming for excessive channel errors and channel failures. Offline functions should include tests of each hardware element of the system, transmission medium tests, and verification of the data network error detection and correction features. Panniar SHP has a "software watchdog" facility implemented by Andritz VA Tech in its system architecture.

5.9.4 Maintenance

The data communications network should be easy to maintain, preferably without interruption of the data transmission function. Completely redundant, independent data networks are desirable, so the control system remains operable if one of the networks fails. Further, a failure of a single element should not lead to a total system failure. Redundancy provides a means for effecting system repairs and provides a method for system tests or training. In practice, this feature is not seen to be properly implemented. At Shahapur, the control system of one of the unit is not working because of loss of one signal. Same is the case with Banbhura and Babbanpur project.

5.10 Physical Transmission Media

Media types used to implement network topologies include unshielded twisted pair, shielded multiple twisted pair, coaxial cable, twin axial cable, or fiber optic cable. The choice of media for a hydroelectric automation application depends on various technical factors like isolation characteristics, transmission bandwidth, signal attenuation, access methods, cost, and immunity to noise. And on other considerations like data transmission needs of application and remote site and control centre location, distance between the site, available link media services and project budget.

It should be noted that the cost of fiber optic cable and equipment is dropping, relative to other physical transmission media. The generally superior characteristics of fiber optics combined with its dielectric isolation make fiber optics well suited for application in hydro power plant control systems. Traditional supervisory control central computer (master) communicating with nonprogrammable RTUs over wire, fiber, radio or microwave; dedicated communications channels.

As mentioned earlier, the choice of the media is based on several characteristics. The table 5.2 provides a comparison of some critical parameters of a few available options of cable media.

Table 5.2: Cable media characteristics [36]

Cable type	Noise immunity	Transmission speed	Transmission length
Shielded, multiconductor twisted pair	Poor	Slowest	Short
Coaxial cable, both baseband and broadband	Good	Fast	Long
Twin-axial cable	Good	Faster	Long
Fiber optic	Best	Fastest	Long

5.11 Database

Hydroelectric automation systems require both real-time and nonreal-time database designs. Real-time designs must be capable of supporting database access requirements of the user interface, SCADA, automatic generation control, event recording, etc. These tasks all must be accomplished in several milliseconds.

Nonreal-time database designs are needed to support historical functions, trending, reporting, and other non-real-time requirements. These functions require massive amounts of data processing that usually dictates a design at odds with real-time requirements. Reporting, trending, maintenance scheduling and other offline functions can be very adequately provided by popular database designs that provide a broad range of user defined characteristics and interfaces.

5.12 User Interfaces

The most critical interface for a power plant automation system is the User Interface (UI). If the operator is not able to use the system easily and conveniently, the system will never be used properly or cost effectively. The operator's needs are critical to the successful operation and use of a power plant automation project. The UI is crucial to the success of the system. UIs offering the look and feel of a personal computer may be desirable to reduce special training.

In order to make the system acceptable to the operations personnel, care must be taken in the selection of the hardware and software used. The hardware options are numerous for both input and output devices as well as the workstations to be used.

a.) Input devices: Input devices are not mutually exclusive and may be combined to incorporate desired features. Typical devices include keyboard, mouse, touch screen, trackball, light pen, etc.

b.) Output devices: Some typical output devices are mimic board, printer, CRT screen, and speech synthesis.

5.13 Plant Interfaces

The plant-to-computer based control system interfaces are important to the success of the automated hydroelectric power plant's control system. The plant interfaces are important to the automation system in order to perform effective monitoring, annunciation, control, etc. Examples of plant interfaces include analog transducer signals, dry contacts (i.e., contacts without sensing voltages) and digital data.

5.14 Input Output List for a Control System Design

Input output list defines the type (analog or digital), number of the inputs and outputs to and from any sub system. After the specifications for all the E&M components of the power plant have been prepared, the task of automation system design is started. The basic requirement of designing the system is to define the control strategy. This is generally specified by the end user or the consultant. For the control system definition deciding the input output list is first and foremost step. A sample input output list obtained from Andrtiz VA TECH for the Project Panniar has been added in Annexure 1.

5.15 Various Possible Control Configurations

Various control configurations are possible in a hydroelectric plant. Control configuration design would depend on the operational and monitoring requirement of the power plant owner and the concept followed by the designer. Thereafter it is optimized to suit the characteristics of the specific site. Following are the different possible control configurations:

a) A control configuration with a redundant PLC for each unit and/or protection and/or common auxiliaries may be used to make system durable, more reliable and versatile. The PLC communicates directly to the SCADA system through Ethernet. This configuration is recommended for relatively higher capacity plants say more than 20 MW.

b) Another control configuration may use single PLC for controlling each unit and another PLC for protection (generator, transformer, and line) and auxiliaries. The communication from PLC to SCADA is direct.

c) In another control configuration we can use PLC for unit control and governor only. But the other functions of protection/ excitation/ common auxiliaries may be created on PCB. PLC communicates directly to SCADA system while the circuits on PCB communicate to SCADA through PLC. This type of configuration may be used for 5-10 MW projects. This configuration (of using PCBs) may also be used to reduce cost when the service provider is only supplying proprietary system.

d) Another configuration may include the use of a proprietary controller for the control of units. (Example DACS controller used by Andritz in Section 6.4)

e) The control of power house may also be provided through a touch screen. Here the sequence of events is started/ stopped by a push button/ key on the panel. The data is stored in the panel and all the parameters may be seen from the panel itself. The disadvantage in this is the non-ease of operation. Screen does not have a provision of printing the log sheet.

In the configuration serial number 1 and 2, a GPS receiver may also be used for real time synchronization especially for different plants located remotely. The preferences and practices at the hydropower plants have been discussed in Chapter 7 and 8.

5.16 Recommendations for Control System

AHEC, IITR is preparing the "Guideline for Monitoring, Control, Protection and Automation of SHP Stations". Some recommendations for the control system to be used in small hydro power plants were prepared under the guidance of Mr. S. K. Tyagi for this guideline.

Table 5.3: Recommended Control System

S. No.	Capacity	Recommended Control System	Remarks
1.	Upto 100 kW	Electronic Load Controller with ballast load. Control of governor, generator, plant, services and switchyard through relay logic with manual operation and monitoring Alternatively, PLC integrated control for governor, generator and plant with a PC with data logging may be selected, if cost permits.	Isolated mode
2 a.	100 kW to 1000 kW	PLC integrated controller for governor, generator and plant. Station services and switchyard will have conventional control. PC with data logging facility should be used.	Figure. 5.3
2 b.	1 MW to 5 MW	A PLC each for turbine and plant control, a PLC for station and switchyard control, along with a PC based SCADA. A redundant PC may also be used. Alternatively, an integrated generation controller for turbine and plant, conventional control for station and switchyard and a PC with data logging facility can be used which will be an economical option.	Figure 5.4 Figure 5.5
3.	5 MW to 25 MW	Separate PLC for governor, plant, services and switchyard, with a master controller and/ or control panel along with one main and one redundant PC for units from 5 MW to 10 MW. Separate PLC for plant, turbine, services and switchyard with control through a PC based SCADA and one redundant PC for units of 10 to 25 MW capacity. Alternatively, a PC based integrated system for governing, plant control, services and switchyard with SCADA can be used.	Figure 5.6 Figure 5.7

In table 5.3, all the figures referred have control panel will have alarms, annunciations and meters in addition to the different controls. All the block diagrams are made for a plant of single unit. A separate plant and turbine controller should be provided for each unit as the number of units increase. If the budget of the project is quite low, then a compromise on the extent of automation can be made according to the choices mentioned in Table 5.3.

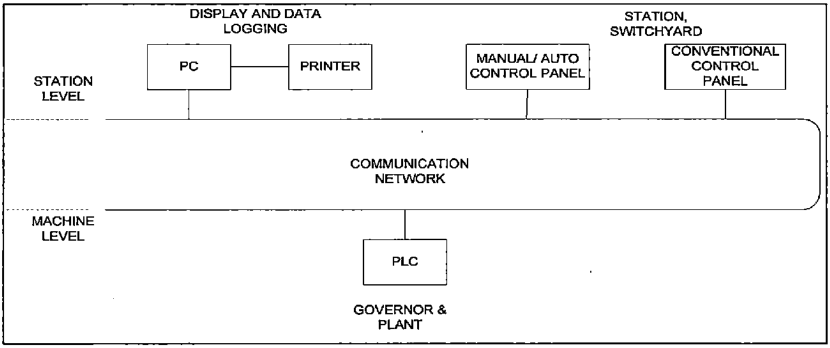

Figure 5.3: Typical configuration for control of hydro power station (100 kW to 1 MW)

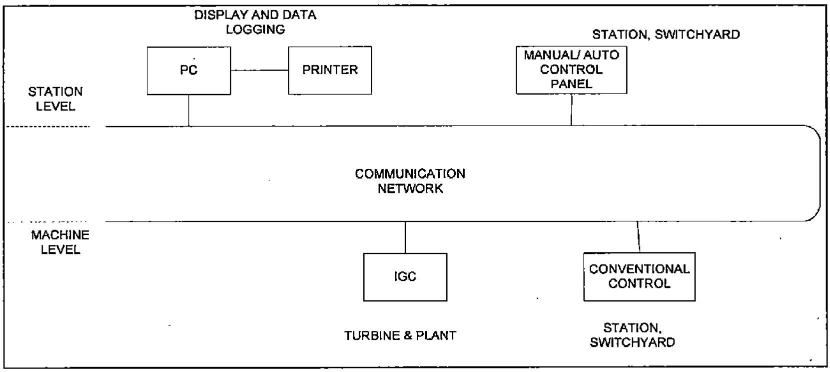

Figure 5.4: Typical configuration of hydro power station (1 MW to 5 MW)

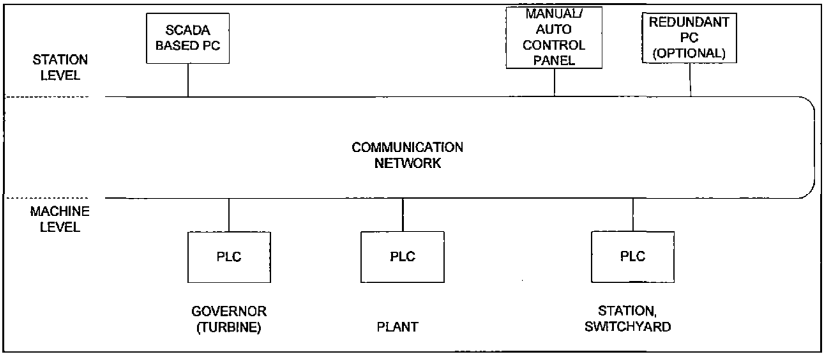

Figure 5.5: Typical configuration of hydro power station (1MW to 5 MW)

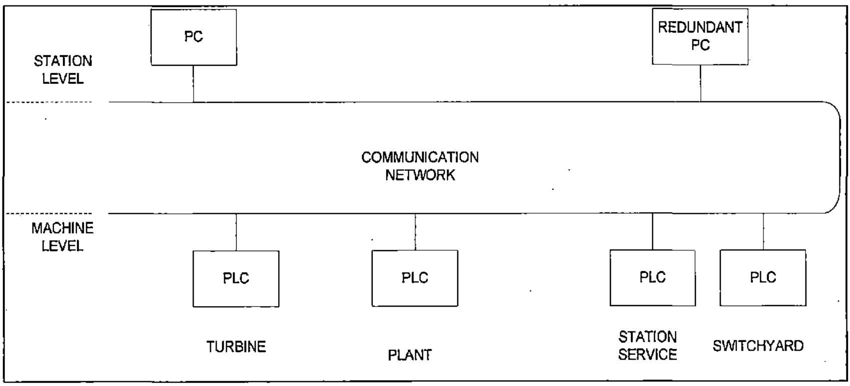

Figure 5.6: Typical configuration for control of hydro power station (5 MW to 10 MW)

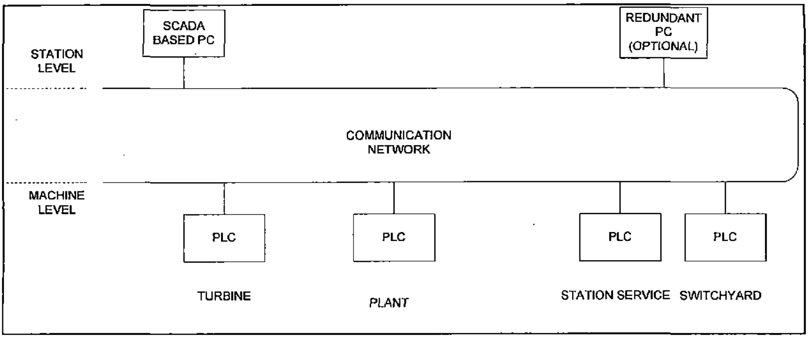

Figure 5.7: Typical configuration for control of hydro power station (10 MW to 25 MW)

5.17 Conclusion

We have learnt about the main components of automation system namely PLC, SCADA and HMI. We can conclude that the choice of mode of controlling a power plant depends on the requirement of the plant owner. The avenues that have been opened up by the automation system are data acquisition capabilities of the system, alarm processing, diagnostics, trending of various parameters and report generation. These trends and reports can be used for a variety of tasks like improving the system efficiency, making maintenance schedules, predicting the performance of the system, etc.

We have understood the system architecture along with the communication, diagnostic and maintenance of the system. A comparison of the physical media would help us find the best media suiting our requirement. We saw that database design is according to the requirement of the system and the choice and design of user interfaces and plant interfaces is very crucial for the successful operation of the system.

We can conclude that there is no fixed configuration for the control system of small hydro power plants. A wide variety of control is being implemented. A compromise is made between the requirement of the owner and the philosophy followed or suggested by the automation service provider. Recommendations provided for the use of control system may be used.

Chapter 6 – Consultation on Present Status Of Automation with Equipment Manufactures

6.1 Introduction

Technical evaluation of the automation of SHP stations required industrial consultation. For this a list of E&M contractors and equipment manufacturers was prepared. The automation system to the power plants is supplied by E&M contractors. These contractors design the automation system by themselves or get it designed through a sub contract. The same is the case of manufacturing the control panels.

Letters were sent to them stating the aim of the study, need of industrial consultation and asking for their assistance in coordinating the visit. Based on the responsiveness, visit to four equipment manufacturers was undertaken: Andritz Hydro Private Limited (Palwal, Haryana), Flovel Mecamidi Energy Private Limited (Faridabad, Haryana), HPP Energy (India) Private Limited (Noida, Uttar Pradesh) and Voith Hydro Private Limited (Noida, Uttar Pradesh). The reason of approaching these companies were, they:

a) Are active and big players in the hydro scenario.
b) Have a wide experience of providing services for many plants.
c) Were responsive to our request for visiting them regarding this study.
d) Have strong alliance with our institute.

A visit to the above mentioned equipment manufacturers who provide services in automation was done during January 2010. The aim of the visit was to gain practical experience, know about the actual status of automation in the industry, to know the various control schemes implemented and the trend of automation in Small hydro plants.

Every manufacturer assigned some members from the team of their automation experts. The various aspects, concerns and working of automation system were discussed with them. Such discussions went on for several days with each manufacturer at their office/ workplace. And the summary of the discussions is presented in this chapter.

The chapter covers the opinion of equipment manufacturers, problems faced by them and their recommendations about automation of Small Hydro Power Plants. Also the chapter includes a comparison of the technical functions/ parameters/ services provided by different service providers. Also an estimate of the cost of automation of some of the plants automated by them is mentioned.

6.2 Status of Automation

As mentioned in Chapter 5, the extent of automation provided by equipment manufacturers depends on the specifications and need of the customer. The equipment manufacturers generally fulfill the requirement of the customers. Only at Andritz VA Tech, it was mentioned that they ask the potential customers (new power plant owners) to visit already automated plants to appreciate the difference caused by automation and then decide the extent of automation to control their power house. At HPP Energy, it is felt that these days everybody wants to use the latest available technology though they not always appreciate or continue using it. At Flovel Mecamidi, they follow the specifications and requirements of the customer. Voith has certain "standard" practices which they follow in every power plant.

Table 6.1 mentions the name of some automated power plants and compares the amount of automation provided by the chosen equipment manufacturers in those example power plants.

Table 6.1: Comparison of the extent of automation

S. No.	Manufacturer	Plant Name, Location	Capacity	Extent of automation	Owner
1.	Andritz VA Tech	Dakpsi IV, Vietnam	3×10 MW	SCADA Based	
		Panniar, Kerala	2×16 MW	SCADA Based	KSEB
2.	Flovel	HRQ, Vietnam	2×3.2 MW	SCADA based	M/S Song Cau Joint Stock Company
		RAD, Jammu	2×7.5 MW	SCADA based	M/S Choudhary Power Projects
3.	HPP Energy	Salag, Dharmshala	1×150 kW	Electronic governor	M/S Dhauladhar Hydro System
		Ching, Shimla	2×500 kW	Electronic Governor	Heteshwari Om Power Enterprises Pvt. Ltd.
		Babbanpur , Punjab	2×500 kW	SCADA based	Polyplex Hydro Group
		Ropar, Punjab	2×850 kW	SCADA based except line and switchyard	PSEB
		Satyakala, Karnataka	4×1.5 MW	PLC based	
4.	Voith Hydro	Asiganga	2×2.25 MW	PLC/ SCADA based	UJVNL
		Bhilangana III SHP	3×8 MW	SCADA based	Bhilangana Hydro PowerLtd.

As observed in Table 6.1, all degrees of automation are being used these days varying from electronic governor to SCADA based automation. There is no specific trend observed in the table 6.1. Some mini hydro plants (i.e. with capacity less than or equal to 2 MW) are using electronic governor while in other cases mini hydro plant are also being operated by SCADA. The plants with higher capacity (than mini hydro) are using PLC based or SCADA based automation.

6.3 Comparison of Functions

As seen in Chapter 4, operation and control of a hydro power plant consists of a wide range of parameters, field devices and functional units. The basic thing in hydro power automation is the automated start up and shut down of the plant. But there are various other functions which can be included in the automated control system.

Table 6.2 covers the various functional parts of power house and the treatment met out to them by the various equipment manufacturers as either "general" or "standard" practice.

Table 6.2: Comparison of functions

S. No.	Particulars	Andritz VA Tech	Flovel	HPP Energy	Voith Hydro
1.	Governor	Digital governor	Digital governor	Digital with auto sync	Digital with auto sync
2.	Protection	Numerical relays	Digital relays or numerical relays	EM Relays upto 500 kW, Else digital or numerical relays	Numerical relays
3.	Meters	Both analog and digital. Sometimes multifunction also.	Both analog and digital.	Both analog and digital.	Digital and Multifunction meter mostly.
4.	Control: local, central, offsite	Provided according to the specifications mentioned in the tender			
5.	Trash rack regulation, Desilting tank, ambient temp control	NA			
6.	Extent of automation ➢ Depends on the requirement of customer	• PLC based Governor • HMI based • SCADA based • only remote monitoring • Remote control implemented	• PLC based Governor • SCADA based automation	• PLC based Governor • HMI based automation • SCADA based automation • only remote monitoring	• PLC based Governor • HMI based • SCADA based

6.4 Control Scheme Used

Following is a discussion of some of the system architectures designed by different automation service providers to give a glimpse of the actual usage/ implementation/ trend of the industry.

Panniar SHP (Andritz VA Tech): The drawing (Figure 6.1) shows the system configuration drawing of Panniar (2×16 MW) Project for the renovation works completed in 2009. This drawing shows the protection relay (generator, transformer and auxiliary transformer) for each unit connected to the DACS controller through IEC 103. The temperature recorder, multifunction meter and energy meter (one for each unit) are connected to the DACS controller through Modbus. Each unit has a turbine governor and a touch panel each which is connected to two operator workstation through a network switch. The communication between turbine governor, controller and SCADA operator workstation is through Ethernet cable. One laser printer and one dot matrix printer is provided.

Bhilangana III (Voith Hydro): The drawing (Figure 6.2) shows the system configuration drawing of Bhilangana (3×8 MW) Project which is scheduled to be commissioned in January, 2011. This system configuration drawing is divided into 3 levels designated as Level-0, Level-1 and Level 2. Level-0 of the drawing is the level of field devices and shows us the general appearance of the system. As is clear from the figure that level-0 shows the excitation panel, Unit Auxiliary Board (UAB) and "auxiliary and other" panel along numerical protection relay and a representation of field devices.

Level 2 takes us to the components inside the panels wherein for each unit we have one PLC, several input output cards, multifunction meter, annunciation window and governor auto synchronizer for each of the three units. Line, transformer, protection devices and common auxiliary systems are combined in panel-4 using one PLC for these functions and another PLC is used for Sequence of Events (SOE) management. A multifunction meter and annunciation is also provided in this panel. Data from field devices at Level-0 is received by Level-1 controller and associated system and the necessary action is taken. All the data from the level-1 controller is passed onto the Level-2 SCADA system terminals through Ethernet. Communication between PLC and multifunction meter and annunciation window is through RS 485 while PLC and Governor communicate through RS 485.The communication between PLC and SCADA system is through Ethernet.

