# AUTOMATION OF SMALL HYDROPOWER STATION

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 declare that the work being presented in the dissertation entitled **"Automation of Small Hydropower Station"** submitted in the partial fulfillment of the requirement of the award of degree of **Master 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 from July 2006 to June 2007 under the guidance and supervision of **Shri S.N. Singh,** Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee and **Shri S.K. Singal,** Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee.

I have not submitted the matter embodied in the report for award of any other degree or diploma.

Date: June 13 , 2007
Place: Roorkee

**(RAJU GUPTA)**

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

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**Date: June 13, 2007** **(RAJU GUPTA)**

# ABSTRACT

Electrical and mechanical operation & Control cost for small hydropower (SHP) contribute to a major portion of capital and annual costs. Conventional methods of control, if applied to control SHP, it becomes totally uneconomical. Most of the SHP sites are in remote areas where manpower is unskilled and has little or no knowledge of operation and control. All these factors contribute to increased outage and frequent shutdown of plants. So operation of a SHP should be as simple as possible involving minimum involvement of manpower. For micro hydro range, using a shunt load governor, which makes load constant hence reducing the control of generator-turbine speed, gates and valves etc., can solve this problem. But this method is uneconomical in large SHPs. Large dump loads are required for it, which is not technically feasible. So digital methods of control and monitoring should be applied to reduce the cost.

Modern microprocessor based programmable Logic controller (PLC) can solve these problems & capable of performing a wide variety of control functions, from discrete logic to closed loop controls. Moreover, its ready availability in the market at reasonable rates has made it an attractive device for use in SHP. The use of PLC based integrated control and protection system in SHP will result in reduced initial cost, less maintenance cost and more efficient operation.

In the present thesis work KEYENCE KV-300 PLC has been used to achieve certain control functions for a hydro-turbine generator demonstration unit in the laboratory of Alternate Hydro Energy Centre as the test system. Programs for various control functions of SHP like automatic unit starting sequence, emergency & fault shutdown, load control, speed control of turbine have been developed in ladder builder for KV version 1.5 software and experimented with demonstration unit successfully. Two Integrated program, by including all above mentioned control programs has been also developed and tested with demonstration unit for the whole control & automation system for a SHP station.

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CHAPTER 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. 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.

Small hydropower is one of the most appropriate options to meet this demand specially in a country like India, 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 control & 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.

Programmable logic controllers (PLC) can be used for monitoring of all parameters as well as 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.

PLC can be programmed according to operational requirements and mode of operation like grid connected and isolated, semi automatic and fully automatic control etc. While using a PLC most of the relays can be replaced by digital relays embedded in PLC and it allows ease of operation in modification. 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. So PLC based plant controller combined with PC based SCADA systems are used for plant monitoring, control and data acquisition and most appropriate for automation a SHP Station.

## 1.1 OBJECTIVE OF PRESENT WORK

The present work is an effort to use a Programmable Logic Controller (PLC) for automation & control for SHP station. Since SHP has cost constraints with it so PLCs are the cheap & reliable tool for SHP automation & control. Although modern PLCs have the capability to perform most of the important control functions of SHP, they have not been utilized as such scale in our country. This work aims at bringing out the capabilities & problems of PLCs to perform control & automation for SHP, and to develop & test programs by doing experimental work with Turbine - Generator demonstration unit to perform such functions.

In order to develop control & automation system, each of the control function of SHP must be thoroughly understood. Therefore, the different aspects related to control system and automation are dealt in chapter 3. The concept of control & automation using PLC has been also discussed. The Experimental set up for present work has been discussed in chapter 4.

Chapter 5 deals with technical details, functions & capabilities of PLC. Developed & tested programs in KV builder software version 1.5 for KV 300 PLC for different control functions have been discussed & their results have been analysed under the heading of control & automation using PLC in chapter 6. Chapter 7 gives conclusion, recommendation work and scope for future work.

CHAPTER 2

# LITERATURE REVIEW

In the present era the enormous development of modern microprocessor based digital systems, coupled with their low cost, and has made them viable in numerous control applications. In many cases these controllers have successfully replaced the conventional analog controllers. With the availability of lower cost microprocessors, digital governors were introduced in the 1980's. Findlay, Davie, et. al. [1] presented the possibility of adaptive governing with digital governor. Kopacek and Zauner [2] had done model investigations and made comparative studies on the performances of analog and digital governors. They provided digital control algorithm and gave sample performance compared to analog controller. Hagen [3] discussed about the advances in control to govern mini and micro hydropower systems. He also discussed about load and flow controls and made comparison between the two. There are several reasons to account for this invasion, the most important being following.

(a) A microprocessor based digital governor is usually cheaper then its analog counterpart.
(b) It offers advanced control capability.
(c) It is smaller and lighter then its analog counterpart while the power consumption is very less.
(d) It offers greater reliability since the number of system components decreases and the problem of system noise be successfully overcome.

Due to these benefits, the implementation of digital controllers is exponentially increasing nowadays. L. Swahn [4] has discussed about the hydropower control using computers. He describes the man machine communication (MMC) system, which includes following controls like.

(a) Signal handling

(b) Load sharing

(c) Auxiliary power supply control

(d) Synchronizing

(e) Excitation control

(f) Turbine governing/speed regulation

(g) Start/stop sequence

With all these controls, facility of various displays like process display, trends display, system status, system dialogue and various diagrams involved in operation are available. He concludes that with one unit, it is possible to change from full operation with an old control system to full operation with the new system.

M. Mourier, C. Digue, J. Lecouturier and H. Piat [5] discuss an automatic control system installed at a hydro plant. They have discussed that how it was possible to extend plant automation to ensure full automatic control of plant without requiring permanent manning. The examples of automated functions include: startup, shutdown, and servo control of reactive power, numerous displays and use of a database.

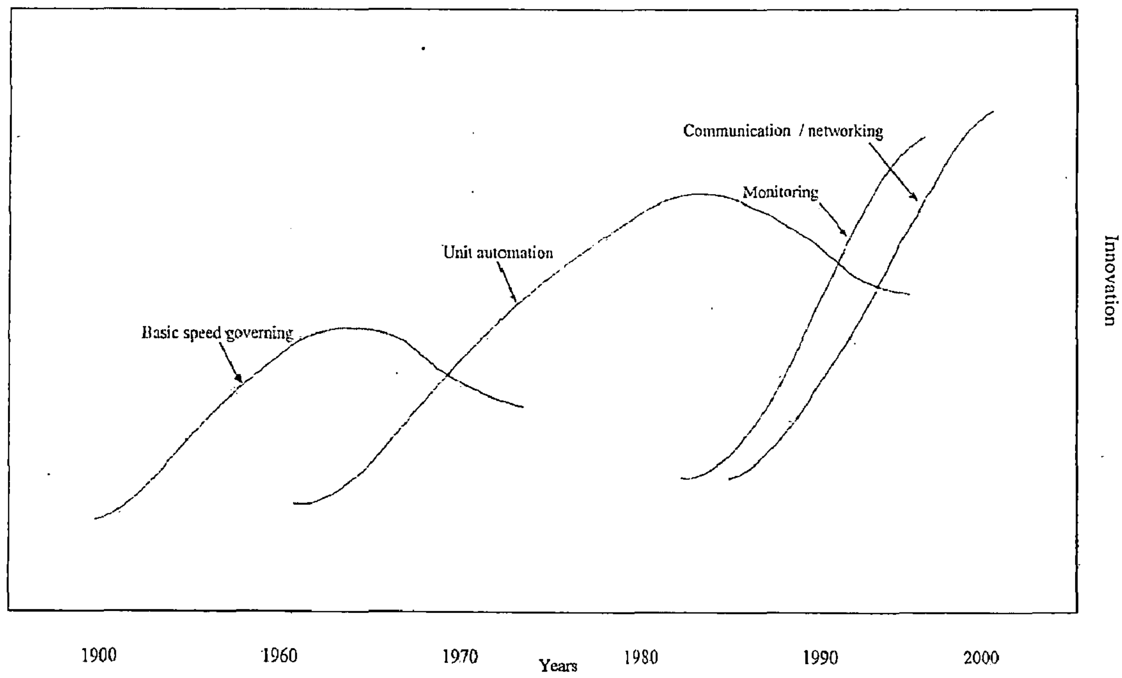



*Fig: 2.1 Trends of Speed Governor Innovation [6]*

Maujen, J. Jouve and J.M. Ferme [6] have discussed electronic speed governing system and concluded that the speed governor is one of the main components necessary for the good performance of units under fluctuating operating conditions. They have given the trends in governors innovation from basic speed governing system to the digital governors with communications and networking capacity as shown in Fig 2.1.

The first generation of v digital programmable components was created in the mid-1970s. At that time it was impossible to produce a digital speed governor at the same cost as an analog governor. But with the development in performance of microprocessors, it has been possible to solve this problem. But in the mean time, as the user's requirements have become more elaborate in conjunction with the automation programs of plants, the correspondence between the user's requirements and the capabilities of governing equipment has increased. Fig 2.1 shows the evolution of the functions associated with a speed governor. First there is a basic function that is speed control of a unit under load. The second innovation was increasing requirement for the automation of generating units. The present application of speed governing systems covers a large operating range, extending from the most simple basic functions to elaborate monitoring and communication functions.

The control and protection systems in hydropower plants have advanced dramatically in recent years. In the first half of the 20th century, 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. Microcomputer aided planning [7] for monitoring/optimization system has proved to be a valuable tool for the economic production of hydropower. The system gathers displays and documents data using spreadsheet, and accesses remote real-time performance data at the hydropower plants. It also schedules operation at hydro-plants for optimal efficiency. For this purpose, a multi-tasking computer is installed which has multiple windows for performing three primary functions.

(a) Data logging

(b) Performance monitoring

(c) Efficiency optimization

Optimization software has been used for most efficient operation of hydro plant to meet the required load scheduling.

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 [8] 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 in integrated control system were discussed by Jerry P. Bevivino [9]. Kornegay [10] has given the benefits of upgrading the governors at Roanke Rapids hydro plant from mechanical to digital control. A number of other plants like the Vianden hydro plant [11], the Nantahala power houses [12], Steward Mountain dam and crosscut hydro [13], etc. have been upgraded using PLC-based control system for better benefits.

Raymond W. Lamb [14] 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 the 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 [15], 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.

CHAPTER 3

# CONTROL & AUTOMATION FOR SHP STATION

## 3.1 CONTROL SYSTEM FOR SHP

The level of control & automation provided in SHP vary considerably depending on the size of plants and operational requirements. Small plants of a few kW ratings may be manually controlled and only basic protective facilities like fuses are provided, whereas bigger plants require more complex control and protection. SHPs connected to large and stable grid usually do not require speed governing and automatic voltage regulation.

One common goal for the small hydropower developers is to maximize revenue by running the plants as efficiently as possible with minimal operation personnel. The way to reach the goal for many developers has been through automating plant controls.

SHP stations are particularly well-suited automatic control because of the relative simplicity of control of both the prime mover and the stored hydraulic energy, which drives it. These plants may be used for short periods as peaking stations when extra generating capacity is needed or as base load station for long periods when an abundance of water for generating power is available.

The term plant automation is used to cover such operations as auto start, auto synchronization, remote control start up or water level control.

Before the advent of microprocessors, power plant controls required costly, complex custom design. Control system designers customized nearly all power generation controllers using various combinations of standard components such as governors, synchronizers, relays, meters and control modules. The more comprehensive the control requirements, the more components are required and the more complex is the connecting circuitry. Because all power plants are not alike, huge numbers of components would be required to cover all of the control possibilities of different power plants, making a standard control system impractical.

Today, as microprocessors are designed specifically for power plant use, software can be designed with the flexibility to perform many different complex tasks, with capabilities that any power plant would required a standard power generation controller is now achievable. The integration of sensing, control, protection, and display functions removes the need and expense of interfacing and installing individual components. Standard power generation controllers reduce power plant control system design and productions cost , by increasing reliability and maintainability, can affect the cost of energy production. In additional, approved software and hardware combination runs turbines more efficiently and produces more kilowatts from the available water. By operating and monitoring several plants concurrently via remote control, the integrated computerized controls reduce the cost also. Studies have shown that renovating older plants with modern automated equipment results in performance comparable with new installations. [16]

## 3.2 TYPICAL CONTROL PARAMETERS NECESSARY TO IMPLEMENT AUTOMATED CONTROL

Automation to be provided in SHP depends upon the type of hydropower development, elements to be controlled, methods of control and control of unit operation. The elements to be controlled in hydro power stations are intake gates, main inlet valve, governor, lubrication system, excitation of the generator, and main circuit breakers. Each of these elements has a particular function in the over all operation. The intake gate and main inlet valve render the plant inoperative and conserve water during shutdown period of the plant. The turbine gates under the control of the governor admit water in the runner in proportion to the load requirements of the turbine. The lubrication system establishes a lubricating film on the bearings during starting and maintains it during operation, and circulates the lubricant so that it can be cooled. The voltage regulator controls the excitation of the generator in keeping with the voltage requirements and demand for reactive power output of the generator. The generator field circuit breaker provides a means of field interruptions during faults and thereby minimizes damage to the generator and the other equipment. The generator circuit breaker serves to connect the generator to the system after the generator has been started. It also disconnects the generator from the system prior to the shutdown or following an electrical fault. [17]

There are many elements that are needed to be controlled in SHP, although machines differ widely in physical appearance, there are comparatively few basic types of turbine and main controls described below are common to all.

(a) Unit Starting/stopping

(b) Normal or emergency shutdown of unit

(c) Load Control

(d) Speed Control

(e) Unit Synchronization

(f) Excitation Control

(g) Main water supply to Turbine Casing

(h) Runner Water admission and relief

(i) Automatic Gain Control (AGC)

(j) Governor Servo System

(k) Governor Derive and Speed Setting

(l) Lubricated System

(m) Generator Cooling System

(n) Braking and Jacking System

(o) Main Breaker Control

(p) Temperature Control

(q) Pressure regulation

(r) Miscellaneous Equipment

### 3.3 METHODS OF CONTROL OF SHP STATION

Various methods of control may be broadly classified under three main headings manual, automatic and supervisory depending on the method of operation.

In the manual control each operation is performed or initiated manually whereas in automatic control a sequence of operations are performed automatically but the initiation of the sequence of operations may be performed manually or automatically.

Supervisory control means the control of a equipment from a remote point when the distance between the controlling point and the equipment to be controlled is so great as to make direct wire connections impracticable or unduly expensive.

Fully automatic control means a single starting impulse starts the unit and after synchronizing, loads the unit automatically.

Further in semi-automatic type of control the unit is brought up-to ready to synchronize condition by the initiation of the sequence of operations by manual starting impulse but the synchronization and loading are done manually.

A great variety of control schemes have been evolved for starting and stopping the units. These schemes range from fully manual, where every operation is performed by mechanical devices, to fully automatic in which closure of one electrical circuit results in the starting of unit auxiliaries, opening of turbine gates, synchronizing and loading of the unit and similarly normal stopping is achieved by another switch which reduces the load, switch off the circuit breaker, shut down the machine and stop all auxiliaries. [18]

### 3.3.1 Manual (Conventional) Control

In manual control, each item in the chain of the starting, synchronizing, loading and stopping sequence is selected and performed in turn by hand whether mechanically or by push buttons.

(a) Take into account the situation of the equipment.

(b) Depending upon the situation, the operators can undertake certain corrections to modify the situation that they have recognized as deficient on the equipment.

(c) Requires full time supervision by the operators.

### 3.3.2 Semi- Automatic Control

In semi automatic control, from a single manual starting impulse a unit may be brought to the ready to synchronize condition by automatic selection, performance, and proving of a sequence of controls. Likewise a similar stopping impulse completely shutdown the unit. Synchronizing and loading remain manual functions from the local and remote control points. The term does not embrace any supervisory control equipment, which may be interposed in the case of long distance remote control.

### 3.3.3 Fully Automatic Control

For fully automatic control, means are provided for running up, automatically synchronizing and loading up to a predetermined quantity on a receipt of a single starting impulse. Subsequent manual variations of loading and excitation may be provided as a remote control function. The corresponding stopping impulse will cause the load to be reduced, the unit to be disconnected from the busbars and the turbine to be shutdown completely. Supervisory control equipment is not included in the scope of the term.

(a) Reads the information on the equipment status operation.

(b) Activates Commands of controls to optimizes the output production

(c) This type of system needs specialized personnel. The operator of the automatic system will still have to the make the necessary changes to the commands or controls, based on the needs or production demands from time to time.

(d) This approach does not request full time supervision by an operator.

### 3.3.4 Supervisory or Remote Control

In supervisory control, communication type apparatus employing the selection of control facilities and the coded transmission intelligence is used. Starting, stopping, switch closing or opening and other functions are initiated from a remote point, together with indications of successful operation of voltage and load and of reception of alarm conditions at the remote control point.

## 3.4 AUTOMATION

Automation (ancient Greek = self dictated) or industrial automation or numerical control is the use of control systems such as computers to control industrial machinery and process, replacing human operators. In the scope of Industrialization, it is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the physical requirements of work, automation greatly reduces the need for human sensory and mental requirements as well. [19]

## 3.5 AUTOMATION FOR SMALL HYDRO POWER 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. [20]

A system for managing, controlling & protecting a SHP operation as shown in Fig 3.1. 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

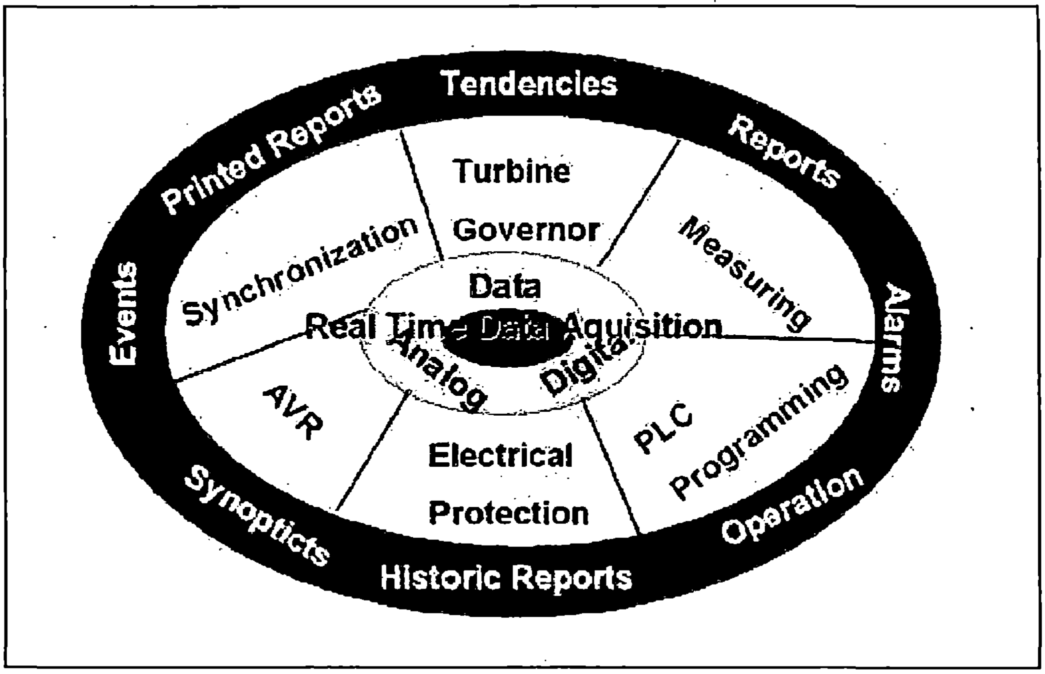



*Fig: 3.1 Typical Diagram of Automation System for SHP Station [21]*

## 3.6 NEED OF AUTOMATION FOR SHP

Initially most of the operations involved in SHP were done manually as the development in digital systems, most of the operations can be done automatically with the use of PLC. The main reason for this is cost effectiveness. While using a PLC most of the relays can be replaced by digital relays embedded in PLC and it allows ease of operation a modification. With PLC, But with the Development in technologies, PLC can do almost every operation involved in control of SHP. It is also cost effective and small in size. Standard PLC can be programmed to handle most of the control requirements. They can be used for full plant automation including governing of The auto-operation includes speed control, load control, excitation control, and level control automatic start/stop sequencing, gate control, start/stop auxiliary systems, and protection requirement etc.

Different controls like turbine control, generator control, and plant control protection systems can be integrated into one system. Continuous monitoring and data recording should also be involved for effective operation. Different operations for protection of mechanical and electric equipment can also be included. Temperature of bearings and generator winding can be continuously monitored. For this purpose different transducers are to be used to sense different parameters like speed temperature, level etc. Present day digital controllers, which have higher speed, higher reliability are best suited and are able to replace the conventional methods of control and governing.

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.

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

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

(c) Provides successful, efficient and smooth operation.

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

## 3.7 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.

(s) Coordination of design

(t) Open system – easily upgraded or added

(u) Lower cost

(v) Reliable operation

### 3.7.1 Benefits in terms of cost

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

### 3.7.2 Problems Associate with Automation

(a) Inadequate field experience

(b) Training needs.

(c) Lack of standardization

## 3.8 CONSIDERATIONS FOR SELECTION OF AUTOMATION FOR SHP

The characteristics and extent of the automation (automatic control system) in small hydro depends on the type of operation of the plant (manned, unmanned, remote controlled), the qualifications of the staff etc.

A simple manual control panel or an automatic sequencer with all the command and control functions can be used.

It is very important to find out the solution that suits the individual case of SHP, bearing in mind the operational requirements and the cost. In this respect, it is very important to consider the consequences of breakdown (plant shutdown, stock of spare parts, possibility of manual operation, black start etc.).

Depending on the site, two type of control can be considered:-

(a) Local control (near to the item to be monitored on protected).

(b) Remote control (distant from the item to be monitored, situated inside or outside the

(c) Plant).The best solution from the point of view of simplicity and effectiveness can be chosen with following considerations in mind.

(d) The automation should be simple as possible to avoid breakdowns and to reduce the duration of outages. It should be designed for easy replacement of wearing parts. The use of modular elements (not standby equipment) will result in reduced shutdown.

(e) The automation should be such that it should be possible to perform a manual start without auxiliary energy (black start) at least locally (isolated load).

(f) The elements requiring control and automation comprise the following:

(g) Speed control to regulate active load.

(h) Voltage control to regulate reactive power control.

(i) Automatic sequencing for startup and shutdown including synchronizing.

(j) Auxiliary control.

(k) Automatic sequencing for emergency shutdown

(l) Data recording and reporting.

(m) Remote control and monitoring

(n) Water level control

(o) Accordingly, automation and control system for SHP can be selected keeping in view the following.

(p) High cost of speed control and automation with currently installed analog flow governors, unit control and protection systems. These systems require attended operation and are mostly based on large capacity hydro units. This is making most of the small hydro units costly and uneconomical to operate.

(q) The manpower as available is likely to be unskilled and further adequate supervision may not be feasible. The cost of operating manpower is an important element in economic viability of small hydro especially in micro hydro range.

(r) Load factors in remote isolated areas are very low especially in initial stages.

(s) Digital generation controllers have been recently developed to take care of speed control, unit control and automation, unit protection and even generation scheduling and have been successfully in operation for the last few years.

(t) Digital generation controllers have been recently developed to take care of speed control, unit control and automation, unit protection and even generation scheduling and have been successfully in operation for the last few years.

(u) PLC based digital control systems have become economical nowadays. It is considered that dedicated digital control system is likely to be reliable and cheaper.

(v) Dedicated PC based system for complete generation control can be easily adopted for data acquisition and storage at a nominal cost and can also be adapted to SCADA system.

(w) In case of small units in micro hydro range, size elimination of flow control governors by use of shunt load governors (electronic load controllers) will make these units economically viable and properly designed will eliminate continuous attendance requirements.

(x) Required automation and data storage function can be added to the Digital Shunt Load Governors.

(y) The dummy loads in the Shunt Load Governors or Electronic Load Controller (ELC) can be useful load system or can be used for supplying domestic energy needs at off peak time.

## 3.9 ROLE OF PLC IN AUTOMATION

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. [22]

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 kV AR 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 then 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 [23]. 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 covert 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 PLCs 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. [22]

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

# CHAPTER 4

# EXPERIMENTAL WORK

## 4.1 EXPERIMENTAL SETUP

It consists of a pump which creates the necessary head and discharge for the turbine. In its suction is a water tank wherein water is drawn by the impeller and pumped into a pump-turbine (It acts as a pump depending on the direction of water flow). The water flow to the turbine can be adjusted by means of a manual control valve or an electrical valve. If electrical control valve is used then the manual valve is kept fully open.

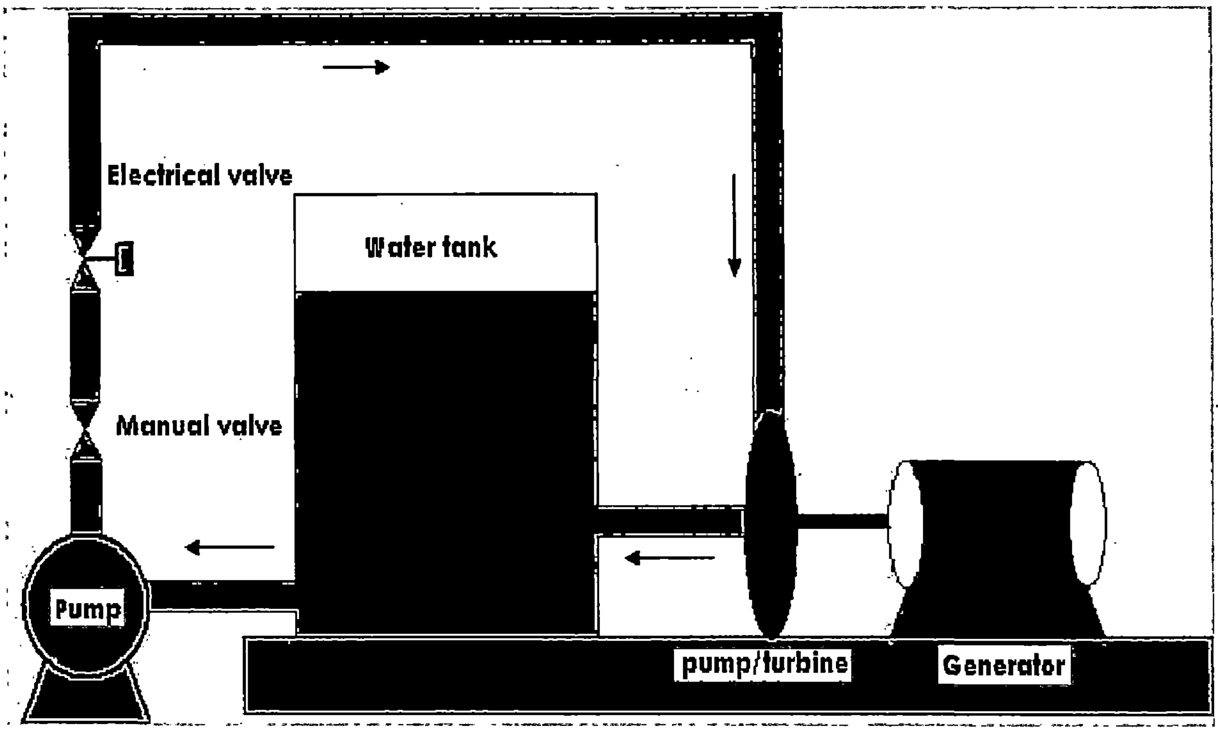



*Fig: 4.1 Schematic of the Hydro-Turbine Generator Test Setup*

The Generator is coupled to the turbine by means of coupling arrangement. The generator terminals are in turn connected to load (bulb load) through the Load control circuit. The load consists of 5 rows of lamps with 3 lamps in each row and they are arranged such that all the 5 bulbs in one column which are connected to a phase, as the generator is of three phase all the lamps are accommodated.

The objective of the thesis work is to develop a PLC based automation system with following capabilities:

(a) Automatic Starting of SHP Station

(b) Automatic shutdown (normal, emergency)

(c) Speed control

(d) Load control

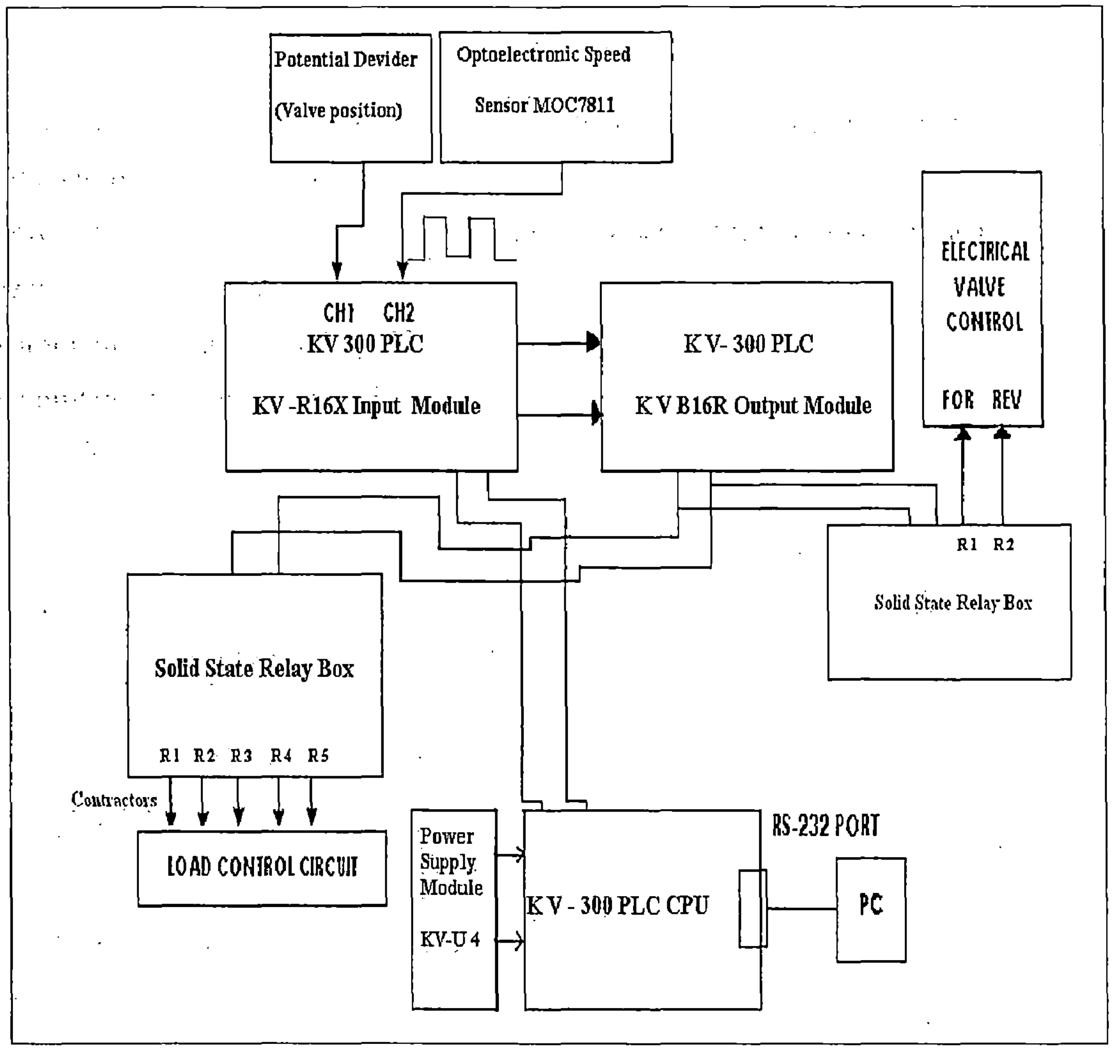



*Fig: 4.2 Block Diagram of Measurement and Control Setup using PLC KV 300*

The above fig shows the block diagram of the whole arrangement of measurement & control set up. The 0 - + Ve 2 Volt analog input of valve position from potential divider and the + 5 V square waves input of speed of turbine from optoelectronic speed sensor are coming to the analog input module KV – R16X of KV 300 PLC. The CPU of PLC is connected personnel Computer by RS 232 C port. The power supply, CPU, input module, output module, analog I/O modules are interconnected with each other. The output signal resulting by execution of programs from output module KV B16R is going to solid state boxes, which are connected to load control circuit and electrical valve control respectively.

