Automation of Small Hydropower Station

Raju Gupta\textsuperscript{1)}, S.N. Singh\textsuperscript{1)} and S.K. Singal\textsuperscript{1)}

1) Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee 247667, India
E-mail: nishafah@iitr.ernet.in, rajugupta21@gmail.com

ABSTRACT

Small hydropower (SHP) is one of the most appropriate options to meet increasing energy demand especially in a country like India, Sri Lanka where a huge power potential in this sector is available. It is clean and renewable in contrast to fossil fuel based generations which pollute the environment and whose resources are depleting fast. But high cost per unit generation is a constraint in case of SHP development. The hurdle of cost effectiveness has slow down the process of small hydropower development.

Control & Operation system for SHP should be simple, reliable, cheap and with minimum interference of operating personal. Control system should be such that remote operation can be performed easily.

The main functions of the controller for automation is to execute starting and the shut down sequences under normal and emergency conditions. In addition to these operating sequences, certain control actions like speed control for synchronization (off line control) and speed control when the machine is put on the grid are also to be performed for frequency control and load sharing. The excitation system should respond with respect to the system requirement that is either to control the voltage or to share the reactive power with the other units operating in parallel.

In this paper an attempt has been made to elaborate the use of Programmable Logic Controller (PLC) for control and automation of SHP station, its advantages and cost effectiveness.

Programmable logic controllers (PLC) can be used for control & automation of SHP Station. The main reason for this is cost effectiveness. Various functions and controls can be achieved by programming the PLC. They can be used for full plant automation including governing of auto-operation includes speed control, load control, excitation control, and level control automatic start/stop sequencing, gate control, start/stop of auxiliary systems, and protection requirement etc. Functions other than control like continuous monitoring, data recording, instrumentation and protections can also be performed. For remote operation, communication with PLC can be performed. For continuous monitoring purpose, a personal computer can be interfaced with PLC and continuous data can be recorded regularly

1 INTRODUCTION

In this age increasing demand of energy has forced us to look at the other options different from conventional means of exploiting energy as conventional sources of energy are exhaustible. The starting point energy crisis is the oil crisis. As the awareness came in early seventies also came the search for the alternatives. Also it was required that the alternatives should be such that, their should not be the major changes required in the system. Renewable energy emerged as the best option. The major renewable are hydro, solar, wind and biomass. The beauty of these renewable energy systems is that they are non-exhaustible.

Hydropower is one of the most promising available energy sources in the world. However, with limited potential and other problem like high construction cost, environmental concerns due to impounding of river water and long gestation period of large hydro have ceased to be offering any long-term solution for our
increasing power demand problem. Small hydropower on the other hand, can be built in less time and are likely to create less environmental problems.

Of all the non-conventional renewable energy sources, small hydro represents the ‘highest density’ resource and stands in the first place in generation of electricity from such sources throughout the world. Emanating from the environmental and depleting conventional sources consciousness, there is an increased thrust on small hydro development in India. Government of India has stimulated considerable enthusiasm in providing speedy development of small hydro. SHP acts as the small centers for power generation even in the remote areas where the basic needs of discharge and head are fulfilled thus emerging as an answer to the search for alternative energy source.

India has one of the world’s largest Irrigation Canal networks with thousands of Dams and Barrages. It has monsoon fed, double monsoon fed as well as snow fed rivers and streams with perennial flows. An identified potential of more than 10,000 MW of small hydro exists in India, though overall potential of 15,000 MW is anticipated. The installed capacity as on 31.3.2005 is 1705.23 MW with an additional 479.29 MW under construction.

The control and protection systems in small hydropower plants have advanced dramatically in recent years. In the first half of the 20th century, small hydropower plants were using hardwired relays for semi-automatic operation of the turbine auxiliaries, and a mechanical governor for speed control. With the development in computer technology, computers are widely used in hydropower stations for various controls. The emergence of the Programmable Logic Controller (PLC) as a factory automation tool in the 1970's proved to be a great advancement to hydro controls. The PLC started to be used as a replacement for hardwired logic. The PLC performed the same functions of the hardwired relays, but with much more flexibility. However, most of the early PLCs had only basic mathematical capabilities. Without higher level math, programming a routine like flow control was extremely complex. With the introduction of microprocessor based PLCs in the early 1980's, they can now include functions like PID loops, real math and other functions. The use of the PLC provided the ability to perform complex control routines, readily incorporate changes, and interconnect with a wide range of devices. Herrin and Sloop have given the function of control system automation using distributed PLC philosophy. They have made the cost and performance analysis and found that the digital controls using PLC were quite beneficial.