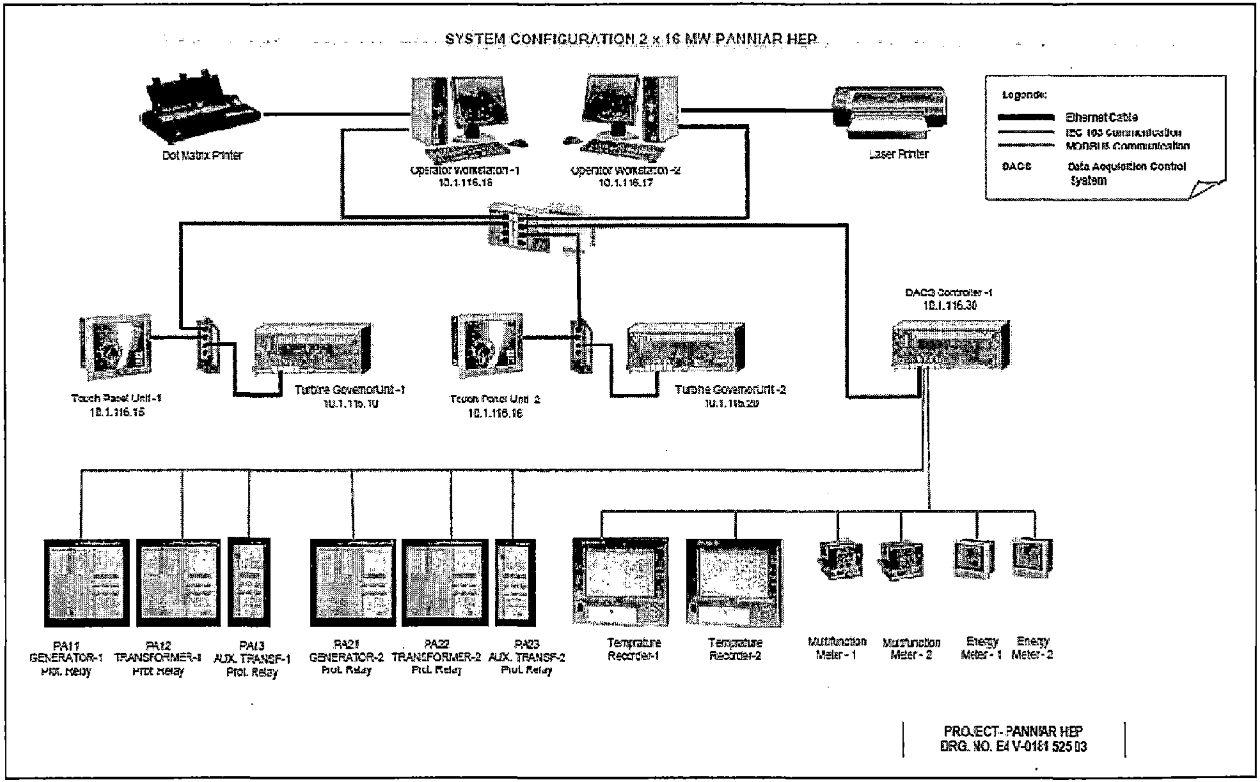

Figure 6.1: System configuration of Panniar SHP (2×16 MW) (courtesy: Andritz VA Tech)

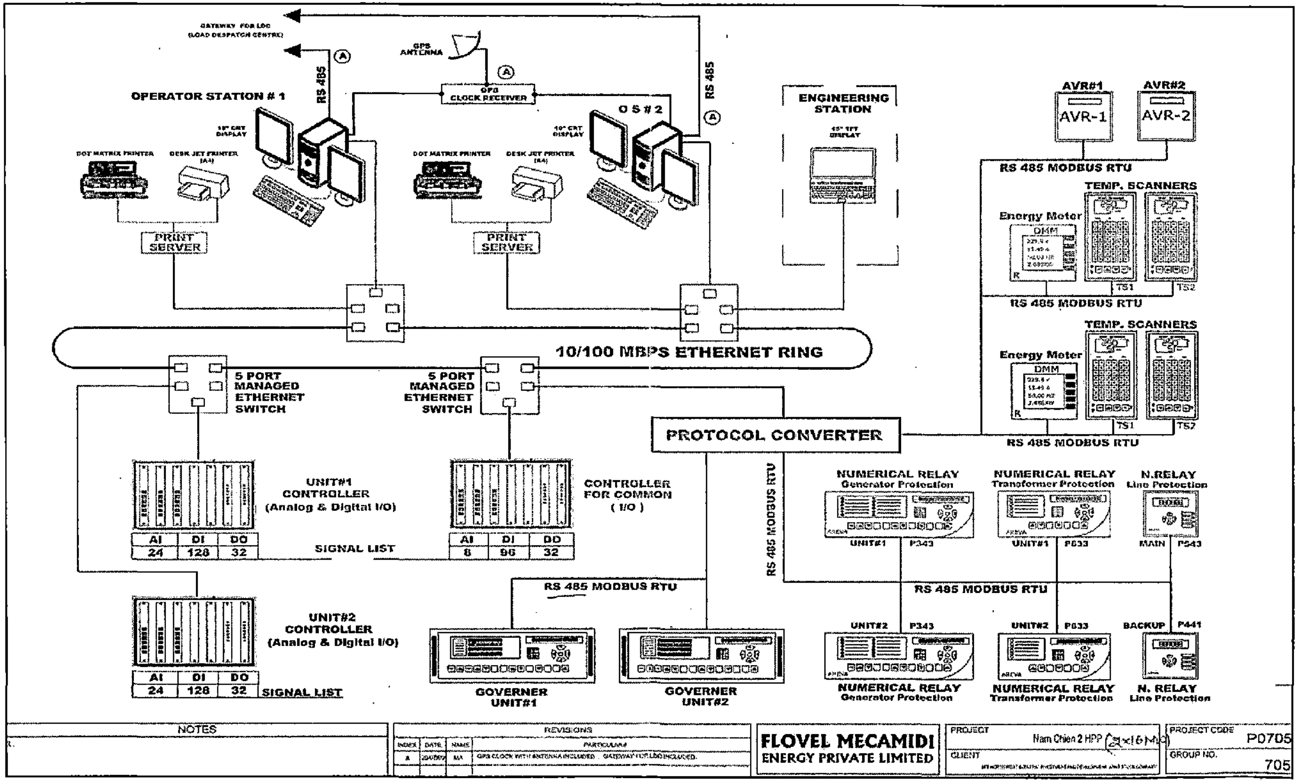

Figure 6.2: Control Configuration of Nam Chien 2 (2×16 MW) (courtesy: Flovel Mecamidi Pvt. Ltd.)

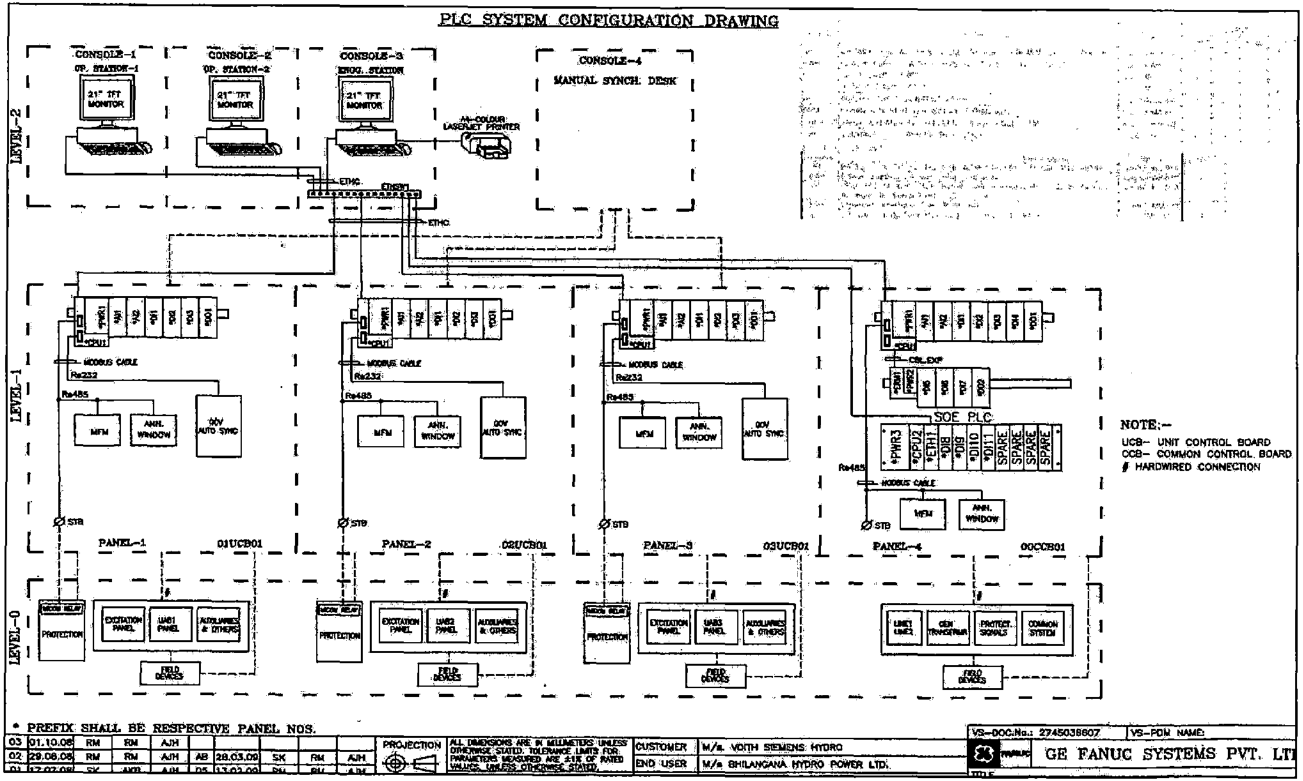

Figure 6.3: System Configuration for Bhilangana III SHP (3×8 MW) (Courtesy: Voith Hydro)

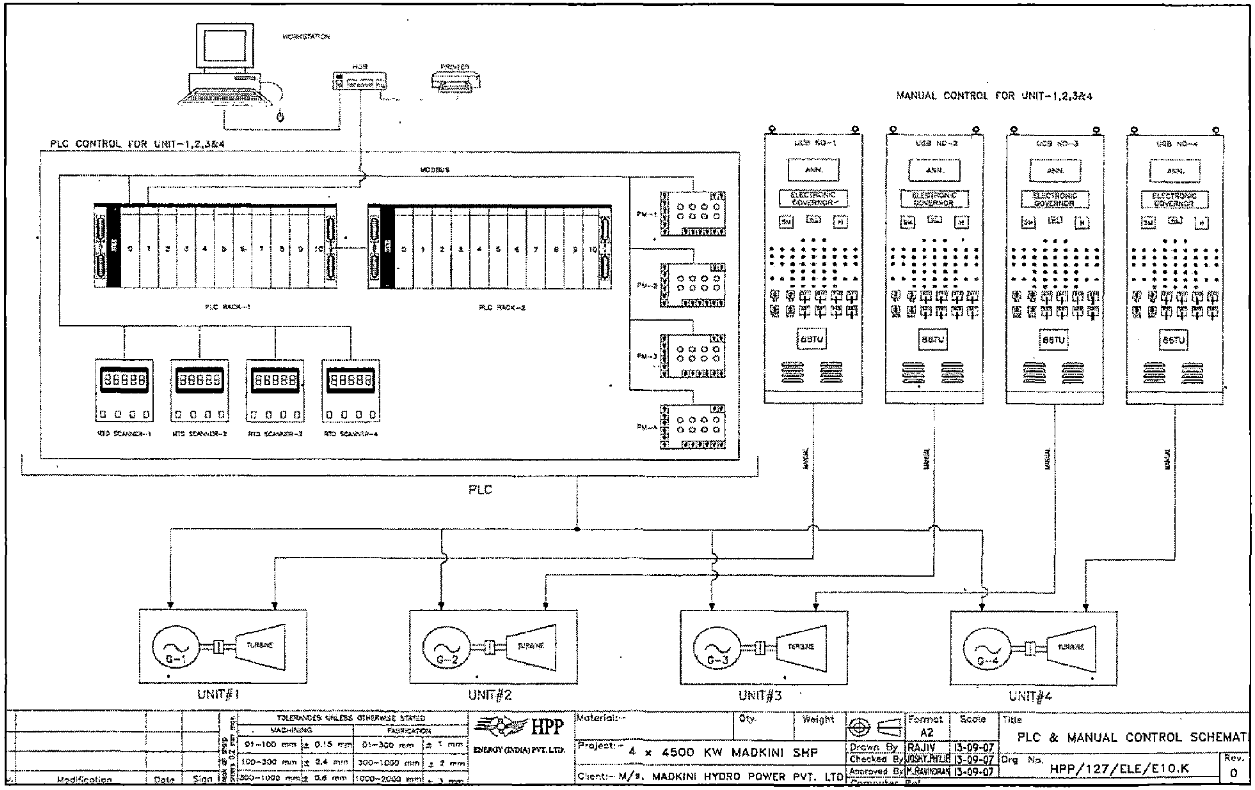

Figure 6.4: Control Configuration of Madkini SHP (4×4.5 MW) (courtesy: HPP Energy Pvt. Ltd.)

Nam Chien 2 HPP (Flovel Mecamidi Pvt. Ltd.): The drawing (Figure 6.3) of Nam Chien 2 (2×16 MW) consists of unit controller, governor, numerical relay protection separate for both the units. Temperature scanners and energy meter, AVR are provided for each unit. These devices communicate to PLC through RS 485. PLC and SCADA communicate through Ethernet switch.

Madkini (HPP Energy Pvt. Ltd.): The scheme provided (Figure 6.4) for Madkini (4×4.5 MW) is not an elaborate one. It just shows manual control, PLC control along with RTD scanners connected to turbine generator set on one side and to operator workstation on other side. The manual controls and the PLC are connected to the field devices. PLC are connected to SCADA terminal for the communication of data to the SCADA system.

6.5 Feedback of Manufacturers

At the time of the visit to manufacturers, some experts on automation were assigned for discussion about the trend and status of automation in Small hydro plants, implemented control schemes, various aspects of automation, their operational experience and feedback.

Table 6.3 covers the essence of the discussions with various people at the companies regarding the company's general views about the automation and its feasibility in Small Hydro Power Plants.

Table 6.3: Feedback of Manufacturers

S. No.	Manufacturer	Manufacturer's Opinion
1.	Andritz VA Tech	• Automation not feasible in micro hydro • Cost of automation is about 1% of the total project cost • Cost of automation is independent of the capacity but rather it depends on the extent of automation provided
2.	Flovel Mecamidi	• Only Electronic Governor is recommended from 1.5 MW to 3 MW and automation is good generally for capacity more than 3 MW (the extent of automation depends on customer's requirement and specification) • Enough spares and backup of hardware, software, manuals should be provided.
3.	HPP Energy	• With tie-ups with International companies, the technology in automation is upto the mark. • PLC costs have reduced so capital cost involved in automation is not much • Remote controlling can be done but not much recommended in Indian Scenario (since instruments are not upto the mark and tend to fail frequently)

4.	Voith Hydro	• Main cost involved in SCADA is in getting the license (OWS and EWS), hardware or programming/ design cost is not much. • Budget is limited in SHP so sometimes bare minimum functionality is provided but no compromise on quality of instruments

6.6 Problems Faced

This section covers the problems encountered in the automation system design/ development/ manufacturing/ implementation. The general view was that with the collaboration with international companies, the technology used is state-of-the-art. The reduction on the prices of electronic goods has contributed to the user's inclination towards trying this system.

A major problem was that of non-usage of the system or not having complete faith in the working of the system as would be discussed in Chapter 8. Some other concerns and problems faced by different automation service providers are mentioned in Table 6.4. The problems are mentioned and a possible solution is provided alongside. This was necessary to bridge the gap between the policy makers, technology providers and end users.

Table 6.4: Problems faced

S. No.	Manufacturer	Problem faced	Proposed solution
1.	Andritz VA Tech	The testing at commissioning stage must be given proper time (it has been noted that once the units start generating, owners don't want to shut them even for "testing")	This requires counseling of the owners by the manufacturers, technical institutions and consultants.
2.	Flovel Mecamidi	Lightening and surges causes damage to instruments in spite of protection- need replacement	Lightening and surge arrestors should be used
		Competition faced from instruments of Chinese market (low cost but quality and service life is poor)	India should start making good quality instruments. (Standard should be made)
3.	HPP Energy	Ignorance of operator about the system: Problem arises when operator, due to ignorance about the system or due to greediness about power production, overlooks or bypasses some protection or any other essential steps.	Proper training of the system operator is essential. He must understand and appreciate each and every component of the system
		Quality of field instruments available in India is not good.	India should start making good quality instruments. (Standard should be made)
4.	Voith Hydro	Can't start the work of automation unless all the departments have finished their design.	

		Software and hardware are updated at a faster rate. Software are updated and upgraded more frequently. So we need to update it and thus problem would be with the maintenance of that system.	

6.7 Recommendations

Manufacturers of various equipments were requested to give their recommendations, if any, for improving the status, popularity and usage of automation system for small hydro power plants. Thus the following recommendations are provided by the equipment manufacturers from their operational experience in the field of automation of small hydro power stations.

a) Selection of operators and imparting proper training to them.

b) Awareness regarding Small Hydro and about automation to the end user (owner/ developer)

c) Sensitizing the consultants

d) Testing at commissioning stage must be given proper time.

e) To follow the O&M manual for a proper working and life of instruments.

f) Quality of field instruments in Indian market should be improved (it is not as good as products in International market). A standard can be developed regarding this.

g) Remote controlling can be done but not much recommended in Indian Scenario (since instruments are not upto the mark and tend to fail frequently)

6.8 Financial data: Cost of automation

The table 6.5 consists of the cost of automation implemented in various power plants.

Table 6.5: Cost of automation as provided by manufacturers

S. No.	Project Name	Service Provider	Automation Cost (Lac INR)	E&M Works Cost (Crores INR)	Total project cost (Crores INR)
1.	RAD SHP (2×7.5 MW)	Flovel Mecamidi	50	20	90.67
2.	Bhilangana SHP (3×8 MW)	Voith Hydro	60	26	192
3.	Asiganga SHP (2×2.25 MW)	Voith Hydro	40	8	28
4.	Nam Chien 2 SHP (2×16 MW)	Flovel Mecamidi	80	42.3	

6.9 Conclusion

Thus we see that technically the status of automation system in India is sound owing to the collaboration with international companies. The extent of automation mostly depends upon the need and requirement of the customer and sometimes the customer's specification is negotiated with the recommendation by the equipment manufacturer. The functions provided by different manufacturers in their automation system do not vary much but there is a wide difference in the control schemes implemented at different power houses. The way of definition of control scheme is standard for a specific service provider but varies from plant to plant depending upon the customer's specifications.

We can conclude that manufacturers' reaction to automation system is mostly positive. Automation system is not considered feasible for micro hydro. Some common problems faced with the automation of small hydro power stations are ignorance of operator, insufficient testing at the time of commissioning, inferior quality field instruments, etc., solution is proposed for them. Manufacturers' have recommended spreading awareness regarding Small Hydro and its automation, sensitizing the consultants, providing proper time at commissioning stage, following the O&M manual, creating a quality standard for filed instruments, etc. The cost of the system is not very high. Thus, adaptability and use of automation system at the power plant and to understand and appreciate it is the need of the hour.

Chapter 7 - Visit To Power Plants : Status Report

7.1 Introduction

The actual scenario of success or failure of an automated operation of small hydroelectric power plants would be clear only with a visit to power stations and interaction with the operating personnel, incharge, manager and owner. Thus contact to power house owner was started.

Initially the power plants referred by the equipment manufacturers were contacted. In parallel to this, a search was started to get the list of automated small hydro power plants. The website of MNRE, AHEC, Central Electricity Authority (CEA), etc was searched. At none of the places, the status of automation for a power plant was mentioned. The awareness of automation is not widespread in case of Small Hydro Power Plants. That's the reason why this information regarding status of automation is not even thought of worth mentioning.

The effort of visiting various equipment manufacturers and also the discussions with the power plant people led to an increased knowledge about the names of automated power plants and the extent of automation provided in them. Thus a list of automated small hydro power stations (including some automated power houses outside the country) has been prepared and is mentioned in the Annexure 2 of the report.

7.2 Background: General Details of Power Plants Visited

The power plants referred to by the equipment manufacturers are mentioned in Chapter 6 section 2. Out of all the power projects, Punjab and Uttarakhand projects were nearby, so we started contacting them (the distance factor was initially considered so as to finish the visits early). The details of all plant owners contacted for visit are compiled in table 7.1.

Table 7.1: Details of Power plant contacted for visit

S. No.	Owner	Plant Name	Address	Contact
1.	Magpie Hydel Construction Operation Industries Private Limited	Athwatoo (2 × 5 MW)	Suite 301, Baba Building, Residency Road, Polo View, Srinagar	Tel:0194-2457998, 2458415; Email: magpiehydel@gmail.com
2.	Bhilangana Hydro Power Ltd	Bhilangana-III (3 × 8 MW)	B-37, Sector-1, Noida - U.P - 201301	Tel:0120-2443716, 2443718; Fax: 0120-2443723

S. No.	Owner	Plant Name	Address	Contact
3.	Choudhary Power Projects	Ranja-Ala-Dunadi HEP (2 × 7.5 MW)	Choudhary tower, 3rd Floor, sector-1A Extension, Trikuta Nagar, Jammu-180012	Telefax: 0191-2477241
4.	Heteshwari Om Power Enterprises Pvt. Ltd.	Ching SHP (2 × 500 kW)	"Vishal House", Opp. Sales India, Ashram Road, Ahmadabad 380009	Tel. No. : 079- 27544592
5.	M/S Dhauladhar Hydro System	Salag SHP (1 × 150 kW)	Vill.- Paplohal, P.O.- Dandwin Tehsil, Distt. - Hamirpur (H.P.)	Tel: 01972 – 283131
6.	Kerala State Electricity Board	Panniar SHP (2 × 16 MW)	Vydyuthi Bhavanam, Pattom, Thiruvananthapuram – 695004	Tel: 0471-2448720; Email: tamg@ksebnet.com
7.	M/S Sai Engineering Foundation & Mahajan Group	Marhi SHP (2×2.5 MW) and Toss SHP (1×5 MW)	Sai Bhawan, Sector-IV, New Shimla	
8.	Polyplex Corporation Ltd.	Babbanpur , (2×500 kW)	B-37 Sector 1, Noida - 201 301	Fax:0120-2443723-24; Tel: 0120-2443716-19 Email: psardana@polyplex.com
9.	Hotel Maurya/ Sri Maruthi Power Gen (India)	Kabini SHP (2 × 1.5 MW)	22/4, Race Course Road, Gandhi Nagar, Bangaluru – 568 009	Tel: 080-22254111, 080-22254115; Email: info@hotelmaurya.com
10.	Pioneer Power Corporation Limited	Someshwara SHP (3×8.25 MW) and Ranganathaswamy SHP (3×8.25 MW)	#156, Golf Link Road, Amarjyothi Layout, Domlur, Bangalore – 560071	Tel: 080-41300550 Fax: 08041300660; Email: pioneergenco@yahoo.co.in; ff@pioneergenco.com
11.	Bhoruka Power Corporation Ltd.	Shahapur (6.6 MW), Neria (2×4.5 MW), Chhayadevi (2×12 MW)	No.48, Lavelle Road, Bangalore-560 001	Tel: 080-22273285; Fax: 080-2245246, 2270605

Response of some was very slow and some were quick in replying. Out of the above mentioned projects, two projects, namely Bhilangana-III (3×8 MW) and Ranja-Ala-Dunadi (RAD) SHP (2×7.5 MW) are not commissioned till the time of this report preparation, so visit to them was ruled out.