The following section gives the specifications of turbine and generator in the demonstration unit. Fig 4.3 shows the view of the turbine generator demonstration unit.

*Fig: 4.3 View of Turbine-Generator Demonstration Unit*

## 4.2 PUMP UNIT :

**Water Lifting Motor Specifications:**

Total head: 32.8 meters

Flow rate: 14.5 liters/sec

Pump input: 8.18kW

Speed: 1450 rpm

The input pump is a constant speed motor pump of 30 H.P and can produce a maximum head of 60 meters and maximum flow of 23.5 Litters.

## 4.3 SYNCHRONOUS GENERATOR:

Terminal voltage: 415V

Reactive power: 12.5kVA

Active power: 10Kw

Phase: 3

Power factor: 0.8

Frequency: 50 Hz

Speed: 1500 rpm

Excitation: 23.5V DC, 2.32 Amps

## 4.4 ELECTRICAL ACTUATOR

The AVCON make 2- way motorized control valve is used most commonly for either ON/OFF or control service [24]. Fig 4.4 shows the electrical actuator.

### 4.4.1 Principle of Operation

An electrical actuator is basically an On-Off type controller which is operated with the conventional 230V, 50Hz supply. It is connected to a Globe valve whose stem is connected to the actuator so that when the actuator is powered then the valve opens or closes until the supply is fed. The actuator has two limit positions based on the two limit switches; one is called the open limit switch and other close limit switch. These two limit switches limit the operation of the motor until two extreme positions the valve can move i.e. Full open and Full close position.

This is done by means of open and close limit switches which have Normally Open (NO) and Normally Closed (NC) contacts, the supply to the motor of the actuator are routed through the NC contact. So whenever the valve reaches the predefined extreme limits then either the Open/Close limit switch is activated or the supply through the NC contact is cut off as this contact changes to NO. In this way the valve is operated either in the forward or reverse direction to open or close the valve respectively.

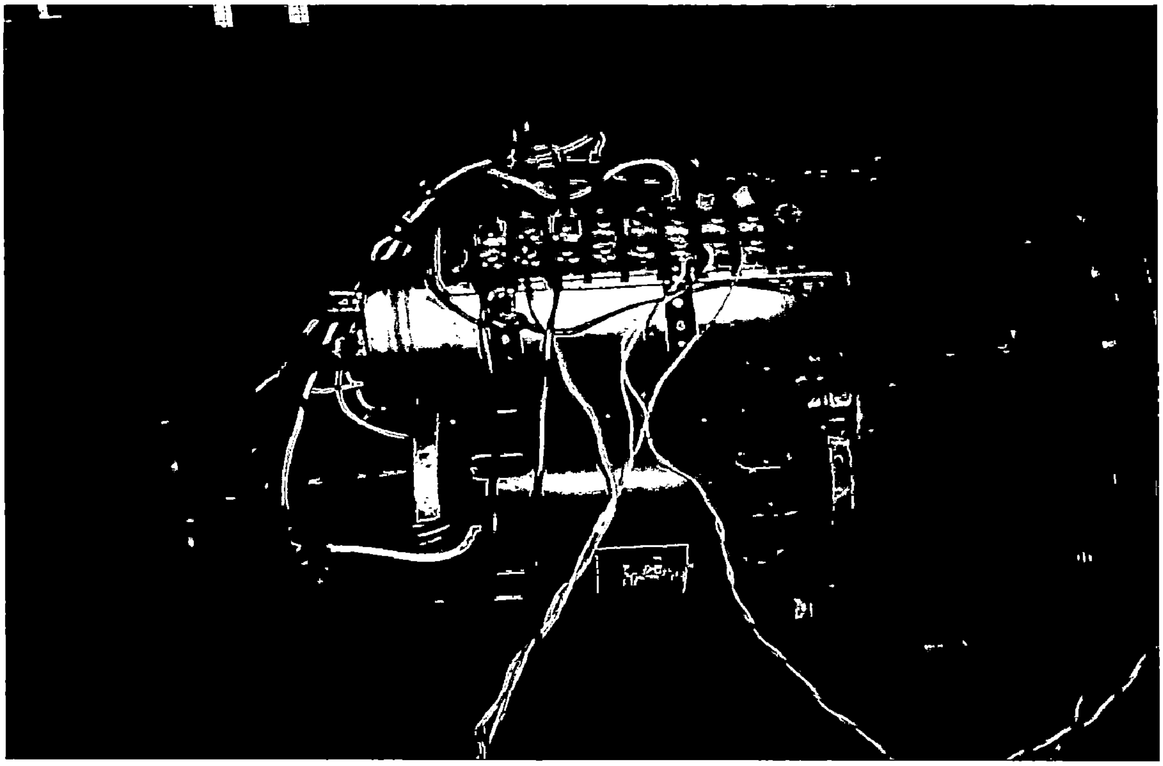


*Fig 4.4 Electrical Actuator*

### 4.4.2 Electrical Connections

The actual electrical connections of the manufacturer are as shown in Fig 4.5 below [24]. This Electrical connection pertains to the 4 to 20 mA servo-controls for the actuator wherein the 4 mA corresponds to full close and 20 mA corresponds to the full open position.

Due to the improper operation of the 4 to 20 mA controller the wiring diagram has been modified after completely removing the servo-controller. The modified connection diagram of the actuator is shown in Fig 4.6 below.

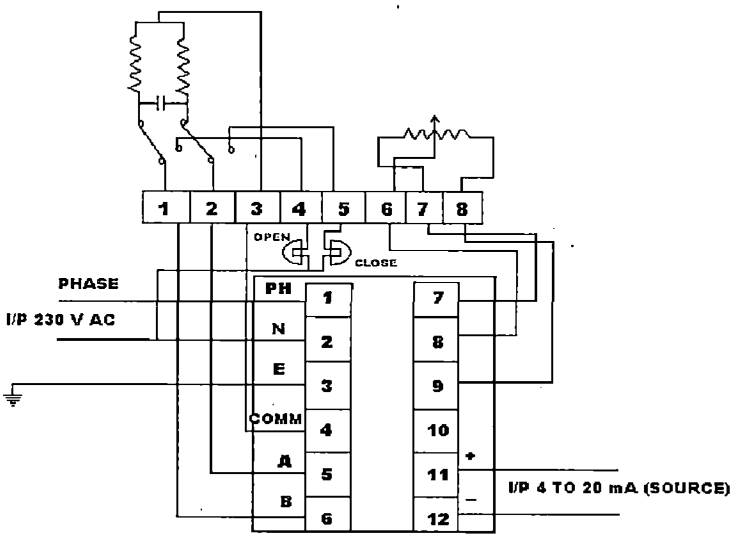



*Fig: 4.5 Actual Electrical Connections [24]*

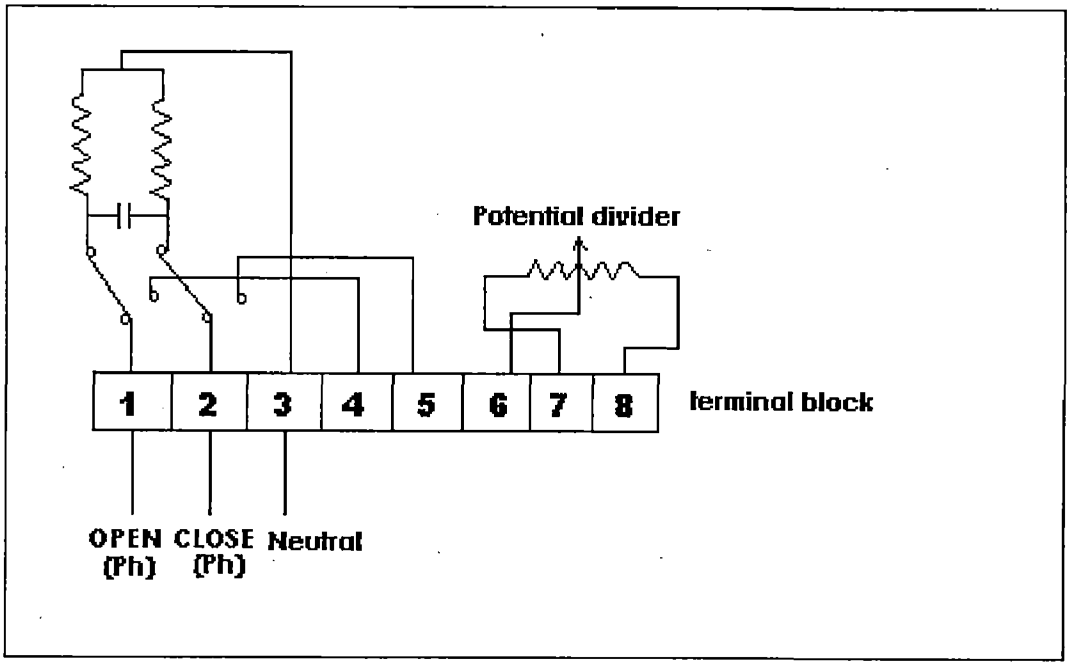



*Fig: 4.6 Modified Electrical Connections*

### 4.4.3 Tuning and Adjustment

The tuning and adjustment is nothing but setting the actuator to be driven within the open and close limits. The following are the steps to be carried out:-

(a) At first the valve is bought to the two extreme conditions. At one extreme the resistance of the variable point 6 in the potential divider with respect fixed point 7 is found to be 90 ohms at full close position.

(b) At another extreme the resistance of the variable point 6 in the potential divider with respect fixed point 7 is found to be 430 ohms at full close position.

(c) A 2V DC source is connected to the fixed POT terminals 7 and 8 and respective voltages at the two extreme voltages are measured, this voltage is further used for online indication of valve position using LABVIEW.

(d) Manually get the valve to the middle position, connect the phase supply to the terminal 1 and neutral to 3 and check whether the valve is opening. Also check whether the open limit switch is working in the extreme condition i.e. the motor of the actuator should stop automatically when open limit switch acts.

(e) Now connect the phase supply to the terminal 2 and neutral to 3 and check whether the valve is closing. Also check whether the close limit switch is working in the extreme condition i.e. the motor of the actuator should stop automatically when close limit switch acts.

(f) The Limit switch positions on the actuator should not be disturbed otherwise the valve may be damaged or the actuator motor winding may burn out.

## 4.5 FABRICATION OF OPTOELECTRONIC SPEED SENSOR

### 4.5.1 Speed sensor MOC7811

The speed sensing is done by fabricating a optoelectronic speed sensor using an optocoupler Integrated Circuit (IC) MOC7811. It has a LED on one side and a phototransistor on the other side. The placement of the sensor is such that the movement of the disc interrupts the light path between the two. [25]

LED current should be in the range of 5 mA to 10 mA. Therefore a series resistance R1 of 570Ω is placed and on phototransistor side a 10K resistance R2.The voltage supply of + 5 Volt has given to both sides as shown in Fig 4.7.

Slotted Disc: A slotted disc fabricated with brass having an outer diameter of 21cm and it has 60 tooth is used. This disc is mounted on the generator shaft whose speed is to be measured. As the generator shaft rotates the disc also rotates with the same rpm.

Since the disc is slotted the rotation of the disc causes the interruption of light at time intervals proportional to the speed of the generator. The speed sensor has been fabricated according to circuit is shown in Fig 4.7 below.

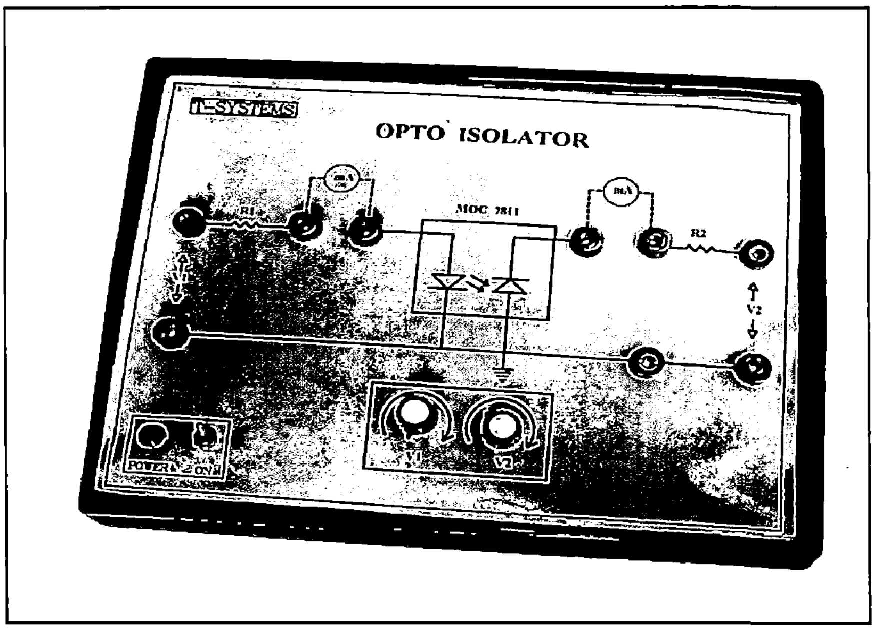



*Fig: 4.7 Optoelectronic Speed Sensor [26]*

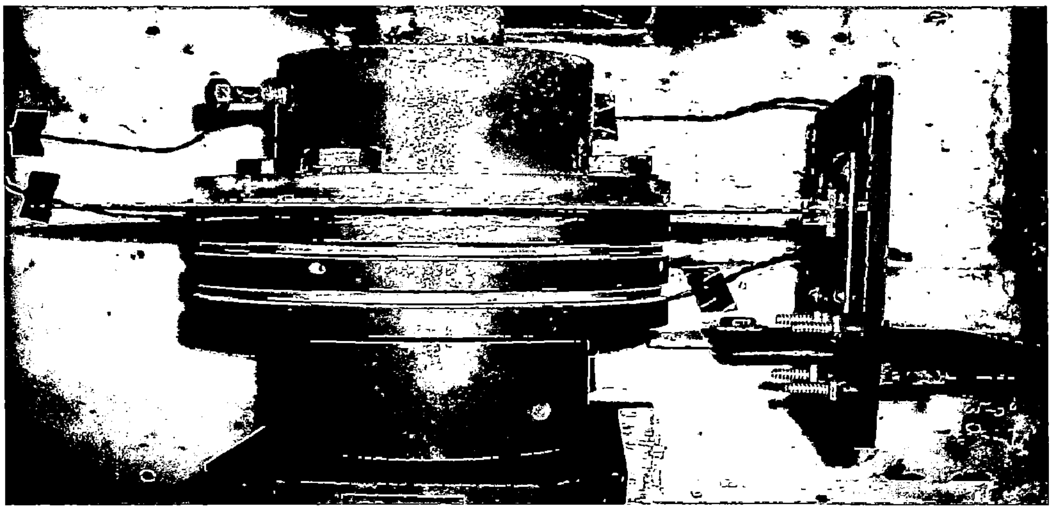


*Figure 4-8 View of Slotted Disc Rotating as an Obstacle between LED & Transistor*

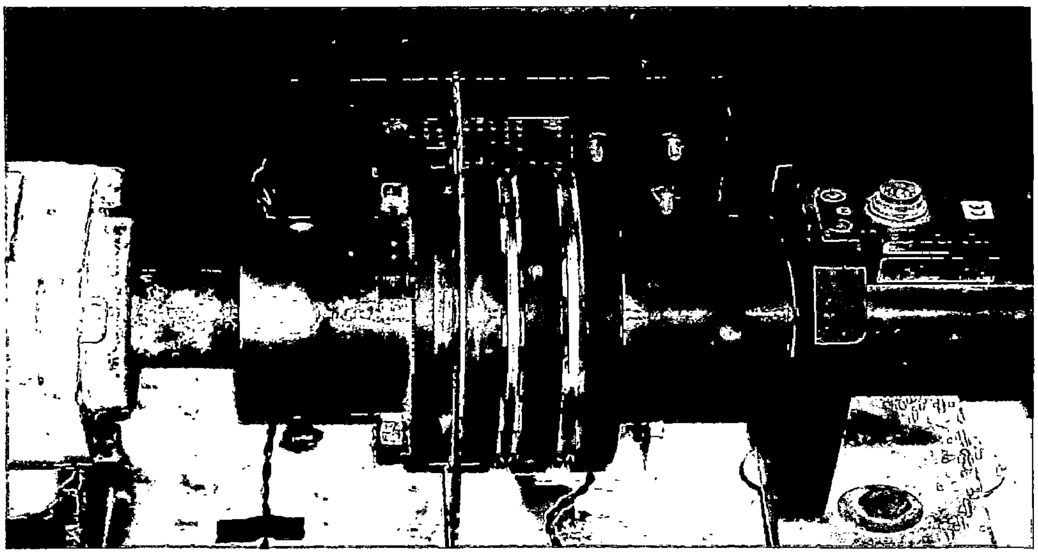


*Figure 4-9 View of Speed Sensor and Disc*

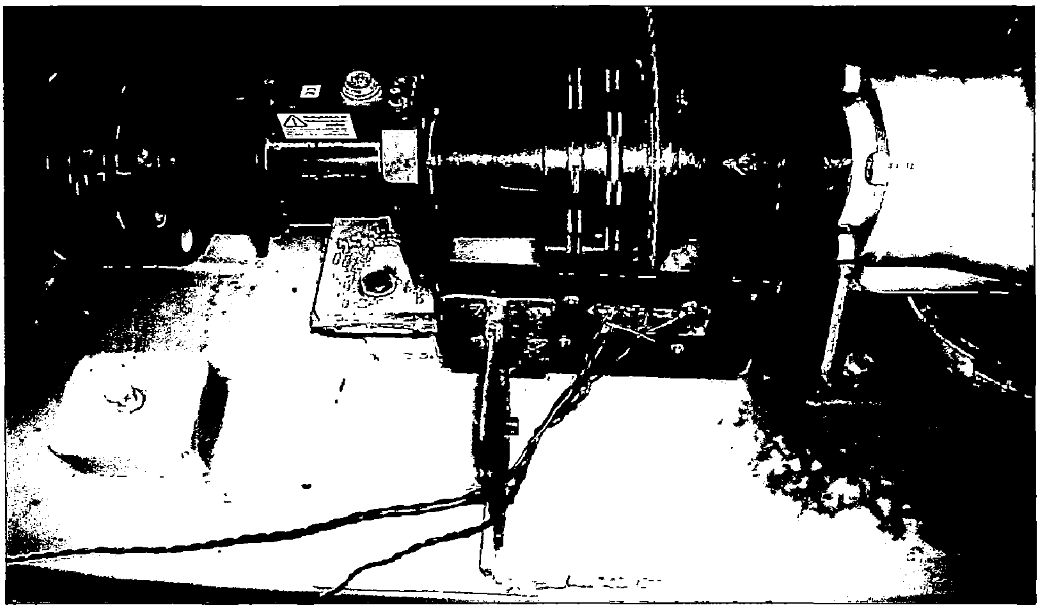


*Fig: 4.10 Speed Sensor & its Wiring Connections*

# TECHNICAL DETAILS, FUNCTIONS & CAPABILITIES OF PLC

## 5.1 PROGRAMMABLE LOGIC CONTROLLERS

### 5.1.1General

Programmable controller is a special type of computer based controller which is used for systems that have both input and output with only two states: on and off. These systems are called discrete state systems. In past, programmable controllers were relay circuits that were used for sequencing of on/off output devices based on on/off inputs. Such inputs include limit switches, push-buttons and thermal trip switches such as thermal overloads on motors.

The discrete state is the expression used to explain that each event in the sequence can be described by specification of the condition of all opening units of the processes. A particular set of conditions is described as a discrete state of the whole system. A special technique for designing and describing the sequence of process events is called a ladder diagram. The ladder diagram is evolved from the early use of electromechanical relays to control the sequence of events in different processes. But nowadays relay control systems have been replaced by computer based method of control the most common of which is called a programmable controller.

Automation of SHP typically involves many operations or steps. Some of these steps must occur in series and some can occur in parallel. Some of events may involve the discrete setting of states in the plant, that is, gates or valves open or closed auxiliaries on or of and some other events may involve regulation of some continuous variable over time or duration of an event. For example it is necessary to maintain a constant frequency and voltage for Synchronization.

### 5.1.2 Ladder Diagram

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.[27]

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 modem 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 any where in ladder diagram changes states, the consequences are immediate.

But the same is not true for computer based programmable controllers. To build a relay based control system, it is necessary to provide certain kinds of special functions not normally associated with relays. These functions are often provided using analog and digital electronic techniques. Such special functions include time delay relays, up/down counters, and real time clocks.

In a hardwired ladder diagram, if event sequence is to be changed, it is necessary to rewire all or part of a panel. It may be some times necessary to add more relays to the system or it may be required to remove some relays from the system.

Therefore it is a need to have such a system in which such tasks can be done easily without any trouble and cost involvement. A number of ingenious methods used to ease this problem of changing the relay program. One of these is to use patch-panels for programming. In these systems all relay contacts and coils are brought to an array of sockets. Cords with plugs in each end are then used to patch the required coils, contacts, inputs and output together in the manner required by ladder diagram.

The patch acts as a memory in which the program is placed. With the development of reliable computers, it was essential and beneficial to replace relay logic based system by computers controller systems.

### 5.1.3 Introduction to PLC

The modern method to provide control is to use a computer based device called a programmable controller (PC) or programmable logic controller (PLC).

Hence 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 of following.

(a) Analog input/ output module.

(b) PID control module.

(c) Communication module.

(d) Graphics display module.

(e) Additional memory.

### 5.1.4 Components of PLC

As shown in Fig 5.1, 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. [27]

### 5.1.4.1 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.

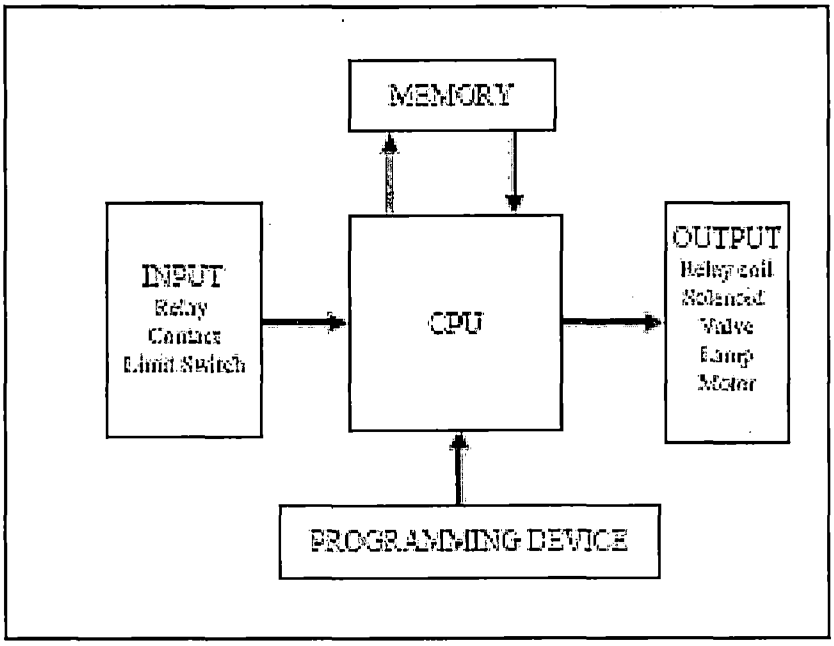



*Fig: 5.1 Schematic of Components of PLC [27]*

### 5.1.4.2 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.

#### 5.1.4.3 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 then 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.

#### 5.1.4.4 Programming and Other Facilities

PLC is first programmed before use for a particular system. Programming is done with graphic representation called ladder diagrams. 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 manufactures. 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.

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 1 K 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. [27]

## 5.2 DISCRIPTION OF KEYENCE KV 300 PLC USED FOR PRESENT WORK

In Present work Experiments were carried out with KEYENCE Super Micro KV 300 PLC over Hydro Turbine Generator demonstration unit at AHEC laboratory to demonstrate the control and automation features. Its CPU is KV 300 microprocessor and uses electrically erasable programmable read only memory (EEPROM). The PLC is small in size, modular in construction and with digital and analog I/O module, total six modules namely:-

(a) Power supply

(b) CPU

(c) Digital input

(d) Digital output

(e) Analog I/O (2 Nos.)

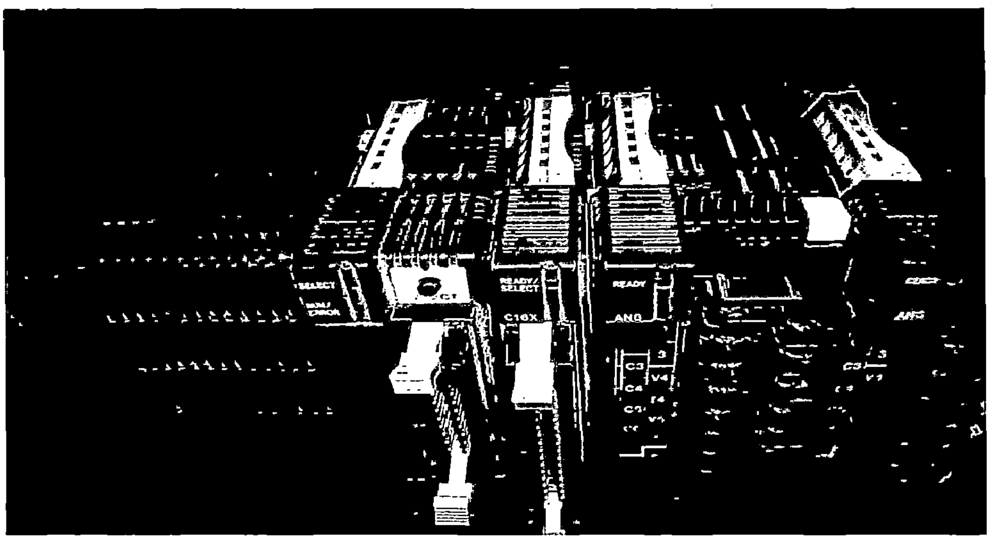


*Fig: 5.2 View of Different Modules of KV -300 PLC*

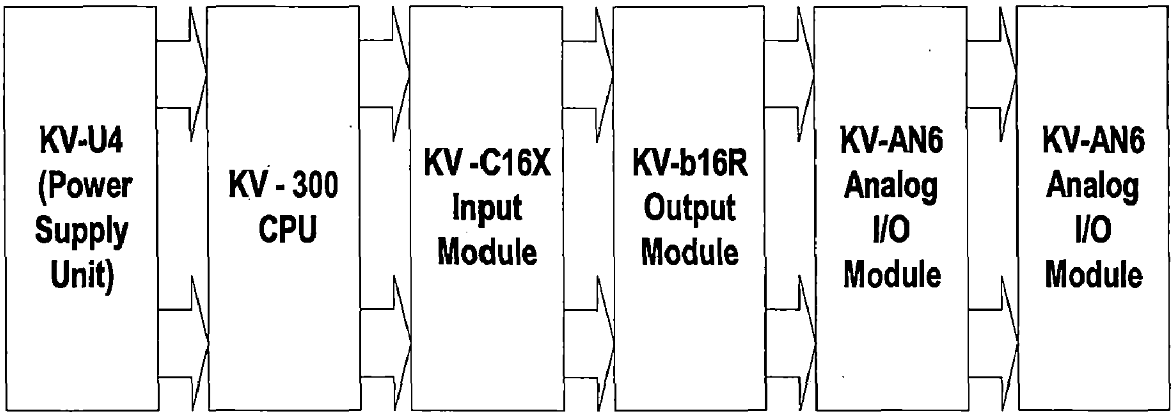



*Fig: 5.3 Schematic of Different Modules of KV-300 PLC*

A brief description of different modules of KV -300 PLC is given as below:-

**5.2.1 Power Supply Module (KV-U4)**

KV -U4 is the name of supply used for this PLC. Input voltage may vary from 100 to 240 V AC with 50/60 Hz. It also has an output of 25 V DC. Total output current is 1.4 A. including main power supply output current. Line noise from the power supply can be reduced by using a 1: 1 insulation transformer.

**5.2.2 Central Processing Unit (CPU) Module (KV-300)**

The CPU module has KV-300, which is a 16-bit microprocessor and its associated components like RAM and EEPROM. It has 10 inputs (numbered from 0000 to 0009) and 4 outputs (numbered from 0500 to 0503). It can be switched to 24 VDC or 5 VDC. The I/O connector configuration in shown in Fig 5.4 .CPU can be connected to RS-232 C port of a personnel computer. I/O specifications are given in table 5.1 and 5.2 as follows.