The advantages of using PLC linked to speed governor were discussed by Barthomeuf et. al. Kornegay has given the benefits of upgrading the governors at Roanoke Rapids hydro plant from mechanical to digital control. A number of other plants like the Vianden hydro plant, the Nantahala power houses, Steward Mountain dam and crosscut hydro, etc. have been upgraded using PLC-based control system for better benefits.

Raymond W. Lamb studied the performance of Programmable Logic Controllers (PLCs) in the control of hydropower plant. He dealt mainly with the performance characteristics of PLC based governor, particularly speed resolution and response times. He stated that the PLC could achieve the full functionality both as a digital governor and as a fully automated, unattended plant controller.

PLC is one of the most powerful tools used for control in hydropower. Control and monitoring of the power station can be easily done by PLC. By making a communication link, governing can also be controlled by PLC, for this there is a need of simplification of wiring between PLC and speed governor. Transmission safety is very important for this purpose. The PLC can acquire governor fault information or all the measurements supplied by the regulation sensors. This information can then be processed in the PLC for data supervision or correlation purposes.

2 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.

A system for managing, controlling & protecting a SHP operation as shown in Fig 1. It is realized by obtaining information in real time, by providing powerful local & remote control system and advance protection system. An automation system consists of:-
(a) Protection System
(b) Control System
(c) Measuring System
(d) Monitoring System

Fig 1: Automation System for SHP Station

2.1 Need of Automation for SHP

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) High cost of control and protection equipment. 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.

(b) 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. The control system should be simple and easy to operate.

(c) 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.

(d) 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.

In view of the above, it is necessary to select control system for SHP which is simple, reliable and cheap. The conventional control system uses separate equipment for turbine governing, generator
excitation control, plant control and protection. They tend to be costly and become complicated to operate and maintain. Control system should be such that remote operation can be performed easily. An Automation System is more relevant in case of SHP due to following reasons.

(e) Hydro Plants are started & stop more frequently.

(f) Hydroelectric units also provide flexibility of changing the mode of operation for example, kW Control, Level Control.

(g) Provides successful, efficient and smooth operation.

(h) Plants are situated in remote areas with difficult to access.

2.2 Benefits of Automation for SHP Station

Normally, we implement an automation system to improve the efficiency, productivity and the operating management of the system, this automation will then better answer to the production needs and services given. Following are the major benefits of Automation System for SHP Station.

(a) Flexibility of changing the mode of operation for example, kW Control, Level Control.

(b) Remote operation possible.

(c) Complete Power plant information available at any time online.

(d) Efficient utilization of Manpower.

(e) Maintenance is easier and quick.

(f) Reduction in down time due to online diagnostics.

(g) Simplicity in installation.

(h) Reduction in Manpower.

(i) Networking capability.

(j) Ability to integrate plant control functions in one hardware system.

(k) Reduced Panel space.

(l) Improved performance

(m) Provides security against wrong operations by the operator.

(n) The system availability improves.

(o) Automatic starting and stopping of machine sets are faster than manual starting and stopping.

(p) Efficiency of power plant can be raised through automation to almost the practical highest value by ensuring optimized operation of each generation unit and optimal load sharing between units.

(q) Guide operator to optimize generation by running units at best efficiency.

(r) Reduced wire and interconnection.
Coordination of design

Open system – easily upgraded or added

Reliable operation

Lower cost
- Cost saving on the installed system: 35%
- Operating staff: 65%
- O & M cost reduction: 34%

3 PROGRAMMABLE LOGIC CONTROLLER (PLC)

Programmable logic controller is basically a digital electronic apparatus; it has a programmable memory for storing instructions to implement specific tasks for control. In early days of development of PLC, it was mainly used to replace hardwired relays in control panels. The main advantage of using PLC is the flexibility over hardwired relays. As mentioned in earlier section, it is very easy to add or subtract or modify the relays and wiring in the form of ladder diagram. The modifications can be done simply by reprogramming of PLC which is very easy.