The plan of visit to Ching SHP and Salag SHP was dropped because no other automated power plant was near them and the extent of automation in these plants is restricted to the use of electronic governor (which is an integral part of all small hydro plants these days, so cannot be taken as a very significant contributor in this study). Visit to Panniar SHP was thought of as quite time consuming and an effort by Dr. Arun Kumar led them to agree to share the data through mail. So the collection of data of Panniar power house was done through mails and telephone.

The visit to last three could be finalized. These plants were visited in April, 2010. Polyplex Corporation Ltd. has a total of 6 power plants on the Kotla canal with capacities ranging from 1 MW to 1.75 MW. Three plants out of these six are using SCADA while the other three are MMI based. Pioneer Power Corporation Limited has two power projects on river Cauvery. Someshwara SHP and Ranganathaswamy SHP both have an installed capacity of 24.75 MW. Someshwara SHP Hydro Project has both SCADA and MMI implemented and Ranganathaswamy SHP Hydro Project uses SCADA for its operation. Kabini SHP is a dam-toe based project in Mysore District of Karnataka with MMI and no manual control implemented as a backup. Kabini SHP is a unique case. Other than Kabini SHP, all the automated power plants heard of till now, have manual control implemented as a backup to the automated control scheme.

7.3 Questionnaire Preparation

A lot of literature was studied and the key issue areas of automation of small hydro power plants were identified. Then the crucial matters were framed into five major attributes and questions were framed based on them. Thus this detailed structured questionnaire was prepared according to those attributes associated with the automation of small hydroelectric power plants. These attributes are:

a) Level of satisfaction
b) Availability of trained operators
c) Ease of understanding operation
d) Maintenance
e) Performance

The feedback to the questions was to be given in terms of ratings: "strongly disagree", "somewhat disagree", neutral, "agree" and "strongly agree". The questionnaire and the data asked from the power plants are mentioned in Annexure 3. This detailed structured format was given to different power plant personnel to get their views regarding automation. The result of this survey is included in Section 8.5.

7.4 Functional Status of Automation

This section describes the status of automation in various small hydro power plants visited. Total thirteen plants are being considered in this comparison. Out of these thirteen, five are run-of-the-river based, seven canal fall based and one dam toe based plant. Thus all the three layouts are covered. Also, of these, half of the plants are from North and half are from South. This covers the geographical dimension of India. The first numerical value in the table 7.2 represents the number of plants where the specified function is installed or implemented. The next column represents the number of power plants actually using the function or where the function is in working condition.

Table 7.2: Comparison of extent of automation and functions implemented

S. No.	Functions under automation	Number of plants with function implemented	Working status
1.	Touch screen available	5	2
2.	SCADA system	7	5*
3.	Auto operation of intake gates	6	6
4.	Trash rack condition monitoring	Nil	Nil
5.	Closing/Opening of all circuit breakers through automation system.	9	6*
6.	Resetting of lockout relays through automation system.	11	5*
7.	Closing/Opening of intake gates/BFV through automation system.	13	7*
8.	Start/Stop of auxiliaries through automation system.	13	7*
9.	Availability of values of current, voltage, MW, MVAR, PF, frequency, GV & RB percentage opening in the HMI.	11	8
10.	Whether HMI is common for controlling and monitoring all units.	12	6*
11.	Annunciation of alarms in HMI.	12	8
12.	Storing of readings in automation system and printing of log sheets, other reports through automation system.	4	2

* Two of the plants here do not operate in automation during flood period and lean period.

From table 7.2 we see that though a lot of functions are implemented at the power house but they are not being used by all. The auto operation of intake gates is seen to be quite successful. Trash rack condition monitoring is not implemented at all. At about half of the places operation of BFV and other auxiliaries is not used in automation. A good number of plants have their parameters being displayed at HMI but logging of parameters through SCADA is not so popular. At half of the plants HMI is not used for controlling and monitoring all units. Reason of non-usage of the system is either "not in operation" or "preference for manual operation mode".

7.5 Status of Automation in Various Plants

This section reports the status of automation as seen at the site. The control configuration diagrams for a few power plants have been drawn on the basis of the understanding developed with the discussion with power plant personnel. The various photographs of the site are included in Annexure 4.

7.5.1 Salar Mini Hydro Power Station

Salar MHP (2×700 kW) at RD 34660 has a siphon intake for semi Kaplan turbine and induction generator. It has a rated discharge of 65.00 cumecs and rated head of 2.78 m. The operation and control of the plant is done by a SCADA system with software by Schnieder. It has two modes of operation namely load control and level control. Start and stop of plant, synchronization, power factor control, operation of main canal gates and operation of bypass gates are under auto mode of operation. Speed, water level, runner blade position and guide vane position are sensed by a single instrument only (no redundancy). The whole control scheme has also been implemented in manual as a back up to the automated control scheme. Trash monitoring and cleaning is manual. Both the units can be started from a single touch but in practice units are started and synchronized one after another with grid. Data is recorded manually and fed into a custom-made software POMS which is detailed in Section 8.2.1.

7.5.2 Dolowal Mini Hydro Power Station

Dolowal MHP (2×700 kW) project at RD 3520 has a siphon intake for semi Kaplan turbine and induction generator. It has a rated discharge of 65.68 cumecs and rated head of 2.67 m. It has exactly the same control as that of Salar.

7.5.3 Banbhaura Mini Hydro Power Station

Banbhaura MHP (2×650 kW) project at RD 61556 has a siphon intake for full Kaplan turbine and induction generator. It has a rated discharge of 64.10 cumecs and rated head of 2.49 m. It is situated on Kotla canal. It uses MMI. The PLC used is Allen Bradley. One touch operation of the machines is possible through the MMI. The intake gates are in automation. The level control is followed at the power plant. All the power plant attributes are available in the MMI system. The power plant can be operated in automated or manual mode by selecting the appropriate operation control.

7.5.4 Babbanpur Mini Hydro Power Station

Babbanpur MHP (2×500 kW) project at RD 86320 has a siphon intake for semi Kaplan turbine and induction generator. It has a rated discharge of 51.58 cumecs and rated head of 2.50 m. It is situated on Kotla canal. At this 1 MW power project using SCADA system with Schnieder PLC, units can be started at one touch of the button. One SCADA terminal is provided. The intake gates are automated. The complete system is replicated for manual mode of operation also. Each unit has a controller associated with it. Along with this, a controller for station auxiliaries is also provided.

7.5.5 Killa Mini Hydro Power Station

Killa MHP (2×875 kW) project at RD 144580 has full Kaplan turbine and synchronous generator. It has a rated discharge of 48.07 cumecs and rated head of 4.60 m. It is situated on Kotla canal. This plant uses MMI control provided on Allen Bradley PLC. It has three types of controls are implemented: position control, level control and load control. But only level control is used in practice.

All the auxiliaries, plant operation, main canal gates, DG for back up can be operated through automated control system. The plant parameters are also displayed. Manual control is also implemented as a backup to the automation system. Synchronization is only in manual.

7.5.6 Sahoke Mini Hydro Power Station

Sahoke MHP (1×1000 kW) project at RD 214800 has full Kaplan turbine and synchronous nerator. It has a rated discharge of 24.36 cumecs and rated head of 5.27 m. It is situated on la canal. This plant uses MMI control system. PLC is of Allen Bradley make. All the ols are implemented in automated as well as manual control. The canal gates are also in ation. This power plant has no trash cleaning system. Guide vane opening indicator is esent – running plant by experience.

7.5.7 Kabini Mini Hydro Power Station

Kabini mini hydro power station is a dam based project of Sri Maruthi Power Gen with a capacity of 2×1.5 MW. This project has MMI based automation with no manual control implemented. It has full Kaplan turbine with Synchronous horizontal generator generating at 660 V and being evacuated at 66 kV. It was commissioned in August 2003. PLC controls OPU, Grease motor, Cooling system, auto breaker closing. The plant is started with one touch (through a key). Emergency stop button is available.

Units are individually started but have separate synchronoscope. No separate governor panel is there. PLC is programmed for governing the system. Monitoring and archiving is done through HMI screen. Its data storage capacity is 3-4 years.

Figure 7.1 shows the general appearance of Kabini Small Hydro Power Station. All the panels are connected to the appropriate field devices. The control of the power plant is from a key located on the Unit Control Board. The alarms and annunciations are available on the touch screen. The output of the data through printer is not possible. Data is recorded manually in log sheets.

7.5.8 Someshwara Small Hydro Project

This project of 3×8.25 MW capacity has both SCADA system and HMI screen, the reason of automation being "*The quest to build a fully automated power plant is the small hydro sector which is first in the state.*", as quoted by management of the plant. It was commissioned during July 2005. It uses a vertical full Kaplan turbine and synchronous generator to tap a rated discharge of 53 cumecs and a rated head of 18.5 m on Cauvery river. Plant has a PLF less than 50%. It works under full load from July to November. During December, plant is under part load for part of the month. And from January to June plant has no generation. There will not be any considerable change in the output of the units in manual mode and automation mode. The gates at the power plant are in manual mode of operation and trash rack cleaning is also done manually.

Control scheme includes manual mode and auto mode for Main Turbine-Generator units and Auxiliary system separately. In auto mode SCADA system through PLC will start up unit upto minimum load. Then load can be increased through command given to SCADA.

PLC is SLC 0.5 and communication is through Ethernet. System has a common synchronizing panel for three units thus units are connected to grid one after another. Control can be position control or load control. The former is followed here. Thus the position of guide vane and runner blade is fixed according to the incoming discharge. There is one SCADA operating terminal along with a printer. The touch screen (HMI) are placed on the corresponding unit control board. Data is recorded in MS Excel sheets but these are self generated and not directly generated from SCADA system.

The control configuration drawing of the Someshwara Plant was prepared on the basis of the understanding of the system developed by the interaction with the power plant personnel. The Figure 7.2 shows this control configuration. Each Unit Control Board has a PLC connected to the field devices and SCADA system. Each unit controller also has an HMI touch screen. The unit control board has multifunction meter for monitoring of various parameters and numerical relays for protection. The annunciation panels are separate for the three units. There is a common synchronizing panel for both automated and manual synchronization. A SCADA computer along with a printer has been provided.

7.5.9 Ranganathaswamy Small hydro project

This 3×8.25 MW project on Cauvery River was commissioned during July 2007. It uses a horizontal Francis turbine and synchronous generator to tap a rated discharge of 7 cumecs and a rated head of 120 m. Plant operates at full load from July to November. During December, plant is under part load for part of the month. And from January to June there is no generation. The control scheme includes manual mode and auto mode for Main Turbine-Generator units and Auxiliary system separately. In auto mode SCADA system will start up unit to minimum load through PLC. Then load can be increased through command given to SCADA. Gates at the power plant are not automated. Trash rack cleaning machine is not present. Data is recorded in MS Excel sheets but these are self generated and not directly generated from SCADA system.

The control configuration drawing of the Ranganathaswamy Plant was prepared on a similar basis as that of previous control configuration of Someshwara. The Figure 7.3 shows this control configuration. Each Unit Control Board has a PLC connected to the field devices and SCADA system. The plant parameters are monitored through multifunction meter and for protection numerical relays are used. The annunciation panels are separate for the three units. There is a common synchronizing panel for both automated and manual synchronization. A SCADA computer along with a printer has been provided.

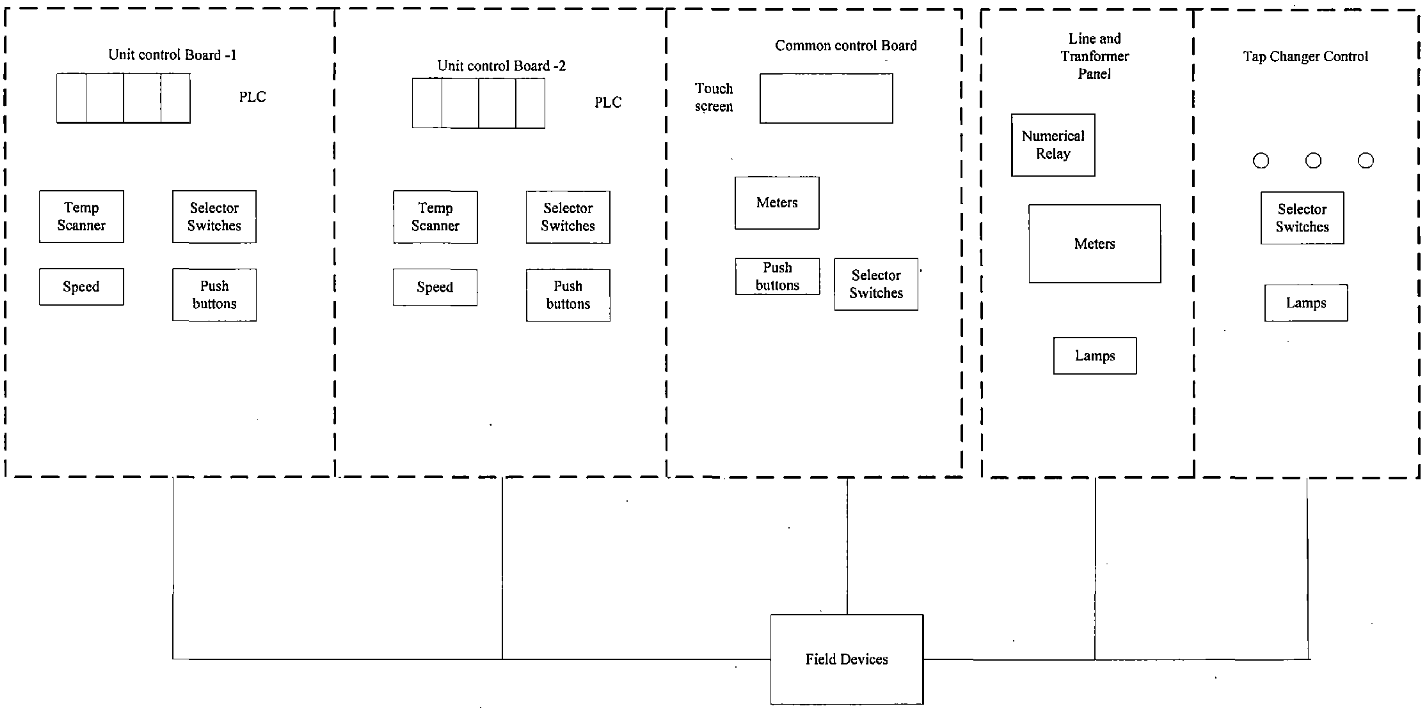

Fig 7.1 Control configuration of Kabini SHP (2×1.5 MW)

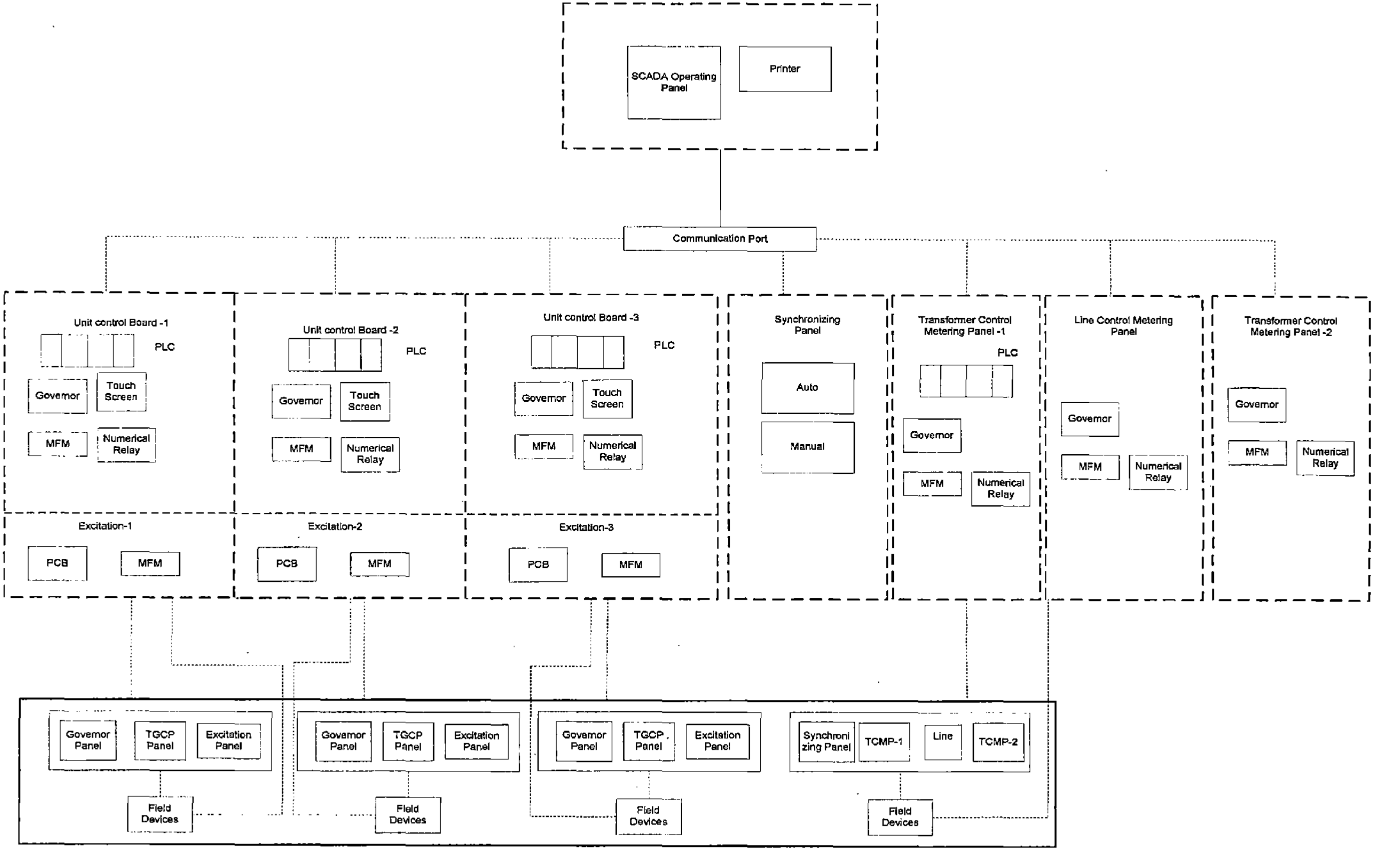

Fig. 7.2: Control Configuration of Someshwara SHP (3×8.25 MW)

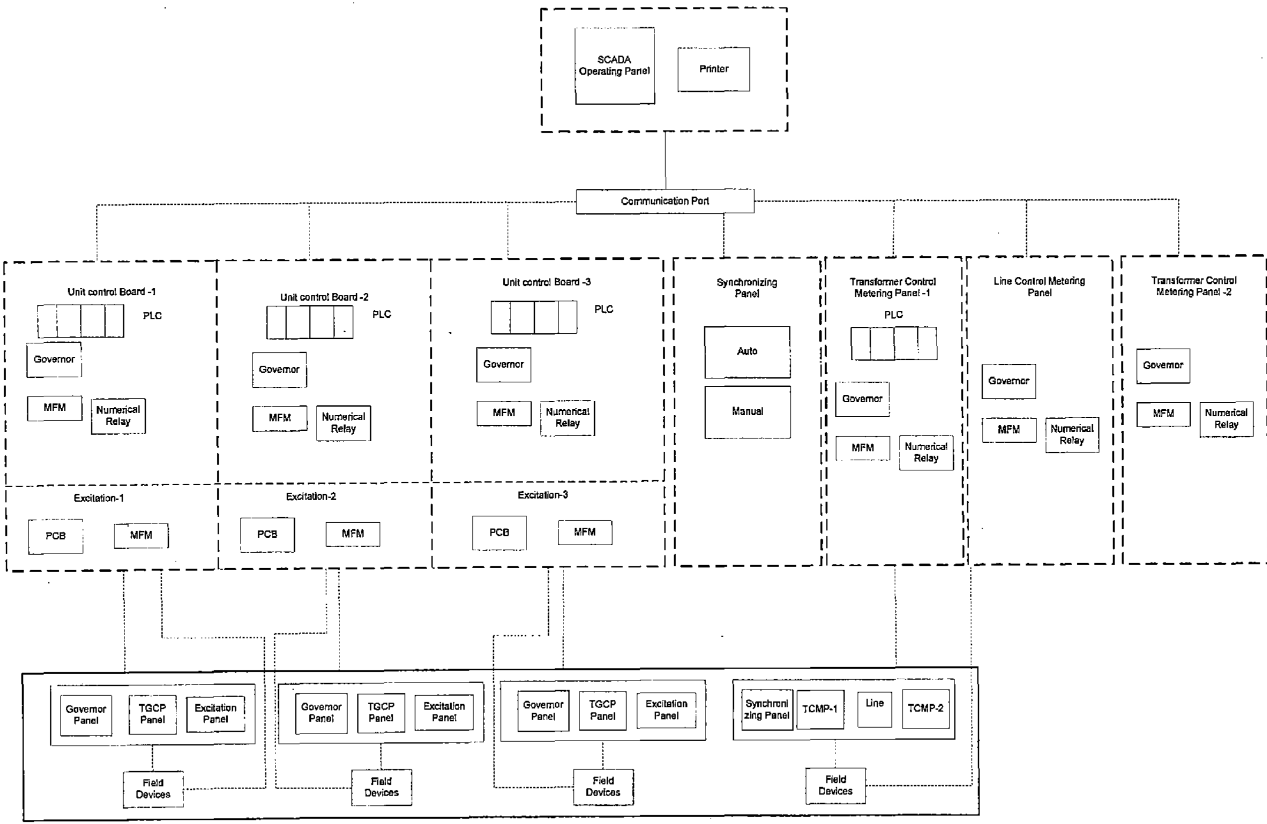

Fig 7.3: Control Configuration of Ranganathaswamy SHP (3×8.25 MW)

7.5.10 Panniar Hydro Electric Project

The Panniar Hydro Electric Station (2×16 MW) is located at the Panniar River. This project is automated after a renovation and rehabilitation. The two units were commissioned in 1963 and 1964. After over thirty five years of operation, the Kerala State Electricity Board renovated and modernized the Panniar power station during 2001-2003 by M/S Alstom-Canada. After renovation, the machines were performing efficiently till 17-09-2007. On 17-09-2007, the powerhouse was flooded with water, mud, stones, sludge, etc due to bursting of Penstock no.2 and failure of Butterfly valve in the valve house. Power plant renovation was taken up by Andritz VA Tech Hydro (VA Tech Escher Wyss Flovel Pvt. Limited). Thus the renovated and refurbished power plant was commissioned in 2009.