***Table 5.1 and 5.2: I/O Specifications of KV – 300 PLC [28]***

***Input specifications***

10 inputs (0000 to 0009)

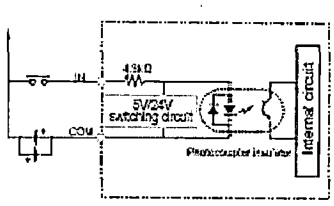
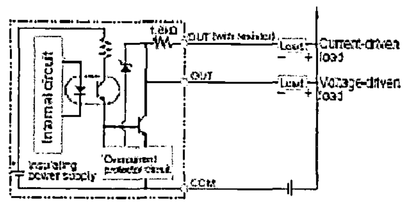
| Input modes | 24 VDC input mode | 5 VDC input mode |
|---|---|---|
| Rated voltage | 26.4 VDC max. | |
| Input voltage and current | 24 VDC 5.3 mA | 5 VDC 1 mA |
| Threshold voltage (ON) | 19 V | 3.5 V |
| Threshold current (OFF) | 1.5 mA | – |
| Threshold voltage (OFF) | – | 1.5 V |
| Common ground | 10 I/O per common terminal | |
| Input time constant | Normal: 10 ms ±20%<br>When HSP instruction is used: 25 µs ±20%<br>When special utility relay 2813 is ON: 10 µs ±20%<br>(for both OFF/ON and ON/OFF switching) | |
| High-speed counter maximum response time | 30 kHz | |

***Output specifications***

4 outputs (0500 to 0503)

| Type of output | Transistor NPN |
|---|---|
| Rated load | 30 VDC 0.1 A |
| Maximum voltage at OFF | 30 VDC |
| Maximum leakage current at OFF | 100 µA |
| Maximum residual voltage at ON | 0.3 V |
| Common ground | 4 I/O per common terminal |
| Maximum switching time | 10 µs (for both OFF/ON and ON/OFF switching) |

***I/O circuit structure***

| Input circuit | Output circuit |
|---|---|
|   |   |

- Both NPN inputs ([+] common) and PNP inputs ([-] common) are available.
- Use a separate power supply for load.

| Pin No. | I/O | Signal | |
|---|---|---|---|
| 1 | I | Input | COM |
| 2 | I | (Interrupt) | 0001 |
| 3 | I | (Interrupt) | 0003 |
| 4 | I | (High speed counter 1) | 0005 |
| 5 | I | (High speed counter 1 phase) | 0007 |
| 6 | I | (High speed counter 1 RES) | 0009 |
| 7 | O | (with resistor) | 0500 |
| 8 | O | (with resistor) | 0501 |
| 9 | O | (with resistor) | 0502 |
| 10 | O | (with resistor) | 0503 |
| 11 | I | (Interrupt) | 0000 |
| 12 | I | (Interrupt) | 0002 |
| 13 | I | (High speed counter 0) | 0004 |
| 14 | I | (High speed counter 0 phase) | 0006 |
| 15 | I | (High speed counter 0 RES) | 0008 |
| 16 | O | | 0500 |
| 17 | O | | 0501 |
| 18 | O | | 0502 |
| 19 | O | | 0503 |
| 20 | O | Output | COM |

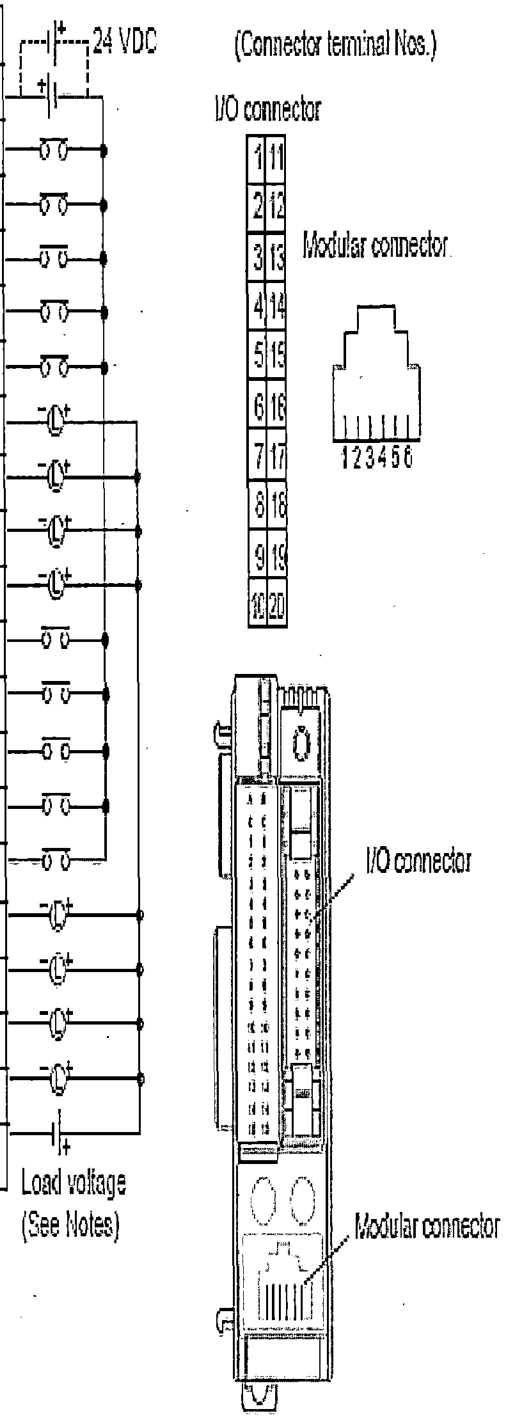


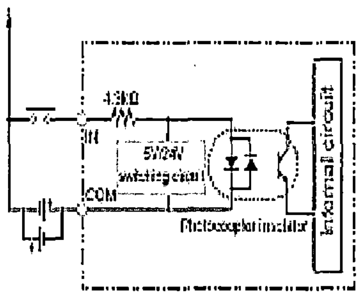

*Fig: 5.4 I/O Connector Configuration of KV 300 CPU*

### 5.2.3 Input Module ( KV –C 16 X)

The input module KV-C16 X ha 16 number of inputs. Input is switchable between 2 VDC and 5 VDC. Specifications of the module are given in table 5.3 and connector diagram i Fig 5.5

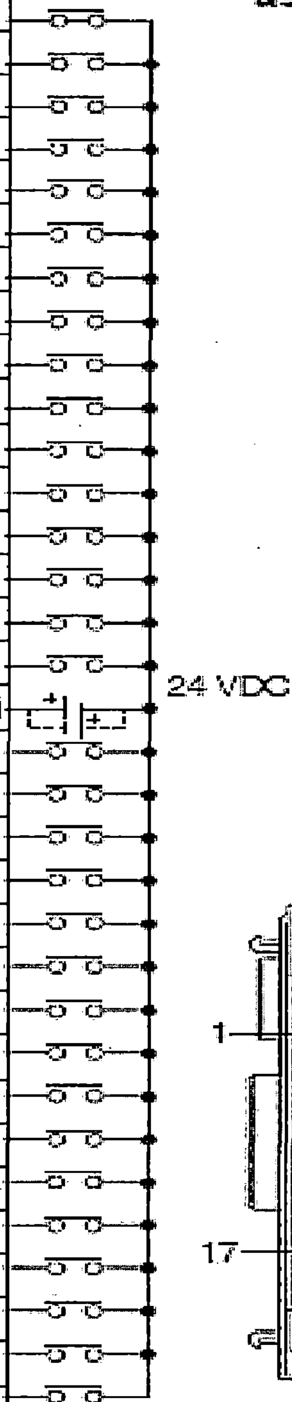
***Table 5.3: System Specification of KV –C 16 X Input Module [28]***

## KV-C16X/C32X Input Modules

| Model | KV-C16X (16 inputs) | | KV-C32X (32 inputs) | |
|---|---|---|---|---|
| Connection to external equipment | Connector (conforms to MIL Standard) | | | |
| Input mode | 24 VDC | 5 VDC | 24 VDC | 5 VDC |
| Maximum rated voltage | 26.4 VDC | | | |
| Input voltage and current | 24 VDC 5.3 mA | 5 VDC 1 mA | 24 VDC 5.3 mA | 5 VDC 1 mA |
| Threshold voltage (ON) | 19 V | 3.5 V | 19 V | 3.5 V |
| Threshold current (OFF) | 1.5 mA | - | 1.5 mA | - |
| Threshold voltage (OFF) | - | 1.5 V | - | 1.5 V |
| Common ground | 16 I/O per common terminal | | 32 I/O per common terminal | |
| Input time constant (3-way switchable) | (OFF → ON)<br>(HI) 25 µs ±20%<br>(MID) 1 ms ±20%<br>(LOW) 10 ms ±20% | | (ON → OFF)<br>(HI) 75 µs ±20%<br>(MID) 1ms ±20%<br>(LOW) 10 ms ±20% | |
| Input impedance | 4.3 kΩ | | | |
| Maximum current consumption | 15 mA | | | |
| Approximate weight | 80 g | | 95 g | |
| Circuit structure |  | | | |

<KV-C32X>

| Pin No. | I/O | Signal |
|---|---|---|
| 1 | I | 000 |
| 2 | I | 001 |
| 3 | I | 002 |
| 4 | I | 003 |
| 5 | I | 004 |
| 6 | I | 005 |
| 7 | I | 006 |
| 8 | I | 007 |
| 9 | I | 008 |
| 10 | I | 009 |
| 11 | I | 010 |
| 12 | I | 011 |
| 13 | I | 012 |
| 14 | I | 013 |
| 15 | I | 014 |
| 16 | I | 015 |
| 17 | I | Input COM |
| 18 | | 100 |
| 19 | | 101 |
| 20 | | 102 |
| 21 | | 103 |
| 22 | | 104 |
| 23 | | 105 |
| 24 | | 106 |
| 25 | | 107 |
| 26 | | 108 |
| 27 | | 109 |
| 28 | | 110 |
| 29 | | 111 |
| 30 | | 112 |
| 31 | | 113 |
| 32 | | 114 |
| 33 | | 115 |
| 34 | | NC |




**Connector Pin assignment**

| | |
|---|---|
| 1 | 18 |
| 2 | 19 |
| 3 | 20 |
| 4 | 21 |
| 5 | 22 |
| 6 | 23 |
| 7 | 24 |
| 8 | 25 |
| 9 | 26 |
| 10 | 27 |
| 11 | 28 |
| 12 | 29 |
| 13 | 30 |
| 14 | 31 |
| 15 | 32 |
| 16 | 33 |
| 17 | 34 |

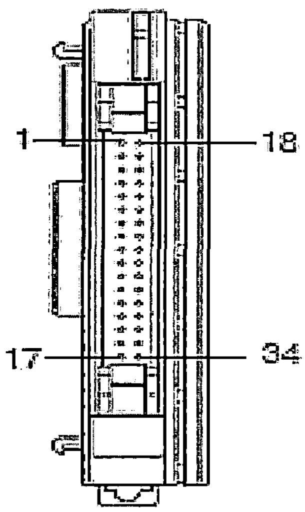



*Fig: 5.5 Connector configuration of K-C16 X Input Module [28]*

### 5.2.4 Output Module ( KV-B16 R)

The output module KV –B16 R has 16 numbers of outputs. It has 8 I/O per common terminal that is 2 common terminals. Connector diagram shows in Fig 5.6 Specifications of module are given in table 5.4 and Specifications of module are given in table 5.4 [28]

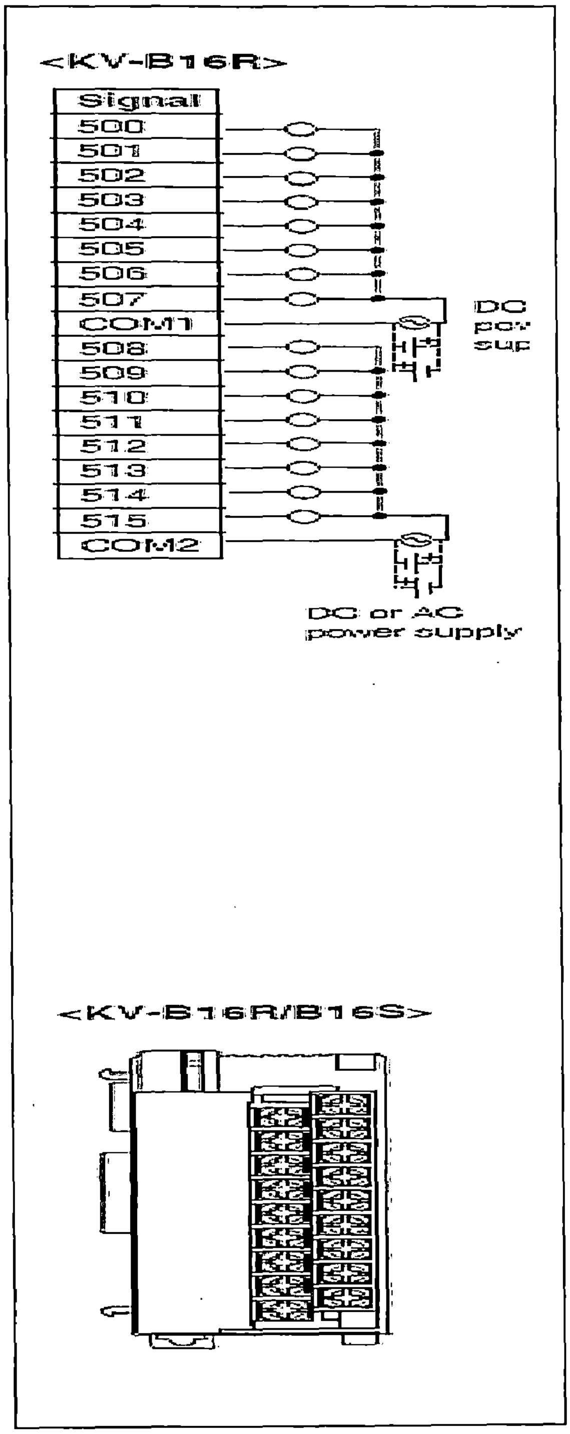
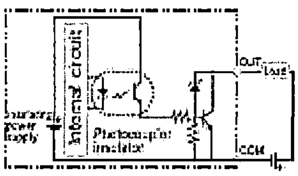
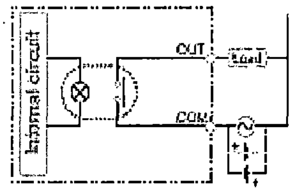
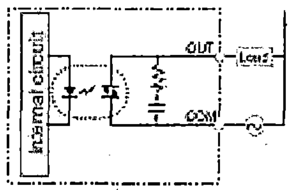



*Fig: 5.6 Connector Configuration of KV-B 16R Output Module [28]*

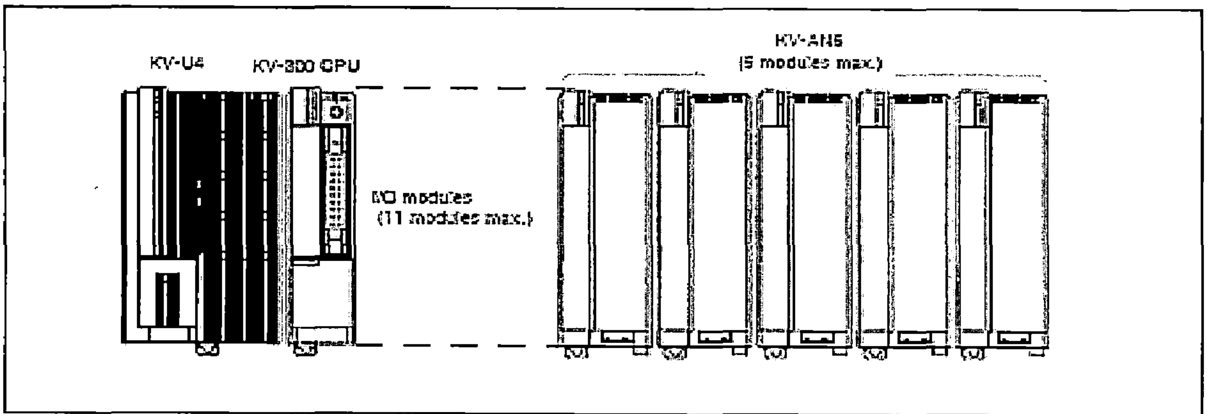
*Table 5.4 System Specification of KV- B16 R Output Module [28]*

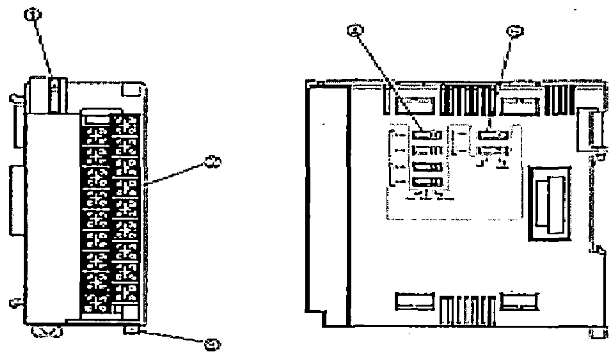
## KV-C32T/B16R/B16S Output Modules

| Model | KV-C32T (32) | KV-B16R (16) | KV-B16S (16) |
|---|---|---|---|
| Connection to external unit | Connector (conforms to MIL Standard) | Removable terminal block | Removable terminal block |
| Type of output | Transistor (NPN) | Relay | Triac |
| Rated load | 30 VDC 0.2 A | 250 VAC/30 VDC 2 A (8 A per common) | 250 VAC 0.3 A (1.2 A per common) |
| Peak load overcurrent | – | 5 A | 20 A |
| Maximum leakage current at OFF | 100 µA | – | 2 mA |
| Maximum residual voltage at ON | 0.5 V | – | – |
| Maximum resistance at ON | – | 50 mΩ | – |
| Common ground | 32 I/O per common terminal (*1) | 8 I/O per common terminal (2 terminals) | 8 I/O per common terminal (2 terminals) |
| Maximum switching time OFF→ON | 10 µs | 10 ms | 1/2 cycle ÷ 2 ms (50 Hz) 12 ms (60 Hz) 10.3 ms |
| Maximum switching time ON→OFF | 100 µs | | |
| Maximum current consumption | 55 mA | 150 mA | 85 mA |
| Approximate weight | 70 g | 200 g | 200 g |
| Circuit structure |  |  |  |

### 5.2.5 Analog I/O Module KV- AN6

The analog I/O module KV- AN6 has both analog/digital and digital/analog conversion functions. The A/D conversion function converts analog input to digital data in specific memory locations of the KV-300 CPU module. The D/A converter on the other and converts the digital data stored in the memory to analog output data for output devices. The digital data are 16 bits but the effective bits are 12 bits starting from the most significant digit. Maximum 5 modules can be used in the PLC and three input and output ranges can be selected with slide switches as shown in Fig 5.7. The inputs/ outputs ranges are -10 to + 10V (Voltage), -5 to + 5V and 0 to 20 mA (current). Block diagram showing the function of the analog I/O modules is shown in Fig 5.8. Terminal pin configuration and connection diagrams for voltage I/O are given in Fig 5.9.



| No. | Part name | Function |
|---|---|---|
| 1 | READY indicator | Lights when power (24 VDC) is supplied to the KV-AN6. |
| 2 | Analog I/O terminal block | Removable terminal block for analog input signals (4 ch.) and analog output signals (2 ch.) |
| 3 | Terminal block lock bar | Lock mechanism used to lock/release the analog I/O terminal block |
| 4 | Input range selection switch | Selects the analog input range for A/D conversion. Provided for each channel. (White represents the switch position.) ±5V ±10V 0 to 20mA |
| 5 | Output range selection switch | Selects the analog output range for D/A conversion. Provided for each channel. (White represents the switch position.) ±5V ±10V |

*Fig: 5.7 Range selection switches of KV-AN6 Analog I/O module [28]*

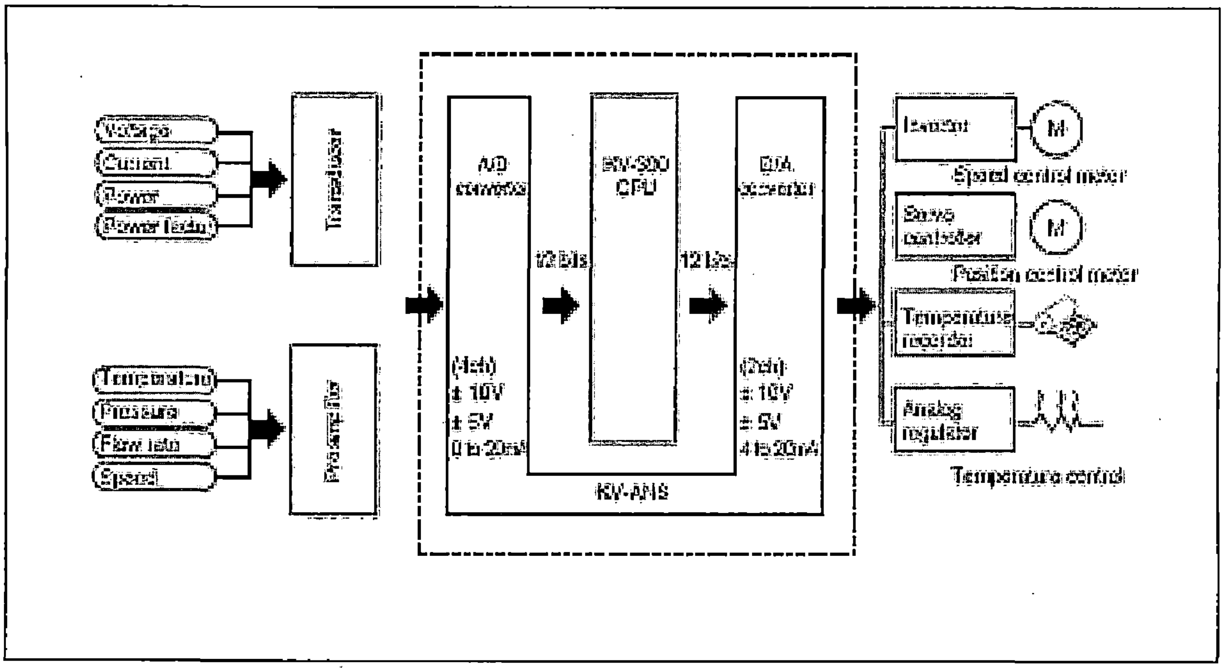



*Fig: 5.8 Configuration of Analog I/O module [28]*

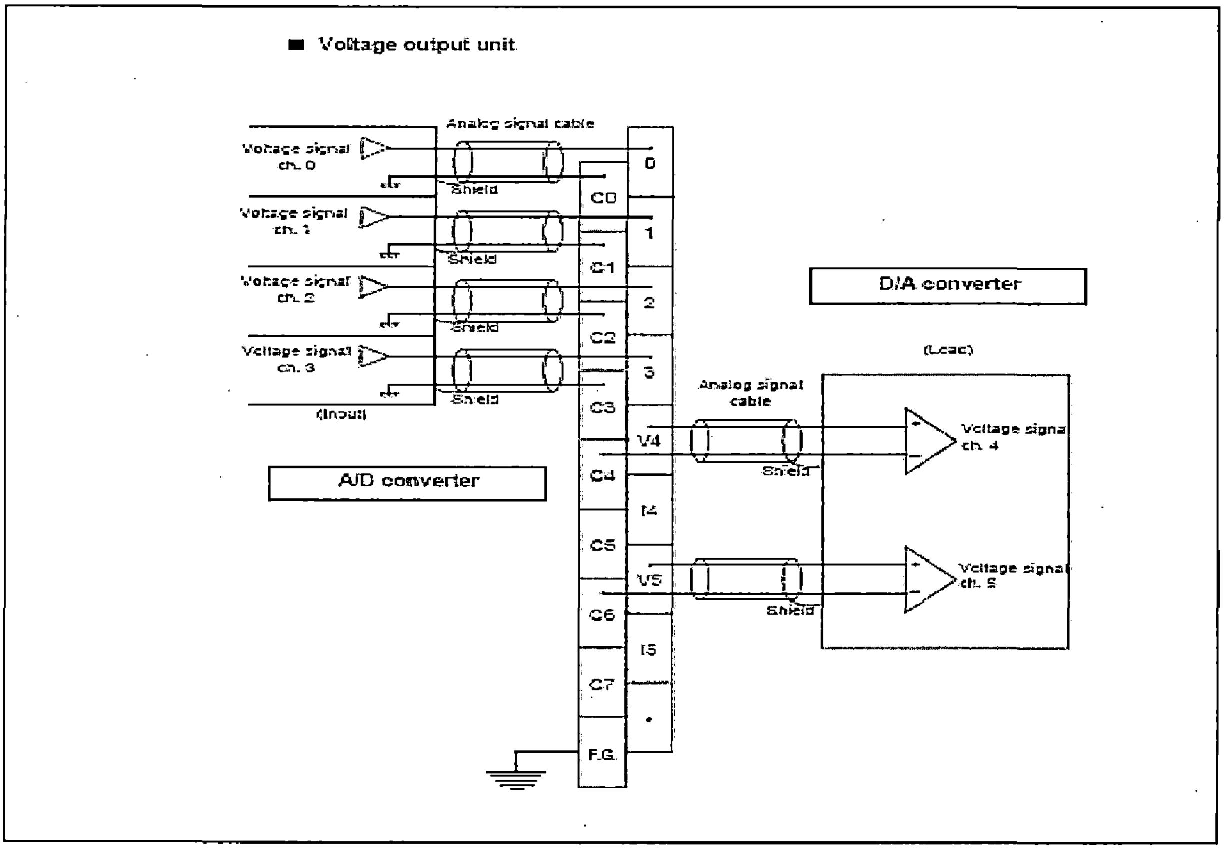



*Fig: 5.9 Wiring Diagram for Voltage I/O signals of Analog I/O module [28]*

The voltage and current conversion tables for A/D & D/A converter for Analog I/O module KV AN-6 are 5.5 and 5.6 respectively [28]

*Table 5.5 Voltage Conversion Table for A/D & D/A converter for Analog I/O Module*

## Voltage conversion table

■ ±10 V range

| | .00 | .10 | .20 | .30 | .40 | .50 | .60 | .70 | .80 | .90 |
|---|---|---|---|---|---|---|---|---|---|---|
| +10 | 32000 | 32320 | 32640 | | | | | | | |
| +9 | 28800 | 29120 | 29440 | 29760 | 30080 | 30400 | 30720 | 31040 | 31360 | 31680 |
| +8 | 25600 | 25920 | 26240 | 26560 | 26880 | 27200 | 27520 | 27840 | 28160 | 28480 |
| +7 | 22400 | 22720 | 23040 | 23360 | 23680 | 24000 | 24320 | 24640 | 24960 | 25280 |
| +6 | 19200 | 19520 | 19840 | 20160 | 20480 | 20800 | 21120 | 21440 | 21760 | 22080 |
| +5 | 16000 | 16320 | 16640 | 16960 | 17280 | 17600 | 17920 | 18240 | 18560 | 18880 |
| +4 | 12800 | 13120 | 13440 | 13760 | 14080 | 14400 | 14720 | 15040 | 15360 | 15680 |
| +3 | 9600 | 9920 | 10240 | 10560 | 10880 | 11200 | 11520 | 11840 | 12160 | 12480 |
| +2 | 6400 | 6720 | 7040 | 7360 | 7680 | 8000 | 8320 | 8640 | 8960 | 9280 |
| +1 | 3200 | 3520 | 3840 | 4160 | 4480 | 4800 | 5120 | 5440 | 5760 | 6080 |
| +0 | 0000 | 320 | 640 | 960 | 1280 | 1600 | 1920 | 2240 | 2560 | 2880 |
| -0 | 0000 | 65216 | 64896 | 64576 | 64256 | 63936 | 63616 | 63296 | 62976 | 62656 |
| -1 | 62336 | 62016 | 61696 | 61376 | 61056 | 60736 | 60416 | 60096 | 59776 | 59456 |
| -2 | 59136 | 58816 | 58496 | 58176 | 57856 | 57536 | 57216 | 56896 | 56576 | 56256 |
| -3 | 55936 | 55616 | 55296 | 54976 | 54656 | 54336 | 54016 | 53696 | 53376 | 53056 |
| -4 | 52736 | 52416 | 52096 | 51776 | 51456 | 51136 | 50816 | 50496 | 50176 | 49856 |
| -5 | 49536 | 49216 | 48896 | 48576 | 48256 | 47936 | 47616 | 47296 | 46976 | 46656 |
| -6 | 46336 | 46016 | 45696 | 45376 | 45056 | 44736 | 44416 | 44096 | 43776 | 43456 |
| -7 | 43136 | 42816 | 42496 | 42176 | 41856 | 41536 | 41216 | 40896 | 40576 | 40256 |
| -8 | 39936 | 39616 | 39296 | 38976 | 38656 | 38336 | 38016 | 37696 | 37376 | 37056 |
| -9 | 36736 | 36416 | 36096 | 35776 | 35456 | 35136 | 34816 | 34496 | 34176 | 33856 |
| -10 | 33536 | 33216 | 32896 | | | | | | | |

■ ±5 V range

| | .00/.50 | .05/.55 | .10/.60 | .15/.65 | .20/.70 | .25/.75 | .30/.80 | .35/.85 | .40/.90 | .45/.95 |
|---|---|---|---|---|---|---|---|---|---|---|
| +5.0 | 32000 | 32320 | 32640 | | | | | | | |
| +4.5 | 28800 | 29120 | 29440 | 29760 | 30080 | 30400 | 30720 | 31040 | 31360 | 31680 |
| +4.0 | 25600 | 25920 | 26240 | 26560 | 26880 | 27200 | 27520 | 27840 | 28160 | 28480 |
| +3.5 | 22400 | 22720 | 23040 | 23360 | 23680 | 24000 | 24320 | 24640 | 24960 | 25280 |
| +3.0 | 19200 | 19520 | 19840 | 20160 | 20480 | 20800 | 21120 | 21440 | 21760 | 22080 |
| +2.5 | 16000 | 16320 | 16640 | 16960 | 17280 | 17600 | 17920 | 18240 | 18560 | 18880 |
| +2.0 | 12800 | 13120 | 13440 | 13760 | 14080 | 14400 | 14720 | 15040 | 15360 | 15680 |
| +1.5 | 9600 | 9920 | 10240 | 10560 | 10880 | 11200 | 11520 | 11840 | 12160 | 12480 |
| +1.0 | 6400 | 6720 | 7040 | 7360 | 7680 | 8000 | 8320 | 8640 | 8960 | 9280 |
| +0.5 | 3200 | 3520 | 3840 | 4160 | 4480 | 4800 | 5120 | 5440 | 5760 | 6080 |
| +0.0 | 0000 | 320 | 640 | 960 | 1280 | 1600 | 1920 | 2240 | 2560 | 2880 |
| -0.0 | 0000 | 65216 | 64896 | 64576 | 64256 | 63936 | 63616 | 63296 | 62976 | 62656 |
| -0.5 | 62336 | 62016 | 61696 | 61376 | 61056 | 60736 | 60416 | 60096 | 59776 | 59456 |
| -1.0 | 59136 | 58816 | 58496 | 58176 | 57856 | 57536 | 57216 | 56896 | 56576 | 56256 |
| -1.5 | 55936 | 55616 | 55296 | 54976 | 54656 | 54336 | 54016 | 53696 | 53376 | 53056 |
| -2.0 | 52736 | 52416 | 52096 | 51776 | 51456 | 51136 | 50816 | 50496 | 50176 | 49856 |
| -2.5 | 49536 | 49216 | 48896 | 48576 | 48256 | 47936 | 47616 | 47296 | 46976 | 46656 |
| -3.0 | 46336 | 46016 | 45696 | 45376 | 45056 | 44736 | 44416 | 44096 | 43776 | 43456 |
| -3.5 | 43136 | 42816 | 42496 | 42176 | 41856 | 41536 | 41216 | 40896 | 40576 | 40256 |
| -4.0 | 39936 | 39616 | 39296 | 38976 | 38656 | 38336 | 38016 | 37696 | 37376 | 37056 |
| -4.5 | 36736 | 36416 | 36096 | 35776 | 35456 | 35136 | 34816 | 34496 | 34176 | 33856 |
| -5.0 | 33536 | 33216 | 32896 | | | | | | | |

***Table 5.6 Current Conversion Table for A/D & D/A converter for Analog I/O Module***

## Current conversion table

■ 0-to-20 mA range

| | .00 | .10 | .20 | .30 | .40 | .50 | .60 | .70 | .80 | .90 |
|---|---|---|---|---|---|---|---|---|---|---|
| +20 | 32000 | 32320 | 32640 | | | | | | | |
| +19 | 28800 | 29120 | 29440 | 29760 | 30080 | 30400 | 30720 | 31040 | 31360 | 31680 |
| +18 | 25600 | 25920 | 26240 | 26560 | 26880 | 27200 | 27520 | 27840 | 28160 | 28480 |
| +17 | 22400 | 22720 | 23040 | 23360 | 23680 | 24000 | 24320 | 24640 | 24960 | 25280 |
| +16 | 19200 | 19520 | 19840 | 20160 | 20480 | 20800 | 21120 | 21440 | 21760 | 22080 |
| +15 | 16000 | 16320 | 16640 | 16960 | 17280 | 17600 | 17920 | 18240 | 18560 | 18880 |
| +14 | 12800 | 13120 | 13440 | 13760 | 14080 | 14400 | 14720 | 15040 | 15360 | 15680 |
| +13 | 9600 | 9920 | 10240 | 10560 | 10880 | 11200 | 11520 | 11840 | 12160 | 12480 |
| +12 | 6400 | 6720 | 7040 | 7360 | 7680 | 8000 | 8320 | 8640 | 8960 | 9280 |
| +11 | 3200 | 3520 | 3840 | 4160 | 4480 | 4800 | 5120 | 5440 | 5760 | 6080 |
| +10 | 0000 | 320 | 640 | 960 | 1280 | 1600 | 1920 | 2240 | 2560 | 2880 |
| +9 | 62336 | 62656 | 62976 | 63296 | 63616 | 63936 | 64256 | 64576 | 64896 | 65216 |
| +8 | 59136 | 59456 | 59776 | 60096 | 60416 | 60736 | 61056 | 61376 | 61696 | 62016 |
| +7 | 55936 | 56256 | 56576 | 56896 | 57216 | 57536 | 57856 | 58176 | 58496 | 58816 |
| +6 | 52736 | 53056 | 53376 | 53696 | 54016 | 54336 | 54656 | 54976 | 55296 | 55616 |
| +5 | 49536 | 49856 | 50176 | 50496 | 50816 | 51136 | 51456 | 51776 | 52096 | 52416 |
| +4 | 46336 | 46656 | 46976 | 47296 | 47616 | 47936 | 48256 | 48576 | 48896 | 49216 |
| +3 | 43136 | 43456 | 43776 | 44096 | 44416 | 44736 | 45056 | 45376 | 45696 | 46016 |
| +2 | 39936 | 40256 | 40576 | 40896 | 41216 | 41536 | 41856 | 42176 | 42496 | 42816 |
| +1 | 36736 | 37056 | 37376 | 37696 | 38016 | 38336 | 38656 | 38976 | 39296 | 39616 |
| 0 | 33536 | 33856 | 34176 | 34496 | 34816 | 35136 | 35456 | 35776 | 36096 | 36416 |

■ 4-to-20 mA range

| | .00 | .10 | .20 | .30 | .40 | .50 | .60 | .70 | .80 | .90 |
|---|---|---|---|---|---|---|---|---|---|---|
| +20 | 32000 | 32320 | 32640 | | | | | | | |
| +19 | 28000 | 28400 | 28800 | 29200 | 29600 | 30000 | 30400 | 30800 | 31200 | 31600 |
| +18 | 24000 | 24400 | 24800 | 25200 | 25600 | 26000 | 26400 | 26800 | 27200 | 27600 |
| +17 | 20000 | 20400 | 20800 | 21200 | 21600 | 22000 | 22400 | 22800 | 23200 | 23600 |
| +16 | 16000 | 16400 | 16800 | 17200 | 17600 | 18000 | 18400 | 18800 | 19200 | 19600 |
| +15 | 12000 | 12400 | 12800 | 13200 | 13600 | 14000 | 14400 | 14800 | 15200 | 15600 |
| +14 | 8000 | 8400 | 8800 | 9200 | 9600 | 10000 | 10400 | 10800 | 11200 | 16000 |
| +13 | 4000 | 4400 | 4800 | 5200 | 5600 | 6000 | 6400 | 6800 | 7200 | 7600 |
| +12 | 0000 | 400 | 800 | 1200 | 1600 | 2000 | 2400 | 2800 | 3200 | 3600 |
| +11 | 61536 | 61936 | 62336 | 62736 | 63136 | 63536 | 63936 | 64336 | 64736 | 65136 |
| +10 | 57536 | 57936 | 58336 | 58736 | 59136 | 59536 | 59936 | 60336 | 60736 | 61136 |
| +9 | 53536 | 53936 | 54336 | 54736 | 55136 | 55536 | 55936 | 56336 | 56736 | 57136 |
| +8 | 49536 | 49936 | 50336 | 50736 | 51136 | 51536 | 51936 | 52336 | 52736 | 53136 |
| +7 | 45536 | 45936 | 46336 | 46736 | 47136 | 47536 | 47936 | 48336 | 48736 | 49136 |
| +6 | 41536 | 41936 | 42336 | 42736 | 43136 | 43536 | 43936 | 44336 | 44736 | 45136 |
| +5 | 37536 | 37936 | 38336 | 38736 | 39136 | 39536 | 39936 | 40336 | 40736 | 41136 |
| +4 | 33536 | 33936 | 34336 | 34736 | 35136 | 35536 | 35936 | 36336 | 36736 | 37136 |

## 5.3 SOFTWARE ANALYSIS

### 5.3.1 Features of KV -300 PLC with KV Builder Ladder Software version 1.5 [28]

**(a) High speed operation**

A minimum instruction execution time of 0.15 microsecond and a minimum scan time of 200 microseconds ensure high speed control.