The benefits from relay logic controllers to computer based controllers because of following reasons.

(a) The input and output variables of discrete system control are binary in nature just as with a computer.

(b) Most of the control relays of the ladder diagram can be replaced by software, it lead to less hardware failure.

(c) It is easy to make changes in a programmed sequence of events when it is only a change in software.

(d) Special functions such as time delay actions and counters are easy to form software.

(e) With the development in semiconductor industry it is very easy to control high power ac/dc in response to low level commands from a computer, such semiconductor devices includes SCRs and TRIACs.

Advanced PLCs are microprocessor based and can perform complex mathematical calculation and function as well as logic, sequencing, timing and counting. Programming of PLC is easy and usually done in ladder diagram or function chart. The ranges of PLCs available nowadays varies from small hand held unit to modular system with add on function modules. The add on modules may consist; Analog input/ output module, PID control module, Communication module, Graphics display module Additional memory.

3.1 Components of PLC

As shown in Fig 2, PLC consists of central processing unit (CPU). It control and supervises all operations, memory for program and data storage, and input/output units which are interfaced with real world. Additional microprocessor can also be employed to control complex, time consuming function such as mathematical processing, PID control etc. For program storage, semiconductor memory devices such as Random Access Memory (RAM) or Erasable Programmable Read Only Memory (EPROM) are used. Size of PLC differs from PLC to PLC and depends number of instructors it can store and process. The input/output channels are isolated from inside using opto-isolators. Both analog and digital I/O modules can be used if required. Each of the commands is discussed below in brief.

3.1.1 Processor

Processor executes a program to perform the operation specified in ladder diagram. The processor performs arithmetic and logic operation on input variable data and determines the proper state of the output variables. The processor functions under a permanent supervisory operating system that directs the overall operations
from data input and output to execution of user programs.

The processor can perform only one operation at a time. It is a serial machine. So it, sequentially samples each of the inputs, evaluates the ladder diagram program and provides each output, and then repeats the whole process. The speed of processor is one of the major components which decide the efficiency of PLC. The speed of controller is dependent on the clock frequency of the processor. The higher, the clock frequency the greater is the speed and faster is the scan/execution time.

3.1.2 Input Modules

The input modules examine the state of physical switches and other input devices and put their state into a form suitable for the processor. The processor can accommodate a number of input these inputs are called ‘channels’. Each of input modules has a certain number of channels per module. Each channel is often provided with an indicator light to show if the particular input is ON or OFF.

3.1.3 Output Modules

The output modules give signal to external devices as required in the ladder diagram. The output module can supply a certain maximum level signal. If required power is more, an external relay can be used. Internally, the output module accepts 1 or 0 input from processor. An output module also has several channels per unit. Each channel can also has indicator to show if the particular channel is being driven ON or OFF. There are two types of I/O digital and analog.

The digital I/O is used for discrete control and analog I/O for continuous control. The digital outputs are driven by either thyristors or relays and can be directly connected to relays, contacts etc. In analog I/O modules, the analog input signal is converted into digital by analog to digital converters and digital signal from PLC is converted into analog signal by digital to analog converter for final control. We can use more than one or two or as required number of input/output modules to solve the purpose.

The temporary memory used during ladder diagram program testing and evaluation is called RAM. This is read and write memory. Once the program is stored in RAM, it can be easily modified.

When a program has been debugged and is considered finished, it is burned into a ROM. This is read only memory that can not be changed and is not affected by power failure. The ROM can be programmed directly by controller programming unit. When the ROM is plugged into the programmable controller, the device is ready to be placed into service.

3.2 Programming and Other Facilities

PLC is first programmed before use for a particular system. There are two main components necessary for operation of any system one is hardware of the system and second is the sequence of events through which the hardware is taken. These two elements are combined to show how the hardware should be driven so that the proper sequence of events can be accomplished. We can achieve this through a program for the system written with symbols for hardware.