The control system of Panniar HEP is built up of Client Server hierarchical control level. The overall plant supervision, Supervisory Control And Data Acquisition (SCADA) System will carry out control and monitoring functions. The SCADA system includes two Digital Governors, Common auxiliary and switchyard PLC and two Operator workstations. The distributed control system concept is implementing in all the control and supervision units.

SAT250 is the SCADA Software installed on the Operator workstation. A diagnostic feature is built in application software of Turbine control system, which monitors the important parameters of machine such as G.V position feedback, Speed etc. Any abnormality in these signal loops will be detected by control system and an output command "Primary signal Faulty" will shutdown the machine quickly.

A "Software Watchdog" feature also monitors the hardware in processor and control system. Any major failures will shutdown the machine quickly. The interruption in other non-important signal as Active Power and Grid Frequency is annunciated as "Secondary Signal Faulty". The unit is kept running under such signal failures. A diagnostic feature is built in application software of Turbine control system, which monitors the important parameters of machine such as G.V position feedback, Speed etc. Any abnormality in these signal loops will be detected by control system and an output command "Primary signal Faulty" will shutdown the machine quickly. Similarly, the software in the system is monitored continuously and if any corruption takes place in Software at any stage, then trip command is initiated with output signal "Software Watchdog faulty". A "Watchdog" feature also monitors the hardware in processor and control system. Any major failures will shutdown the machine quickly.

7.5.11 Shahapur Mini Hydro Schemes

The Shahapur mini hydro schemes, of 6.6 MW, comprises of 5 independent power plants designated as Scheme 1, Scheme 2, Scheme 3, Scheme 4 and Scheme 5. These schemes are spread over a distance of 15 kms. Of these, Scheme 3 is centrally located and power from the other schemes is pooled at this scheme and transmitted further to Karnataka Power Transmission Corporation Limited (KPTCL) substation. Scheme 3 being centrally located is manned by engineers while the other schemes are manned by technicians. It was observed that there were inordinate delays in restarting of machines at these schemes due to lack of expertise of the technicians. Hence it was decided to implement the automation of the plants so that all the schemes can be controlled from Scheme 3 such that the engineer at Scheme 3 has access to all the information at the other schemes and can effectively operate and control the Schemes. In the first stage, Scheme 1 and Scheme 3 are automated with the provision of remote operation of Scheme 1 from Scheme 3 through an optic fiber link.

The automation system at Scheme 3 comprises of

a) Unit Control board for Scheme 1
b) Unit Control board for Scheme 3
c) Unit Control board for Switchyard at Scheme 3
d) Optic Fibre link for communication between Scheme 1 & Scheme 3
e) HMI work station for two units and switchyard
f) Portable engineering and maintenance tool box in a notebook PC

The control system is organized in a decentralized manner and provides control from remote for Scheme 1 and from local for Scheme 3. The automation system can be operated in 3 modes.

a) Auto mode: By a single click of the mouse, the machine can be brought from standstill to line operation (synchronized with the grid) and vice versa. In this mode all the steps in the start/stop sequence, like auxiliaries on/off, excitation on/off, etc. will be carried out automatically.

b) Step by Step mode: In the Step by Step mode, each step of the start stop sequence will be executed on the click of the mouse.

c) Manual mode: The manual mode is used to start all the auxiliaries and is used mainly during testing.

The automation system equipment constitutes a state of the art computer based hydro-electric power plant automation system. The automation system uses the following standard product platforms of the "Neptun" systems developed specially for automation of the hydro projects by VA Tech SAT GmbH & Co.,

a) SAT200 - the central control room computer system.
b) SAT1703 ACP - the Automation System

Every single functional area consists of an Automation Component SAT1703, several processing elements and the necessary amount of peripheral boards. Open loop and close loop control functions are created according to IEC 61131-3. Functions implemented in the power house are machine starting, stopping and synchronization, closing/opening of transformer breakers, valves, monitoring of all parameters in HMI, remote operation of Scheme 1 from Scheme 3.

7.5.12 Chhayadevi Mini Hydro Project

This project of 2×12 MW has a Digital Governor & Digital Voltage Regulator. This system has auto sequencing implemented but neither has SCADA nor does it has any touch screen type HMI. VA TECH SAT make TC-1703 Control system for Digital Governor and VA TECH SAT make GMR3 Control system for Digital Voltage Regulator. The system architecture consists of speed control & monitoring schemes, auto starting cum auto sequencing scheme and synchronizing scheme. The operation of machines i.e. start & stop of auxiliaries, start & stop of machines, auto synchronizing, emergency shutdown is performed by the automation system.

7.5.13 Neria Mini Hydro Project

This project of 2×4.5 MW capacity uses PLC based MMI, governor and auto synchronizer. The project has control implemented at only plant level and no central control. Its system architecture consists of a processor, 5 digital input modules, 2 digital output modules, 2 analog input modules, auto synchroniser and MMI. Automated operation is extended to operation of machines i.e. start & stop of auxiliaries, start & stop of machines, auto synchronizing, emergency shutdown. Machine starts, synchronises and loads upto minimum load. Further load increasing is done manually through push buttons. MMI displays status of auxiliary systems and alarms.

7.6 Conclusion

We have observed that in spite of implementation of a lot of functions, they are not being used. The auto operation of intake gates is seen to be quite successful. Trash rack condition monitoring is not implemented at all. At about half of the places operation of BFV and other auxiliaries is not used in automation. A good number of plants have their parameters being displayed at HMI but logging of parameters through SCADA is not so popular. At half of the plants HMI is not used for controlling and monitoring all units. Reason of non-usage of the system is either "not in operation" or "preference for manual operation mode".

We have also seen the implemented automation system at various power plants. At one location no manual control is implemented as back up to the automated control scheme and at other place the automated control scheme is implemented on PLC but it makes no interaction with human (no HMI present). All the power plants include local control and start stop sequence through controller and centralized control through the control room. Some of them include auto synchronizing. But none of them includes turbine operation optimization (efficiency maximization) or trash monitoring or head loss monitoring. The data at the site are recorded somewhere manually and at other places through MS excel sheets. The central control is followed by six power plants and offsite control is followed at one power plant. One case of rehabilitation and renovation is also included.

Chapter 8 – Status Of Automation

8.1 Introduction

The previous chapter dealt with the extent of automation at different power plants and the reporting of the control system implemented under automation. But it was observed that at many places the implemented system was either not functioning or not being used because of preference given to manual over operation. This chapter deals with the actual status of the working of the automation system implemented the power plant discussed in Chapter 7.

This chapter also covers discussion of the feedback of different power plant personnel, the problems faced by them and the probable solutions to them. It also covers the result of the survey questionnaire feedback of the different personnel at the site.

8.2 Status of Automation System

This section covers the status of the automated control system implemented at the various power plants. This section has been divided on the basis of the companies owning the power plant. Initially the general and overall discussion about the company is mentioned. The views of any higher official of the company, wherever possible, are discussed before giving the status of the control system at the power houses and specifying the problems faced at the power houses.

8.2.1 Polyplex Hydro Corporation Limited

The power plants visited in Punjab are owned by Punjab Hydro Power Ltd. and Kotla Hydro Power Ltd. This is to be noted that both of these companies are subsidiaries of Polyplex Hydro, Noida. Since all the power plants are under the same company thus their "views" and "way of operation" is combined under a single heading in this section. In all the other parts of the thesis, the power plants are discussed as a part of the individual companies.

The operators at the power plants visited in Punjab are ignorant about the use of automation and the advantages gained thereby. Narangwal (1500 kW) at RD 69500, Chupki (1500 kW) at RD 47000, Dalla (1000 kW) at RD 180000 and Tugal (1500 kW) at RD 128000 on Abohar Branch Canal were developed with centralized control by Punjab Energy Development Agency (PEDA) but the operation were unsuccessful.

Some of the operators and supervisors at the plants covered in this study have worked at the above mentioned power plants and have experienced the non-operation of automation system. This non-operation was mainly due to the lack of proper training about the automation system. This has caused a fear in them for the system. The system is alien to them, sort of a black box. They are very comfortable in operating the plant in manual mode. But this is not the absolute case. Some operators find the system useful (appreciate the data logging capability to check the status of various devices at the time of any fault.) but they are following the operating sequence blankly. They don't know the capabilities of the system. They are trained by their senior supervisors and thus again a lack of proper training is felt.

Also at all the power plants under Polyplex Hydro, inspite having automated control system based on either SCADA or MMI, the operation of all the plants are done manually. The reason at some place being "faulty" automated system and at other places it's the preference or ease of operation at manual mode. We suggest the use of self diagnostic feature for control system hardware and software. This would alert the operators beforehand and would reduce the problems.

All the plants are operating the main canal gates in automation. At Salar, the SCADA system is being used for monitoring the data. The operators prefer SCADA than HMI because of its data logging (archiving) capacity and interaction with the user.

Faults in the automation system are reported to seniors. But the seniors or the management money involved in calling the experts and fault correction. They are concerned with generation immaterial of the mode of operation. Experts from the manufacturers or service providers charge approx Rs. 4000/hour.

Moreover an interesting thing noticed was they have developed a system called POMS (Plant Operation and Maintenance System) which is used for logging all the data of the power house into the system and sharing it with the higher officials. This could have been easily done using the sheets generated by the SCADA system. But the unawareness about all the functions of the system and how to use them could have been the reason of the implementation such a system (POMS). But they call it a decision of the higher management in which they have "no control". We appreciate the use of POMS system but this is a clear indication of the ignorance about the SCADA system. Moreover, The logged data is not used for any analysis.

Now individual power plants under Polyplex Hydro are explained.

a. Salar MHP: The system at Salar is SCADA based but the operation of the plant is done manually. A strange thing was reported that the automated mode of operation takes a longer time for start/ stop sequence of the machine than the manual operation of machine. Reason for this is reported that the auto operation is done in fixed pulses while in manual mode the pulse lengths can be changed by the operator, thus causing quicker action. The power plant people don't realize the harm they are causing to the machinery by this action.

b. Dolowal MHP: This plant has the same configuration as that of Salar and the status is also similar.

c. Banbhaura MHP: Though automation was in MMI but the operators don't find it user friendly. Here the fear for the system was very evident. The reasons cited were lame. This site experiences frequent grid failure which causes damage in cards due to surges. When asked about the damage in case of manual operation, they agreed regarding the damage but they fix the problems of instruments used in manual operation mode in about half an hour. This highlights their ignorance about the system. A solution of using surge arrestors was suggested, this was disregarded on the ground that grid substation is nearby so even surge arrestors can't resist it.

This automation system having touch screen as HMI didn't operate since the starting. PLC had a problem in processor and also, it was facing some problems with the signals to the auxiliaries. After a long wait they got it repaired and also a spare processor is used for any future problem. But the operation of the power house was in manual mode. The person talked to have an experience of 10 years in hydro.

d. Babbanpur MHP: This station uses SCADA based automation. But as reported by the operators, the reason of fault is not clear when unit trips. This shows the unawareness about the automation system. At this station, the operation through automation system is neither used when the discharge is almost rated nor in lean discharge. But on an average discharge, the operator would prefer auto operation of machine.

The reactions of the operators were mixed here. (The reactions may be influenced also. Our disappointment in the response about the system at the previous power plants might have led them to respond in a diplomatic way). They don't think that automation system does any help in fault detection as the alarms and annunciation is present in manual mode of operation also.

At the time of fault, the status of all the equipments is time stamped. And the operator is a bit relaxed. The data logging in daily log register is done after cross checking from SCADA panel and manual panel. They don't monitor the level of trash or the real reason behind the increase in water level. The training of new operators is through the old & experienced operators.

e. Killa MHP: The operators here are new and since their arrival the system is not working. They are unaware of the automated system (MMI). Their views are based on the views of seniors and on the experience of Babbanpur project where some of them worked.

According to them, efficiency is better in manual mode of operation. PLC at this site does not respond to the commands related to auxiliaries in a proper manner. The possible reason can be control system design problem or card problem. At present, they do not operate the system through PLC. Though they receive the status of many attributes on the HMI and monitor the attributes from the screen. Trash is high, affects generation (this power house has no trash removal mechanism. Manual cleaning of trash rack is done.)

The operators are of the opinion that the data shown on screen is reliable. They would prefer auto mode, if it works properly and with more efficiency. The operators prefer SCADA than HMI because of its data logging (archiving) capacity and interaction with the user.

f. Sahoke MHP: The operators here prefer manual operation of plant than auto operation but at the same time are satisfied with auto gates. Also they would prefer SCADA than MMI- running the plant with one touch and then monitoring the whole thing by the SCADA system. They recommend the use of trash rack cleaning machine in all power plants (since it's not present here). System (except canal gate operation) is working in manual since commissioning. Level meter reading wrong- some problem with display (sensor seems fine since it is calibrated time to time). Guide vane opening indicator is not present – running plant by experience.

Overall the people in the power house have the opinion that the automation is good for implementation. They appreciate the data logging facility.

A set of the power house personnel is ignorant and is satisfied in manual mode of operation. Other set appreciates the system but follow it blankly. A set of power house personnel are willing to work or use but are not much aware about the system. All these things point to the need of training of power house personnel and creating awareness about the automation system.

8.2.2. Sri Maruthi Power Gen

Kabini MHP has been commissioned in 2003 without any manual control and the operators here do not have any issues against automation or working in automated mode. The plant is in a well maintained condition. There has not been any manual control implemented in this plant and has received its major outages on account of grid failure only and not related to the automated system.

This complete automated system does not ensure an unmanned operation. There is a need of operator for surveillance and to take corrective action in case of any malfunction. Electrical engineer at site is of the opinion that it saves the complications that the manpower faces and time and makes the operator relaxed. This multifunctional system does the maximum work and operator's duty is to supervise it.

The general problem areas at any power plant are that of trash, silt and grid failure. At this site, first two of the causes i.e. silt and trash is not present. The major outages caused at this power plant are due to grid failures only. Some other causes of outages at the site are earth fault, high temperature, and main supply failure.

8.2.3 Pioneer Genco Ltd.

According to the manager, there are no problems in hardware of the automated control system. They have experience with issues related to the software i.e. the manufacturers provided general control software for site instead of the case specific control scheme. This causes many problems, for example improper relay co-ordination, grid stability issues, etc. So the design of any automation system must be case specific.

According to the manager, maximum cost of automation of the project is less than 2% of total cost. But they would not want to spend even 2% of total cost for small hydro automation. They would recommend its implementation only if the system is cost effective. Also if the automation system is implemented, its best use should be made.

At both of the power houses, gates are not automated. They have operators who monitor the level of water, operate the gates and communicate the status to the operators through intercom. Also there is no provision of discharge measurement at the site.

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At both of the power houses, gates are not automated. They have operators who monitor the level of water, operate the gates and communicate the status to the operators through intercom. Also there is no provision of discharge measurement at the site.

The operation of the power plant in automation is done in days of normal discharge. During rainy season and lean season, the operation of the power plant is done in manual since no communication of the discharge or the position of gates is sent to the SCADA system.

a. Someshwara: At Someshwara, personnel had some organizational issues and were hesitant to share their views. The operators opine that automated operation takes more time in starting and loading while shutdown is almost the same time. There will not be any considerable change in the output of the units i.e. efficiency in manual mode and automation mode.

Head loss is not monitored at the site. It is guessed through the reduction in load (at full discharge and head, without any other apparent reason, if there is decrease in generation then the reason can be trash. Plant is shut down and canal is dewatered, cleaning is done manually or through motor cranes by help of labor.

b. Ranganathaswamy: The operators opine that automated operation takes more time in starting and loading while shutdown is almost the same time. There will not be any considerable change in the output of the units in manual mode and automation mode. The trends from SCADA are not being generated from some time. But no problem in input output cards. The communication of 66 kV is not being communicated on SCADA system. The MS excel sheets showing the data of the power plants are not generated by the SCADA system.

They are planning to put a trash cleaning device at the station. Silt sometimes creates loads of problem, need to stop the machine, drain water and clean it. Some other reasons of outage are grid related like line fault, earth fault, unbalanced load, etc.

8.2.4 Bhoruka Power Corporation Ltd.

During the visit to Bangalore, a visit to Managing Director, Bhoruka Power Corporation Ltd was paid. This company has several small hydro power plants commissioned and is claimed to be the first company in Indian private sector to successfully commission hydro power station in post-Independence era. The decision of this visit and thus the arrangement of the meeting on a very short notice were possible entirely due to the strong alliance of Dr. Arun Kumar with Managing Director.

According to him, technology is not costly, the loss with its non-usage would be much more than the capital cost incurred in using automation. Touch screen is a thing all can afford and must be promoted. Quality of transducers should be improved- locally also. Field instruments quality should be improved. The specifications given to equipment manufacturers for the designing of the system are poor.

He felt that there is a mental block which has to be improved among the power plant owners. Instead of being money oriented- we should be delivery (output) oriented and technology oriented. All care should be taken at specifications, design, manufacturing, installation and commissioning.

Even the consultants and manufacturers should be sensitized. Their concerns should be discussed. Basic design criteria should follow this sequence of priority:

a) Optimization of energy generation
b) Reliability of plant
c) Low maintenance
d) Capital cost

Capital cost should be the last concern. Design flaws should be taken care of at initial stages. As far as the control logic is concerned he recommends that first logic should be defined by developers and then all the specifications of site, e.g. grid stability, water flow, etc, should be checked by manufacturers and then controls of PLC should be added/replaced.

Since the data of the three projects, namely Shahapur, Neria and Chhayadevi were taken through mail so the actual status is mentioned to the same as was reported by the officials. At Shahapur, one of the two machines is working in manual mode since the last six months, due to communication error step 2 failure. (OPU System pressure not build up). Present working status of Neria and Chhayadevi is satisfactory. There are no problems reported.

8.2.5 Kerala State Electricity Board

Panniar Power Project was commissioned in 2009 after rehabilitation and renovation. Since the data of Panniar project was taken through correspondence so the working of the power plant is believed to be good, as reported. There are no problems reported.

8.3 Reason of Implementing Automation

The reasons of implementing the automation system varied greatly in from the quest to be the first one to implement the new technology to the adaptation of the latest technology. Some of the reasons are mentioned as under:

Chhayadevi SHP was automated to make use of new technical developments for company's growth. The main aim was to minimize the time of startup/stop and to eliminate human error in operation control which may damage the equipment/machine. Shahapur schemes has five power plants far away from each other thus centralized control was implemented to control and monitor all the units monitor from single place. Automation of Neria SHP was included in design stage itself to adopt latest technologies. Ranganathaswamy SHP and Someshwara SHP were automated in the quest to build state's first fully automated power plant is the small hydro sector.

8.4 Various Benefits Observed by End Users

The benefits of automation system were mentioned in Chapter 1, the benefits as observed by the end users have been cited as under. Benefits experienced by the users are important to understand the extent of benefits realized at the site. At Chhayadevi SHP, automation system helped in reducing starting time of machine, reducing downtimes with perfect fault locating, accurate monitoring and maintaining data for long time. At Shahapur SHP, it has enhanced skills of engineers, simplified the understanding of the logic of operations, helped in smooth operations of the machines. Fault diagnoses have become very easy, operating cost of the plant has reduced & employee's skills have improved. At Neria SHP, starting and loading of machine upto minimum load is done by one PB operation. Start up of the machine is faster, synchronization of the machine is quicker, prestart checks are made easier as all information related to turbine floor is available on the touch screen, cam relation between runner blade and guide vane is accurate, less manpower required, and maintenance has become easy due to effective & immediate feedback of problems.

The advantages experienced by Someshwara SHP are correct sequence of operations, fast synchronizing of generator, fast loading and water level controlling. At Ranganathaswamy SHP, the system has helped the maintenance people in planning equipment maintenance schedules and also keeps track of possible faults that may occur in future. It has reduced man power and time. Operating procedure has becomes foolproof thus helps in protection of unit. Generation increases since the recovery of machine is quicker.

At Babbanpur SHP, the operators have become more relaxed by the use of automation system. The advantage of automation at Killa is that it has made fault detection and correction easy and the operation in auto mode is safe. Accurate constant level maintained at intake and automatic voltage regulation. Automation system at Sahoke SHP has reduced monitoring work. Easy synchronization along with set point generation is the best feature at Salar SHP.

8.5 Results of Survey Questionnaire

The detailed structured questionnaire was designed with various features of automation. These features were to be rated with the ratings as mentioned under and were given a numerical rating as:

a) Strongly disagree- 1
b) Somewhat disagree- 2
c) Neutral-3
d) Somewhat agree- 4
e) Strongly agree- 5

The structured format of the questionnaire had five main attributes namely level of satisfaction, availability of trained operators, ease of understanding operation, maintenance and performance. According to the questionnaire, these attributes had some questions under each of it. Thus using the numerical weightage, the maximum value of each attribute is mentioned in Table 8.1. The data taken from power plant and the survey questionnaire template is attached in Annexure 3.

Table 8.1: Weightage of different attributes

S. No.	Attributes	Maximum Numerical weightage or feedback rating
1.	Level of Satisfaction	20
2.	Availability of trained operators	15
3.	Ease of understanding operation	20
4.	Maintenance	20
5.	Performance	35

The questions asked under each attribute were given the rating as explained earlier in this section. Thus table 8.1 shows the maximum possible feedback rating for all the attributes by assigning the highest possible :weightage to all the questions i.e. '5'. The maximum possible feedback rating is different for different attributes because of the changes in the number of questions under each attribute. In the second attribute – "Availability of trained operators" either first or second question is to be evaluated, thus the maximum weightage is 15 inspitee of four questions.

The fields/areas/ dimensions of the survey was quite large covering well diversified fields of personnel covered Sr. managers, managers, Sr. engineers, engineers, site incharge, supervisors, technicians and operators. However, at all the stations interview of all the persons could not be done due to the unavailability of many of them.

The operators at Killa HEP are new and since their arrival the system is not working. Their views were based on the views of seniors and on the experience of Babbanpur project where some of them worked. A similar story is for Sahoke HEP. Thus both of the plants are not used in the analysis. Thus only Babbanpur is considered in Kotla Hydro Power Ltd.