The two-wire line reduces wiring and is capable of scanning numerous I/O through as many as 1760 ports (14 ports per CPU) at speeds below 500 microsecond. It securely detects all high speed pulses from sensors.

**(b) Input through 2-channel high speed counters**

KV-300 CPU is equipped with two 16 bit, high speed counters, each of which can be used with the two counter comparators. Four interrupt points at CTCO, CTC1, CTC2, and CTC3 turn on when the counter current value matches the set value. The maximum input pulse frequency is 30 kHz, and reset signals can be input from hardware.

**(c) Direct clock pulse**

A high-speed counter permits pulse output upto 50 kHz.

**(d) Selection of input relay time constant**

The input time constant for relays, including input terminal modules, can be switched to any of three levels.

**(e) Interrupts**

Interrupts can be generated at input relays 0000 (INT0), 0001 (INT1), 0002 (INT2), and 0003 (INT3). When the high-speed comparator is used, interrupts can also be generated at CTC0, CTC1, CTC2, and CTC3, allowing execution of interrupts within program routines. This ensures fast response without scan time delays.

**(f) Calculation of pulse width and interval**

For INT3, interrupts can be switched at the rising edge/falling edge through special utility relay No. 2206. By transferring data from high-speed counter 1 (CTH1) to TM 30

When the interrupt is generated, the pulse width and interval can be calculated.

**(g) Arithmetic functions for KV-AN 6 and data memory**

Execution of ITVL instruction issues the max/min/average of data memory and by specifying the A/D input channel, the max/min/average of the A/D input can be easily calculated.

**(h) Constant scan time mode**

The KV 300 CPU supports operations under constant scan time.

**(i) "Output disabled" function**

Turning on special utility relay number-2300 turns off all output relays. Upon completion of a single scan, relay 0500 to 0515 and 7000 to 17915 are cleared before each output signal value is sent to I/O ports.

**(j) "Input refresh disabled" function**

Turning on special utility relay no-2320 prevents execution of user programs even during normal operation. This function pauses user program in normal operation made.

**(k) Storage of contact comments**

The KV - 300 CPU can store contact comments internally. When a ladder diagram is viewed from the KV-300 CPU, contact comments appear with the diagram.

## ;.4 PROGRAMMING OF KV-300 PLC

Programming of KV -300 PLC is done in ladder diagram through either hand held programmer or a personal computer. In present work programming is done through PC. The name of software used for programming is KV Ladder Builder Software Version 1.5. Main features have already been discussed. The programming part utilizes contacts, coils, timers, counters, mathematical operations and interrupts, etc. Every relay, timer and counter etc is assigned a specific number and it is to be used wherever is need. Program can be checked for errors without connecting it to PLC in simulator mode. There are following modes of operation.

**(a) Edit mode**

It is used to edit any program to change relays, counters, connections or for modification. New ladder program can also be made. We can also change programs while KV –CPU connected.

**(b) Simulator mode**

In this mode, created ladder diagram program is not connected to KV- CPU, but it can confirm the operation with either a ladder diagram or time chart. Simulator does following functions

(i) Confirm a ladder diagram or time chart
(ii) Freely change the current value and set value of the timer, counter or data memory.
(iii) Forcibly set/reset an element.
(iv) Operation in one step or one scan.
(v) View an element comment during simulation

**(c) Monitor mode**

(i) In monitor mode we can monitor element on/off status, current T/C value, and initial T/C value, as well as modify forced set/reset elements, current T/C value, and initial T/C value on ladder diagram.
(ii) In this mode following functions can be done
(iii) Ladder Monitor
(iv) Optional element monitor
(v) Time chart monitor
(vi) Change data memory address value.
(vii) There are different elements, which are used for programming purpose as discussed below.

### 5.4.1 Internal Utility Relays

The PLC has a maximum of 876 internal utility relays and 160 special utility relays. These internal relays are software relays that are used in programs. Special utility relays have their specific usage and are not used for any other purpose. The special utility relays are used only as contacts and not as coils.

### 5.4.2 Timers and Counters

There are 250 numbers of timers/counters that can be included in program. There are three categories of timers namely 0.1 sec, 0.01 sec and 1.0 millisecond Timer. The counters are normal counters, high-speed counters and up-down counters. Timers and counters can be used both as normally open (N.O) contacts and normally closed (N.C) contacts. The numbers assigned to them are from 0 to 149. But limitation is that timer and counter can not share the same number.

### 5.4.3 Data Memory and Temporary Memory

Data memory and temporary memories are used to store a data for arithmetic operations. They are not used for programs that consist of contacts, coils and timers. Data memory retains data for arithmetic operations and their results. Temporary memory is used for temporary storage of data for arithmetical operations. Some parts of data memory are reserved for analog I/O and serial interface modules.

### 5.4.4 Scan Time and Response Delay

The scan time is the total time taken for reading the input, executing the program and giving the output. The shortest scan time for KV-300 is 200 microseconds. The scan time depends on the length of program and nature of operation' in the program. A constant scan time can be set in the PLC so that each scan time will be equal. This setting can be included in the program if required.

CHAPTER 6

# PROGRAMS DEVELOPED FOR CONTROL & AUTOMATION USING PLC AND THEIR RESULTS

Programs have been developed & tested in KV builder software version 1.5 for KV 300 PLC for different controls.

## 6.1 INPUT SIGNALS USED IN CONTROL & AUTOMATION IN PRESENT WORK

In a SHP station there are many input parameters , which can be used as feedback for implementing control & automation, but since this work has been experimented on a turbine generator demonstration unit so there are only two input signals, which have been used for all the control and automation work for hydro-turbine demonstration unit. Even though the programs have developed on general basis by considering all necessary parameters of a SHP station & by slight or no modification can be implemented at any SHP station with all necessary hardware & instrumentation requirement.

### 6.1.1 Input Signal for Valve Position from Electrical Actuator

The +2 Volt supply is given between terminal 7 & 8 from – 5 to +5 volt range function generator. The input signal is going to the analog input module KV – R16X of KV 300 PLC in the form of 0 - + 2 Volt signal of valve position from potential divider terminal either 6 & 7 or 7 & 8. The signal will be 0 volt at fully open position it will vary linearly from 0 to 2 volt according to the position of valve and will be reached to 2 volt at valve fully close position. So there will be 0 Volt at 0 % opening of valve and + 2 Volt signal at 100 % opening. So a linear curve can be calibrated between voltage and %age of valve opening. The PC is connected to PLC CPU by RS- 232 port. Thus signal from potential divider gives the valve position as shown in Fig 6.1.

### 6.1.2 Input Signal for Speed of Turbine from Optoelectronic Speed Sensor

The optoelectronic speed sensor has been fabricated by using IC MOC7811 of

Motorola. The details are given in chapter 4 and circuit diagram of speed sensor is shown in Fig 6.2. + 5 V square waves input of speed of turbine from optoelectronic speed sensor are going to input module of PLC .We can see the shape & magnitude of these square wave on Cathode ray oscilloscope(CRO) the pulse interval of these pulses varies as speed of time interval varies so , by considering pulse interval a parameter. Program has been developed for speed control.

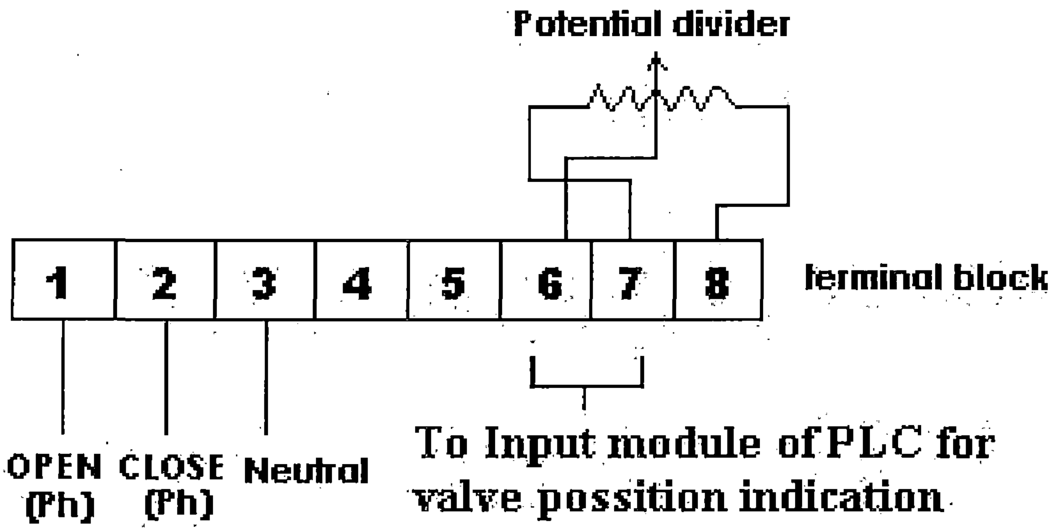



*Fig: 6.1 Potential Divider for Valve Position Indication*

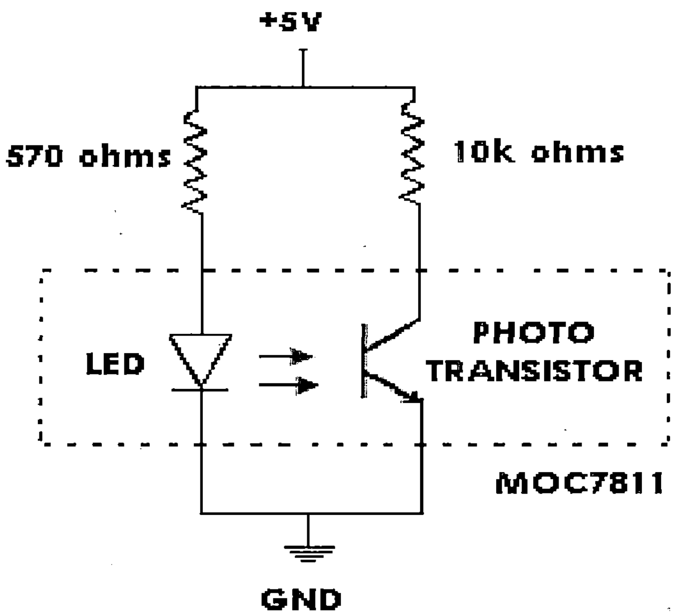



*Fig: 6.2 Circuit diagram of Speed Sensor*

## 6.2 AUTOMATIC STARTING OF SHP UNIT

For automatic starting only a single remote pulse needed. In an automatic start, pre-start conditions are verified, auxiliary systems are started and post-start conditions are checked. When all conditions are met, the shutdown solenoids are energized, enabling the gate to move. At this point, the wicket gates are opened, the machine is set to settle at speed-no-Load. Synchronizing is then done with the supply at the bus. When the circuit breaker closes, an automatic operating mode is engaged until intervention by an operator. Setting should be such that in case of failure of PLC, Manual control can be provided. The arrangement for implementation of automatic starting and shutdown (normal, emergency) using KV -300 PLC is shown in fig 6.3. On running of program the relays of PLC will glow and a sequence of functions will be executed. The outputs from KV B16R Output module will go to solid state box .There are two solid state relays have been used in this box. The solid state relay has four terminals , two for power supply and two for control signal, power supply signal is according to load connected to it , and control signal is between 3- 24 Volt D.C. Two solid state relays have been controlled by the output coming through PLC output module by connected to channel 0 and channel 3. The output of solid state relays are connected to terminal 1, 2 and 3 of electrical actuator and these terminals are internally connected to I phase , 230 volt motor starting winding as shown in Fig 6.3.

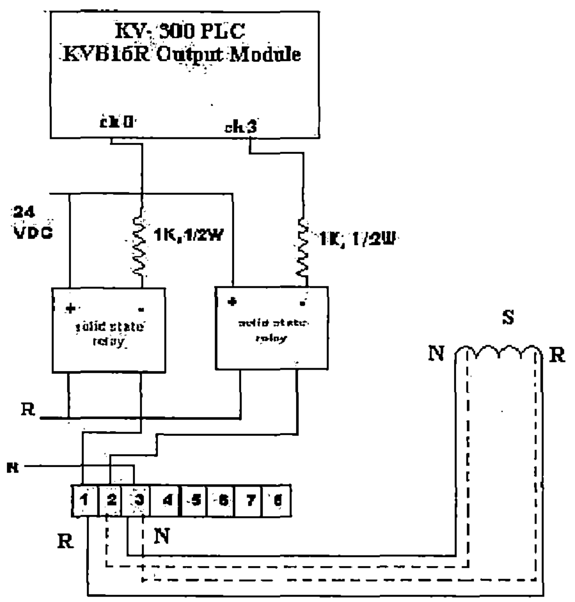



*Fig: 6.3 Connection Diagram for Automatic Starting & Shutdown*

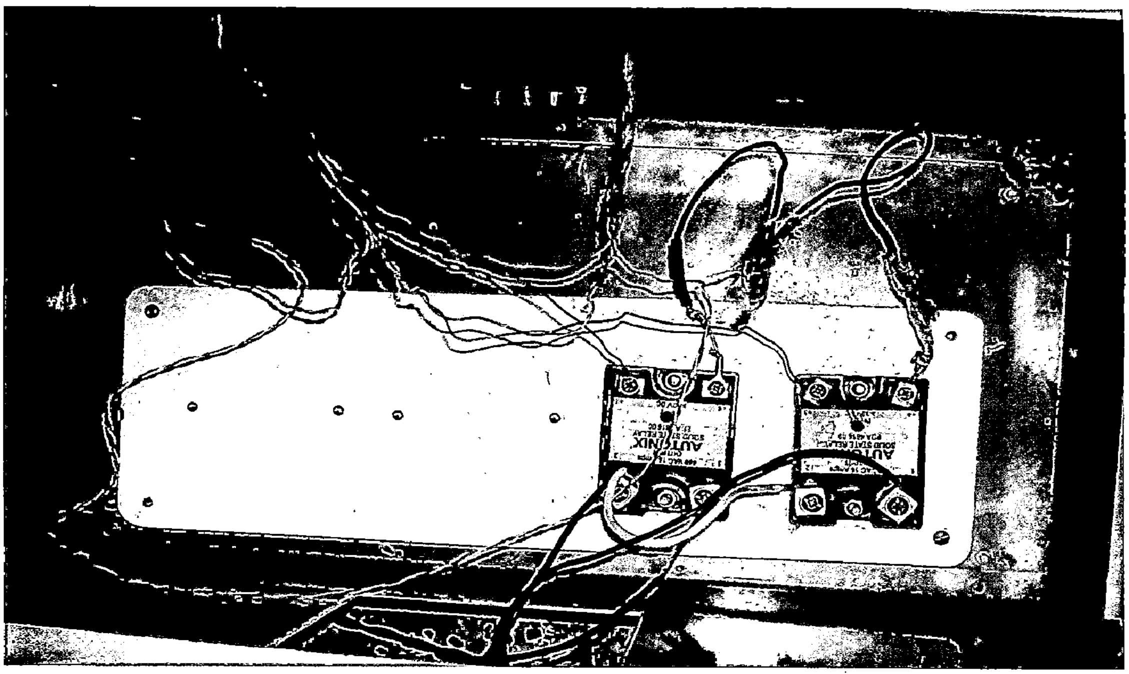


*Fig: 6.4 Connections of Solid state Relays to Electrical Actuator and PLC*

### 6.2.1 Program for Automatic Starting (AUSTART)

Automatic starting of SHP unit is has been performed Using KV 300 PLC. Scheme for automatic starting is shown in Fig. 6.5 This scheme involves certain kind of sequence; it leads to automatic starting of the unit. Programs have been developed to achieve this sequence by using KV ladder builder software version 1.5. It considers sequence of various functions to start the plant when a remote starting pulse comes and also some sequence for necessary functions to be performed to close the unit at normal stopping or normal shutdown.

According to the program the as soon as execution will be started by clicking the mouse, the various functions will performed as specified in the program I (AUSTART) shown in Fig 6.6, developed on the basis scheme shown in Fig 6.5. This program is for automatic starting, so following sequence of functions has been performed.

#### 6.2.1.1 Description of Program for Automatic Starting (AUSTART)

(a) Connect all the connections as discussed in the Fig 6.1 and 6.3. Then provide power supply to KV -300 PLC and connect it Program I to the PLC.

(b) Click on execute continuous option available in monitor window, as soon as u click the execution of program will start and sequence of functions will be followed

(c) Contact 7000 is Normally Closed (NC) will act as starting pulse is continuously coming. This gives signal to relays 7500, 7501 and 7502 to on the close field switch, reset shutdown and set master control functions.

(d) Following the above functions, Hardware relay 8500 of PLC-KV 300 will be closed, which is connected to solid state relay (SSR1) and will on the electrical inlet valve. This relay will be on for 1 min, in this time electrical actuated inlet valve moves from fully closed to fully open position. Also relays for breaks & jacks off, on standby governor oil pump and on lubricating oil pump will be closed simultaneously .In the same way all auxiliaries are opened and then guide vanes are opened.

(e) Then final stage relay is on , synchronizing signal is given and then signal to hardware relay 8501 of PLC to put the unit on to gird or load ( load in present case).

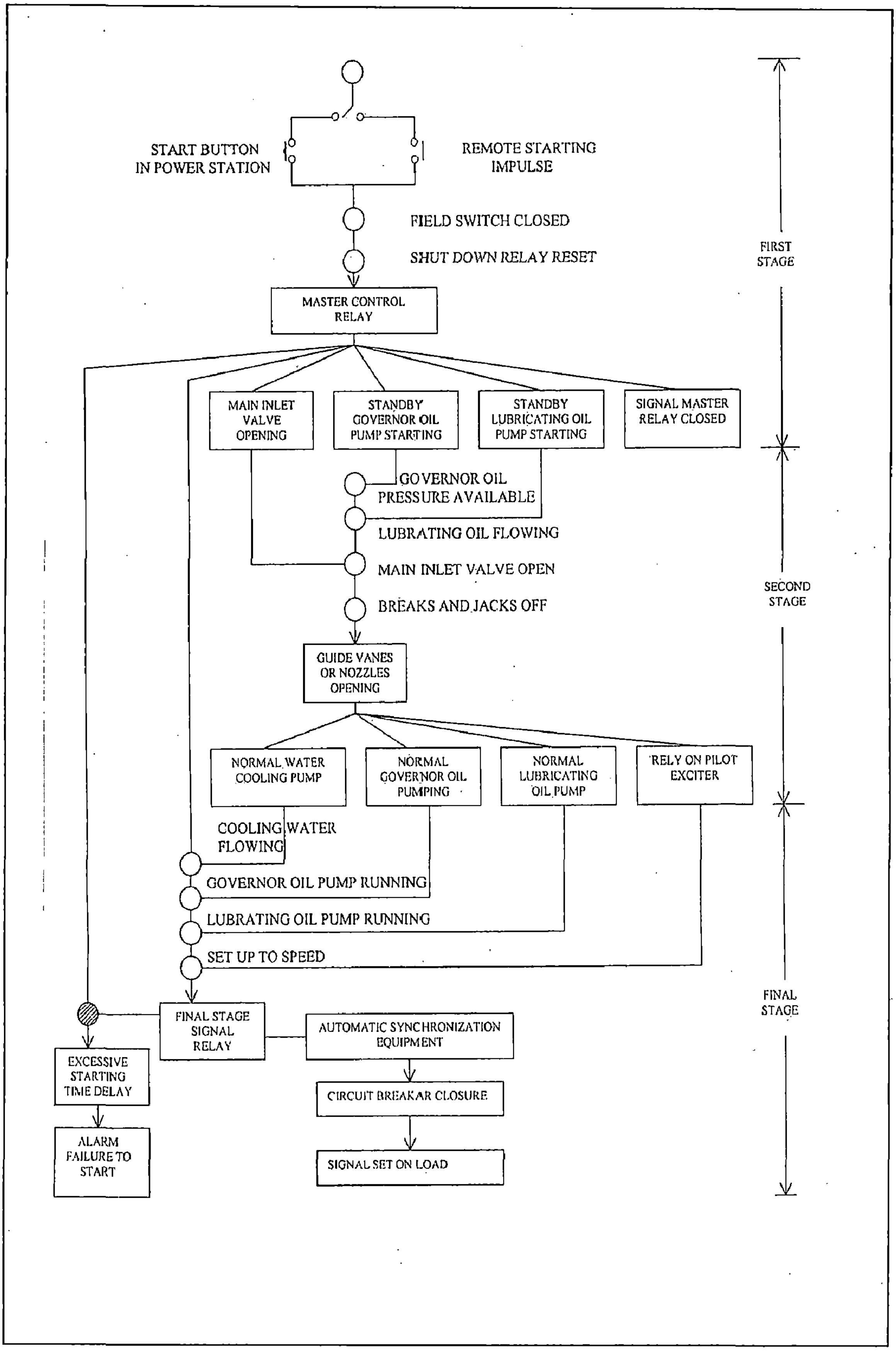
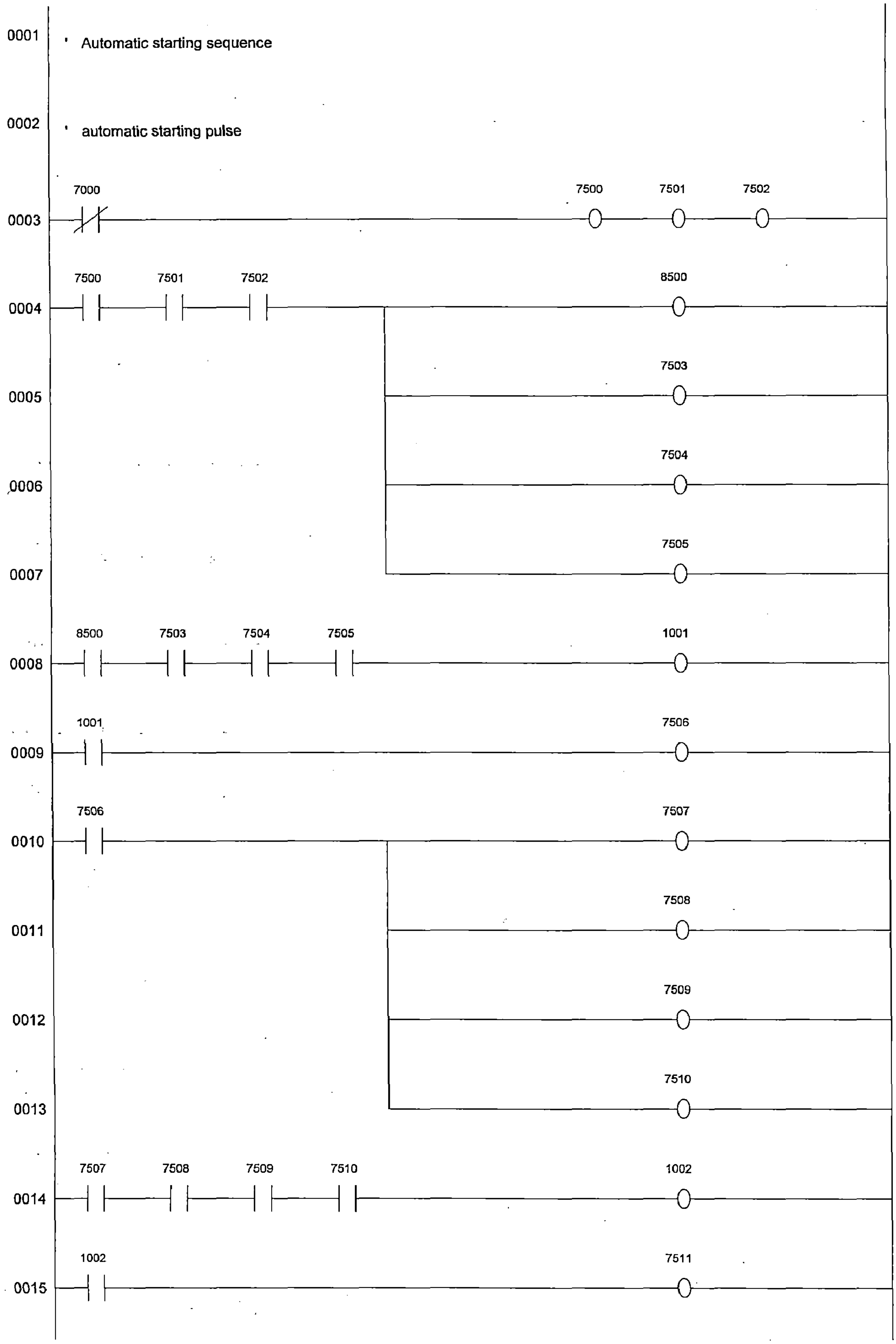



*Fig: 6.5 Flow Diagram for Sequential of Automatic Starting of SHP Station [29]*


0001 ' Automatic starting sequence
0002 ' automatic starting pulse
0003 7000 7500 7501 7502
0004 7500 7501 7502 8500
0005 7503
0006 7504
0007 7505
0008 8500 7503 7504 7505 1001
0009 1001 7506
0010 7506 7507
0011 7508
0012 7509
0013 7510
0014 7507 7508 7509 7510 1002
0015 1002 7511

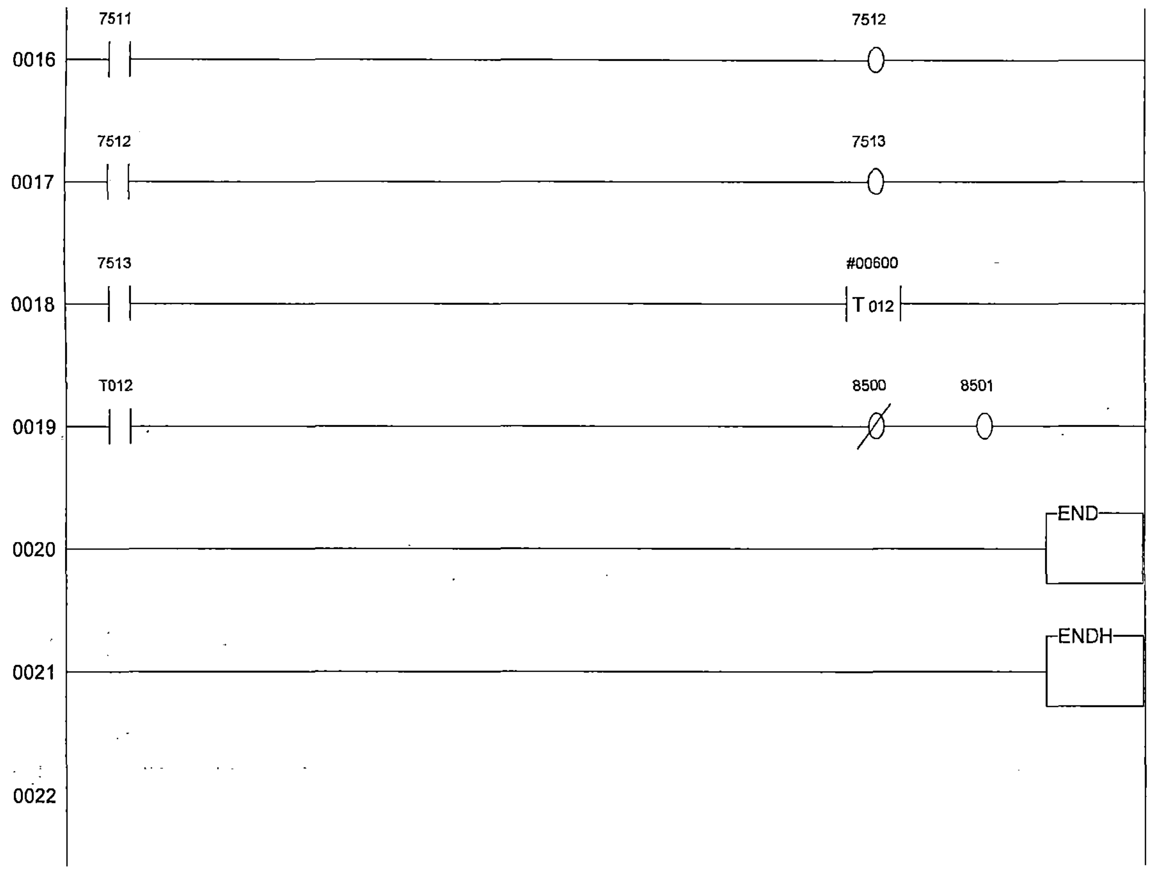



*Fig: 6.6 Program for Automatic Starting of SHP Station (AUSTART)*

## 6.3 AUTOMATIC STOPPING/ SHUT DOWN OF SHP STATION

There are generally two ways, by which a SHP Plant can be stop. One is normal and other is in case of fault or emergency condition.