Therefore a special representation of hardware and its connection can be developed which makes combination of the hardware and events sequence description clear. This schematic is called a ladder diagram. It is an outgrowth of early controllers that operated from ac lines and used relays as primary switching elements

Thus ladder diagram is a symbolic and schematic way of representing both system hardware and process controller. It is called a ladder diagram because the various circuit devices connected in parallel across the ac line from something that looks like a ladder, with each parallel connection a rung on the ladder. In construction of ladder diagram, each rung of ladder is composed of a number of conditions or input states and a single command output. The nature of input states determines if the output is to be energized or not energized. Special symbols are used to represent various circuit elements in a ladder diagram.
One way of operation is to use physical relays to put together in a circuit that satisfies the requirement of the ladder diagram. Such a control system is called a relay sequencer or relay logic panel. In early days of plant control, this was the only way to provide control. It is still used in many applications even today, although modern computer-based controllers have replaced many relay-based systems.

The ladder diagram continues to be used today because it has evolved into a very efficient method of defining the event sequence required in a control system. In case of hardwired control circuit, it was very important to realize that with relay control, each rung of the ladder is to be evaluated simultaneously because the switches and relays were all hardwired to ac power if any switch anywhere in ladder diagram changes state, the consequences are immediate.

In the ladder diagram relays are represented by their contact and coils. Other standard functions like timers, counters, arithmetic operations etc have their specific representation. This makes the programming easily understandable. Every relay, timer and each element of ladder diagram is represented by numbers which are nothing but their memory locations. These differ from PLC to PLC, specified by manufacturers. Usually a separate programmer is provided for entering the programs into PLC. Programming can also be done from personal computer once the software for it is installed.

3.3 Types of PLCs

The types of PLC depend on the memory size and maximum number of input/output channels that the system can support. PLCs can be classified as small PLCs which have 40 input and 40 output points with 1K of memory size. Medium PLCs have 128 input and 128 output points with 4K memory. Large PLCs have 7128 input and 17128 output points with 74K memory.

Use of different size of PLC depends on number of relays and I/O channels we need. Small PLCs can be used to replace hardwired logic relays, timers, counters etc used to control individual machinery. Medium and large PLCs are very powerful and they are usually modular in constructions. They have faster processors with co-processors and have advanced modules like PID control, remote I/O, diagnostic and monitoring etc.

4 AUTOMATION & CONTROL OF SHP STATION USING PLC

Operation of a system involves more than simply regulating a controlled variable. The requirement of regulation means that some variable tends to vary in continuous fashion because of external influences. But the case in SHP is very different, there are a great many processes in SHP in which it is not a variable that has to be controlled but a sequence of events.

The objective of automation of SHP is to get electricity from water. Such an operation will typically involve many operations and steps. Some of these steps would occur in series and some would occur in parallel. Some events may involve discrete setting of states in the plant like valves open or closed, accessories on or off, and so on. Other events may involve regulation of some continuous variable over time or duration of operation. For example it is very important to maintain constant speed of one machine to remain in synchronization with other machine. So operation of SHP is a combination of discrete as well as continuous processes.

In early days of development, microprocessor was an important mean to do these tasks but the number of relays was unaffected. But with help of PLC, use of hardwired relays is minimized. A large PLC has enough number of relays to do all the operations. The advantages of these relays are that these are digital, so minimum damage to the system, cost reduction and less maintenance is involved in their use. If there is any need to change the control system, only the program is to be changed and it can be done easily without any cost involvement.

PLC is able to perform these operations very effectively. PLC is best suited for discrete control system. Where the sequence of events are programmed to form a ladder diagram. For example the sequence of events in starting up of a machine involves discrete state control, like sensing of pressure switches, limit
switches etc. Other events are purely continuous or may be combination of both discrete and continuous process.

In continuous processes we may need to convert the analog signal to the acceptable value to the PLC and then with A/D converter it is converted to digital input to processor. A control algorithm is to be developed to get a control signal to control the variable. There is always a set value to which the variable is taken. By calculating the error, algorithm can be applied to get a control signal. This control signal is the converted to analog signal and then amplified to control the variable.