The comparison is done in three ways and thus the results are obtained by:

a) Comparison in the viewpoint of companies
b) Comparison in the type of SHP plants
c) Comparison on the basis of designation

For each company, the questionnaires filled by all the personnel were averaged to get a result for that company. The rating obtained was tabulated graphically for each of the company. The name of the company is represented as follows in the graph, namely: Bhoruka Power Corporation Ltd (BPCL), Sri Maruthi Power Gen (SMPG), Pioneer Genco Ltd. (PGL), Polyplex Hydro Pvt. Ltd. (PHPL) and Kotla Hydro Pvt. Ltd. (KHPL).

Table 8.2: Comparison of Views of company

Attributes	Company	Power Plant	Designation	Rating	Average Rating
Satisfaction Level	BPCL	Chhayadevi	Manager	19	0.85
		Neria	Manager	17	
		Shahapur	Manager	14	
		Chhayadevi	Engineer	20	
		Neria	Engineer	17	
		Shahapur	Engineer	18	
			Sr. Manager	14	
	SMPG	Kabini	Engineer	16	0.78
			Operator	15	
	PGL	Ranganathaswamy	Manager	11	0.55
	PHPL	Dolowal	Operator	17	0.68

		Salar	Operator	17	
		Banbhaura	Operator	7	
	KHPL	Babbanpur	Operator	10	0.50
Availability trained operators	BPCL	Chhayadevi	Manager	13	0.84
		Neria	Manager	10	
		Shahapur	Manager	12	
		Chhayadevi	Engineer	14	
		Neria	Engineer	12	
		Shahapur	Engineer	14	
			Sr. Manager	13	
	SMPG	Kabini	Engineer	9	0.70
			Operator	12	
	PGL	Ranganathaswamy	Manager	12	0.80
	PHPL	Dolowal	Operator	10	0.67
		Salar	Operator	10	
		Banbhaura	Operator	10	
	KHPL	Babbanpur	Operator	9	0.60
Understanding operation	BPCL	Chhayadevi	Manager	20	0.93
		Neria	Manager	15	
		Shahapur	Manager	19	
		Chhayadevi	Engineer	19	
		Neria	Engineer	16	
		Shahapur	Engineer	19	
			Sr. Manager	22	
	SMPG	Kabini	Engineer	17	0.90
			Operator	19	
	PGL	Ranganathaswamy	Manager	12	0.60
	PHPL	Dolowal	Operator	17	0.53
		Salar	Operator	11	
		Banbhaura	Operator	4	
	KHPL	Babbanpur	Operator	14	0.70
Maintenance	BPCL	Chhayadevi	Manager	19	0.88
		Neria	Manager	17	
		Shahapur	Manager	18	
		Chhayadevi	Engineer	20	
		Neria	Engineer	14	
		Shahapur	Engineer	15	
			Sr. Manager	20	
	SMPG	Kabini	Engineer	11	0.73
			Operator	18	

	PGL	Ranganathaswamy	Manager	14	0.70
	PHPL	Dolowal	Operator	6	0.27
		Salar	Operator	4	
		Banbhaura	Operator	6	
	KHPL	Babbanpur	Operator	10	0.50
Performance	BPCL	Chhayadevi	Manager	33	0.80
		Neria	Manager	23	
		Shahapur	Manager	21	
		Chhayadevi	Engineer	34	
		Neria	Engineer	25	
		Shahapur	Engineer	30	
			Sr. Manager	31	
	SMPG	Kabini	Engineer	27	0.81
			Operator	30	
	PGL	Ranganathaswamy	Manager	22	0.63
	PHPL	Dolowal	Operator	16	0.50
		Salar	Operator	18	
		Banbhaura	Operator	18	
	KHPL	Babbanpur	Operator	15	0.43
Legends:					
BPCL: Bhoruka Power Corporation Ltd					
SMPG: Sri Maruthi Power Gen					
PGL: Pioneer Genco Ltd.					
PHPL: Polyplex Hydro Pvt. Ltd.					
KHPL: Kotla Hydro Pvt. Ltd.					

The company wise comparison (Figure 8.1) shows Bhoruka Power Corporation Ltd. is most "satisfied" with the overall automation system with rating of 0.85. The response of Kotla Hydro Power Ltd. is a bit poor in "satisfaction level" with 0.50 feedback rating. The range of feedback for "availability of trained operators" varies from 0.60 to 0.84. The "ease of understanding" of the system is best rated by BPCL at 0.93. At the same time, PGL and PHPL rated t at 0.60 and 0.53 respectively. According to PHPL, the system is quite difficult to "maintain". This was evident at the time of visit, their system was not working properly and they were using manual mode of operation. The "maintenance" of the system varies from as low as 0.27 to as high as 0.88. The "performance" of the system is rated between 0.43 by KHPL and 0.81 by SMPG. The results of this survey may also be concluded in the sense that companies of north side of India (PHPL and KHPL) are less satisfied than the companies of the south side of the country (BPCL, PGL and SMPG).

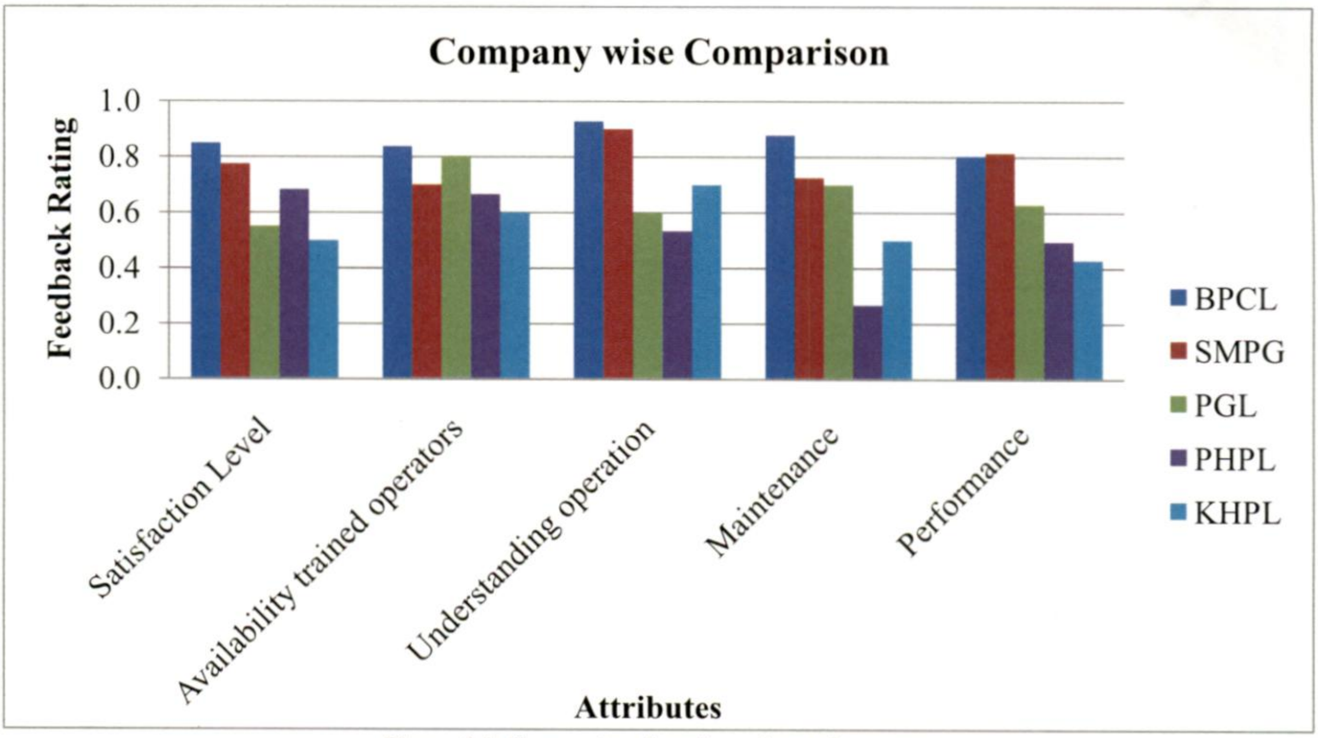


Figure 8.1: Comparison based on views of company

The comparison of feedback for different types of power plants i.e. Run-of-river (ROR), Dam Toe based (DTB) and Canal Based (CB) is shown in Table 8.3. For this the power plants of same kind were sorted together and the feedback ratings of all are averaged. The graphical representation of this comparison is shown in Figure 8.2.

Table 8.3: Survey Feedback for different types of SHP Plants

Attributes	Category	Power Plant	Designation	Rating	Average rating
Satisfaction Level	ROR	Chhayadevi	Manager	19	0.84
		Chhayadevi	Engineer	20	
		Ranganathaswamy	Manager	11	
		Neria	Engineer	17	
		Neria	Manager	17	
	DTB	Kabini	Engineer	16	0.78
			Operator	15	
	CB	Shahapur	Manager	14	0.69
		Shahapur	Engineer	18	
		Dolowal	Operator	17	
		Salar	Operator	17	
		Banbhaura	Operator	7	
		Babbanpur	Operator	10	
Availability	ROR	Chhayadevi	Manager	13	0.81

trained operators		Chhayadevi	Engineer	14	
		Ranganathaswamy	Manager	12	
		Neria	Engineer	12	
		Neria	Manager	10	
	DTB	Kabini	Engineer	9	□□70
			Operator	12	
	CB	Shahapur	Manager	12	0.72
		Shahapur	Engineer	14	
		Dolowal	Operator	10	
		Salar	Operator	10	
		Banbhaura	Operator	10	
		Babbanpur	Operator	9	
Understanding operation	ROR	Chhayadevi	Manager	20	0.82
		Neria	Manager	15	
		Chhayadevi	Engineer	19	
		Neria	Engineer	16	
		Ranganathaswamy	Manager	12	
	DTB	Kabini	Engineer	17	0.90
			Operator	19	
	CB	Shahapur	Manager	19	0.71
		Shahapur	Engineer	19	
		Dolowal	Operator	17	
		Salar	Operator	12	
		Banbhaura	Operator	4	
		Babbanpur	Operator	14	
Maintenance	ROR	Chhayadevi	Manager	19	0.84
		Neria	Manager	17	
		Chhayadevi	Engineer	20	
		Neria	□ngineer	14	
		Ranganathaswamy	Manager	14	
	DTB	Kabini	Engineer	11	0.73
			Operator	18	
	CB	Shahapur	Manager	18	0.49
		Shahapur	Engineer	15	
		Dolowal	Operator	6	
		Salar	Operator	4	
		Banbhaura	Operator	6	
		Babbanpur	Operator	10	
Performance	ROR	Chhayadevi	Manager	33	0.78
		Neria	Manager	23	
		Chhayadevi	Engineer	34	
		Neria	Engineer	□5	

		Ranganathaswamy	Manager	22	
	DTB	Kabini	Engineer	27	0.81
			Operator	30	
	CB	Shahapur	Manager	21	0.56
		Shahapur	Engineer	30	
		Dolowal	Operator	16	
		Salar	Operator	18	
		Banbhaura	Operator	18	
		Babbanpur	Operator	15	
Legends:					
ROR: Run-of-river					
DTB: Dam Toe Based					
CB: Canal Based					

If we compare on the basis of different types of power plant (Figure 8.2), canal based project people gave least rating to their system in all the attributes and run-of-river project were the most happy with the system and gave maximum ratings. "Satisfaction level" of power plants varied from 0.69 for CB to 0.84 for ROR. The "availability of trained operators" was found to be best by ROR projects with 0.81 rating. DTB don't find trained operators easily and rated it at 0.70. Dam toe based plant find the automation system 'easy to understand' with 0.90 rating. At the same time, canal based projects find it average with 0.71 rating. Canal based projects found the automation system difficult to maintain with 0.49 rating while run-of-river found maintenance normal at 0.84 rating. In case of performance of the system, run-of-river and canal based were almost satisfied to the same level while canal based project dint agree with it. The rating for 'performance' varies from 0.56 to 0.81.

The third comparison is done on the basis of the designation of the personnel. It is shown in Table 8.4. A similar way was adopted to get the result of this section. All the personnel of same rank were sorted in one category. The opinion of general manager, Sr. manager and managers were merged under "Manager" category. Feedback of Sr. engineers and engineers were merged under "Engineer" category and similarly, site incharge, supervisors, technicians and operators all fell into the category of "Operator". The feedback ratings given by each "category" was averaged to get the result.

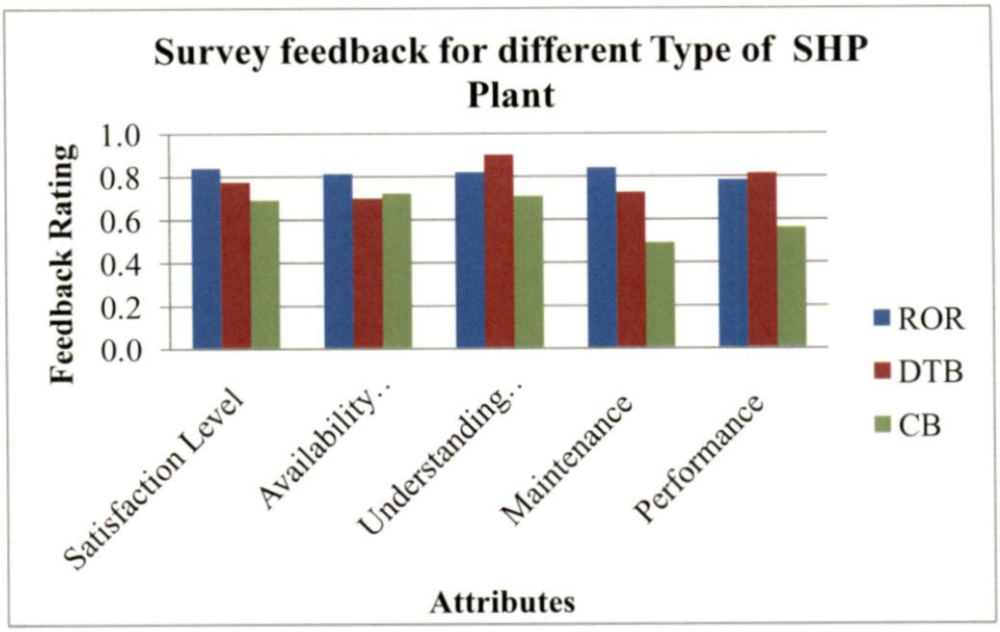


Figure 8.2: Survey feedback for different type of SHP plant

Table 8.4: Feedback based on designation

Attributes	Category	Power Plant	Designation	Rating	Average Rating
Satisfaction Level	Manager	Chhayadevi	Manager	19	0.75
		Neria	Manager	17	
		Shahapur	Manager	14	
		Ranganathaswamy	Manager	11	
		Bhoruka	Sr. Manager	14	
	Engineer	Kabini	Engineer	16	0.89
		Neria	Engineer	17	
		Shahapur	Engineer	18	
		Chhayadevi	Engineer	20	
	Operator	Kabini	Operator	15	0.66
		Dolowal	Operator	17	
		Salar	Operator	17	
		Banbhaura	Operator	7	
		Babbanpur	Operator	10	
Availability trained operators	Manager	Chhayadevi	Manager	13	0.80
		Neria	Manager	10	
		Shahapur	Manager	12	
		Ranganathaswamy	Manager	12	
		Bhoruka	Sr. Manager	13	
	Engineer	Kabini	Engineer	9	0.82
		Neria	Engineer	12	
		Shahapur	Engineer	14	

		Chhayadevi	Engineer	14	
	Operator	Kabini	Operator	12	0.68
		Dolowal	Operator	10	
		Salar	Operator	10	
		Banbhaura	Operator	10	
		Babbanpur	Operator	9	
Understanding operation	Manager	Chhayadevi	Manager	20	0.88
		Neria	Manager	15	
		Shahapur	Manager	19	
		Ranganathaswamy	Manager	12	
		Bhoruka	Sr. Manager	22	
	Engineer	Kabini	Engineer	17	0.89
		Neria	Engineer	16	
		Shahapur	Engineer	19	
		Chhayadevi	Engineer	19	
	Operator	Kabini	Operator	19	0.65
		Dolowal	Operator	17	
		Salar	Operator	11	
		Banbhaura	Operator	4	
		Babbanpur	Operator	14	
Maintenance	Manager	Chhayadevi	Manager	19	0.88
		Neria	Manager	17	
		Shahapur	Manager	18	
		Ranganathaswamy	Manager	14	
		Bhoruka	Sr. Manager	20	
	Engineer	Kabini	Engineer	11	0.75
		Neria	Engineer	14	
		Shahapur	Engineer	15	
		Chhayadevi	Engineer	20	
	Operator	Kabini	Operator	18	0.44
		Dolowal	Operator	6	
		Salar	Operator	4	
		Banbhaura	Operator	6	
		Babbanpur	Operator	10	
Performance	Manager	Chhayadevi	Manager	33	0.74
		Neria	Manager	23	
		Shahapur	Manager	21	
		Ranganathaswamy	Manager	22	
		Bhoruka	Sr. Manager	31	
	Engineer	Kabini	Engineer	27	0.83
		Neria	Engineer	25	
		Shahapur	Engineer	30	

		Chhayadevi	Engineer	34	
	Operator	Kabini	Operator	30	0.55
		Dolowal	Operator	16	
		Salar	Operator	18	
		Banbhaura	Operator	18	
		Babbanpur	Operator	15	

From Table 8.4 and figure 8.3, it is clear that engineers are more satisfied with the overall system than managers or operators. The 'satisfaction level' of operators is lowest at 0.66 while engineers are most satisfied with 0.89 rating. Ironically on the point of availability of trained operators, the manager and engineers are better satisfied than operators themselves. The 'ease of availability of operators', according to engineers and managers, is good and rated it 0.80 but operators themselves find it difficult and rated it at 0.68. Same is the case

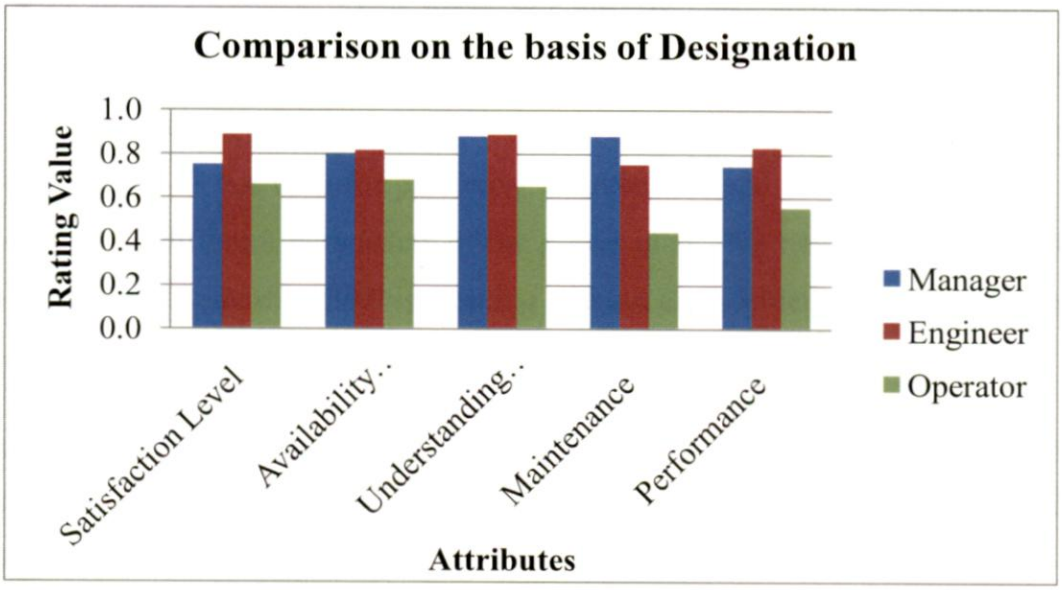


Figure 8.3: Comparison on the basis of designation

with the "ease of understanding of the system". Managers and engineers rate the "ease of understanding operation" of the system at 0.88 and 0.89 respectively while operators rate it at 0.65. On the point of maintenance, the operators are least satisfied with a rating as low as 0.44, flowed by engineers with 0.75 and managers at 0.88 rating. Regarding the performance of the system, engineers have rated more than managers 0.83, 0.74 and 0.55 respectively.

8.6 Operating Staff at Various Power Plants

It is considered that due to automation, the need of staff would decrease significantly. It has been noted that the need of operators and supervisors is not reduced to a great extent. The manpower used earlier for checking the status of auxiliaries is not required, else the operators and supervisors are required to take action in case of need. Also the technical and maintenance staff would be required in almost the same number in automated and manual mode of operation. Following is the number of operating staff used at various power plants.

Pioneer Genco Ltd.: Per shift: 1 electrical engineer, 1 mechanical engineer, 1 technician and 1 fitter is present.

Bhoruka Power Corporation Ltd.: Per shift: 1 electrical engineer, 2 helpers- ITI electrician & ITI fitter

Maintenance staff: 1 engineer, 2 helpers – 1 electrical & 1 mechanical

Sri Maruthi Power Gen: Per shift: 1 diploma, 1 ITI, 1 incharge, 1 civil engineer, 1 security.

8.7 Conclusion

Thus we have seen different problems at the power houses and discussed the reasons or solutions to those problems. Most often the problem was with the ignorance and/ or acceptance of the system. Other problems are common design of the plant automation system, diagnosis of automation system. We have observed that data logging is done by the system but the data is not used for predictive maintenance and control and same is the case with the trends of different parameters of the power plant. We have also observed the plant with no manual back control which is working without any problem. Also we saw the case of a rehabilitation and renovation project which is working equally well.

The reason for implementing automation was generally to adopt the latest technology. Most of the benefits mentioned in Chapter 1 have been realized at various power plants. The fault detection is one of the most popular benefits of the system.

The result of survey questionnaire revealed that companies in South end of the country are more satisfied with the automation system. The automation system was found to be more successful in run-of-river plants and least successful in canal based projects. The operators gave least ratings in all the attributes than managers and engineers. Thus the actual users of automated system are less contented with the system as a whole. This points out the ignorance about the system and highlights the need of training of operators. The section where number of operating personnel at the plant is mentioned shows that requirement of operating staff reduces but not to a great extent.