### 6.3.1 Program for Normal Shutdown

In case of shutdown in normal condition all the functions can be performed in proper way as there is enough time to shut all axillaries & equipment as no fault or emergency condition. For normal stopping of unit 1003 internal relay will be closed by a remote unit pulse, so load will decrease gradually and will reach to no load condition, some necessary sequence is performed and then hardware relay 8503, connected to electrical actuator through solid state relay will be on for 1 minute and move the inlet valve from fully open to fully close position and unit will be shutdown under normal condition.

### 6.3.2 Program for Fault or Emergency Shutdown

The stopping or shutdown procedure is changed for fault or emergency shutdown than normal one. Certain protective measures are provided for proper operation of SHP if these measures are not met then condition may lead to shut down of the plant. The scheme on which program II (AUSTOEM) shown in Fig 6.8, has been developed are shown in Fig 6.7. Fault shutdowns are variations of the normal stop sequence. In emergencies, the generator breaker and lockout relays trip and the shutdown solenoids are de-energized closing the wicket gates at their fastest rate. A restart is allowed when the fault is cleared and the lockout relay reset. For non-emergency faults, a normal shutdown will be initiated and on the breaker trip a lockout relay trip is initiated. A restart is allowed when the fault is cleared and the lockout relay reset.

The main difference of programming approach of normal shutdown and fault and emergency shutdown is minimize the time of closure of unit as much as possible and When a fault or emergency condition occurs the corresponding contact will get signal and 1003 will be closed but the same contact has been closed in normal shutdown case by a remote unit pulse. At occurrence of fault or emergency condition the real the protection of all equipment and auxiliaries should be achieved, so, in case of fault of emergency shutdown the whole load should be disconnected immediately in one shot and necessary actions should be performed to shutdown the whole plant.

### 6.3.3 Description of Program for Automatic Stopping/Shutdown (AUSTOEM)

(a) Steps from starting of unit to put on load or grid have been already mentioned in the 6.2.1.1.

(b) In the case of normal stopping internal utility relay 1003 will be closed by a remote unit which will again close the shut down relay 7514, which will make all will start switching off the load in gradual way.

(c) In the case of fault or emergency shutdown whenever any fault comes like unbalance condition or over current or over voltage or over speed ( as in this case)or high bearing temperature or governor oil failure or emergency trip condition occurred, the corresponding relay will on ,Immediately all the load will be switched off in one shot

(d) For example, in this program if condition of over speed occurs, then digital input is to be given to 7004 to make it on, it will close internal utility relay 1003 which will again close the shut down relay 7514, which will make generator breaker off. After 1 minute, main valve will be closed, after 1 minute, guide vanes will be closed and then after 1minute, breaks will be applied.

(e) Thus all the necessary functions in proper sequence will take place and unit will shutdown within one minute by actuating solid state relay (SSR2) using hardware relay 8503 of PLC to move the electrical actuator valve from fully open to fully close position and plant will be shut down immediately .

Since there are difference in only input signal for shutdown necessary programming sequence of various functions for both normal and fault or emergency condition has been developed in one program II

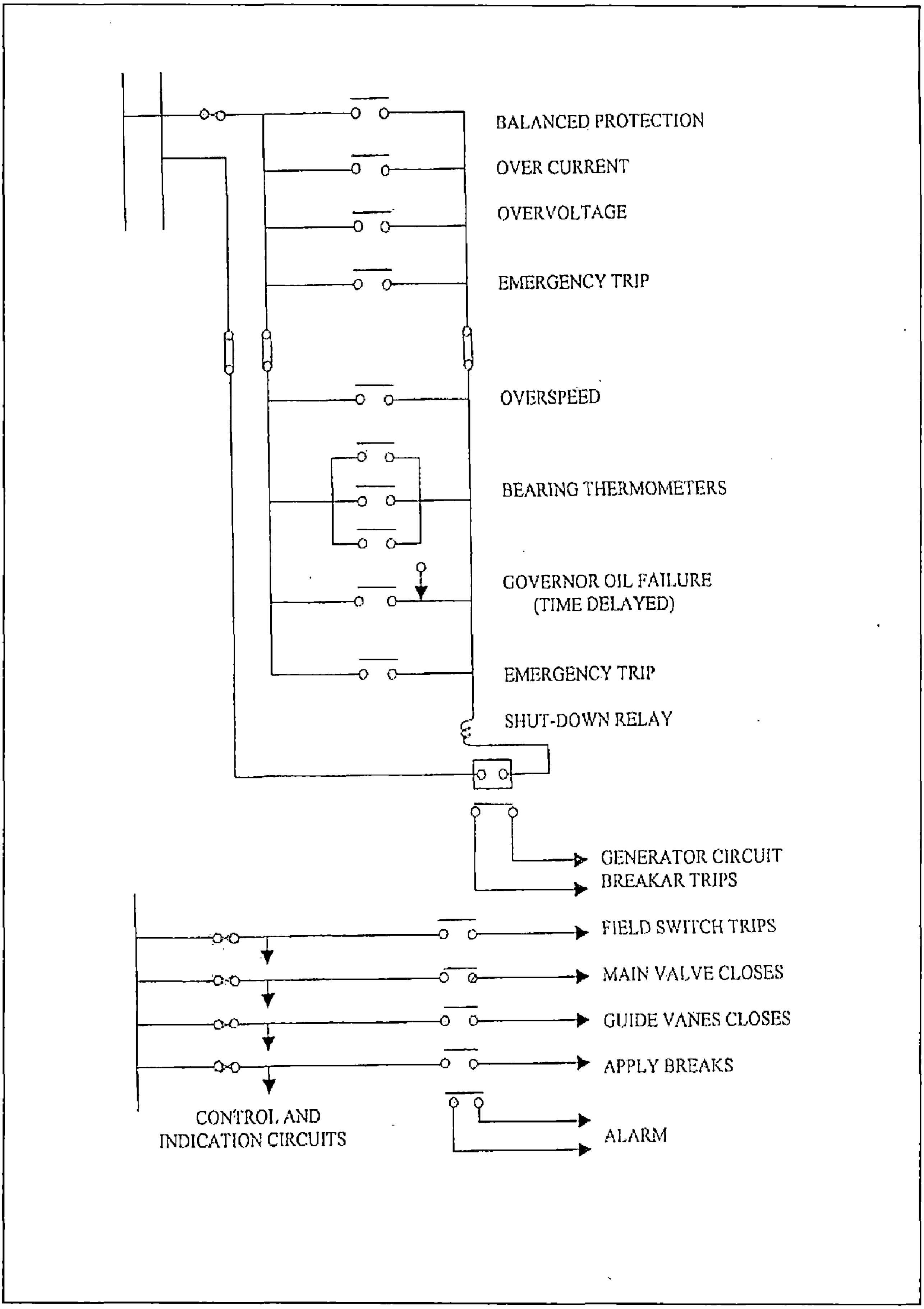
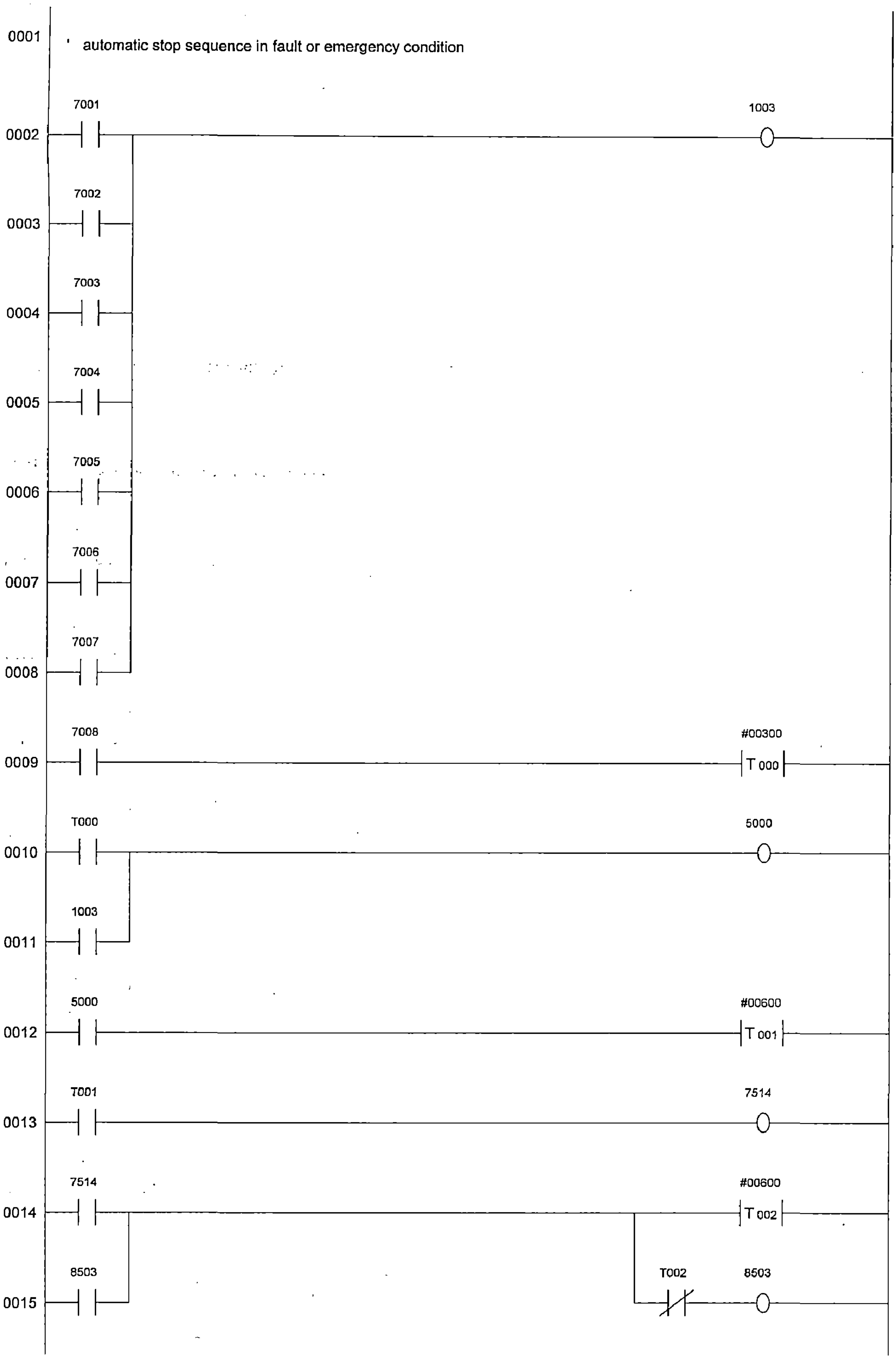



*Fig: 6.7 Sequence of Fault and Emergency Shutdown of SHP Station [29]*


0001
' automatic stop sequence in fault or emergency condition
0002
7001
1003
0003
7002
0004
7003
0005
7004
0006
7005
0007
7006
0008
7007
0009
7008
#00300
T 000
0010
T000
5000
0011
1003
0012
5000
#00600
T 001
0013
7001
7514
0014
7514
#00600
T 002
0015
8503
T002
8503

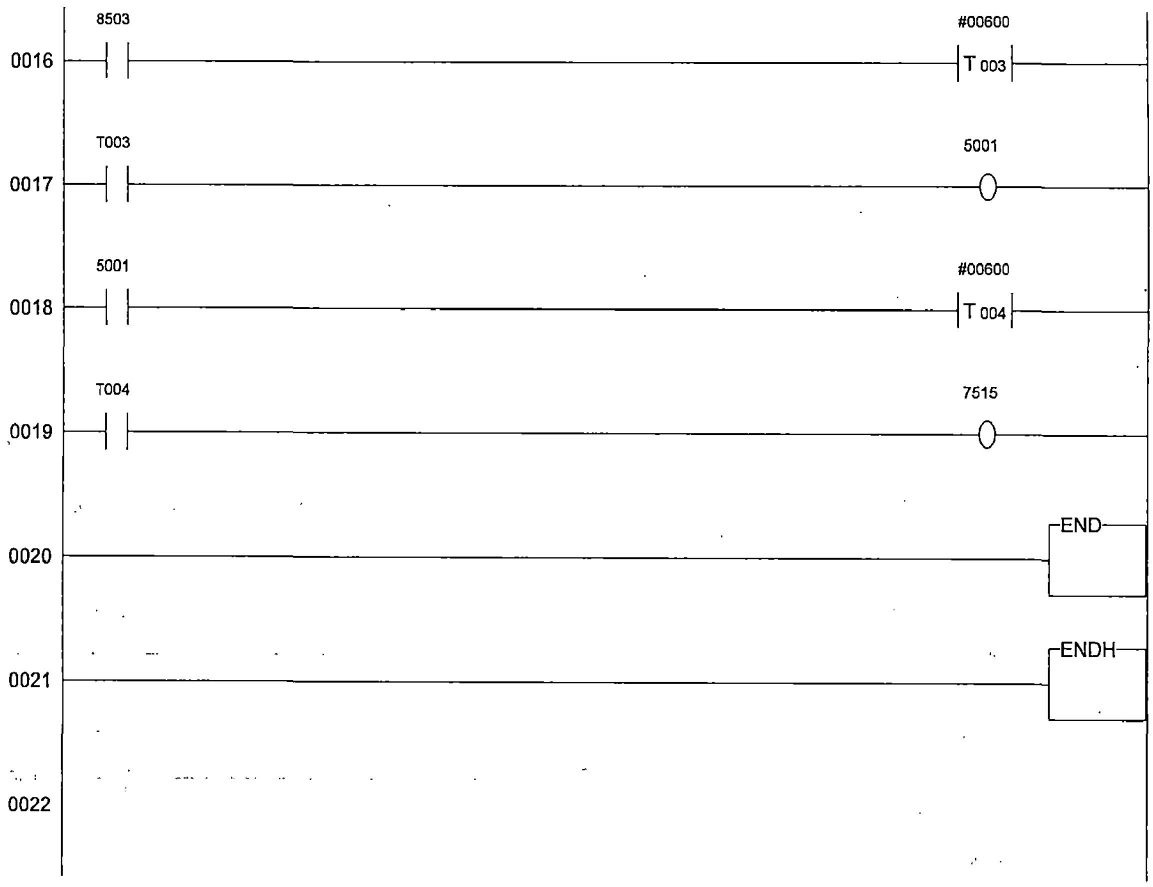



*Fig: 6.8 Program for Automatic Shutdown of SHP Station (AUSTOEM)*

## 6.4 LOAD CONTROL FOR SHP STATION

In the Present work generator is fed with lamp load (resistive load) in five steps. The maximum load the generator can take is 3 kW, so each step loads the generator by 0.6 kW.

### 6.4.1 Load Wiring:

The load consists of five rows of bulbs with each row consisting of 3 bulbs 200W each. The wiring is done such that at a time load on the three phases is the same as seen from Fig 6.11 the load consists of 5 lamps each connected to R, Y, and B phases connected through the contactors.

There is a provision for the bulbs to be operated manually by means of a switch. But in the present arrangement the manual switch have been bypassed by using three phases Contractors switches, which are connected to the solid state relays as shown in Fig 6.10. Five solid state relays have used one for each row. The Fig 6.9 below shows the photograph of load wiring diagram with contactors. In the present work load control has been achieved by using these relays, when the associated relays glows in the program III (LDCONNRM) and IV (LDCONEM), the corresponding contractor switch get closed through assigned solid state relay & the load row associated to the contractor will on. In the same manner gradually load will increase from no load to full load in five steps one for each row and decreases gradually (in normal shut down ) or in one shot (in fault or emergency shutdown) by opening contractors through Solid state relays according to programming sequence.

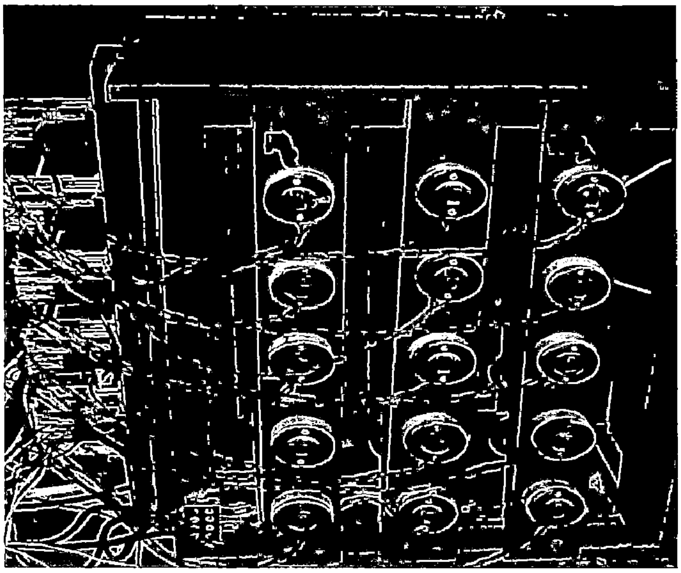


*Fig: 6.9 Wiring Diagram of Lamp Loads through Contractors*

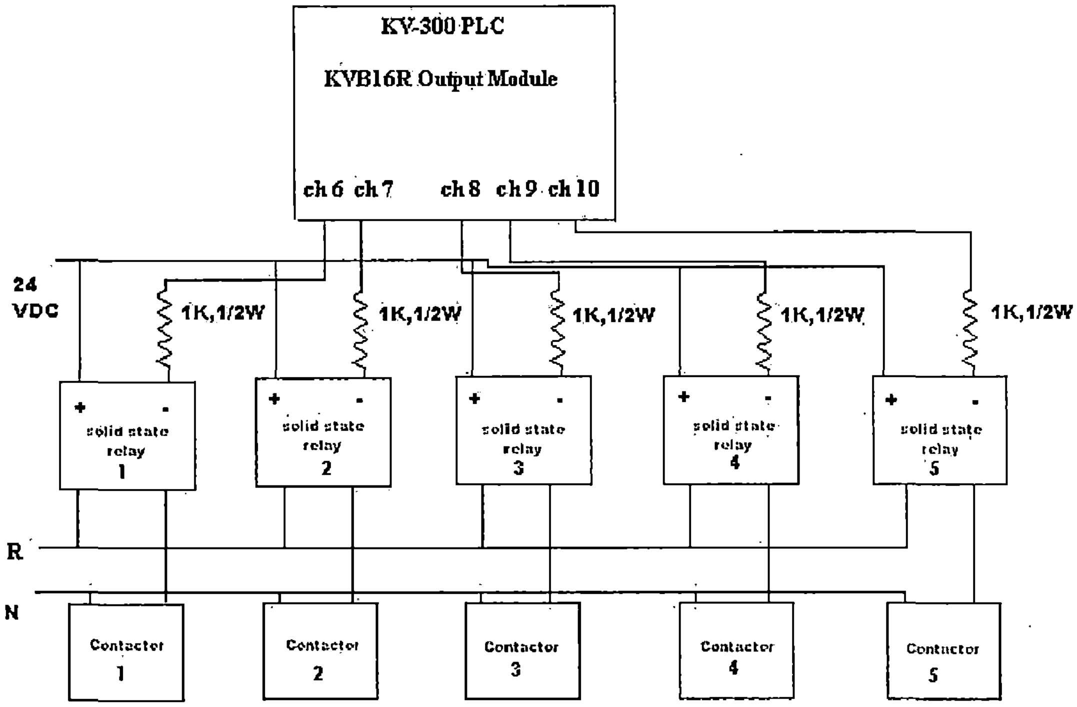



*Fig: 6.10 Schematic of Connection Diagram of Load Control Circuit*

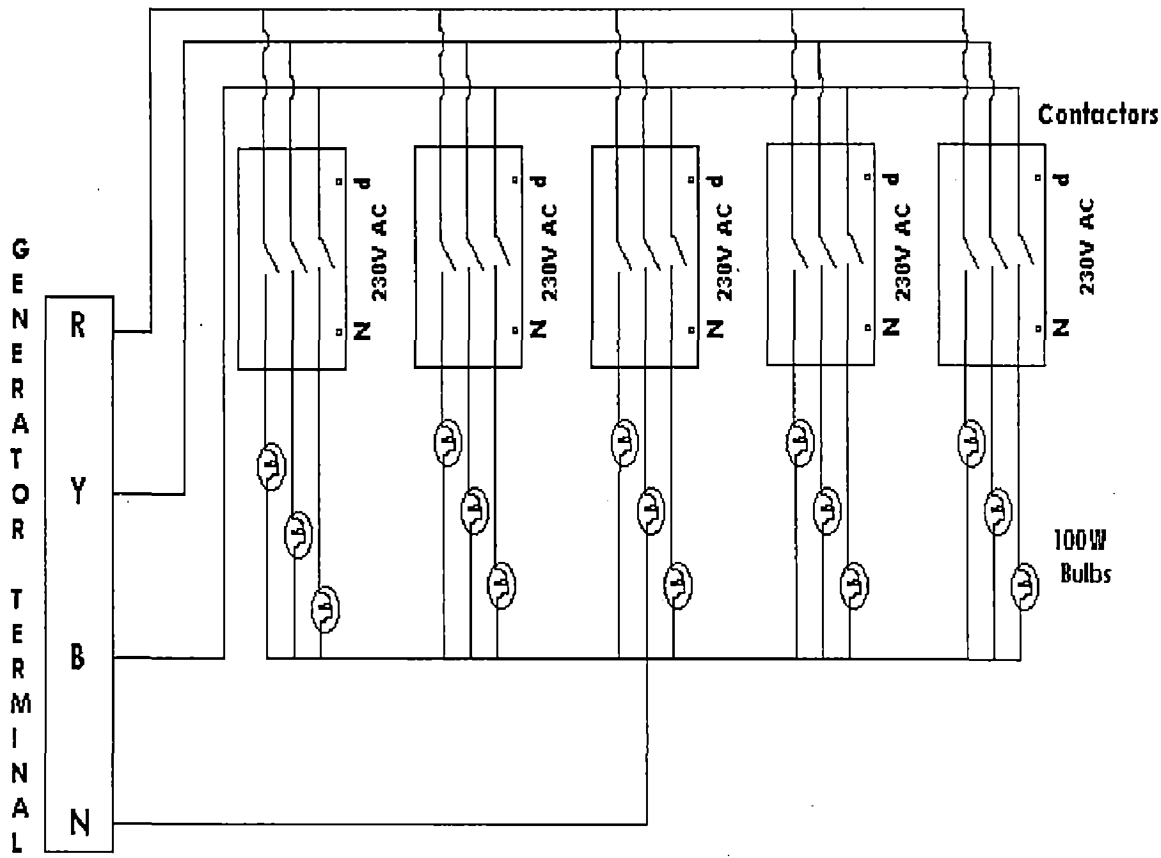



*Fig: 6.11 Connection Diagram of Contractors Switches*

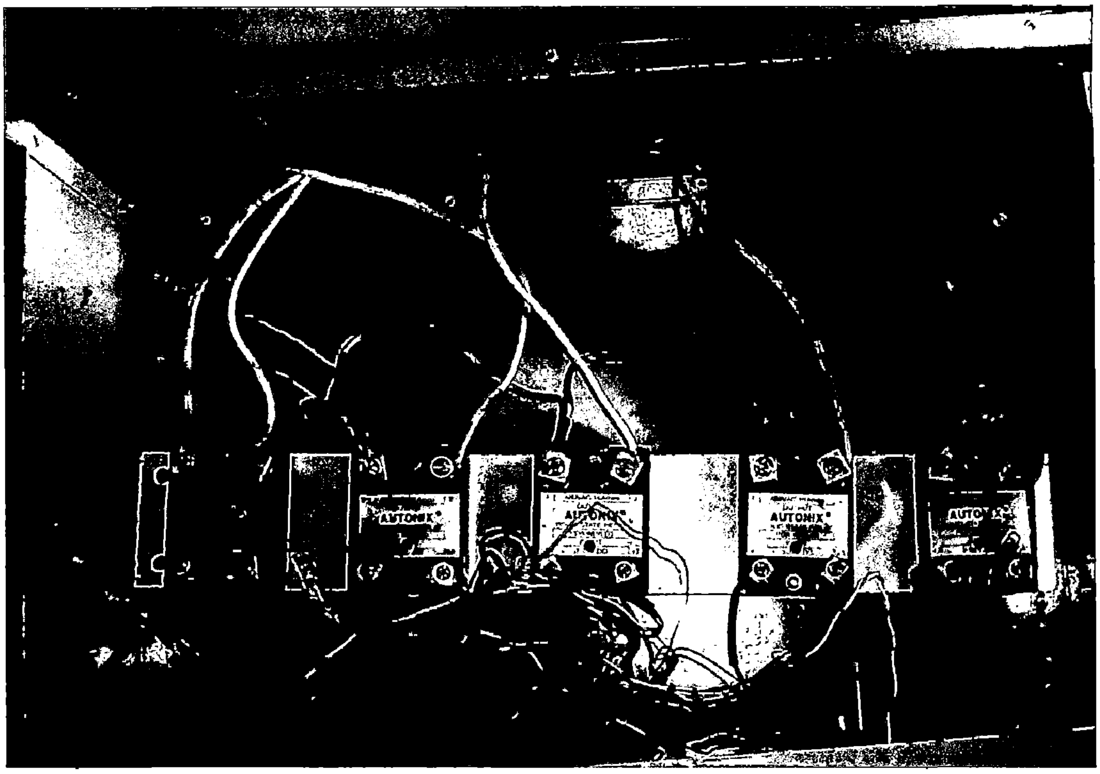



*Fig: 6.12 View of Solid State Relays & their Connections*

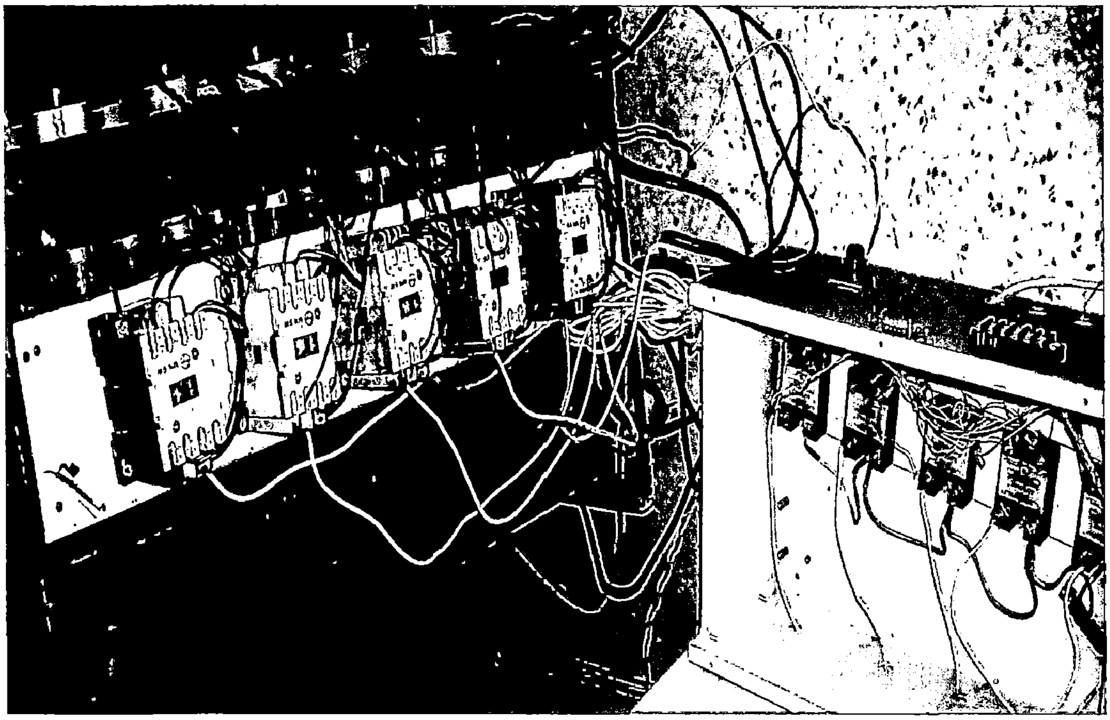


*Fig: 6.13 View showing Connections of Solid State Relays & Contactor Switches*

### 6.4.2 Load Control using PLC

The set up for load control has been discussed above. The Load control procedure are different for normal and fault or emergency condition At the of starting SHP unit load should be increased gradually as sudden load may cerate problems , so load will increase gradually from no load to full load. For normal stopping of unit load will decrease gradually and will reach to no load condition. In case of fault or emergency shutdown immediately all the load will be switched off in one shot. The programs III and IV have been developed for load control in normal and fault or emergency condition are shown in Fig 6.14 and 6.15 respectively.

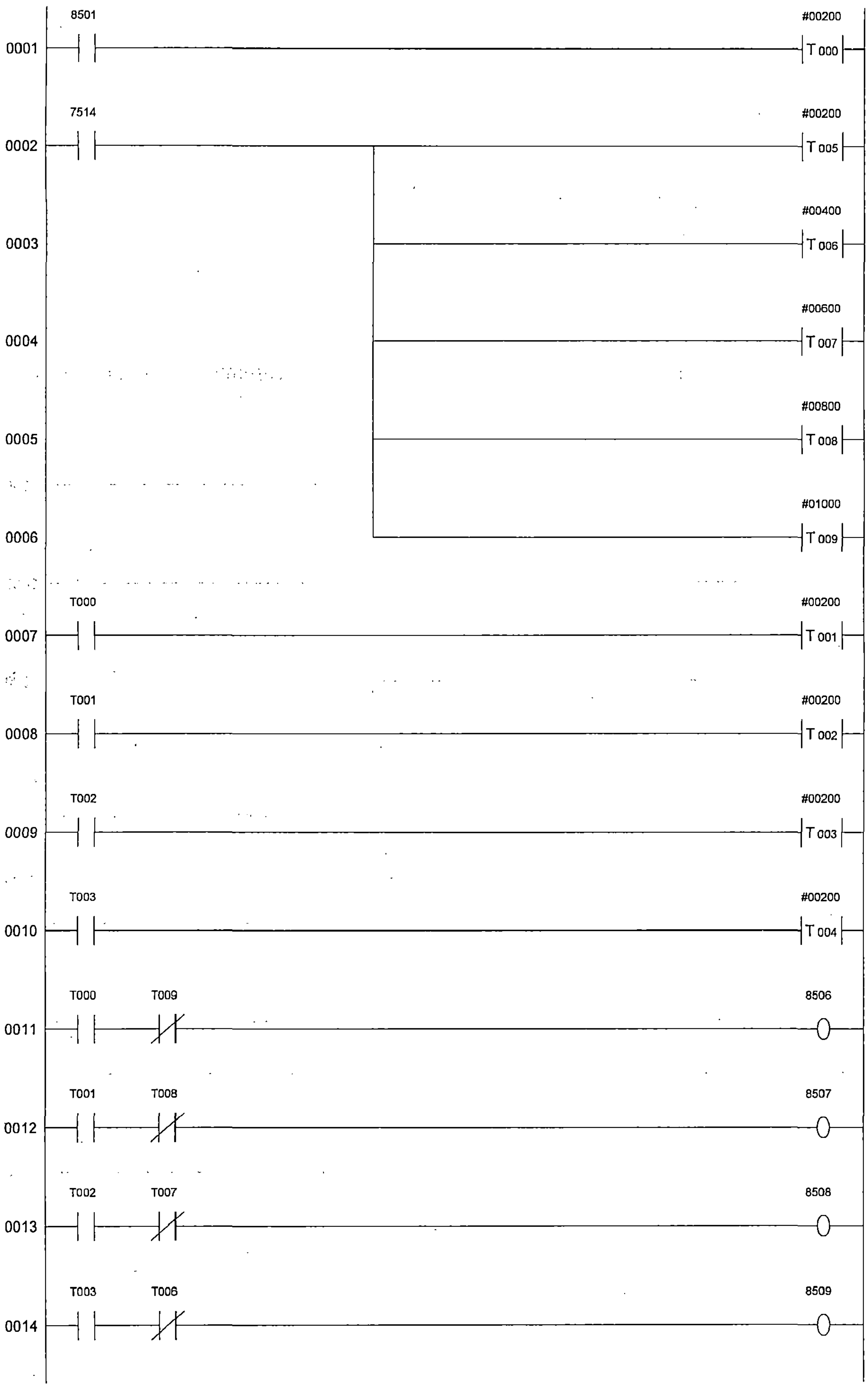
#### 6.4.2.1 Description of Program III (LDCONNRM) and IV (LDCONEM)

(a) Program III and IV are same for load control at the starting of SHP unit. The load will start increase gradually from no load to full load in 5 steps, when relay 8501 will be energized. Following it 5 solid state relays will be energized, associated to PLC relays 8506 to 8510.The solid state relays will further made contractor switch close and load will increase in five steps.