For precise control a PID algorithm can be developed. There are separate modules available in PLC for this purpose they are named as PID module. Depending on the control action, speed and accuracy of system response, the error signal may be amplified using any or combination of proportional, integral or derivative action they can be combined with each other to get desired control action. For all continuous controls such as governor control, load control, level control, flow control and kVAR or power factor control etc. a PID algorithm can be developed in the form of ladder diagram and PLC can be used for purpose of control.

Programmable logic controllers (PLC) can be used for auto operation of SHP. Various functions and controls can be achieved by programming the PLC. Various functions other than control like continuous monitoring, data recording, instrumentation and protections can also be performed. For remote operation, communication with PLC can be performed. For continuous monitoring purpose, a personal computer can be interfaced with PLC and continuous data can be recorded regularly, PLC can be programmed according to operational requirements and mode of operation like grid connected and isolated, semi automatic and fully automatic control etc. In this way all the functions can be integrated into a single PLC, which will result in overall cost reduction, ease of operation and maintenance.

Programmable Logic Controller (PLC) type plant controller combined with PC based SCADA systems are used for plant control and data acquisition. This makes the system economically viable and thus can be suitable for many SHPs for generation control and automatic. It is considered that dedicated digital control systems with interface with digital P.C., for redundancy as well data acquisition and storage can perform all functions of governing, unit control and protection as well as for data storage and also provide redundancy and are more economical, dependable and are easily available. These systems with redundancy and back up manual control facility of speed and unit control in emergency can be low cost option.

Monitoring and control and data acquisition system (SCADA system) can be a part of the P.C. based digital governor and generation control equipment. Provision of data storage of one month as proposed with 16 MB of RAM memory and a 540 to 850 MB Hard Drive as part of the PC based governing and control system can be provided. This data could be retrieved on a floppy drive after one month for examination. As the communication links develop the data can also be transmitted via a Modem to a remote point for examination and supervisory control to convert into a SCADA system.

In this way almost each and every control requirement of control can be integrated into PLC for auto operation. One major consideration is to be given to select the size of PLC for a particular SHP. It can be small, medium or large as discussed earlier. If number of functions is more then we have to go for large PLC. Further if the needs are not fulfilled then a number of PLC can be used which can communicate with each other and with supervisory computers. In this way, unit control and data recording becomes very easy. Thus a supervisory control and data acquisition can also be achieved with PLC and supervisory computer. Following are the Major Role of PLC in Automation of SHP

(a) Automatic Start Sequence
(b) Automatic Shutdown (Normal, Emergency).
(c) Digital Governing using PLC
(d) Speed Governing
(e) Position Control
(f) Excitation Control with PLC
(g) Protection System with PLC
(h) Alarm and Annunciation using PLC
5 CONCLUSIONS

The conventional methods for plant control may be uneconomical if applied to SHP due to high cost, so integrated automation and control has become the solution for making it efficient and cost effective. The programmable logic controller (PLC) is the key device for such integrated automation. The followings following conclusion can be made by aforesaid.

(a) Digital control and automation has a number of advantages over other conventional types being used in SHP such as lower cost, simple operation and maintenance, adaptability to future changes, etc. So conventional methods for control in SHP are to be replaced by digital controls.

(b) With a single unit and minimal auxiliaries in a SHP station, a simple PLC scheme with manual back-up control system should be provided

(c) Modifications in program can be done even when PLC is connected to the system, so no need to stop the operation.

(d) Since PLC has thousands of software relays, so with a PLC based system, number of hardwired relays may be reduced. Therefore cost reduction may be achieved.

(e) In comparison to conventional systems, PID scheme is much easier to be implemented with PLC based system.

(f) For monitoring and data logging of a remotely operated plant, a personal computer should be interfaced with PLC. Redundancy of plant can be effectively improved with digital system like PLC

(g) The programmable logic controller is the best-suited device for integrated control and automation system in SHP. So, Programmable logic controllers (PLC) based automation & control system is recommended for use in SHP station and hence their use must be encouraged.

REFERENCES

www.hydro.power.alstom.com/home/turnkey_plants/mini_hydro_plants/control_systems/7337.EN.php?languageId=EN&dir=/home/turnkey_plants/mini_hydro_plants/control_systems/&mode=PRINTER_FRIENDLY.