Chapter 9 - Financial Analysis

9.1 Introduction

However technological feasible or advantageous any new technology is but if it is not economically viable, it cannot gain popularity. Here some scenarios have been considered and the analyses have been done for them. The outage data and cost data used in the analysis have been taken from the power plants and assumptions made are mentioned wherever used.

The following types of financial analysis done namely:

a.) Loss due to closure of plant operation for trash cleaning
b.) Loss due to head loss caused by trash blockage
c.) Loss due to change in startup time
d.) Loss of water during startup
e.) Fatigue during start-up and shut-down
f.) Loss of opportunity

The revenue in all the cases has been calculated considering that the tariff is INR 2.5/ unit. The following formulae are used throughout the chapter:

1. Power Equation, $P = 9.81 \times Q \times H \times \eta$
2. Energy Equation, $E = P \times t$
3. Revenue = $E \times 2.5$

Where, P = Power (kW)
Q = Discharge (cumecs)
H = Head (m)
η = Efficiency
E = Energy (kWh)
t= time (hour)

9.2 Losses Due To Closure of Plant Operation for Trash Cleaning

Trash is a menace to run-of-river hydropower projects. In India, we have trash racks cleaned either manually or mechanically. Often the frequency of cleaning the trash rack is based on experience-based-judgment, convenience and man power available at the power house.

During night especially the cleaning of trash rack is not regular. Many times, trash sticks to the trash rack so hard that the unit is shut down to clean.

Such outage data was collected from eight power houses, namely Dolowal, Salar, Banbhaura, Babbanpur, Killa, Sahoke, Someshwara and Ranganathaswamy. The first six plants are canal based and latter two are run-of-river. Table 9.1 shows the capacity, discharge and head for each power house. The total outage time/ year has been collected from the power house. Thus the annual energy lost is calculated using energy equation. The revenue loss is calculated by taking the cost of energy to be INR 2.5/ unit.

The annual loss caused by closure due to trash rack cleaning is found to be almost same for all the cases as is clear from Table 9.1. Since the plants are all of different capacities so to neutralize this effect of different capacities, the revenue loss is divided by the installed capacity (kW) and the result is shown in loss per installed capacity (INR/ kW). This is shown in figure. 9.1. It is found to be maximum at Dolowal. This power plant is the first on this Kotla canal so it is expected that it would receive maximum trash. The loss reduces for the next plant Salar but is significant for Banbhaura and Babbanpur. The loss is minimum for Ranganathaswamy.

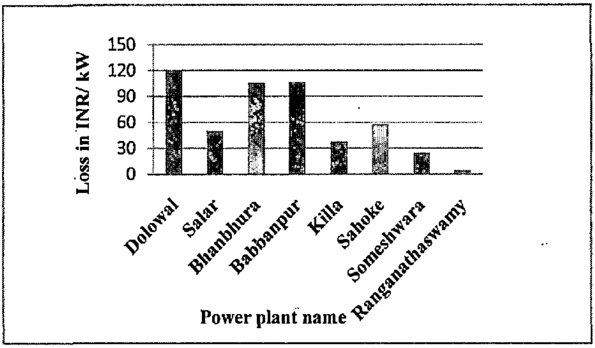


Figure 9.1: Annual loss due to closure for cleaning trash rack

Table 9.1: Loss due to closure of plant operation for cleaning trash rack

Name	Dolowal SHP	Salar SHP	Banbhaura SHP	Babbanpur SHP	Killa SHP	Sahoke SHP	Someshwara SHP	Ranganathaswamy SHP
Capacity (kW)	1400	1500	1300	1000	1750	1000	24750	24750
Discharge (cumecs)	65.68	65	64.1	51.58	48.07	24.36	159	27
Head (m)	2.67	2.78	2.49	2.5	4.6	5.27	18.5	120
Total Outage time (min)	3430	2600	2821	2910	2484	1796	588	1107
Energy lost (kWh)	66765.92	30186.10	55331.46	42707.46	26298.55	23303.71	243199.34	47049.07
Revenue lost @ INR 2.5/kWh in lacs	1.67	0.75	1.38	1.07	0.66	0.58	6.08	1.18
Loss in INR /kW	119.22	50.31	106.41	106.77	37.57	58.26	24.57	4.75

9.3 Losses Due to Head Loss Caused by Trash Blockage

The frequency of trash cleaning should be based on technical and economic consideration (rather judgment and convenience based). The water level upstream as well as downstream of trash rack should be monitored and on its pre-decided head loss (drop in water levels), the cleaning should happen.

Trash is more during rainy season and less during other period. We assume rainy period of 4 months. Since throughout the country, the time and season of rains vary, so next thing to find is the rainy season for power house location i.e. determining the months of heavy trash. For this, the time of outages due to trash cleaning for the specific power plants was arranged in decreasing order. The result of this arrangement is shown in Table 9.2:

Table 9.2: Months of heavy trash according to the outage time provided

	Dolowal	Salar	Banbhaura	Babbanpur	Killa	Sahoke
1.	July	July	July	July	July	April
2.	May	April	May	April	April	July
3.	April	May	April	May	May	May
4.	June	June	June	February	September	December
5.	September	August	March	June	June	June
6.	March	September	September	September	February	September

Thus the period of heavy trash is taken to be April, May, June and July.

Head monitoring at the power plants is not being followed. Thus, various durations for head loss are being assumed for canal based projects. Figure 9.2 shows the case when a net head loss of 0.1 to 1.0 m occurs in 3 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.55 m for canal based projects in India. Figure 9.3 shows the case when a net head loss of 0.1 to 1.0 m occurs in 6 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.51 m for canal based projects in India. Figure 9.4 shows the case when a net head loss of 0.1 to 1.0 m occurs in 12 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.52 m for canal based projects in India. Figure 9.5 shows the case when a net head loss of 0.1 to 1.0 m occurs in 24 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.55 m for canal based projects in India.

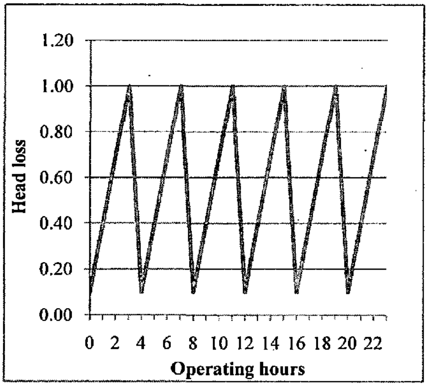


Figure 9.2: Head Loss due to accumulation of trash when cleaning is done after 3 hours for canal based project

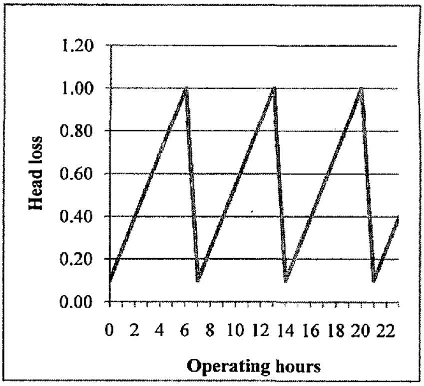


Figure 9.3: Head Loss due to accumulation of trash when cleaning is done after 6 hours for canal based

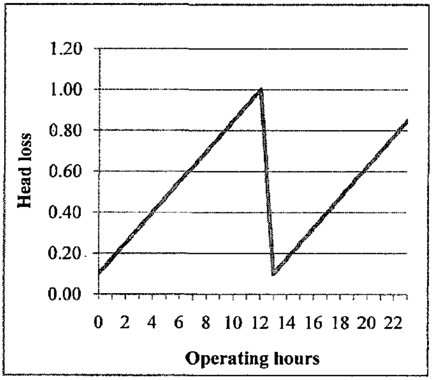


Figure 9.4: Head Loss due to accumulation of trash when cleaning is done after 12 hours for canal based project

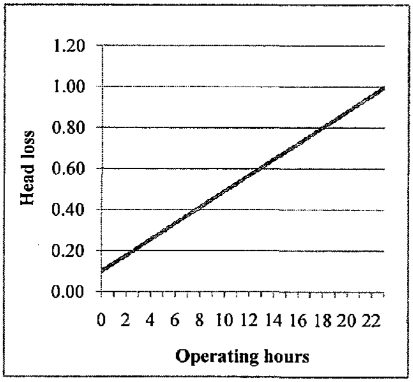


Figure 9.5: Head Loss due to accumulation of trash when cleaning is done after 24 hours for canal based

Similarly for a run-of-river plant, no head monitoring is done. Thus, various durations for head loss are being assumed for run-of-river projects. Figure 9.6 shows the case when a net head loss of 0.1 to 1.8 m occurs in 3 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.95 m for run-of-river plants in India. Figure 9.7 shows the case when a net head loss of 0.1 to 1.8 m occurs in 6 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.88 m for run-of-river plants in India. Figure 9.8 shows the case when a net head loss of 0.1 to 1.8 m occurs in 12 hours

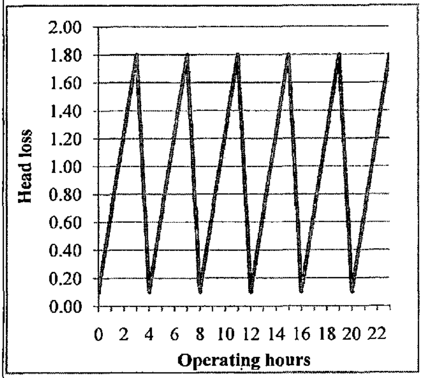


Figure 9.6: Head Loss due to accumulation of trash when cleaning is done after 3 hours for run-of-river

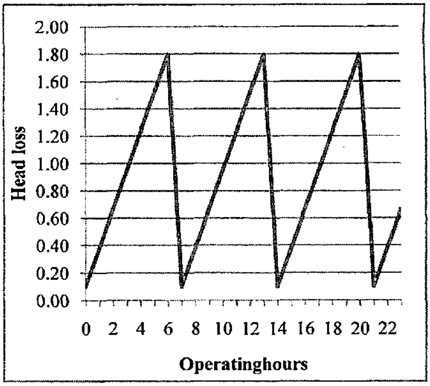


Figure 9.7: Head Loss due to accumulation of trash when cleaning is done after 6 hours for run-of-river project

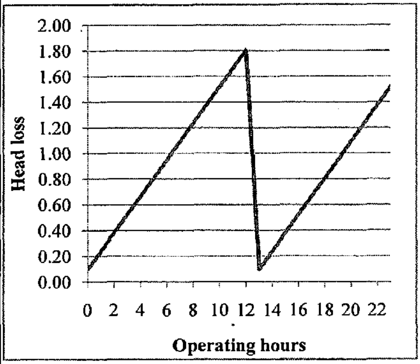


Figure 9.8: Head Loss due to accumulation of trash when cleaning is done after 12 hours for run-of-river

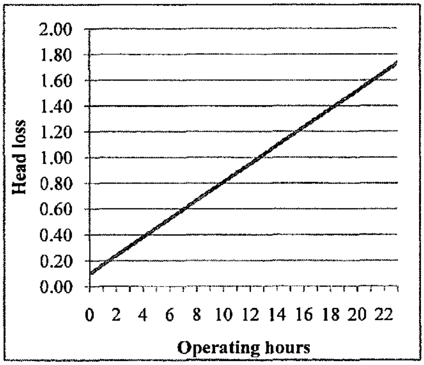


Figure 9.9: Head Loss due to accumulation of trash when cleaning is done after 24 hours for run-of-river project

duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.89 m for run-of-river plants in India. Figure 9.9 shows the case when a net head loss of 0.1 to 1.8 m occurs in 24 hours duration and cleaning of trash takes 1 hour. The average head loss during the day is = 0.92 m for run-of-river plants in India.

Run-of-river plants being considered here are Someshwara and Ranganathaswamy. According to the discussion done in the power plant, the period of rain is from June to September, so the period heavy trash and thus high head loss is taken to be the same as said above.

In Table 9.3, head loss is used as head in power equation and for calculating energy. The analysis here is done for cleaning period of 6 hours. The energy loss is maximum for Someshwara and Ranganathaswamy due to the high discharge and head values at these sites while the power projects at Punjab have almost same values. To do away with the dependency of the result on the installed capacity we calculate the result in terms of revenue loss per installed capacity. As is clear from Figure 9.10, the value of revenue lost per installed capacity is comparable in case of Dolowal and Salar. Likewise the values are similar for the next three sets of two projects each.

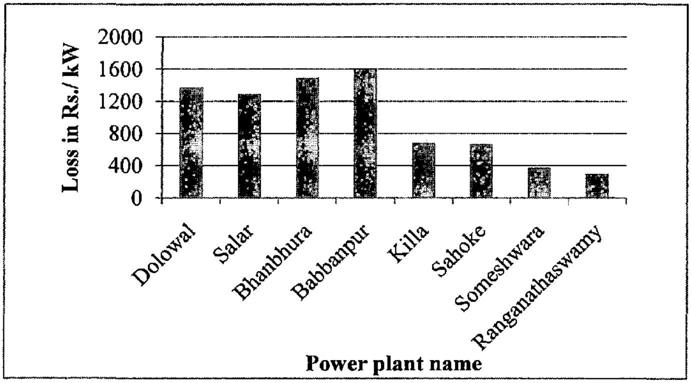


Figure 9.10: Loss due to trash accumulated during rain

Table 9.3: Loss due to trash accumulated during rain

Name	Dolowal SHP	Salar SHP	Banbhaura SHP	Babbanpur SHP	Killa SHP	Sahoke SHP	Someshwara SHP	Ranganathaswamy SHP
Capacity (kW)	1400	1500	1300	1000	1750	1000	24750	24750
Discharge (cumecs)	65.68	65	64.1	51.58	48.07	24.36	159	27
Head (m)	2.67	2.78	2.49	2.5	4.6	5.27	18.5	120
Head Loss (m)	0.51	0.51	0.51	0.51	0.51	0.51	0.88	0.88
Total Outage time (hour)	2928	2928	2928	2928	2928	2928	2928	2928
Energy lost (kWh)	779342.61	771273.89	760594.72	612035.50	570386.71	289049.72	3255404.02	552804.46
Revenue lost @lac INR 2.5/kWh	19.48	19.28	19.01	15.30	14.26	7.23	81.39	13.82
Loss in INR/kW	1391.68	1285.46	1462.68	1530.09	814.84	722.62	328.83	55.84

9.4 Loss due to Change in Startup Time

Enquiry regarding the saving of time in start-up of machine in automation mode led to the result that there is no time saving and automated mode takes more time in operation than the manual mode. The reason given for this discrepancy of time of operation was that the automated control system works on fixed pulses while in manual operation the pulse duration is variable.

This statement by the power house was made on the basis of assumption of efficient operator. But skill, experience, knowledge, efficiency and decision making power of all the operators are not the same. Thus we can't expect the time taken for start-up of the power plant to be same by all the operators. In case of automation system, the operation of the power plant is not dependent on operator and his skill. So this is to be expected that the time of start-up and synchronization of machine is reduced in case of automated system. At Neria mini hydro scheme, the time of operation was conforming to what is expected. This is shown in Table 9.4

Table 9.4 Time of manual and automated start-up of Neria mini hydro scheme

S. No.		Manual Operation	Auto operation
1.	Starting of plant	05-10 min	06 min
2.	Normal shutdown	04 – 06 min	04 min
3.	Synchronisation	01-03 min	02 min
4.	Emergency shutdown	10 sec	10 sec

To confirm our view of time taken in automated and manual start-up of power plant, a study in the simulator lab was done. As mentioned in Chapter 3, there are two power houses simulated in the real time digital simulator laboratory of AHEC, namely Rajwakti and Narangwal. Rajwakti is a relay logic based system having an auto/manual start-up sequence and a manual synchronization in both the cases. Narangwal uses a SCADA based system and has auto/manual start. Synchronization does not come into picture since it uses induction generator. The outcome of this study at simulator lab is shown in the Table 9.5.

Table 9.5: Time of manual and automated start-up at Real time digital simulator of AHEC

	Time (min)			
	Rajwakti SHP		Narangwal SHP	
	Manual	Automation	Manual	Automation
Start sequence time	5	3	10	5
Synchronization time	3	NA	NA	

The calculations are done on the basis of the time of start-up for Neria plant and the results of two simulated plants at Real time Digital Simulator at AHEC. Evaluating the loss for a single start-up. This analysis is being done to assess the quantum of energy lost while the unit is starting up. The analysis is shown in Table 9.6.

Table 9.6: Start-up in auto vs. manual mode

Name	Neria SHP	Rajwakti SHP	Narangwal SHP
Capacity (kW)	9000	3600	1500
Discharge (cumecs)	60	10	28.4
Head (m)	17.5	52	2.82
Start-up time in manual (min)	8	5	10
Start-up time in auto (min)	6	3	5
Difference in time (min)	2	2	5
Energy lost in startup (kWh)	300	120	125
Revenue lost @ INR 2.5/kWh	750	300	313

The outcome of the analysis shows that the cost/ start-up would increase from INR 300 to INR 750 for different power plants if manual operation of the plant is done.

9.5 Loss of Water during Startup

The hydro power plants are established to generate electricity continuously. Any outage- forced or planned- accounts to loss of generation. The time taken for the start-up of the power plant after any outage also causes loss of the revenue. The amount of energy (and thus revenue) lost in such a way has been quantified in this section. The aim of this quantification is to show the loss with every start-up. The use of automated control system helps in improving the operation of the plant (Section 9.7) and condition of equipment (Section 9.6), thus the number of outages of the plant can be reduced. The analysis would help us realize the need of quick startup and to minimize the number of outages.

For calculating the cost of startup, we are considering the number of outages (as obtained by power plant data) and time taken by the start-up of plant (as reported by the plant personnel). Thus, the total time taken in startup= Number of outages × time taken for start-up. The obtained time is then multiplied with the energy generation to check the revenue lost. This revenue is divided by the number of outages to give the start-up cost in terms of loss per outage. This has been shown in Table 9.7.

Table 9.7: Annual cost of Start-up

Name	Dolowal SHP	Salar SHP	Someshwara SHP	Ranganathaswamy SHP
Capacity (kW)	1400	1500	24750	24750
Discharge (cumecs)	65.68	65	159	27
Head (m)	2.67	2.78	18.5	120
Total number of outages	1395	978	735	763
Start-up time (min)	3	3	10	7
Total time of startup=	4185	2934	185	5341
Energy lost in startup kWh	97650	403425	25437.5	734387.50
Revenue lost @ lac INR 2.5/kWh	2.44	10.09	0.64	18.36
Annual Cost/ start-up (INR/ start-up)	175	1031.25	86.52	2406.25

Table 9.7 show the annual cost of startup varies from as low as INR 87 to as high as INR 2407. As is evident from figure 9.11, annual cost per start-up is found out to be maximum for Ranganathaswamy. This reason may be accounted for by the non-availability of proper discharge during half of the time of the year and also the large capacity of the plant.

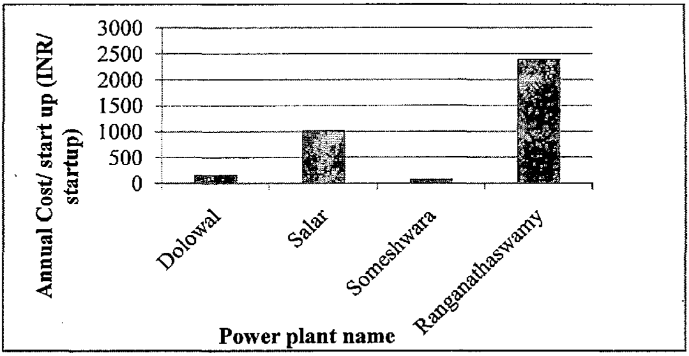


Figure 9.11: Annual cost of start up

9.6 Fatigue during Start-Up and Shut-down

During the periods of start-up and shut-down high variations of mechanical and thermal loads occur in turbine and generator [65]. These mechanical and thermal loading causes fatigue of the machines. Failure rates are also increased from fatigue processes occurring during load variations.

The life of the machines is also reduced due to mishandling. It has been stated in [63] that each startup of power plant causes a reduction of 15 hours of life of generator windings.

The reduction in life of winding has been taken as the reduction in the life of the E&M works cost. This analysis has been done for the plants whose E&M works cost were known.

The assumptions for this analysis are:

a.) Life of generator is 40 years, thus life of E&M works= 40 years
b.) Additional startups= 150/year
c.) Reduction in life of winding = 15 hours/ start-up

Thus, in 40 years, reduction in life of winding = 15 hrs/ start-up * 150 start-up/ year *40 year = 90000 hours =10.27 years

Thus reduction in life= 10.27 years

Final life of E&M works = 40-10.27= 29.73 years

Depreciation is calculated at the original and reduced life. Since depreciation is taken as an expense and is deducted from the net profit. So with the reduction in life, the depreciation increases and thus (non-cash) expense increases. Thus reduces our profits i.e. contributing to the loss. This has been calculated in Table 9.8 for Nam Chien SHP, RAD SHP, Bhilangana III SHP, Someshwara SHP and Ranganathaswamy SHP.

As is evident from Table 9.8 and figure 9.12, the reduction in profit caused by depreciation due to reduction in life of E&M works is quite much. This loss is one of those "indirect losses" which the power plant people don't realize. The mishandling, disoperation and frequent start-up/ shut-down of the equipment reduces its life which causes monetary losses.

9.7 Loss of Opportunity

While carrying out maintenance and renovation works, the historical data of the plant parameters, behavior of machines and fault/ failure of equipment is very helpful in making decision. With manual data logging, the scope of retrieval of data gets limited to one or two years. While in case of an automated control system, the data can be archived for several years. Moreover, the software is programmed to make the trends and may also predict the behavior of certain components. Thus in the case of manually controlled power house, this opportunity of predictive maintenance is lost. Moreover, during renovation, due to the lack of proper data about the equipment, the real cause of problem cannot be identified and thus it is decided to be replaced instead of renovating the problem area. This is the loss of opportunity for correct action to be taken.

Any malfunction of the machine or failure of any equipment need to be recorded even if it is due to the negligence of the operator. In a manually operated power plant all data are logged manually. Thus there is a chance of manipulation of the data and/ or status of the plant by the operator. The operator may tamper with the data or may not log it at all. This would cause that the system is not attended properly at the time of maintenance and may harm the system on long term basis or reduce its operating life. This is the loss of opportunity for the improvement or proper correction of the system.