(b) For normal shut down in program III, load control at the time of stopping of SHP unit will be different to program IV in case of fault or emergency condition.

(c) In program III, when the stop signal by relay 7514 will come, the relays 8506 to 8510 will turn off in sequence in five steps, like 1$^{st}$ 8506 will go off then 8507and so on. Thus the whole load will be switched off step by step.

(d) In program IV, when the stop signal by relay 7514 will come, the relays 8506 to 8510 will turn off in one shot. Thus the whole load will be switched off immediately.


0001
8501
#00200
T 000
0002
7514
#00200
T 005
0003
#00400
T 006
0004
#00600
T 007
0005
#00800
T 008
0006
#01000
T 009
0007
T000
#00200
T 001
0008
T001
#00200
T 002
0009
T002
#00200
T 003
0010
T003
#00200
T 004
0011
T000
T009
8506
0012
T001
T008
8507
0013
T002
T007
8508
0014
T003
T006
8509

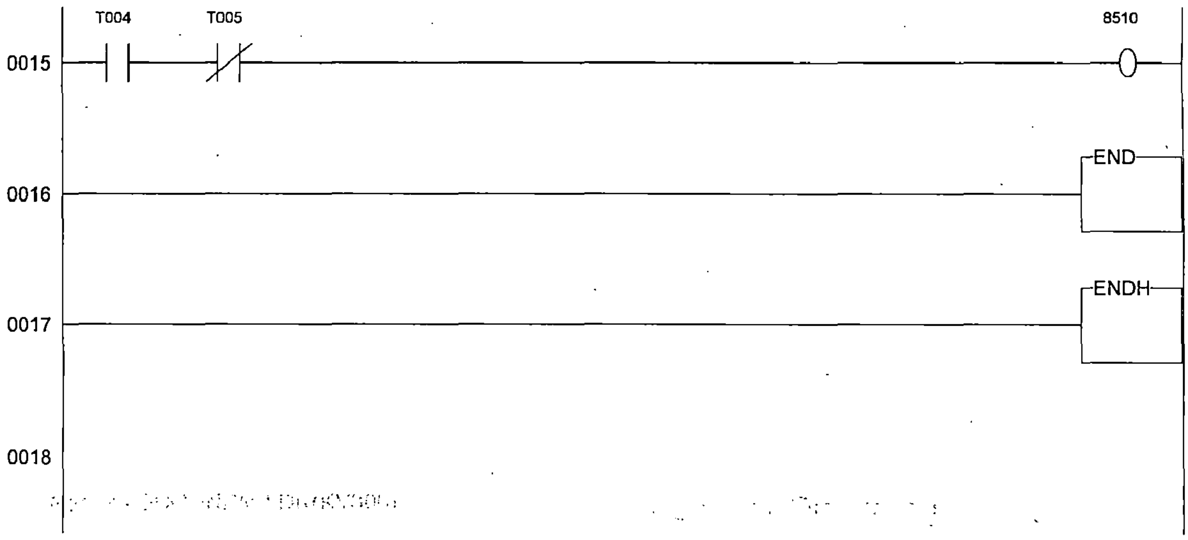
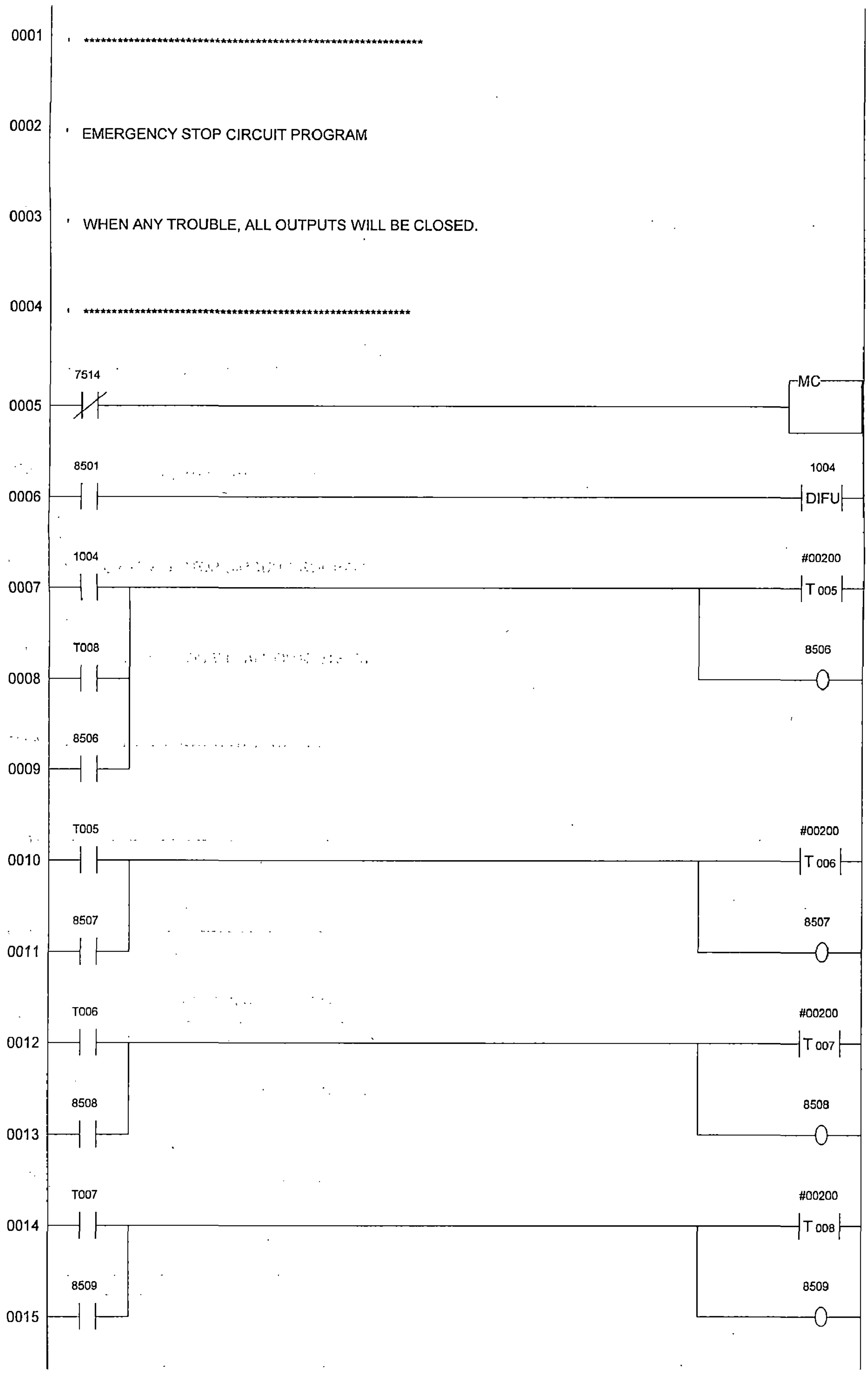



*Fig: 6.14 Program for Load Control in Normal Shutdown Condition (LDCONNRM)*



0001 ' **************************************************************
0002 ' EMERGENCY STOP CIRCUIT PROGRAM
0003 ' WHEN ANY TROUBLE, ALL OUTPUTS WILL BE CLOSED.
0004 ' ************************************************************
0005
7514
MC
0006
8501
1004
DIFU
0007
1004
#00200
T 005
0008
T008
8506
0009
8506
0010
T005
#00200
T 006
0011
8507
8507
0012
T006
#00200
T 007
0013
8508
8508
0014
T007
#00200
T 008
0015
8509
8509

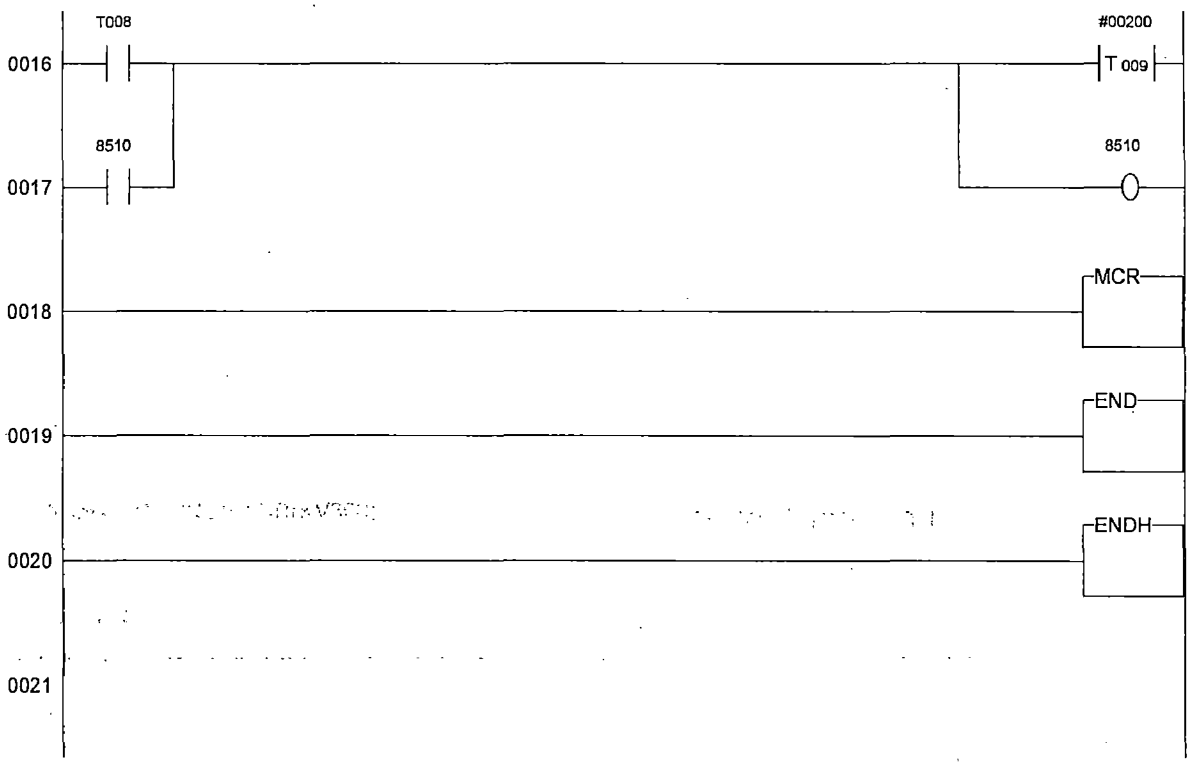



*Fig: 6.15 Program for Load Control in Fault or Emergency Shutdown Condition (LDCONEM)*

## 6.5 SPEED CONTROL FOR SHP STATION

The speed control or speed governing is done in order to maintain the speed of the generator within a specified band which is user selectable, this means that we are indirectly maintaining the frequency of the generator within specified limits. In the present case tubine is directly coupled with generator so speed of turbine is same as generator. The generator is a 4 pole machine with rated speed of 1500 rpm.

In the present work the speed if turbine is sensed by optoelectronic speed sensor discussed in section 4.5.The input signal from speed sensor is connected to Input module KV C16X as discussed in 6.1.2.The output of senor is 0 to + 5 Volt square wave, also connected to Cathode ray Oscilloscope (CRO) to see the pulses shown in Fig 6.16

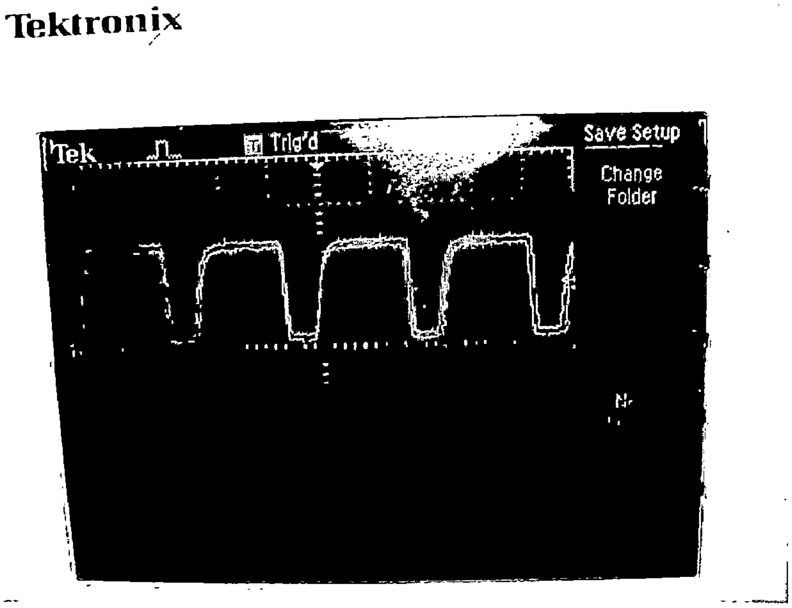



*Fig: 6.16 View of Square Wave Pulse on CRO*

CRO shows the speed of turbine in rotation per minute (RPM). The pulse interval is varying inversely proportional to the speed of turbine or frequency as its just opposite of frequency. The frequency is nothing but the pulse count per sec or rpm of the generator. This count when divided by 30 gives the frequency of the generator. The output count of the speed sensor is compared with that of the range counts set in the program to make further decision on the basis of speed.

The variation is speed is mainly come due to variation in load demand with constant discharge, or variation in discharge with constant load. So speed of turbine or generator can be kept constant by controlling discharge for varying load or by controlling load for varying discharge. So out of these two one parameter will act as process load and other is controlled variable.

In case of varying load speed control has been achieved by controlling discharge by electrical actuated inlet valve. In this speed control is basically an ON/OFF TYPE control i.e. the control valve or electrical actuator is either driven in the forward or reverse direction depending on the error in speed from the set point. The important feature of the control is having a dead band selectable by the user which a range of rpm over which the controller should not respond. Having an ON/OFF control with dead band eliminates oscillations in the control output. The main consideration in choosing the dead band depends on how much speed is affected after turning off the supply to the actuator in either forward or reverse direction. This is due to the fact that the actuator may have inertia which keeps it driving the valve even if the supply to it is cut off.

The speed of turbine or generator can also controlled by adjusting load. Though this type of control is feasible for only plants which are isolated or not connected to grid and are of very small capacity plants like mini or micro hydro as it is not possible to adjust the for higher capacity plants. In this case the load will be controlled variable. The load is adjusted to maintain the speed constant for a given discharge, for this speed of turbine or generator is sensed and compared with a suitable operating range and load has been adjusted according to that to kept speed constant.

### 6.5.1 Speed Control using PLC

In the present work input signal of speed of turbine is coming as 5 V pulses from an optoelectronic speed sensor. The sensor having one LED and one phototransistor, it produces a pulse whenever phototransistor receives LED light. Since there are 60 teeth in allotted disk mounted on shaft of turbine, so it produces 60 square pulses per revolution of shaft. So actual time interval of square wave pulse will be

Time interval = 1 / frequency or rotation per sec

Take speed of turbine as rated speed 1500 rpm the time interval will be

1500 rpm = 1500 /60 = 25 rps or Hz ,

Time interval = 1/25 = 0.04 sec or 40000 micro sec or 4000 *10 micro second

The speed can be measured by PLC by measuring time interval of the pulse received. Interrupt instruction of PLC can be used for it. Here the pulses from an internal clock are used for measurement of time. The input signal for the sensor is made to trigger the interrupt of the PLC and the time interval between two interrupts is measured by counting the internal clock between the two interrupts. The measurement unit can be made as small as one microsecond. This gives a good resolution of speed measurement.

The interrupt pin 03 (interrupt instruction) of PLC CPU has been used to measure the speed of the turbine .The positive going edge of the input pulse are made to interrupt the PLC and the time between two interrupts is measured. The Program V shown in Fig 6.17

### 6.5.2 Description of Program V (SPCON)

(a) Initiate the PLC by enabling interrupt, resetting data memory DM 0000 and high speed counter CTH1, set internal relay 2813 to be able to receive high speed pulses. Start high-speed counter to count 10 micro sec pulses from internal clock of the PLC through 2201 relay.

(b) Multiply the contents of data memory DM 0000 by 60, as there are 60(no. of teeth in slotted disc) pulses per revolution of turbine and store it in DM 0001.

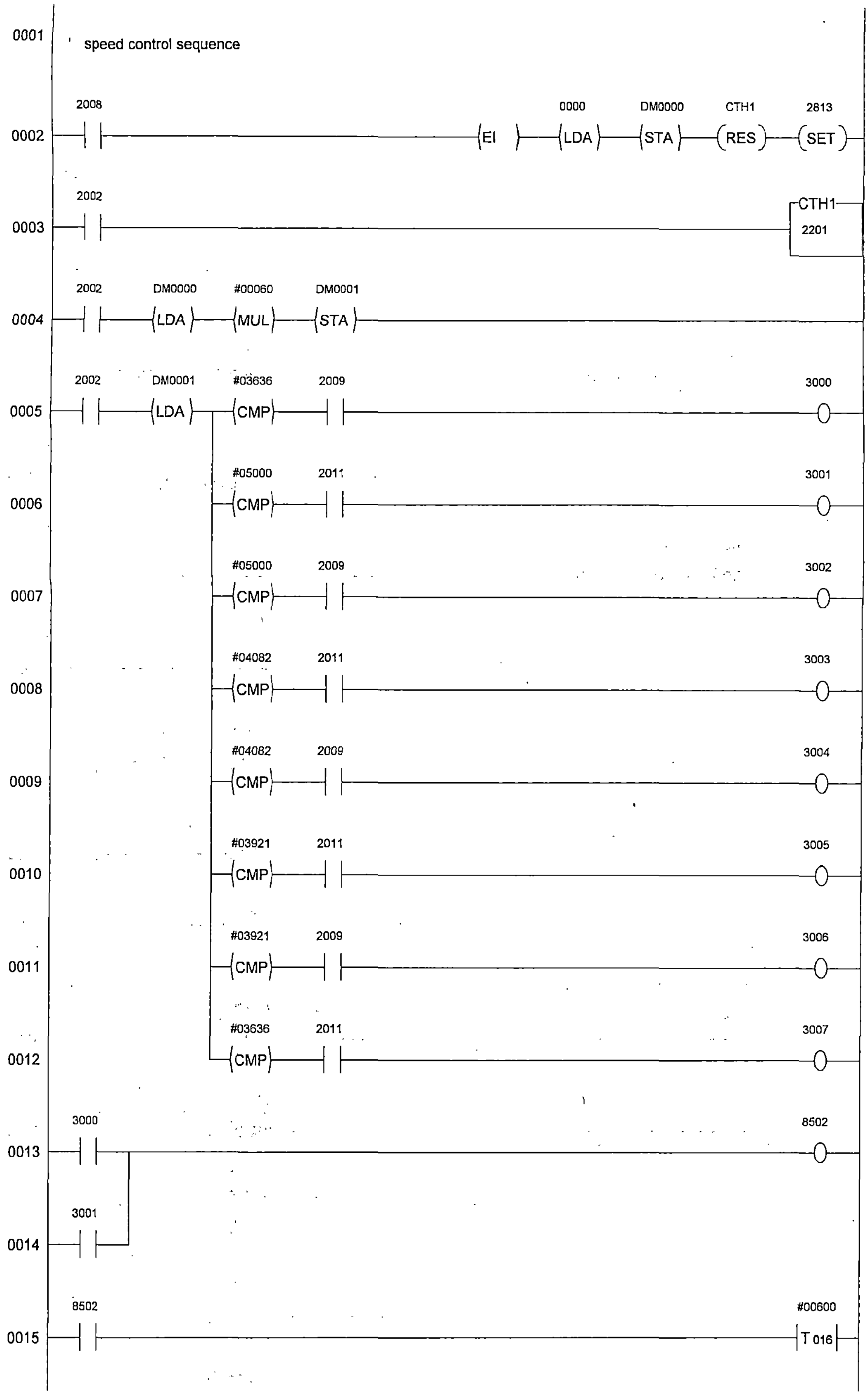
(c) The speed of turbine has been compared with various ranges like for less then 1200 rpm ( under speed) , over speed ( greater than 1650 rpm ), in normal speed range ( between 1470 to 1530) , over load ( between 1200 to 1470) , under load ( between 1530 to 1650) etc.

(d) The above function has been achieved by comparing the content of DM 0001 with time intervals greater than 5000 μs ( under speed) , over speed ( less than 3636 μs ), ), in normal speed range ( between 3921 μs to 4082 μs) , over load ( between 4082 μs to 5000 μs) , under load ( between 3636 μs to 3921 μs) etc. If the contents less than setting, relay 2009 turns on. If content larger than setting, relay 2011 turns on, and these relays subsequently turns on other relays on.

(e) Turn on output relays 8502, 5002, 8504 and 8505 based on above comparison respectively. The relays relay 8502 will glow when in case of either under speed or over speed. Thus create a fault signal and will turn on relay 7004, which further make on internal utility relay 1003 to shutdown the plant in fault or emergency condition.

(f) Execute interrupt program for every positive pulse of the input 003.

(g) At each interrupt, read value of present count of high-speed counter (content of TM 30) and subtract the count value at the preceding interrupt (content of TM 02). This gives the time interval, store it in DM 0000. Compare this result with required/ preset value and operate output relays accordingly.


0001
' speed control sequence
0002
2008
0000
DM0000
CTH1
2813
EI
LDA
STA
RES
SET
0003
2002
CTH1
2201
0004
2002
DM0000
#00060
DM0001
LDA
MUL
STA
0005
2002
DM0001
#03636
2009
3000
LDA
CMP
0006
#05000
2011
3001
CMP
0007
#05000
2009
3002
CMP
0008
#04082
2011
3003
CMP
0009
#04082
2009
3004
CMP
0010
#03921
2011
3005
CMP
0011
#03921
2009
3006
CMP
0012
#03636
2011
3007
CMP
0013
3000
8502
0014
3001
0015
8502
#00600
T 016

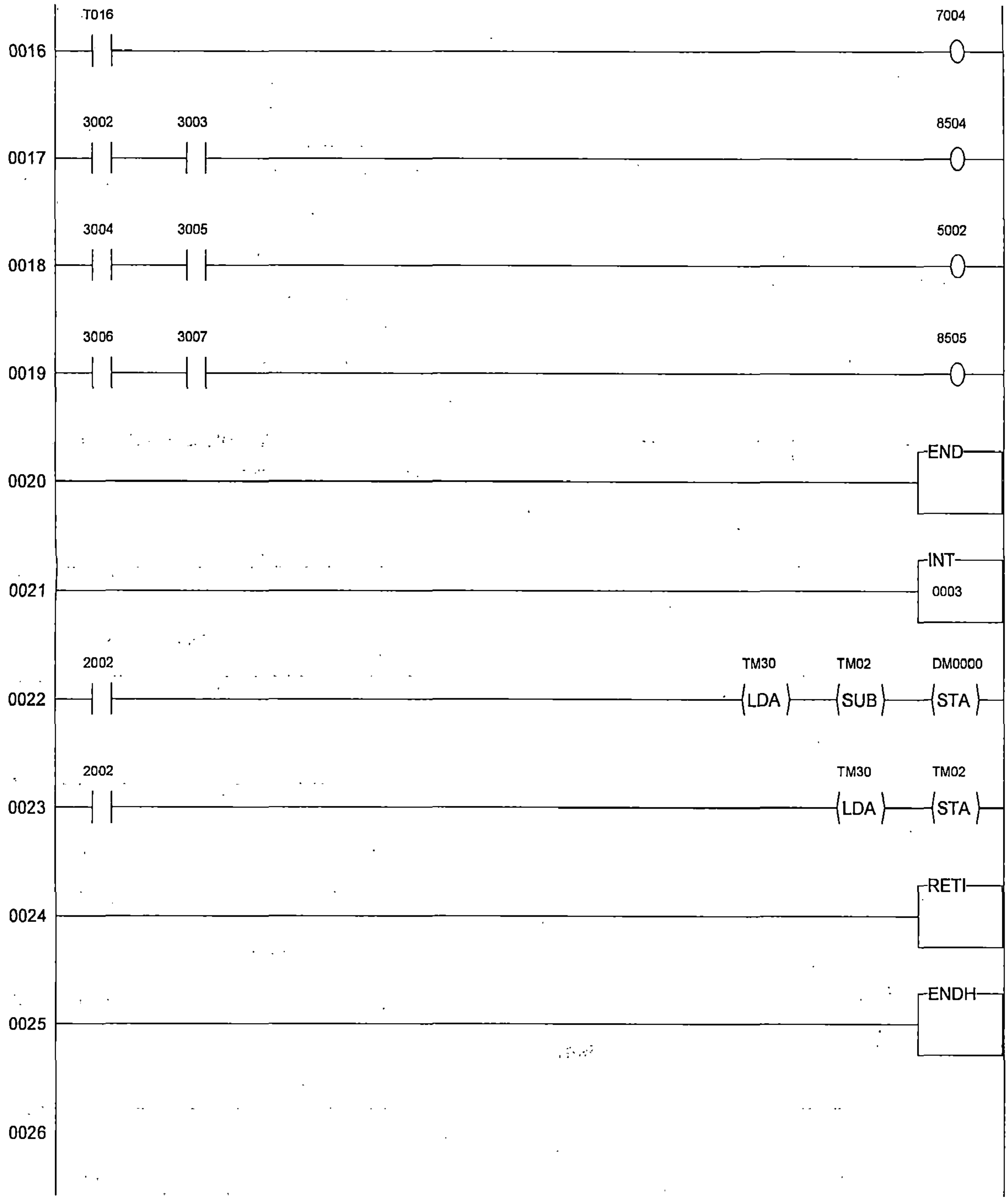



*Fig: 6.17 Program for Speed Control (SPCON)*

## 6.6 INTEGRATED PROGRAM FOR CONTROL AND AUTOMATION OF SHP STATION.

Two integrated program by including all the discussed control function has been developed and tested on turbine – generator demonstration unit successfully. 1st program INTPRG is for automatic starting with speed control, load control along with normal shutdown and the other program ITNPRG1 is for starting with speed control, load control along with fault or emergency shut down shutdown as shown in Fig 6.18 & 6.19 respectively.

### 6.6.1 Description of Integrated Programs (INTPRG & INTPRG1)

(a) Connect all the connections as discussed in the Fig 6.1 and 6.3. Then provide power supply to KV -300 PLC and connect it Program I to the PLC.

(b) Click on execute continuous option available in monitor window, as soon as u click the execution of program will start and sequence of functions will be followed

(c) Contact 7000 is Normally Closed (NC) will act as starting pulse is continuously coming. This gives signal to relays 7500, 7501 and 7502 to on the close field switch, reset shutdown and set master control functions.

(d) Following the above functions, Hardware relay 8500 of PLC-KV 300 will be closed, which is connected to solid state relay (SSR1) and will on the electrical inlet valve. This relay will be on for 1 min, in this time electrical actuated inlet valve moves from fully closed to fully open position. Also relays for breaks & jacks off, on standby governor oil pump and on lubricating oil pump will be closed simultaneously .In the same way all auxiliaries are opened and then guide vanes are opened.

(e) Then final stage relay is on , synchronizing signal is given and then signal to hardware relay 8501 of PLC to put the unit on to gird or load ( load in present case).

(f) The load will start increase gradually from no load to full load in 5 steps, when relay 8501 will be energized. Following it 5 solid state relays will be energized, associated to PLC relays 8506 to 8510.The solid state relays will further made contractor switch close and load will increase in five steps.

(g) Initiate the PLC by enabling interrupt, resetting data memory DM 0000 and high speed counter CTH1, set internal relay 2813 to be able to receive high speed pulses. Start high-speed counter to count 10 micro second pulses from internal clock of the PLC through 2201 relay.

(h) Multiply the contents of data memory DM 0000 by 60, as there are 60(no. of teeth in slotted disc) pulses per revolution of turbine and store it in DM 0001.

(i) The speed of turbine has been compared with various ranges like for less then 1200 rpm ( under speed) , over speed ( greater than 1650 rpm ), in normal speed range ( between 1470 to 1530) , over load ( between 1200 to 1470) , under load ( between 1530 to 1650) etc.

(j) The above function has been achieved by comparing the content of DM 0001 with time intervals greater than 5000 μs ( under speed) , over speed ( less than 3636 μs ), ), in normal speed range ( between 3921 μs to 4082 μs) , over load ( between 4082 μs to 5000 μs) , under load ( between 3636 μs to 3921 μs) etc. If the contents less than setting, relay 2009 turns on. If content larger than setting, relay 2011 turns on, and these relays subsequently turns on other relays on.

(k) Turn on output relays 8502, 5002, 8504 and 8505 based on above comparison respectively. The relays relay 8502 will glow when in case of either under speed or over speed. Thus create a fault signal and will turn on relay 7004, which further make on internal utility relay 1003 to shutdown the plant in fault or emergency condition.

(l) Execute interrupt program for every positive pulse of the input 003.

(m) At each interrupt, read value of present count of high-speed counter (content of TM 30) and subtract the count value at the preceding interrupt (content of TM 02). This gives the time interval, store it in DM 0000. Compare this result with required/ preset value and operate output relays accordingly.

(n) For normal shut down load control at the time of stopping of SHP unit will be different from case of fault or emergency condition.

(o) When the stop signal by relay 7514 will come, the relays 8506 to 8510 will turn off in sequence in five steps, like 1st 8506 will go off then 8507and so on. Thus the whole load will be switched off step by step.

(p) When the stop signal by relay 7514 will come, the relays 8506 to 8510 will turn off in one shot. Thus the whole load will be switched off immediately

(q) In the case of fault or emergency shutdown whenever any fault comes like unbalance condition or over current or over voltage or over speed ( as in this case)or high bearing temperature or governor oil failure or emergency trip condition occurred, the corresponding relay will on ,Immediately all the load will be switched off in one shot.

(r) For example, in this program if condition of over speed occurs, then digital input is to be given to 7004 to make it on, it will close internal utility relay 1003 which will again close the shut down relay 7514, which will make generator breaker off. After 1 minute, main valve will be closed, after 1 minute, guide vanes will be closed and then after 1minute, breaks will be applied.

(s) Thus all the necessary functions in proper sequence will take place and unit will shutdown within one minute by actuating solid state relay (SSR2) using hardware relay 8503 of PLC to move the electrical actuator valve from fully open to fully close position and plant will be shut down immediately .

### 6.6.2 Details of Instruction used in Programs

The contacts, relays, timers, high speed counters, interrupt signals are used in programs are shown along with their function as below.