Table 9.8: Losses due to fatigue during start-up

Project Name	Capacity (kW)	E&M Works Cost (Lacs INR)	Initial depreciation (INR/year)	Final Life of E&M works	Final Depreciation (INR/year)	Loss due to depreciation (lac INR)	Loss (INR/ kW)
RAD SHP	15000	2000	50.00	29.73	67.27	177.38	1182.56
Bhilangana SHP	24000	2600	65.00	29.73	87.45	230.60	960.83
Someshwara SHP	24750	4598	114.95	29.73	154.66	407.81	1647.71
Ranganathaswamy SHP	24750	3129	78.23	29.73	105.25	277.52	1121.29
Nam Chien 2 SHP	32000	4230	105.75	29.73	142.28	375.17	1172.40

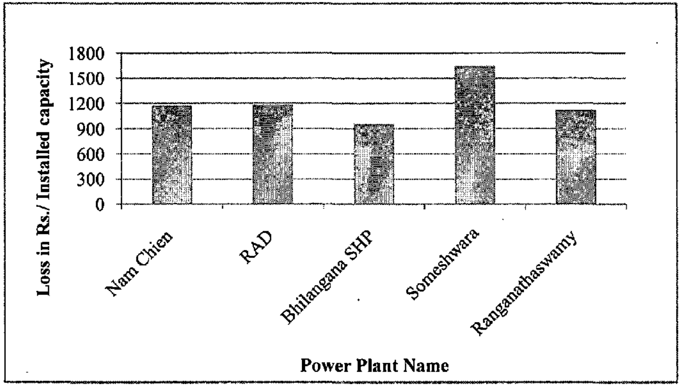


Figure 9.12: Losses due to Fatigue during start-up

9.8 Cost of Automation as a Percent of Total Cost

Table 9.9 mentions the cost of automation of small hydro power plants as obtained from manufacturers and power plant owners.

Table 9.9: Cost of automation as a percent of total cost

S. No.	Project Name, Location	Automation Cost (Lac INR)	E&M Works		Total project cost	
			Cost (Lac INR)	Percent automation (%)	Cost (Lac INR)	Percent automation (%)
1.	RAD SHP (2×7.5 MW)	50	2000	2.5	9067	0.55
2.	Bhilangana SHP (3×8 MW)	60	2600	2.31	19200	0.31
3.	Asiganga (2×2.25 MW)	40	800	5	2800	1.43
4.	Someshwara (3×8.25 MW)	50	4598	1.08	9670	0.51
5.	Ranganathaswamy (3×8.25 MW)	70	3129	2.23	8268	0.84

The percentage calculated shows that the cost of automation is less than 5% of the E&M works cost and about 1 to 2% of the total cost in any case.

9.9 Conclusions

Thus the various analyses of the data from the real power plant shows that the losses are numerous and can be reduced by the use of automation. The practice of cleaning of trash rack after "seeing" loss of generation should be discouraged. The analysis done in section 9.2 and 9.3 show the importance of trash monitoring. Use of automated startup of plant may cause a saving of upto INR 750/ startup. An annual loss of 0.64 lacs to 18 lacs is caused due to loss of water during startup. Fatigue caused to equipments during start-up/ shut-down causes reduction in life and thus reduction in profits. The reduction in profit ranges from INR 960 to INR 1640/ kW. Thus, we have seen various analyses which prove that automation system helps in reducing losses due to proper data logging, improved maintenance and efficient working of the system. It is concluded that percentage cost of automation is less than 5% of the E&M works cost and about 1 to 2% of the total cost in any case.

Chapter 10- Conclusions, Recommnedations And Future Work

10.1 Results and Conclusions

From this study of automation of small hydro power plants, we may draw the following conclusions:

10.1.1 Technical

1. State-of-the-art automation system technology is available in India due to tie-ups with International companies. But we have seen that poor quality and non-reliability of field instruments and non-availability of manpower is a problem.

2. A large variation in the control configuration and the system architecture of the small hydro power plants has been observed. The definition of control configuration depends on the requirement of site and is generally specified by the user. A compromise is made between the requirement of the owner and the philosophy followed or suggested by the automation service provider.

3. We saw some instances which show that if the design of the plant automation system is not custom made to the requirements of the plant, it would not be workable in long duration. The recommendations discussed in chapter 5 may be used as a reference for the control system definition for a small hydro power project.

4. User interface should be interactive and easy to understand for example the operators do not find touch screen so interactive. At many power houses, the operators are unable to detect the fault so the control system hardware and software can include a self diagnostic feature for assistance.

10.1.2 Human Resource

1. Most common problem at the power houses is the ignorance about the system and/ or the acceptance of the system. The full potential of the automation system is not being realized for example, data logging is done by system but the trends are not used for predictive maintenance and control. In small hydro scenario, the automation system has just

replaced the operator whereas the system can do a lot more work than just start stop sequence and event logging.

2. We saw the case of slackness of the management of the power plant regarding the use/ maintenance of automation system. They were concerned with the generation of the power but not about the efficiency of generation or the use of automation system. This led to the use of manual mode of control by operators.

3. The problem with the implementation and usage of automation in small hydro power plants is that of the mindset of people. Training of the operating personnel is required for making them understand the whole system and its working so that they can appreciate the difference that an automation system can bring.

4. The result of survey questionnaire revealed that small power plants in South India are more satisfied with the automation system especially on run-of-river plants. Plants on canal falls are less successful especially in North India. The operators are less satisfied than managers and engineers. Thus the actual users of automated system are less contented with the system as a whole. This again points out the ignorance about the system and highlights the need of training of operators.

5. It was seen that the requirement of operating staff reduces but not to a great extent.

10.1.3 Financial

1. The percentage of cost of automation has been found to be less than 5% of the E&M works cost and about 1 to 2% of the total project cost.

2. The analyses of the data from several power plants show that many losses can be reduced by the use of automation.

3. Use of automated startup of plant may cause a saving of upto INR 750/ startup. An annual loss of INR 0.64 lacs to INR 18 lacs is caused due to loss of water during startup. Fatigue during start-up/ shut down cause reduction in life of equipment. This results in decrease in profit due to increased depreciation. The reduction in profit ranges from INR 960/kW to INR 1640/ kW.

4. The automation system helps in improving the reduction in profits due to proper data logging, improved maintenance and efficient working of the system.

10.2 Recommendations

The following recommendations for the implementation, usage and popularity of the automated control system are being given:

10.2.1 Technical

1. The design of the automated control system for any power plant should be proper and case specific. The control system hardware and software should have a self diagnostic feature.

2. The option of operating the equipments at best efficiency point should be included in the control system design of all the power plants.

3. Automation of intake gates should be done. Monitoring of head loss at trash rack should be followed at the power house. If reliable equipments are available, trash rack cleaning can also be automated.

4. Utilizing the full potential of the system and using all the functions incorporated in the system. The system can do a lot more work than just start stop sequence and event logging.

10.2.2 Operational

1. To follow the O&M manual for a proper working and life of instruments.

2. Proper testing at the time of commissioning should be done.

3. Providing spare cards at the power plant.

10.2.3 Human Resource

1. Creating awareness about all aspects of automation of plants to the end users i.e. owners, consultants, financers, operators, etc.

2. Selection of operators and supervisors and impart proper training on automaton including subsequent maintenances especially diagnostics and if possible changes of cards, etc.

10.2.4 Policy Level

Automation of small hydro plants be accepted as a standard norm by all stakeholders especially owners, consultants and operators. For this, availability of reliable equipments should be ensured and training opportunity should be made available to the operator. Training institutes should demonstrate of use of automation system and training should be done for creating awareness and making people learn about the operation and maintenance of the system.

10.3 Further Work Proposed

The advantages of adaptation of automation in control and operation of small hydro power plants may be highlighted using the following proposals:

1. The variation of head loss at the trash rack has been assumed for the analysis in this study. Measurement of actual head loss across the trash rack may be carried out.

2. The quantum of indirect losses has been done computed considering the reduction in life on account of start-up/shut down as well as loss of opportunity of getting electricity. Other attributes such as reduction in life due to mishandling of the equipments, harm to equipment if maintenance/ replacement is not done on proper time, etc may be evaluated in future.

3. Reduction in operating costs (staff, O&M, etc.) due to use of automation of the system may be estimated in detail in future.

Annexure 1- Sample Input Output List for Control System Design (Courtesy: Andrtiz VA Tech)

ANDRITZ Hydro

PROJECT : 2X16 MW PANNIAR HEP **LIST OF GOVERNOR I/O SIGNALS** **DATE : 07.08.2009**

S.No.	Long Text	Type	Location (source)	RELAY NO.	MODULE	Location (Destination)	Remarks
	SCADA SIGNAL LIST						
	UNIT 1						
1	LOWER GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX1		SCADA	HARD
2	UPPER GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX2		SCADA	HARD
3	THURST BEARING OIL LEVEL LOW	DI	GRMP	SX3		SCADA	HARD
4	GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX4		SCADA	HARD
5	SPARE	DI		SX5		SCADA	HARD
6	SPARE	DI		SX6		SCADA	HARD
7	GEN BEARING HIGH OIL LEVEL STATUS	DI	GRMP	SX7		SCADA	HARD
8	SPARE	DI		SX8		SCADA	HARD
	UNIT 2						
9	LOWER GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX9		SCADA	HARD
10	UPPER GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX10		SCADA	HARD
11	THURST BEARING OIL LEVEL LOW	DI	GRMP	SX11		SCADA	HARD
12	GUIDE BEARING OIL LEVEL LOW	DI	GRMP	SX12		SCADA	HARD
13	SPARE	DI		SX13		SCADA	HARD
14	SPARE	DI		SX14		SCADA	HARD
15	GEN BEARING HIGH OIL LEVEL HIGH	DI	GRMP	SX15		SCADA	HARD
16	SPARE	DI		SX16		SCADA	HARD
	COOLING WATER SIGNALS COMMAN						

17	CW PUMP 1 ON/OFF	DI	CWP	SX17		SCADA	HARD
18	CW PUMP 2 ON/OFF	DI	CWP	SX18		SCADA	HARD
	COOLING WATER SIGNALS UNIT 1						
19	OIL SUMP TEMP. HIGH	DI	OPU PANEL	SX19		SCADA	HARD
20	OIL SUMP CW FLOW OK	DI	OPU PANEL	SX20		SCADA	HARD
21	STATOR CW FLOW OK	DI	CW TATB	SX21		SCADA	HARD
22	UGB COOLING WATER FLOW OK	DI	CW TATB	SX22		SCADA	HARD
23	LGB COOLING AWTER FLOW OK	DI	CW TATB	SX23		SCADA	HARD
24	THURST BAERING CW FLOW OK	DI	CW TATB	SX24		SCADA	HARD
25	TGB CW FLOW OK	DI	CW TATB	SX25		SCADA	HARD
	COOLING WATER SIGNALS UNIT 2						
26	SPARE	DI		SX26		SCADA	HARD
27	SPARE	DI		SX27		SCADA	HARD
28	OIL SUMP TEMP. HIGH	DI	OPU PANEL	SX28		SCADA	HARD
29	OIL SUMP CW FLOW OK	DI	OPU PANEL	SX29		SCADA	HARD
30	STATOR CW FLOW OK	DI	CW TATB	SX30		SCADA	HARD
31	UGB COOLING WATER FLOW OK	DI	CW TATB	SX31		SCADA	HARD
32	LGB COOLING AWTER FLOW OK	DI	CW TATB	SX32		SCADA	HARD
33	THURST BAERING CW FLOW OK	DI	CW TATB	SX33		SCADA	HARD
34	TGB CW FLOW OK	DI	CW TATB	SX34		SCADA	HARD
	GEN. TRANSFORMER SIGNALS UNIT 1						
35	GT BUCHHOLZ RELAY TRIP	DI	TRMP	SX35		SCADA	HARD
36	GT BUCHHOLZ RELAY ALARM	DI	TRMP	SX36		SCADA	HARD
37	GT WINDING TEMP. TRIP	DI	TRMP	SX37		SCADA	HARD
38	GT WINDING TEMP ALARM	DI	TRMP	SX38		SCADA	HARD
39	SPARE	DI	TRMP	SX39		SCADA	HARD
40	GT SURGE RELAY TRIP	DI		SX40		SCADA	HARD
41	GT OIL LEVEL LOW	DI	TRMP	SX41		SCADA	HARD
42	86T OPTD.	DI	TRMP	SX42		SCADA	HARD
43	GT OIL TEMP. TRIP	DI	TRMP	SX43		SCADA	HARD
44	GT OIL TEMP. ALARM	DI	TRMP	SX44		SCADA	HARD
	GEN. TRANSFORMER SIGNALS UNIT 2						
45	GT BUCHHOLZ RELAY TRIP	DI	TRMP	SX45		SCADA	HARD
46	GT BUCHHOLZ RELAY ALARM	DI	TRMP	SX46		SCADA	HARD

47	GT WINDING TEMP. TRIP	DI	TRMP	SX47		SCADA	HARD
48	GT WINDING TEMP ALARM	DI	TRMP	SX48		SCADA	HARD
49	SPARE	DI		SX49		SCADA	HARD
50	GT SURGE RELAY TRIP	DI	TRMP	SX50		SCADA	HARD
51	GT OIL LEVEL LOW	DI	TRMP	SX51		SCADA	HARD
52	86T OPTD.	DI	TRMP	SX52		SCADA	HARD
53	GT OIL TEMP. TRIP	DI	TRMP	SX53		SCADA	HARD
54	GT OIL TEMP. ALARM	DI	TRMP	SX54		SCADA	HARD
	BREAKER AND ISOLATOR SIGNALS						
55	E-SWITCH-1 OPEN	DI	TRMP1	SX55		SCADA	HARD
56	E-SWITCH-1 CLOSE	DI	TRMP1	SX56		SCADA	HARD
57	E-SWITCH-2 OPEN	DI	TRMP2	SX57		SCADA	HARD
58	E-SWITCH-2 CLOSE	DI	TRMP2	SX58		SCADA	HARD
59	89T1 OPEN	DI	TRMP1	SX59		SCADA	HARD
60	89T1 CLOSE	DI	TRMP1	SX60		SCADA	HARD
61	89T2 OPEN	DI	TRMP2	SX61		SCADA	HARD
62	89T2 CLOSE	DI	TRMP2	SX62		SCADA	HARD
63	CHECK SYNC RELAY OPTD.	DI	SYNC.PANEL	SX63		SCADA	HARD
64	SPARE	DI		SX64		SCADA	HARD
65	ISOLATOR -1 OPEN	DI	TRMP1	SX65		SCADA	HARD
66	ISOLATOR-1 CLOSE	DI	TRMP1	SX66		SCADA	HARD
67	ISOLATOR-2 OPEN	DI	TRMP2	SX67		SCADA	HARD
68	ISOLATOR-2 CLOSE	DI	TRMP2	SX68		SCADA	HARD
69	A CKT BKR CLOSED	DI	TRMP1	SX69		SCADA	HARD
70	A CKT BKR OPEN	DI	TRMP1	SX70		SCADA	HARD
71	B CKT BKR CLOSED	DI	SYNC.PANEL	SX71		SCADA	HARD
72	B CKT BKR OPEN	DI	SYNC.PANEL	SX72		SCADA	HARD
73	C CKT BKR CLOSED	DI	TRMP2	SX73		SCADA	HARD
74	C CKT BKR OPEN	DI	TRMP2	SX74		SCADA	HARD
75	ISOLATOR -3 OPEN	DI	SYNC.PANEL	SX75		SCADA	HARD
76	ISOLATOR-3 CLOSE	DI	SYNC.PANEL	SX76		SCADA	HARD
77	ISOLATOR-4 CLOSED	DI	SYNC.PANEL	SX77		SCADA	HARD
78	ISOLATOR-4 OPEN	DI	SYNC.PANEL	SX78		SCADA	HARD
79	ISOLATOR -5 CLOSED	DI	TRMP1	SX79		SCADA	HARD

80	ISOLATOR-5 OPEN	DI	TRMP1	SX80		SCADA	HARD
81	ISOLATOR-6 OPEN	DI	TRMP2	SX81		SCADA	HARD
82	ISOLATOR-6 CLOSE	DI	TRMP2	SX82		SCADA	HARD
	COMMAN AUXILLARIES SIGNAL						
83	SPARE	DI		SX83		SCADA	HARD
84	DEWATERING PUMP 1 ON	DI	CWP	SX84		SCADA	HARD
85	DEWATERING PUMP 2 ON	DI	CWP	SX85		SCADA	HARD
86	FLOOD ALARM	DI	CWP	SX86		SCADA	HARD
87	BATTERY CHARGER HELTHY	DI	BATT.CHAR.	SX87		SCADA	HARD
88	FIRE FIGHTING SYSTEM OPERATED	DI	FFS	SX88		SCADA	HARD
89	LT PANEL TRIP CKT DC HEALTHY	DI	LTAC	SX89		SCADA	HARD
	GENERATOR PROTECTION PANEL SIGNAL UNIT 1						
90	GEN. BEARING WATER IN OIL	DI	GRMP	SX90		SCADA	HARD
91	SPARE	DI		SX91		SCADA	HARD
92	DRS OPTD.(UEGENT FAULT)	DI	GRMP	SX92		SCADA	HARD
93	DRS OPTD. (NON URGENT FAULT)	DI	GRMP	SX93		SCADA	HARD
94	SPARE	DI		SX94		SCADA	HARD
95	DRS COMPACT FAILURE (PA11)	DI	GRMP	SX95		SCADA	HARD
96	GEN BRAKE OK	DI	GRMP	SX96		SCADA	HARD
97	TUR. BEARING TEMP. TRIP	DI	GRMP	SX97		SCADA	HARD
98	TUR. BEARING OIL FLOW LOW	DI	GRMP	SX98		SCADA	HARD
	GENERATOR PROTECTION PANEL SIGNAL UNIT 2						
99	GEN. BEARING WATER IN OIL	DI	GRMP	SX99		SCADA	HARD
100	SPARE	DI		SX100		SCADA	HARD
101	DRS OPTD.(UEGENT FAULT)	DI	GRMP	SX101		SCADA	HARD
102	DRS OPTD. (NON URGENT FAULT)	DI	GRMP	SX102		SCADA	HARD
103	SPARE	DI		SX103		SCADA	HARD
104	DRS COMPACT FAILURE (PA21)	DI	GRMP	SX104		SCADA	HARD
105	GEN BRAKE OK	DI	GRMP	SX105		SCADA	HARD
106	TUR. BEARING TEMP. TRIP	DI	GRMP	SX106		SCADA	HARD
107	TUR. BEARING OIL FLOW LOW	DI	GRMP	SX107		SCADA	HARD
	COMMAN						
108	PRV1 OPERATED	DI	PRV SYS.	SX108		SCADA	HARD
109	PRV2 OPERATED	DI	PRV SYS.	SX109		SCADA	HARD

110	BUTTERFLY VALVE 1 OPENED	DI	VALVE HOUSE	SX110		SCADA	HARD
111	BUTTERFLY VALVE 1 CLOSED	DI	VALVE HOUSE	SX111		SCADA	HARD
112	BUTTERFLY VALVE 2 OPENED	DI	VALVE HOUSE	SX112		SCADA	HARD
113	BUTTERFLY VALVE 2 CLOSED	DI	VALVE HOUSE	SX113		SCADA	HARD
114	DRS 1 LIGHT FAILURE (PA13)	DI	TRMP-1	SX114		SCADA	HARD
115	DRS 1 COMPACT FAILURE (PA12)	DI	GRMP-1	SX115		SCADA	HARD
116	DRS 2 LIGHT FAILURE (PA23)	DI	TRMP-2	SX116		SCADA	HARD
117	DRS 2 COMPACT FAILURE (PA22)	DI	GRMP-2	SX117		SCADA	HARD
118	U1 EXCITATION OFF	DI	TRMP	SX118		SCADA	HARD
119	U2 EXCITATION OFF	DI	TRMP	SX119		SCADA	HARD
120	SPARE	DI		SX120		SCADA	HARD
121	SPARE	DI		SX121		SCADA	HARD
122	U1 GEN. BEARING VB TRIP	DI	GRMP	SX122		SCADA	HARD
123	U2 GEN. BEARING VB TRIP	DI	GRMP	SX123		SCADA	HARD
124	U1 EXCT. PANEL FAULTY	DI	GRMP	SX124		SCADA	HARD
125	SPARE	DI		SX125		SCADA	HARD
126	U2 EXCT. PANEL FAULTY	DI	GRMP	SX126		SCADA	HARD
127	SPARE	DI		SX127		SCADA	HARD
128	SPARE	DI		SX128		SCADA	HARD
129	SPARE	DI		SX129		SCADA	HARD
	COMPRESSED AIR SYSTEM						
130	AIR COMPRESSER PUMP-1 ON	DI	ACP	SX130		SCADA	HARD
131	AIR COMPRESSER PUMP-2 ON	DI	ACP	SX131		SCADA	HARD
132	PRESSURE HIGH IN AIR RECIVER	DI	ACP	SX132		SCADA	HARD
133	PRESSURE LOW IN AIR RECIVER	DI	ACP	SX133		SCADA	HARD
134	SPARE	DI		SX134		SCADA	HARD
135	SPARE	DI		SX135		SCADA	HARD
136	U1 EXCT. AUTO ON	DI	EXCT. PANEL	SX136		SCADA	HARD
137	U1 EXCT. MANUAL ON	DI	EXCT. PANEL	SX137		SCADA	HARD
138	U2 EXCT. AUTO ON	DI	EXCT. PANEL	SX138		SCADA	HARD
139	U2 EXCT. MANUAL ON	DI	EXCT. PANEL	SX139		SCADA	HARD
140	ISOLATOR-7 OPEN	DI		SX140		SCADA	HARD
141	ISOLATOR-7 CLOSE	DI		SX141		SCADA	HARD
142	ISOLATOR-14 OPEN	DI		SX142		SCADA	HARD

143	ISOLATOR-14 CLOSE	DI		SX143		SCADA	HARD
144	SPARE	DI		SX144		SCADA	HARD
ANALOG INPUT							
1	U1 UGB X-AXIS VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
2	U1 UGB Y-AXIS VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
3	U1 LGB X-AXIS VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
4	U1 LGB Y-AXIS VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
5	U1 TGB VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
6	U1 GTB VIBRATION	AI	VIB. PANEL 1			SCADA	HARD
7	U2 UGB X-AXIS VIBRATION	AI	VIB. PANEL 2			SCADA	HARD
8	U2 UGB Y-AXIS VIBRATION	AI	VIB. PANEL 2			SCADA	HARD
9	U2 LGB X-AXIS VIBRATION	AI	VIB. PANEL 2			SCADA	HARD
10	U2 LGB Y-AXIS VIBRATION	AI	VIB. PANEL 2			SCADA	HARD
11	U2 TGB VIBRATION	AI	VIB. PANEL 2			SCADA	HARD
12	U2 GTB VIBRATION	AI	VIB. PANEL 2			SCADA	HARD

Annexure 2-List Of Automated Small Hydro Power Plants

S. No.	Plant Name	Location	Capacity (MW)	Extent of automation	Owner	Commissioned
1	Asiganga		2×2.25	PLC/ SCADA based	UJVNL	
2	Babbanpur	Punjab	2×0.50	SCADA based	Kotla Hydro Power Pvt. Ltd.	July-04
3	Banbhaura	Punjab	2×0.65	SCADA based	Punjab hydro Power Pvt. Ltd.	April-03
4	Bhilangana III		3×8	SCADA based	Bhilangana Hydro Power Ltd., Noida	
5	Ching		2×0.50	Electronic Governor	Heteshwari Om Power Enterprises Pvt. Ltd., Ahemdabad	
6	Dakpsi IV	Vietnam	3×10	SCADA Based		
7	Dolowal	Punjab	2×0.7	SCADA based	Punjab hydro Power Pvt. Ltd.	April-03
8	Espar Pak Ltd.	Andhra Pradesh	1×1.3	SCADA based	Espar Pak Ltd.	April-00
9	Espar Pak Ltd.	Andhra Pradesh	1×0.55	SCADA based	Espar Pak Ltd.	August-99
10	HRQ, Vietnam	Vietnam	2×3.2	SCADA based	M/S Song Cau Joint Stock Company	
11	Hydro Power Free Lanka	Sri Lanka	1×1.6	SCADA based	Hydro Power Free Lanka	April-03
12	Hydro Power Free Lanka (Pvt.)	Gampola, Sri Lanka	1×1.6	SCADA based	Hydro Power Free Lanka (Pvt.),	December-03
13	Hydro Power Services	Kalawana , Sri Lanka	1×1.7	SCADA based	Hydro Power Services	April-08
14	Hydro Power Services	Kalawana , Sri Lanka	1×0.9	SCADA based		April-08
15	Hydrodyanamics	Sri Lanka	2×0.6	SCADA based		July-05
16	Janapadu Hydro Power Project	Andhra Pradesh	1×1.0	SCADA based	Janapadu Hydro Power Project	September-10

17	Kabini	Karnataka	2×0.5	PLC based with MMI	Maruthi Power Gen	
18	Killa	Punjab	2 x 0.875	PLC based with MMI	Kotla Hydro Power Pvt. Ltd.	November-05
19	Nam Chien, Vietnam	Vietnam	2×16	SCADA based		
20	Panniar, Kerala		2×16	SCADA Based	KSEB	
21	RAD	Jammu	2×7.5	SCADA based	M/S Choudhary Power Projects	
22	Ranganathaswamy	Karnataka	3×8.25	SCADA based	Pioneer Power Corp. Ltd.	
23	Ropar	Punjab	2×0.850	SCADA based except line and switchyard	PSEB	
24	Sabbanahally-I	Karnataka	1×0.85	SCADA based	Vijayalakshmi Power Projects	June-02
25	Sabbanahally-II	Karnataka	1×0.85	SCADA based	Vijayalakshmi Power Projects	September-02
26	Sahoke	Punjab	1×1.0	PLC based with MMI	Kotla Hydro Power Pvt. Ltd.	
27	Salag, Dharmshala		1×0.150	Electronic governor	Private (M/S Dhauladhar Hydro System Hamirpur)	
28	Salar	Punjab	2×0.65	SCADA based	Punjab hydro Power Pvt. Ltd.	April-03
29	Satyakala	Karnataka	4×1.5	PLC based		
30	Shivani Power Spinners Ltd.	Andhra Pradesh	1×0.80	SCADA based	Shivani Power Spinners Ltd.	March-00
31	SKJ Power Project Ltd	Andhra Pradesh	2×0.75	SCADA based	SKJ Power Project Ltd	January-99
32	Someshwara	Karnataka	3×8.25	SCADA based	Pioneer Genco Ltd.	
33	Sri Dhanalakshmi Cotton & Rice Mills Ltd.-Power Division	Andhra Pradesh	2×0.794	PLC based with MMI	Sri Dhanalakshmi Cotton & Rice Mills Ltd.-Power Division	December-97

34	Sri Dhanalakshmi Cotton & Rice Mills Ltd.-Power Division	Andhra Pradesh	2×1.07	PLC based with MMI	Sri Dhanalakshmi Cotton & Rice Mills Ltd.-Power Division	November-97
35	Sri Dhanalakshmi Cotton & Rice *Mills Ltd.*-Power Division	Andhra Pradesh	2×1.235	PLC based with MMI	Sri Dhanalakshmi Cotton & Rice Mills Ltd.-Power Division	October-97
36	Sri Jayalakshmi Power Corp. Ltd.	Andhra Pradesh	2×1.0	SCADA based	Sri Jayalakshmi Power Corp. Ltd.	March-00
37	Sri Jayalakshmi Power Corp. Ltd.	Andhra Pradesh	2×1.0	PLC based with MMI	Sri Jayalakshmi Power Corp. Ltd.	February-00
38	Trident Power System Ltd.	Andhra Pradesh	2×1.0	PLC based with MMI	Trident Power System Ltd.	October-99
39	Trident Power System Ltd.	Andhra Pradesh	2×1.0	PLC based with MMI	Trident Power System Ltd.	August-99
40	Tsiazompaniry	Madaggascar, Africa	2×2.6	SCADA based		

Annexure 3 – Data from Power Plants and Survey Questionnaire Template

The following data was asked from the power plant.

a) Various components of automation
b) Control hierarchy
c) System architecture
d) Functions implemented in the power house
e) Present working status of automation in plant
f) Time taken (minutes) for the following;

S. No.		Manual Operation	Auto operation
5.	Starting of plant		
6.	Normal shutdown		
7.	Synchronisation		
8.	Emergency shutdown		

g) Grid failure history (Cause, Time duration and action)
h) Grid fluctuations (Cause, Time duration and action)
i) Output generation (total amount generated, amount used in auxiliaries, thus the total energy for revenue) for one year
j) Outage data for one year
k) Amount of head loss during the year due to trash (may be given as a range)
l) Total cost (including Civil works cost, E&M works cost, administration cost, etc.)
m) Amount spent on automation as a percentage of total cost.

SURVEY QUESTIONNNAIRE TEMPLATE
"FEASIBILITY OF AUTOMATION IN SMALL HYDRO POWER PLANTS"

Please answer the questions below:

1. What does automation mean to you?
2. What led you to automation of power plant?
3. What is the help you received by automation in your power plant?
4. The most attractive feature of automation?

5. In relation to automated power plant, kindly rate your level of satisfaction with the following attributes on the following scale:

Particular	Strongly disagree (1)	Somewhat disagree (2)	Neutral (3)	Somewhat agree (4)	Strongly agree (5)
Level of satisfaction					
Are you satisfied with the performance of your automated system					
You think all the power plants of all capacities should have automation					
Cost of operation reduces when automation is used					
Automation system has made me relaxed about the operation of the power plant					
Availability of trained operators					
Availability of trained operators for operation is good					
If no, the operator learns the operation by himself on experience basis					
The operator needs a special training for operating an automated system					
The institute/ centre providing the training for operators are sufficient and/or satisfactory					
Ease of understanding operation					
The operation of automated is easy to understand/ follow/ operate					
User friendly					
Ease of maintenance					
Response time to faults reduces					
Maintenance					
Replacing the parts is easy					
Fault detection is simplified					
Fault correction is easy					
your engineers are able to solve the problem occurring in the					

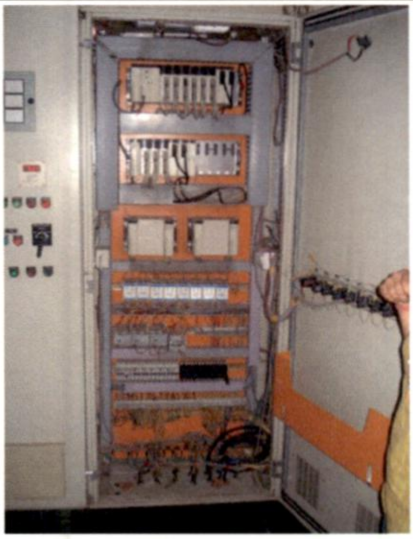
Particular	Strongly disagree (1)	Somewhat disagree (2)	Neutral (3)	Somewhat agree (4)	Strongly agree (5)
system Please mention the approx down time.					
Performance					
The logged data in SCADA system helps improve the performance of the machine					
Logged data can be used to prevent the machine failure/ fault occurrence					
The logged data in SCADA system helps to predict the performance of the machine					
Automation system during installation is not at all a problem					
The after sale service by service provider is excellent					
Downtime of machine has drastically reduced					
Automation system is highly reliable and I recommended it strongly					

Name (Optional):
Post:
Company:
Date:
Signature (Optional):

Annexure 4- Photographs of Various Power Plants Visited

Salar SHP

Intake gates at Salar SHP



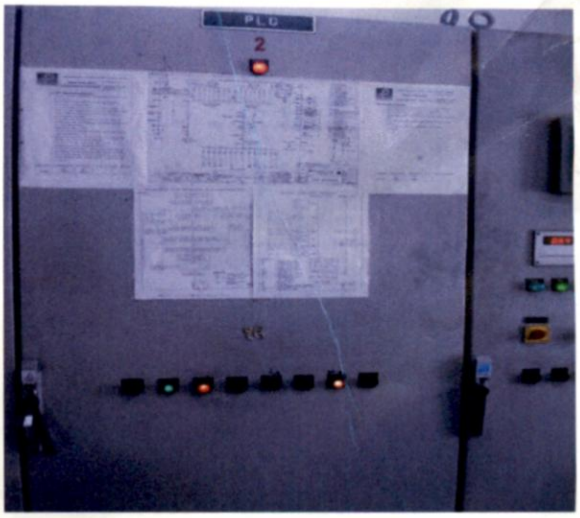
Inside panel view of a unit control board at Salar SHP

Unit Control Board at Salar SHP

Dolowal SHP

Trash and Trash cleaning machine at Dolowal SHP

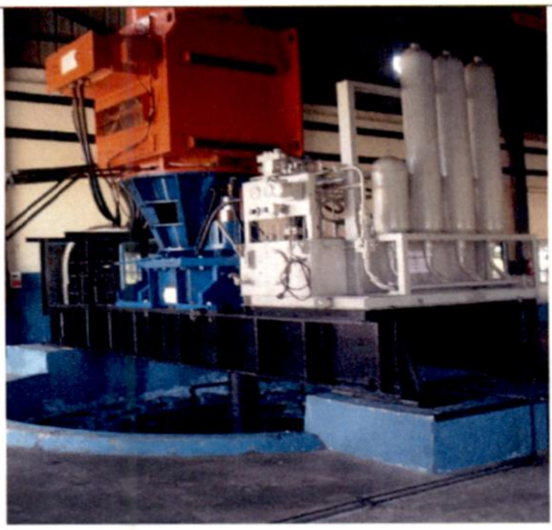
Induction generator at Dolowal SHP



PLC Panel at Dolowal SHP

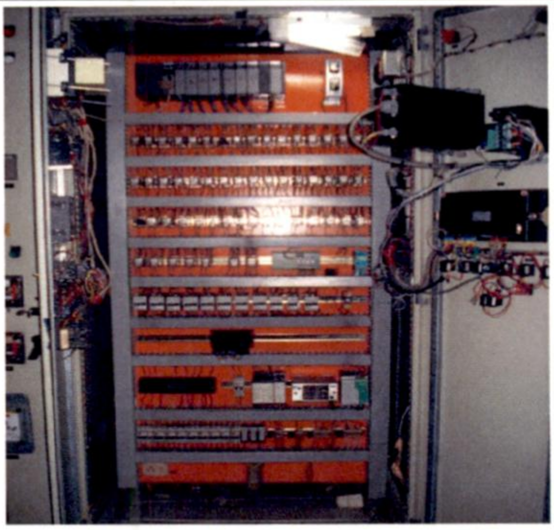
Unit Control Board at Dolowal SHP

Banbhaura SHP



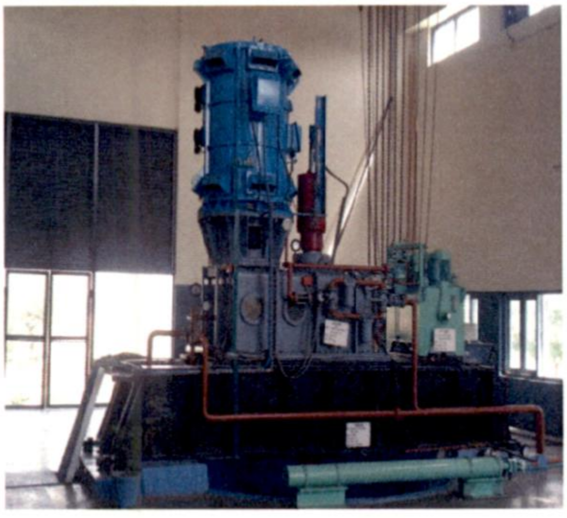
Induction generator at Banbhaura SHP

Control room at Banbhaura SHP

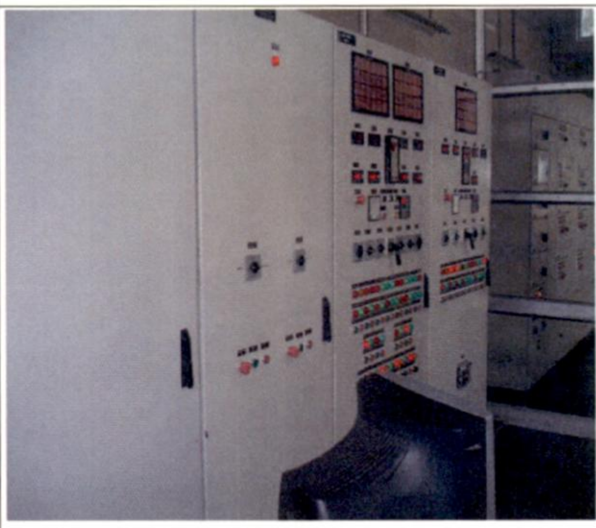


View inside the PLC panel at Banbhaura SHP

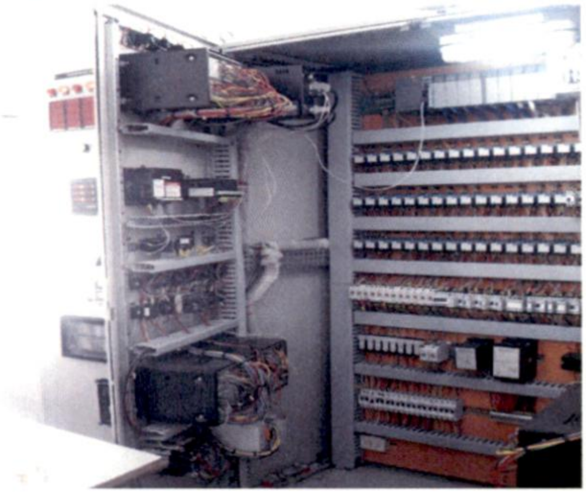
Intake at Babbanpur SHP



Induction Generator at Babbanpur SHP

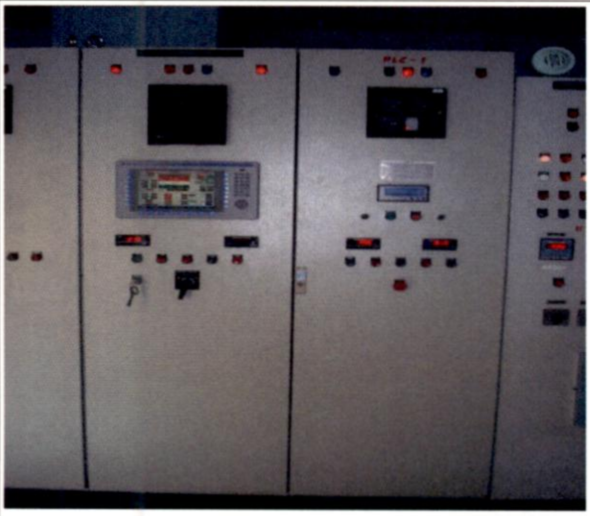


Control room with SCADA panel at Babbanpur SHP

	
Protection panels at Babbanpur SHP	**Intake gates at Sahoke SHP**
	
Tail race at Sahoke SHP	**Generator at Sahoke SHP**
	
Control panel at Sahoke SHP	**Opened panel showing PLC at Sahoke SHP**

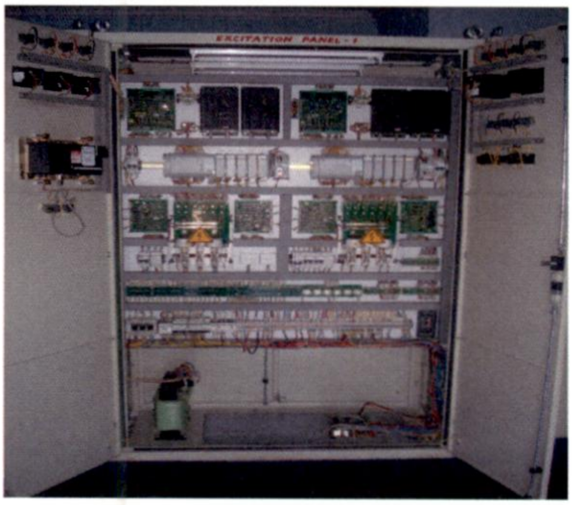
Head race gates at Someshwara SHP

Intake gates at Someshwara SHP



Touch screen and temperature scanner at Someshwara

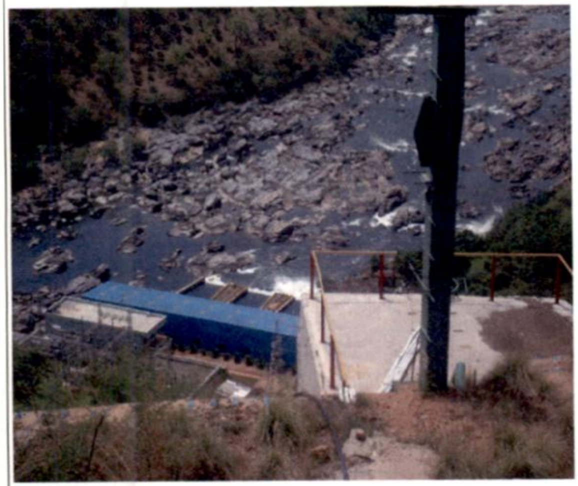
Annunciator at Someshwara SHP



PCB based Excitation control panel at Someshwara

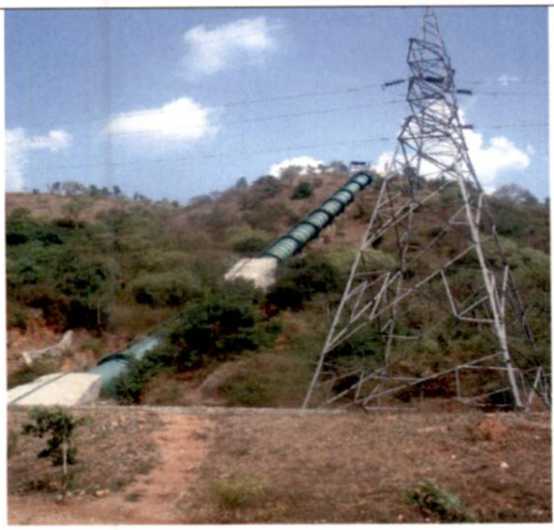
ta

Power channel at Ranganathaswamy SHP



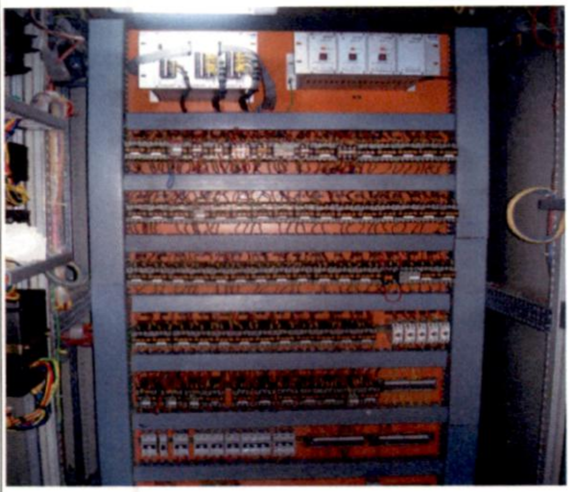
Bird's eye view of Ranganathaswamy power house

Tail race at Ranganathaswamy SHP

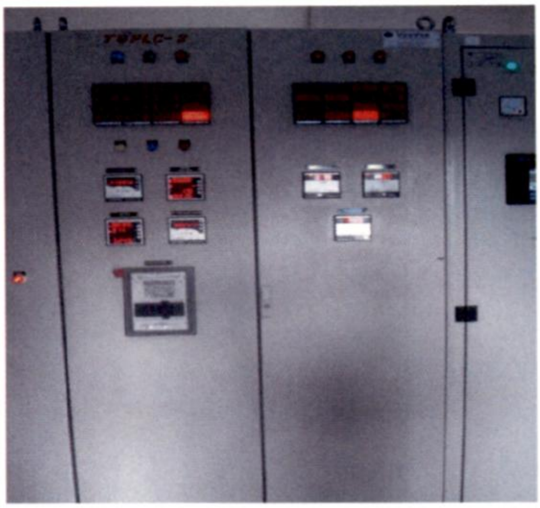


Penstock at Ranganathaswamy SHP

Francis turbine at Ranganathaswamy SHP



Unit control board with PLC at Ranganathaswamy



TG PLC panel at Ranganathaswamy SHP

Protection panel at Ranganathaswamy SHP

Synchronization and line panel at Ranganathaswamy SHP

Excitation panel at Ranganathaswamy SHP

SCADA terminal at Ranganathaswamy SHP

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