**(a) External Input relay**

| | | | |
|---|---|---|---|
| LD | 7000 | : | Remote starting Pulse |
| LD | 7001 | : | signal for governor failure |
| LD | 7002 | : | Signal for unbalance condition |
| LD | 7003 | : | Signal for over current |
| LD | 7004 | : | Signal for over speed or under speed |
| LD | 7005 | : | Signal for over current |
| LD | 7006 | : | Signal for over voltage |
| LD | 7007 | : | Signal for Bearing Temperature |
| LD | 7008 | : | Signal for Emergency Trip |

**(b) Output Relay**

| | | | |
|---|---|---|---|
| OUT | 7500 | : | Close Filed switch |
| OUT | 7501 | : | Reset Shut down Relay |
| OUT | 7502 | : | Set Master Control Relay |
| OUT | 7503 | : | Run Stand by Governor Oil Pump |
| OUT | 7504 | : | Start Lubricating Oil pump |
| OUT | 7505 | : | Middle Stage Signal Relay |
| OUT | 7506 | : | Open Guide Vanes or Nozzles |
| OUT | 7507 | : | Run Normal Water Cooling Water Pump |
| OUT | 7508 | : | Run Normal Governor Oil Pump |
| OUT | 7509 | : | Run Normal Lubrication Oil Pump |
| OUT | 7510 | : | Set Relay On Pilot Exciter |
| OUT | 7511 | : | Final Stage Signal Relay |
| OUT | 7512 | : | Start Automatic synchronization |
| OUT | 7513 | : | Close circuit Breaker |
| OUT | 7514 | : | Switch off the Load |
| OUT | 7515 | : | Alarm |

| | | | |
|---|---|---|---|
| OUT | 8500 | : | Open Main Inlet Valve |
| OUT | 8501 | : | Signal to Load the Unit |
| OUT | 8502 | : | Signal for Under or Over Speed |
| OUT | 8503 | : | Signal to Close Inlet Valve |
| OUT | 5000 | : | Shutdown the Relay |
| OUT | 5001 | : | Close Guide Vanes |
| OUT | 8504 | : | Signal to Over Load |
| OUT | 8505 | : | Signal to under Load |
| OUT | 5002 | : | Signal to Normal Load |
| OUT | 8506 | : | Signal to I Step Load |
| OUT | 8507 | : | Signal to II Step Load |
| OUT | 8508 | : | Signal to III Step Load |
| OUT | 8509 | : | Signal to IV Step Load |
| OUT | 8510 | : | Signal to V Step Load |

**(c) Internal Relay**

| | | |
|---|---|---|
| 1000 | : | Internal Utility Relay |
| 1001 | : | Internal Utility Relay |
| 1002 | : | Internal Utility Relay |

**(d) Special Relays**

| | | |
|---|---|---|
| 2002 | : | Always on relay |
| 2008 | : | Always on relay |
| 2009 | : | on when internal register is less than setting |
| 2011 | : | on when internal register is greater than setting |
| 2201 | : | Set internal clock pulse of counter 10 micro sec |
| 2813 | : | to receive high speed pulses |

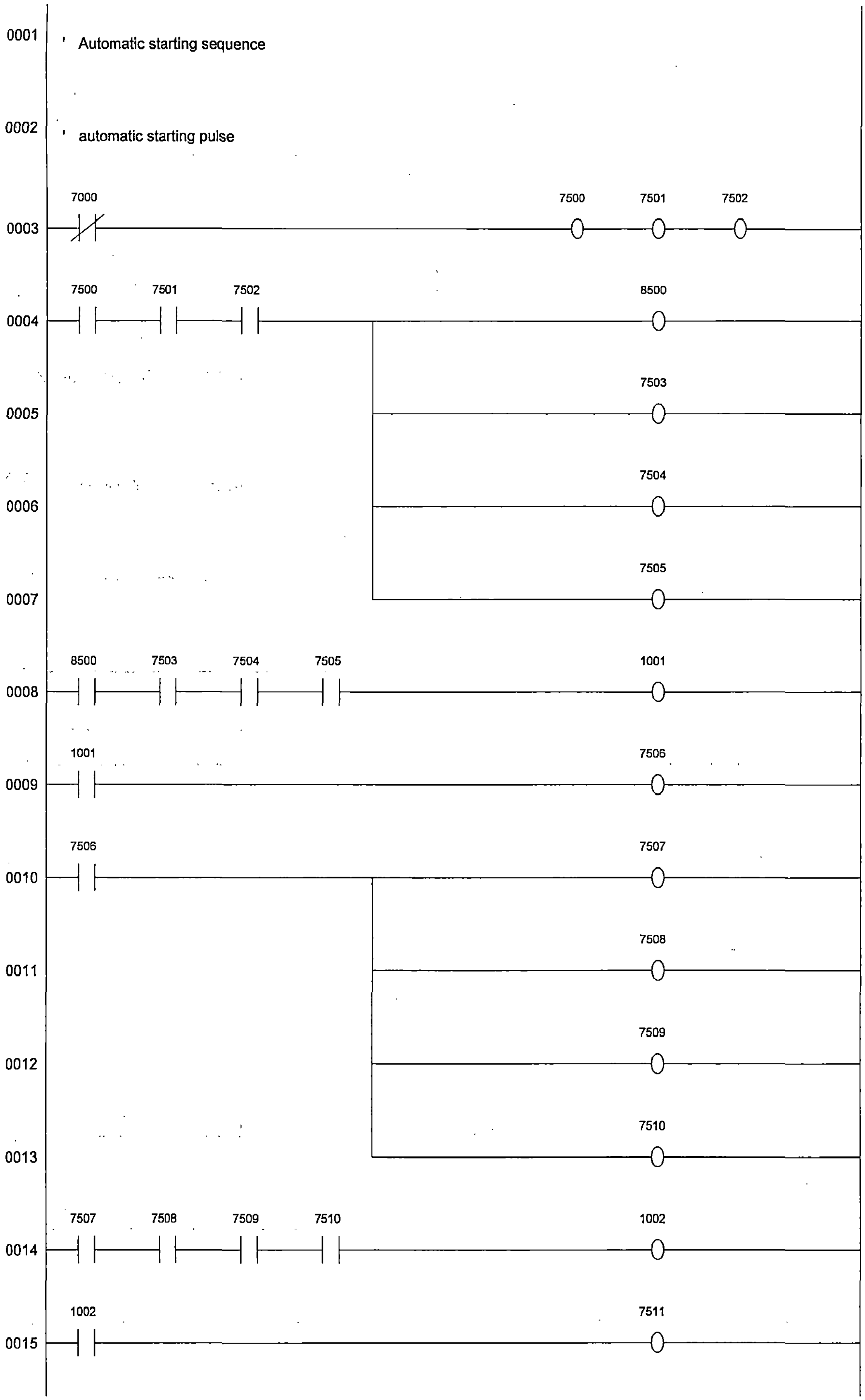
**(e) High speed counter**

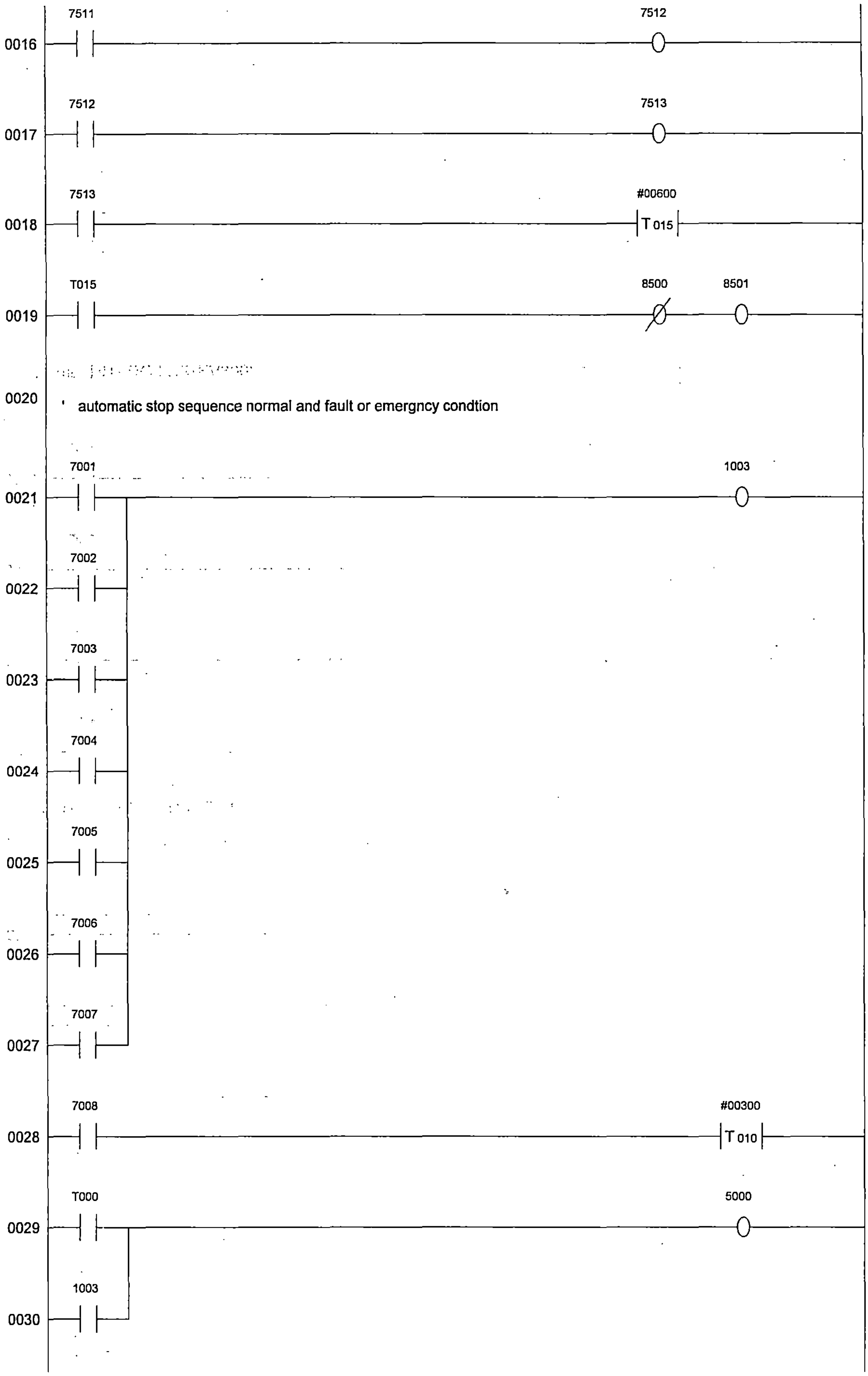
| | | |
|---|---|---|
| CTH1 | : | High speed counter |

**(f) Timers**

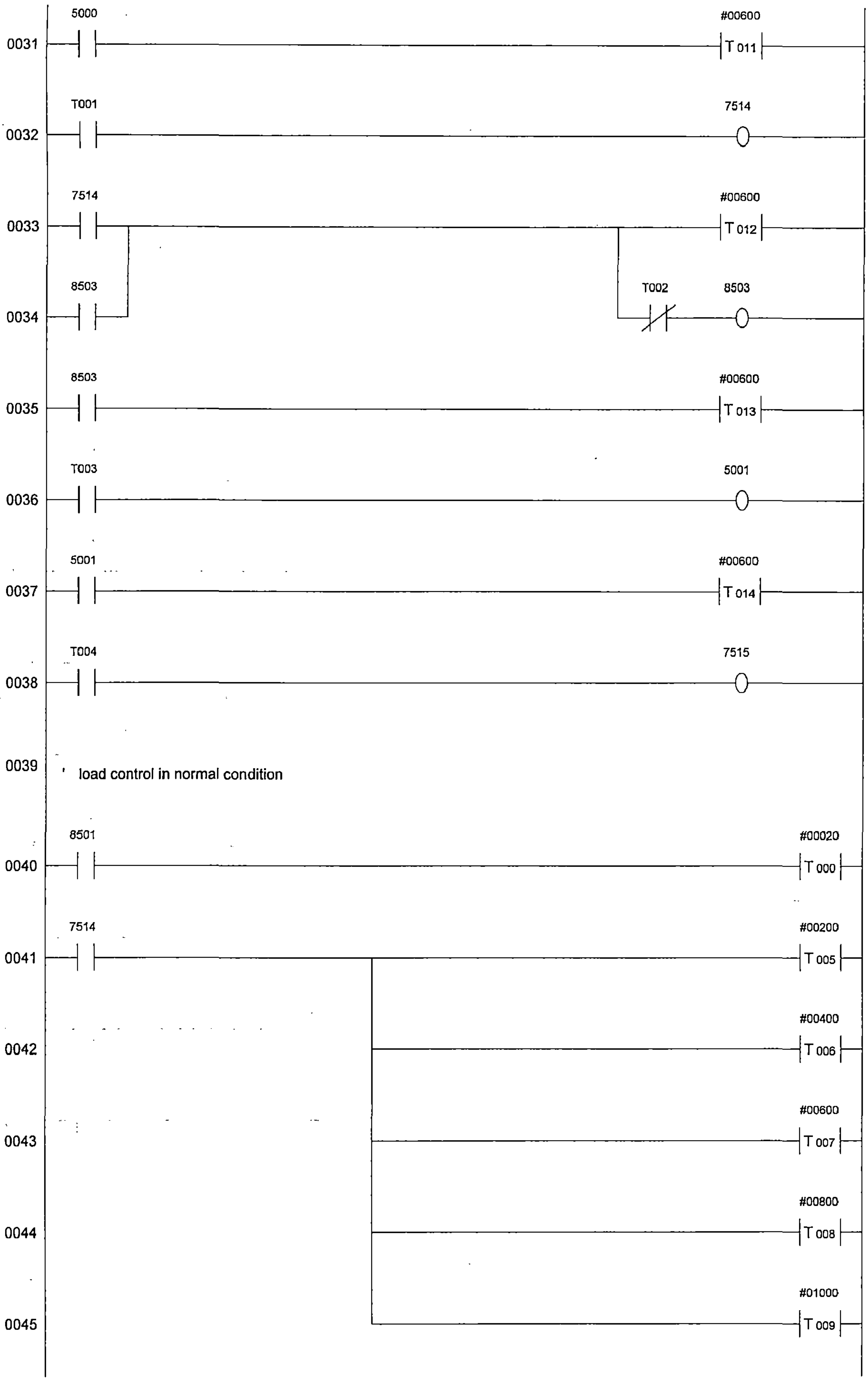
| | | | |
|---|---|---|---|
| TMR | 000 | : | #0020 |

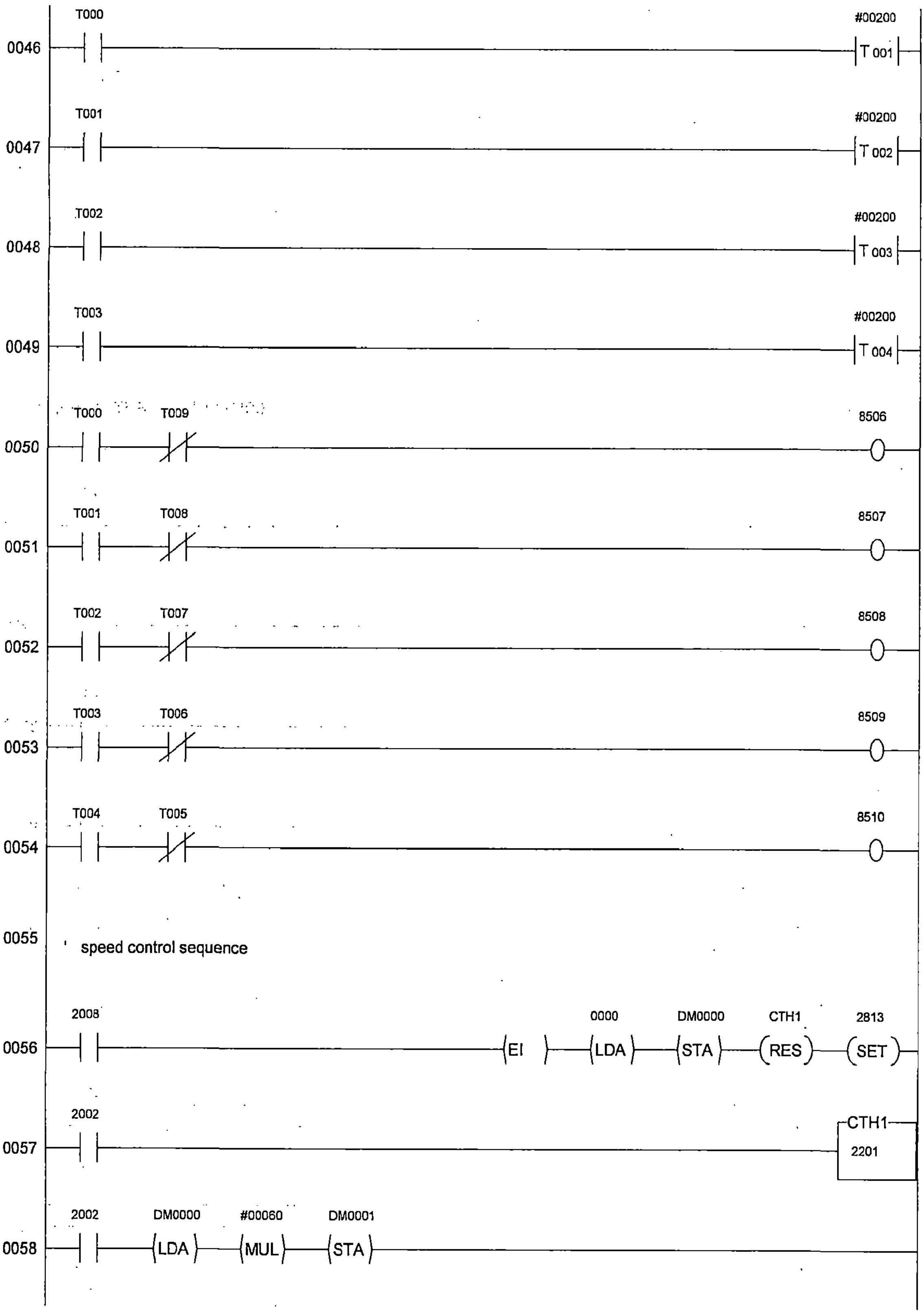
| | | | |
|---|---|---|---|
| TMR | 001 | : | #00200 |
| TMR | 002 | : | #00200 |
| TMR | 003 | : | #00200 |
| TMR | 004 | : | #00200 (20 sec as internal clock is set 0.1 sec) |
| TMR | 005 | : | #00200 |
| TMR | 006 | : | #00400 |
| TMR | 007 | : | #00600 |
| TMR | 008 | : | #00800 |
| TMR | 009 | : | #01000 |
| TMR | 010 | : | #00300 |
| TMR | 011 | : | #00600 |
| TMR | 012 | : | #00060 |
| TMR | 013 | : | #00600 |
| TMR | 014 | : | #00600 |
| TMR | 015 | : | #00600 |
| TMR | 016 | : | #00600 |

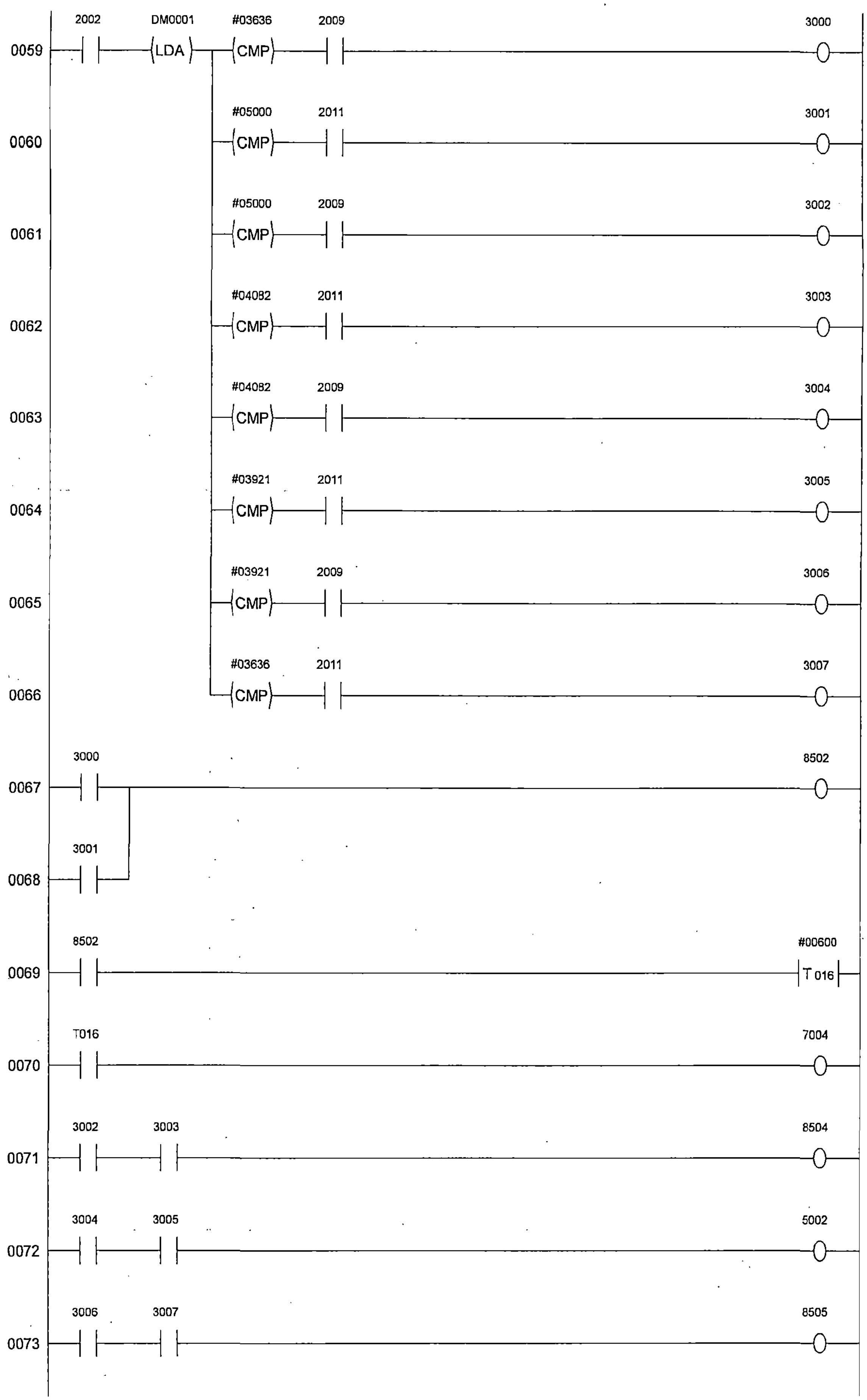

0001 ' Automatic starting sequence
0002 ' automatic starting pulse
0003
7000
7500
7501
7502
0004
7500
7501
7502
8500
0005
7503
0006
7504
0007
7505
0008
8500
7503
7504
7505
1001
0009
1001
7506
0010
7506
7507
0011
7508
0012
7509
0013
7510
0014
7507
7508
7509
7510
1002
0015
1002
7511



0016
7511
7512
0017
7512
7513
0018
7513
#00600
T 015
0019
T015
8500
8501
0020
' automatic stop sequence normal and fault or emergncy condtion
0021
7001
1003
0022
7002
0023
7003
0024
7004
0025
7005
0026
7006
0027
7007
0028
7008
#00300
T 010
0029
T000
5000
0030
1003


0031
5000
#00600
T 011
0032
T001
7514
0033
7514
#00600
T 012
0034
8503
T002
8503
0035
8503
#00600
T 013
0036
T003
5001
0037
5001
#00600
T 014
0038
T004
7515
0039
' load control in normal condition
0040
8501
#00020
T 000
0041
7514
#00200
T 005
0042
#00400
T 006
0043
#00600
T 007
0044
#00800
T 008
0045
#01000
T 009


0046
T000
#00200
T 001
0047
T001
#00200
T 002
0048
T002
#00200
T 003
0049
T003
#00200
T 004
0050
T000
T009
8506
0051
T001
T008
8507
0052
T002
T007
8508
0053
T003
T006
8509
0054
T004
T005
8510
0055
' speed control sequence
0056
2008
EI
0000
LDA
DM0000
STA
CTH1
RES
2813
SET
0057
2002
CTH1
2201
0058
2002
DM0000
LDA
#00060
MUL
DM0001
STA


0059
2002
DM0001
LDA
#03636
CMP
2009
3000
0060
#05000
CMP
2011
3001
0061
#05000
CMP
2009
3002
0062
#04082
CMP
2011
3003
0063
#04082
CMP
2009
3004
0064
#03921
CMP
2011
3005
0065
#03921
CMP
2009
3006
0066
#03636
CMP
2011
3007
0067
3000
8502
0068
3001
0069
8502
#00600
T 016
0070
T016
7004
0071
3002
3003
8504
0072
3004
3005
5002
0073
3006
3007
8505

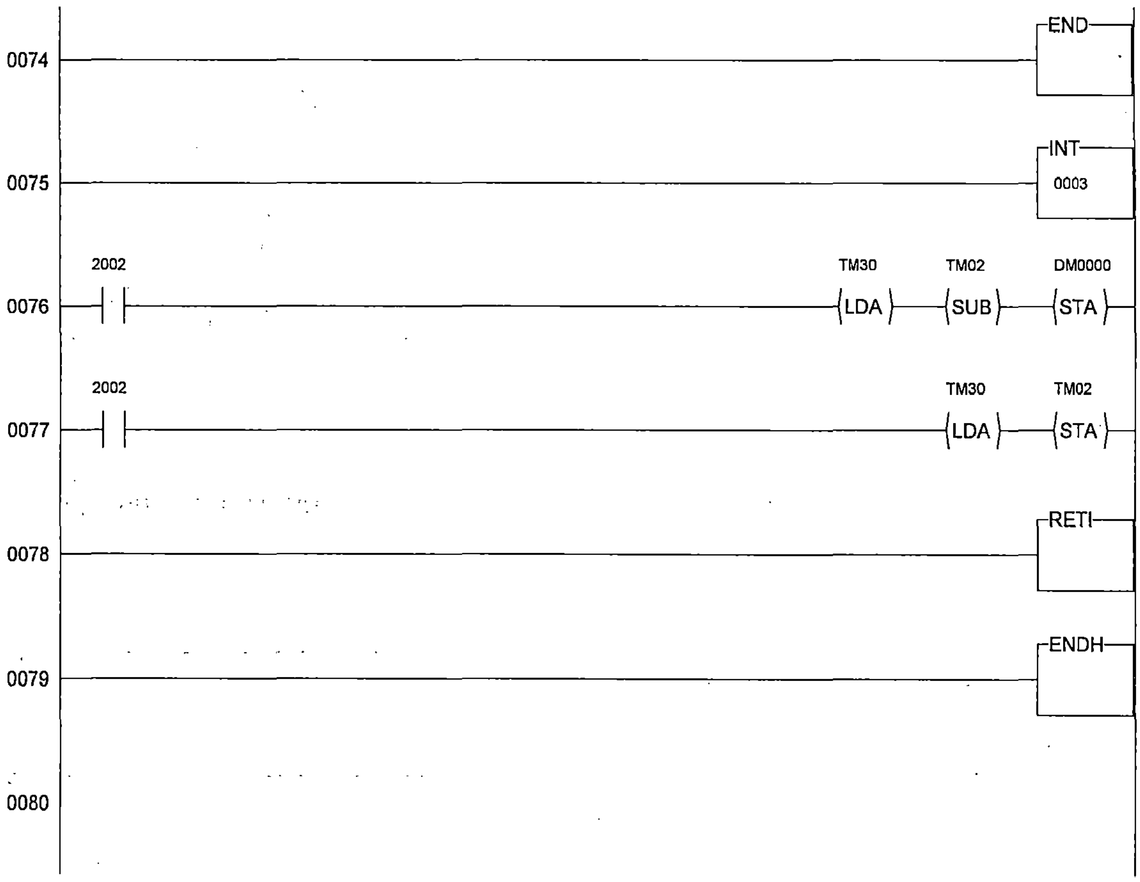
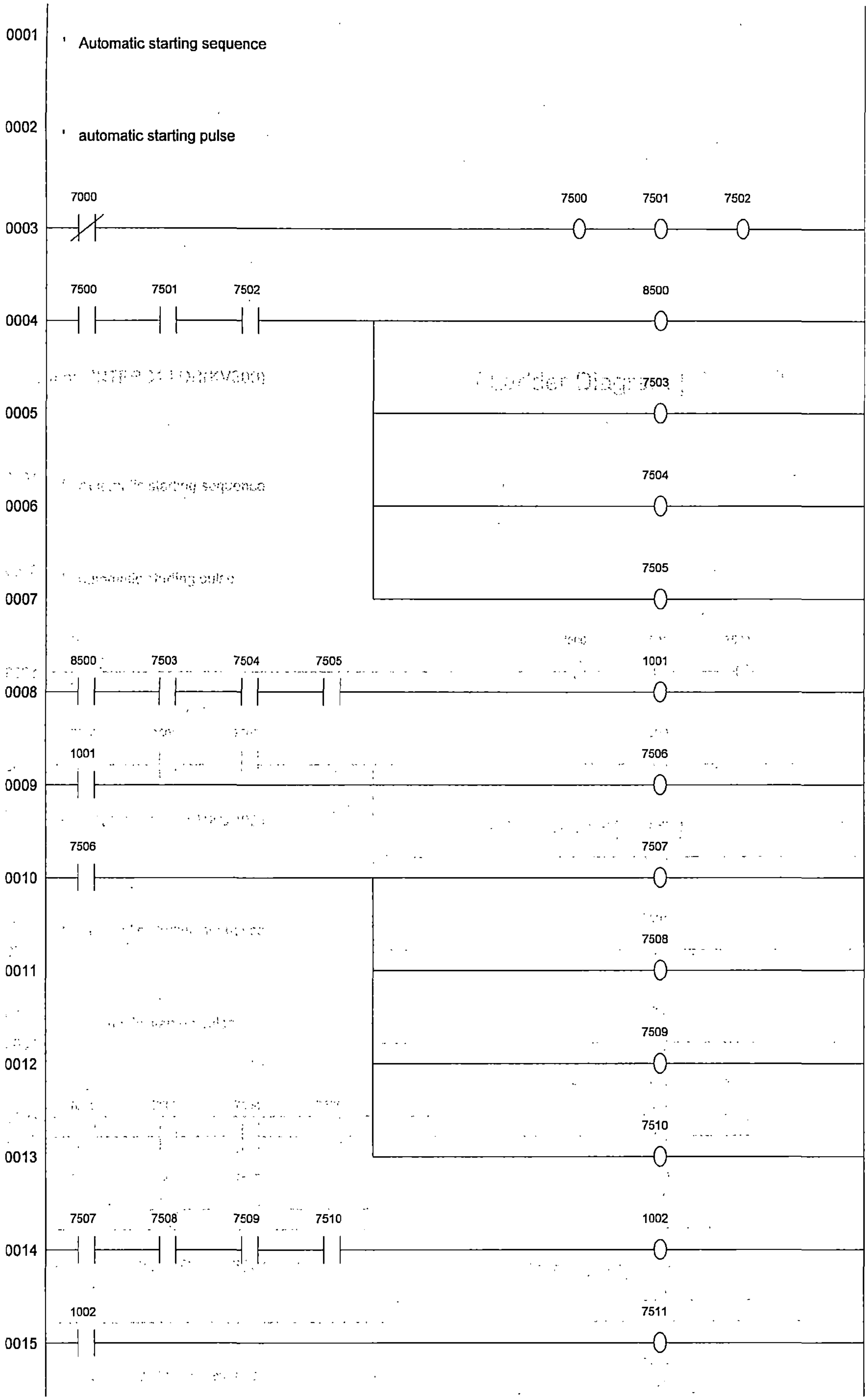
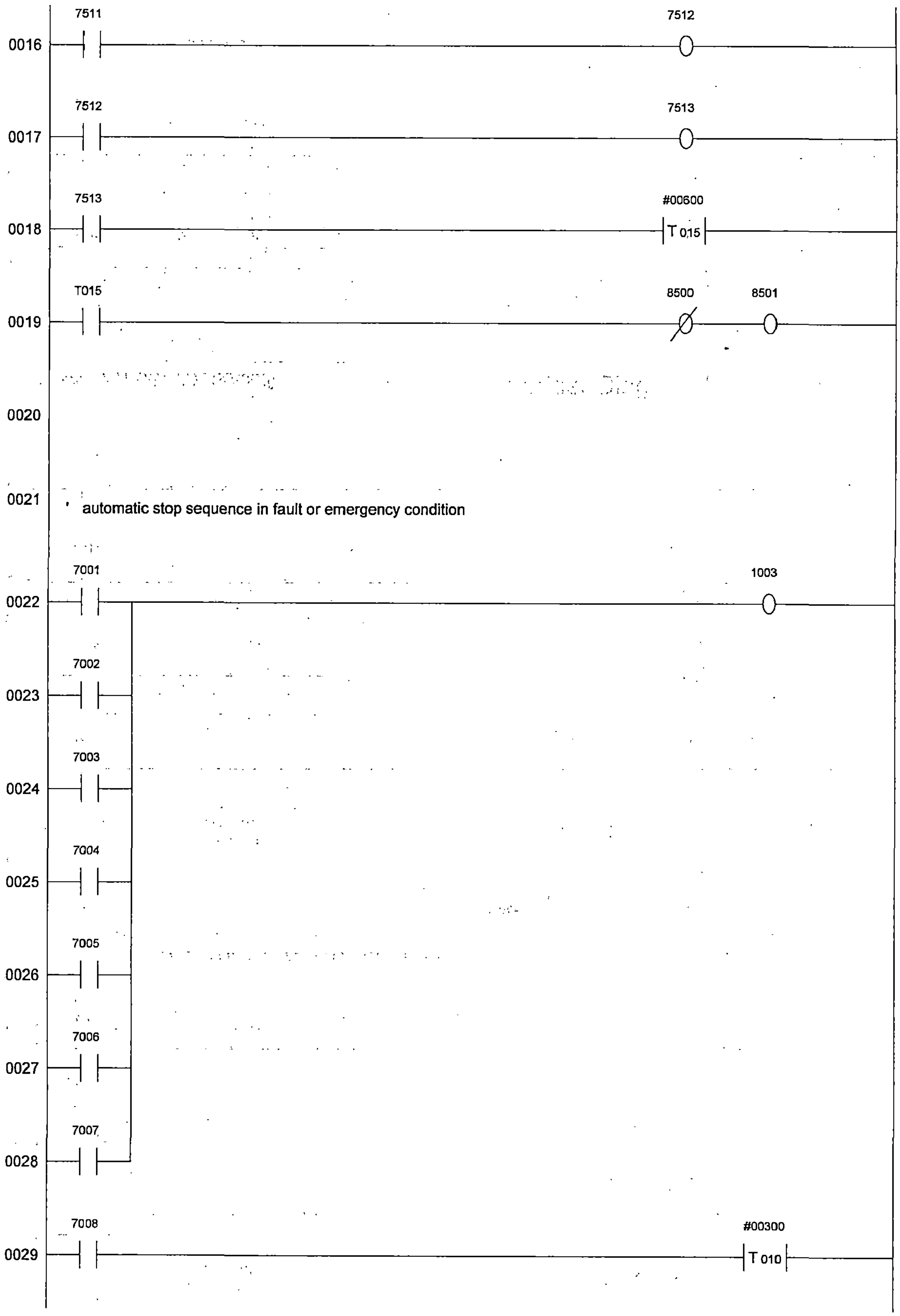
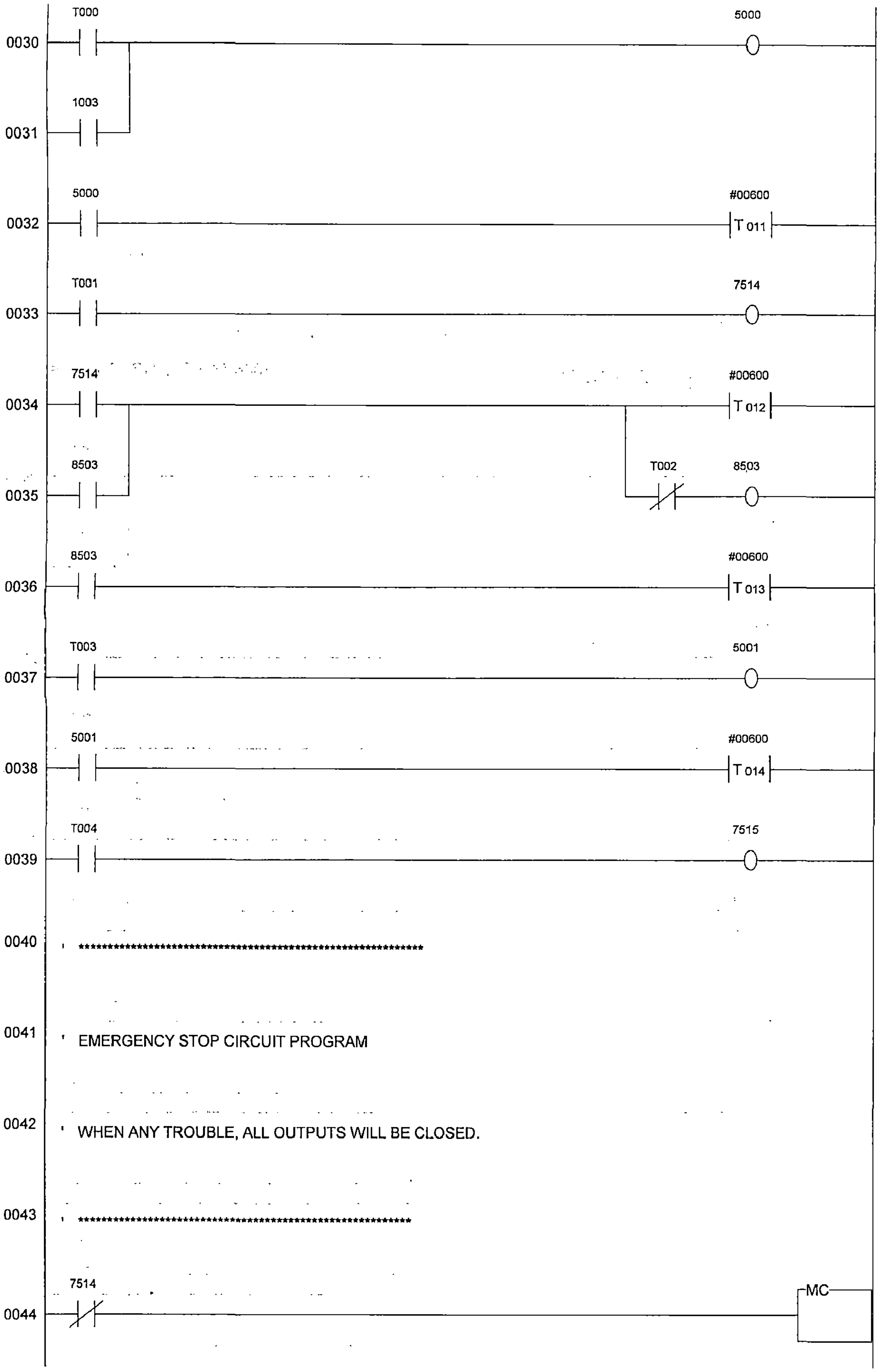
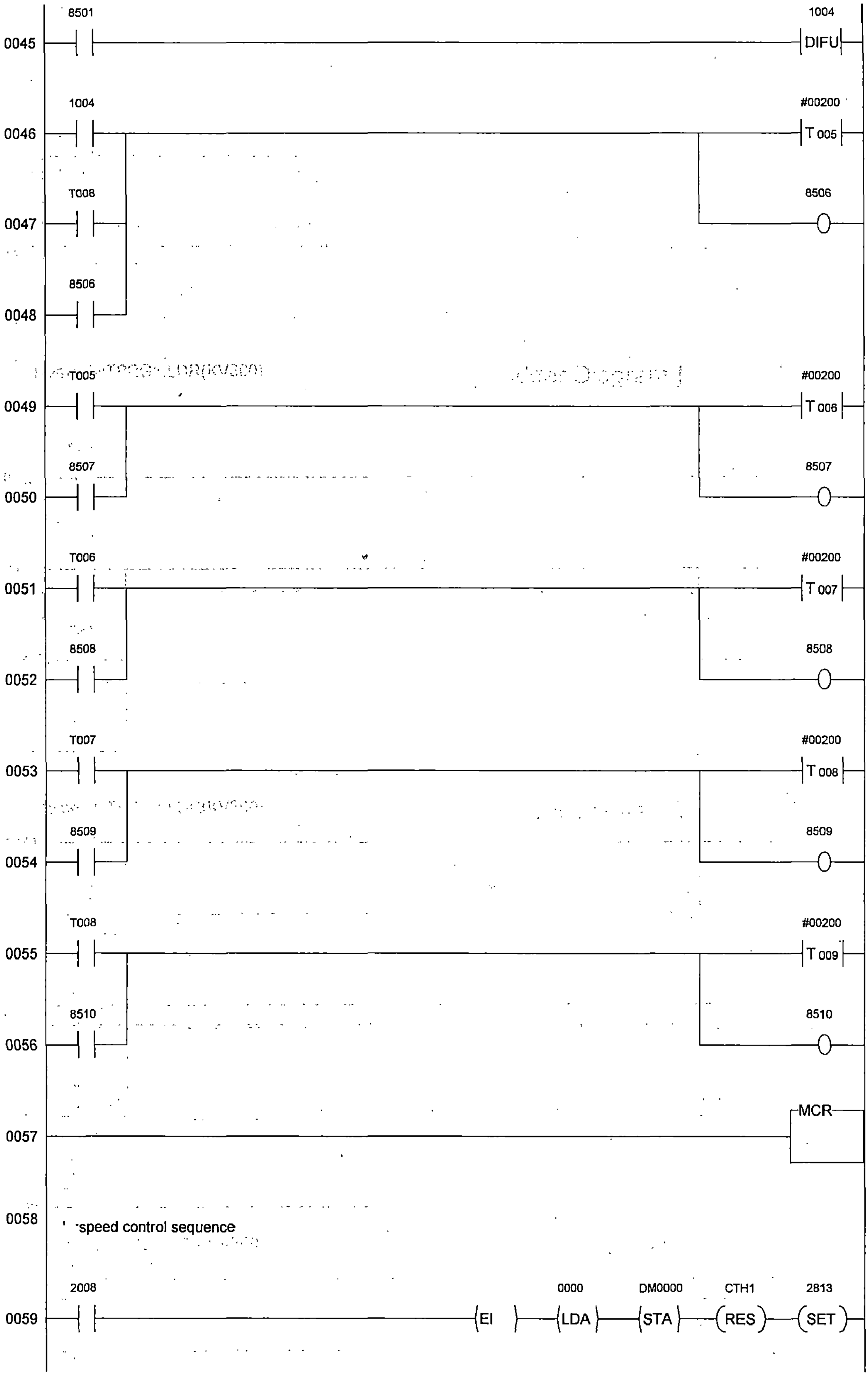


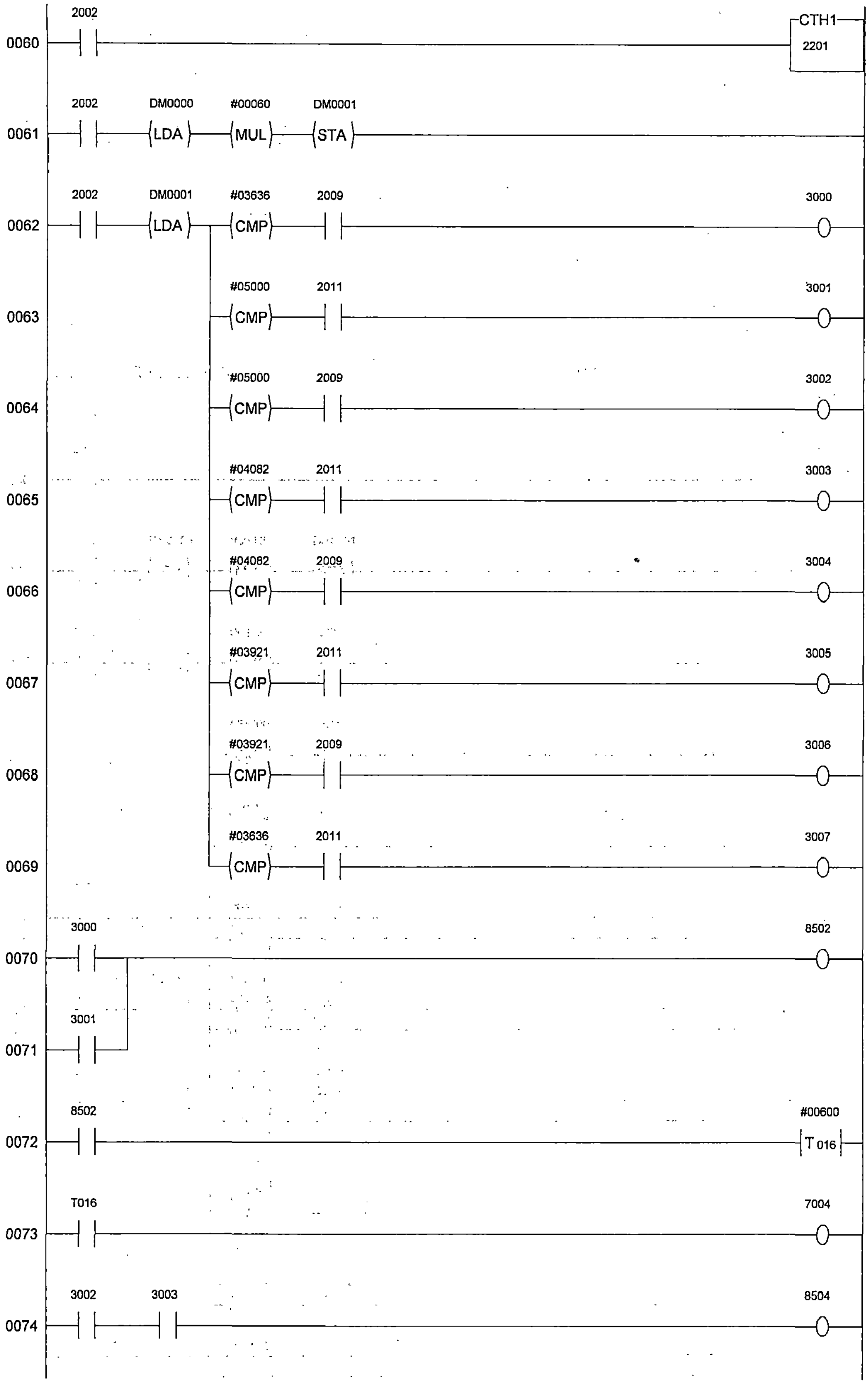

*Fig: 6.18 Integrated Program for Automatic Starting with, Speed Control, Load Control in Normal Shutdown Condition (INTPRG)*


0001 ' Automatic starting sequence
0002 ' automatic starting pulse
0003 7000 7500 7501 7502
0004 7500 7501 7502 8500
0005 7503
0006 7504
0007 7505
0008 8500 7503 7504 7505 1001
0009 1001 7506
0010 7506 7507
0011 7508
0012 7509
0013 7510
0014 7507 7508 7509 7510 1002
0015 1002 7511


0016
7511
7512
0017
7512
7513
0018
7513
#00600
T 015
0019
T015
8500
8501
0020
0021
automatic stop sequence in fault or emergency condition
0022
7001
1003
0023
7002
0024
7003
0025
7004
0026
7005
0027
7006
0028
7007
0029
7008
#00300
T 010


0030
T000
5000
0031
1003
0032
5000
#00600
T 011
0033
T001
7514
0034
7514
#00600
T 012
0035
8503
T002
8503
0036
8503
#00600
T 013
0037
T003
5001
0038
5001
#00600
T 014
0039
T004
7515
0040
' ***********************************************************
0041
' EMERGENCY STOP CIRCUIT PROGRAM
0042
' WHEN ANY TROUBLE, ALL OUTPUTS WILL BE CLOSED.
0043
' ***********************************************************
0044
7514
MC


0045
8501
1004
DIFU
0046
1004
#00200
T 005
0047
T008
8506
0048
8506
0049
T005
#00200
T 006
0050
8507
8507
0051
T006
#00200
T 007
0052
8508
8508
0053
T007
#00200
T 008
0054
8509
8509
0055
T008
#00200
T 009
0056
8510
8510
0057
MCR
0058
' speed control sequence
0059
2008
EI
0000
LDA
DM0000
STA
CTH1
RES
2813
SET


0060
2002
CTH1
2201
0061
2002
DM0000
LDA
#00060
MUL
DM0001
STA
0062
2002
DM0001
LDA
#03636
CMP
2009
3000
0063
#05000
CMP
2011
3001
0064
#05000
CMP
2009
3002
0065
#04082
CMP
2011
3003
0066
#04082
CMP
2009
3004
0067
#03921
CMP
2011
3005
0068
#03921
CMP
2009
3006
0069
#03636
CMP
2011
3007
0070
3000
8502
0071
3001
0072
8502
#00600
T 016
0073
T016
7004
0074
3002
3003
8504

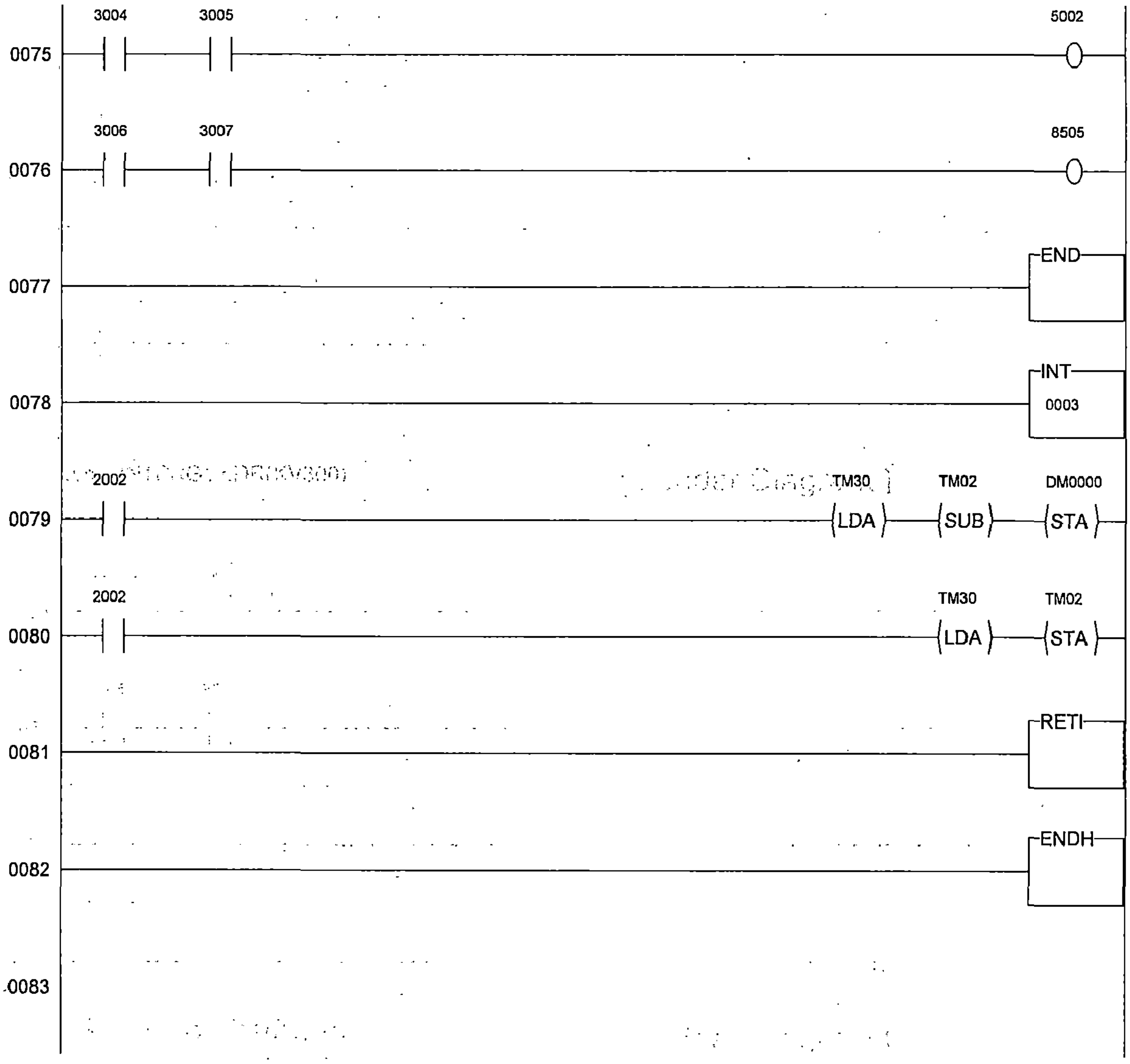



*Fig: 6.19 Integrated Program for Automatic Starting with, Speed Control, Load Control In Fault or Emergency Shutdown Condition (INTPRG1)*

## 6.7 APPLICATIONS OF THE INTEGRATED PROGRAMS

The above programs can be applied in most of the control actions that are dependent on speed. The following will be some of the applications.

(a) Braking of turbine-generator sets. After the shutdown command is given, the brakes are not applied immediately. Brakes are applied when the speed have slowed down to a certain value so as to reduce wear and tear. This speed can be set in the program and brakes are applied only when the speed goes below the preset value.

(b) Switching on of excitation in synchronous generators. In many cases, the excitation of the generator is switched on only when the speed reaches 80% to 90% of the rated speed. This is because full voltage at low frequency is harmful to the generator. Automatic switching of the excitation can be achieved with this program by setting the desired speed.

(c) Over-speed protection. The program can be used to shutdown machines in case of over speed.

(d) Switching on of induction generator to grid. When induction generator is used in SHP, it is switched on to the grid when the speed of the machine reaches near the synchronous speed (normally +/- 10% within synchronous speed). The PLC program can be utilized for automatic connection of induction generator to grid.

(e) Speed governing. The measured speed when subtracted from reference gives the speed error, which can be used for speed governing of turbine.

# CONCLUSIONS AND RECOMMENDATIONS

## 7.1 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 were concluded from this present work

(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.

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

(c) 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.

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

(e) Redundancy of plant can be effectively improved with digital system like PLC

(f) The programmable logic controller is the best-suited device for integrated control and automation system in SHP and hence their use must be encouraged.

(g) By the experiment performed in the present work on the hydro-generator demonstration unit with KEYENCE KV-300 PLC following programs in KV Ladder builder software version 1.5 were developed

(i) Automatic starting sequence

(ii) Normal stopping/ shutdown

(iii) Fault and emergency shutdown

(iv) Load control in normal shutdown condition

(v) Load control in fault and emergency condition

(vi) Speed control

(h) Two integrated programs has been also developed by including all the above mentioned controls for the whole automation and control of SHP station with a single input command. One for automatic starting with speed control, load control along with normal shutdown and the other program for starting with speed control, load control along with fault or emergency shut down shutdown

(i) Speed control program can be easily accomplished by using ITVL instruction available in the software, but the accuracy is not high, as the unit of time measurement is large. Hence it may be used for lower frequency range of pulses where accuracy and fast response are not necessary.

(j) The speed control program using INT instruction gives a good accuracy of measurement; hence used for speed control in present work. The chattering of relays has been avoided by using wide range of speed. The speed measurement program can be applied to the following in SHP:

(i) Control of turbine-generator brakes to operate below specified speed.

(ii) Switching on of excitation above specified speed.

(iii) Over-speed protection of machine.

(iv) Switching on of induction generator to grid.

(v) To obtain the speed of machine in speed governing.

(k) It has been concluded from experimentation work that implementation of units start-stop scheme in PLC can be done by just writing the ladder diagram of the scheme into the PLC and giving input/output connections through solid state relays. This eliminates the tedious task of using large number of relays and their interconnections. Modifications can be easily made in the control scheme by making changes in the ladder diagram. This is very useful, as minor changes are usually required at site at the time of installation and commissioning.

## 7.2 RECOMMENDATIONS

The following points may be highlighted in connection with the present study:

(a) The Conventional methods for control in SHP are to be replaced by digital controls to make it cost effective.

(b) Programmable logic controller (PLC) based automation & control system is recommended for use in SHP station.

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

(d) For monitoring and data logging of a remotely operated plant, a personal computer should be interfaced with PLC.

(e) Proper care must be taken to ensure continuity of power supply to the PLC. Uninterruptible power supply (UPS) may be used to supply power to the PLC. Proper protection should also be made against surges that may damage the PLC.

## 7.3 SCOPE FOR FUTURE WORK

(a) Development of voltage regulation techniques.
(b) Implementation of excitation control.
(c) Provision for torque measurement.
(d) Development of PID control in closed loop system.
(e) Measurement of wicket gate or blade position.
(f) Turbine and generator high bearing temperature indication.

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1. Raju Gupta, S.N. Singh and S.K. Singal, "Automation of Small Hydropower Station" 'Hydro Sri Lanka' International Conference on small Hydropower' Kandy, Sri Lanka, abstract accepted, full paper submitted and conference will be held on 22 -24 October, 2007.

2. Raju Gupta, S.N. Singh and S.K. Singal, "PLC Based Monitoring and Automation of Small Hydro Power Station" 'Hydro Sri Lanka' International Conference on Advances on Energy Research (ICAER)' Indian Institute of Technology(IIT) Bombay, India, abstract accepted, full paper submitted and conference will be held on 12th to 14th December, 2007.

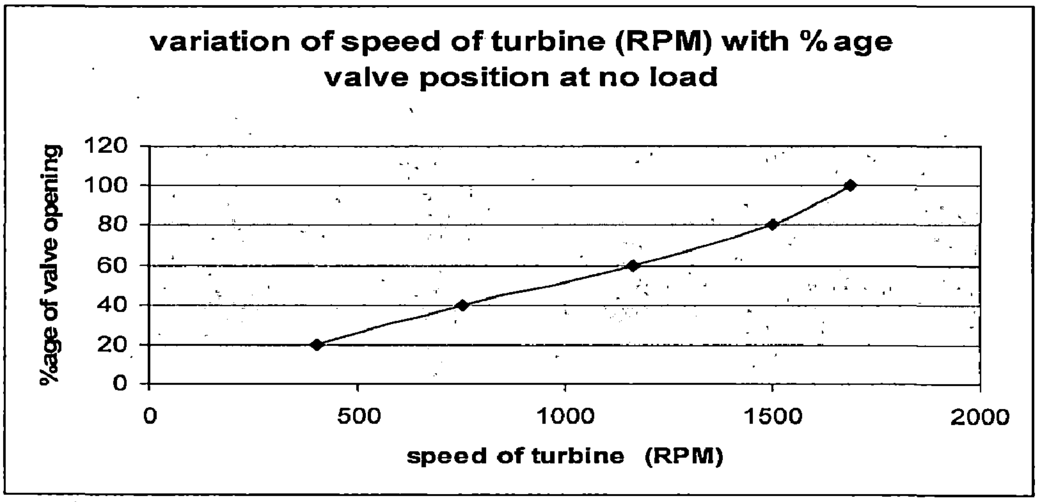
# APPENDIX 1

The main variable parameters which have been used in the present work are valve position indication from electrical actuator, speed of turbine from optoelectronic speed sensor (frequency) and value of load. These three variables are correlated to each other and will get affect by each other.

The table below indicates the variation of speed of turbine or frequency with %age of vale opening at no load condition.

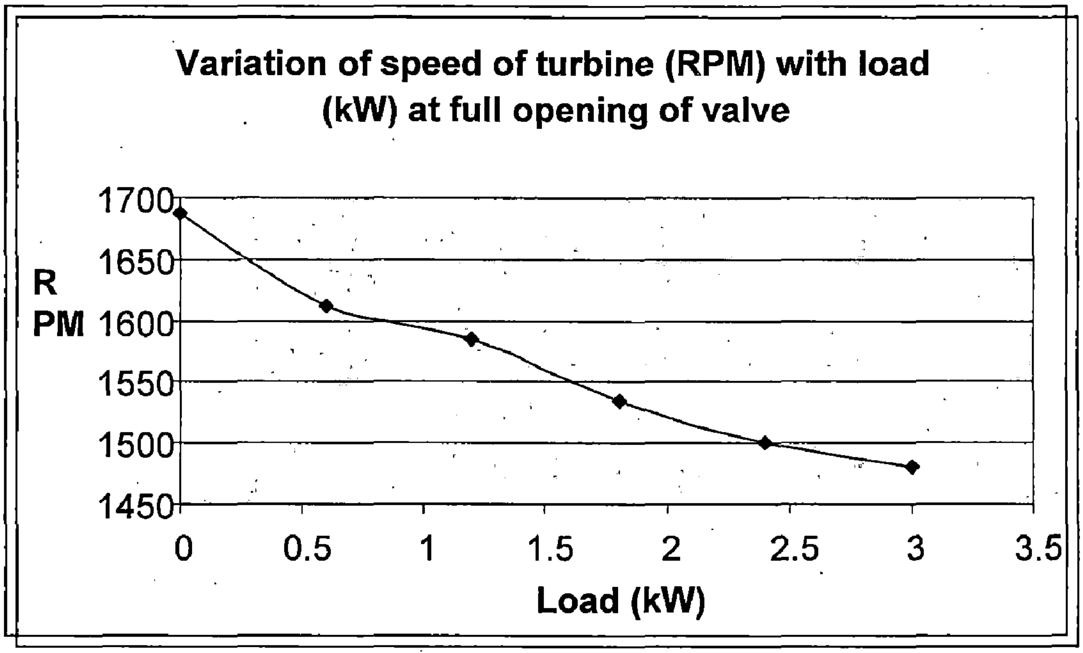
There can be two methods one is at constant inlet discharge speed will be controlled by adjusting load; in other case for a load control can be achieved by varying inlet discharge by electrical actuator valve.

| SL NO. | %age of valve (gate ) opening | Discharge(Q) $m^3$/sec | Speed of turbine (RPM) | Frequency (Hz) | Load (kW) |
|---|---|---|---|---|---|
| 1 | 20 | 0.00450 | 400 | 13.33 | 0.00 |
| 2 | 40 | 0.00930 | 750 | 24.42 | 0.00 |
| 3 | 60 | 0.0132 | 1167 | 38.42 | 0.00 |
| 4 | 80 | 0.0175 | 1501 | 49.98 | 0.00 |
| 5 | 100 | 0.0220 | 1687 | 56.1 | 0.00 |



The variation of speed of turbine or frequency with load at full discharge is shown in table below.

| SL NO. | %age of valve (gate ) opening | Discharge(Q) $m^3$/sec | Load (kW) | Speed of turbine (RPM) | Frequency (Hz) |
|---|---|---|---|---|---|
| 1 | 100 | 0.0220 | 0.00 | 1687 | 56.1 |
| 2 | 100 | 0.0220 | 0.60 | 1611 | 55.00 |
| 3 | 100 | 0.0220 | 1.20 | 1584 | 53.5 |
| 4 | 100 | 0.0220 | 1.80 | 1534 | 51.6 |
| 5 | 100 | 0.0220 | 2.40 | 1501 | 50.8 |
| 6 | 100 | 0.0220 | 3.00 | 1480 | 50.1 |




Thus the above figures and tables shows variation in parameters, which has been occurred during the implementation of control programs in experimental work.