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PROTECTION AND CONTROL OF STEAM TURBINE GENERATOR- USING PLC

Palash Kumar Bhowmik[1], **Mrinmoy Dey**[2]

[1]Dept. of Instrumentation, Eastern Refinery Limited, Chittagong-4000, Bangladesh
[2]Lecturer, Dept. of EEE, Chittagong University of Engineering and Technology, Chittagong-4349, Bangladesh

Email: pkbcuet@yahoo.com[1], mrinmoycuet@yahoo.com[2]

Abstract- *The protection and control system of boiler, turbine and generator which is a very sophisticated system involving modern technologies, is of utmost importance in any thermal power plants. In this paper the protection and control features of boiler, steam turbine and generator and discusses the main features of the system, structure and implementation for smooth automatic operation by using programmable logic controller (PLC) has been outlined. The demand of higher quality, greater efficiency and automated system has increased radically in the globalised world. To cope with this advancement this paper will be considered as an approach. In this study the protection and control features of a steam turbine is categorized in three phases: Boiler startup and fuel selection protection, Turbine self and mechanical protection and Generator protection. In the first phase, if all the protection features of boiler start up and fuel selection are silent condition and all the alarms are reset state only then the boiler will start up after completion of the furnace pre purging. Otherwise the master and other associated auxiliary fuel valves will be tripped. The second phase covers mainly all the mechanical protection of the steam turbine such as bearing failure, over speed, governor failure and also the generator circuit breaker open condition. If any protection feature initiates than turbine is tripped and close the trip and throttle (T&T) valve. In the third phase, the closing of the T&T valve or initiation of any generator protection features according to ANSI will disconnect the generator lockout relay to make the generator excitation off and disconnect the generator circuit breaker. Thus the entire cycle is carried out at various stages and each phase is detailed out in this study. This study proposes better flexibility in operation and control with low cost and less time for trouble shooting by PLC compared to the existing instrumentation system of 3MW STG unit of Ebara Power Engineering Company Ltd. in Eastern Refinery Ltd. It is anticipated that this paper will be very effective as the needs for automation is growing day by day.*

Keywords: PLC, Boiler and turbine protection and control, Sucosoft V5.02 Moeller PLC software

1. INTRODUCTION

Demand for high quality, greater efficiency and an automated machine has increased day by day in the industrial sector as well as power plants. Power plants require continuous monitoring and inspection at frequent intervals. There are possibilities of errors at measuring and various stages involved with human workers and also the lack of few features of microcontrollers. Thus this paper takes a sincere attempt to explain the advantages that will be obtained by implementing automation system. The boiler & turbine control which is the most important part of any power plant, and its automation is the precise effort of this paper. In order to automate a power plant and minimize human intervention, there is a need to develop PLC based system that monitors the plant and helps reduce the errors caused by humans [5]. The internal storage of instruction of PLC is used for implementing function to control various types of machines and processes through digital or analog input/ output modules. PLC systems are used to monitor and control a plant or equipment in industries such as power plants, energy, oil and gas refining and transportation [4-7].

2. PLC MODULE SET UP

A PLC is a 'digital operating system' designed specially for use in an industrial environment, which uses a programmable memory for its internal operation of user-orientated instructions and for implementing specific function such as logic, sequencing, timing, counting and arithmetic [2-6].

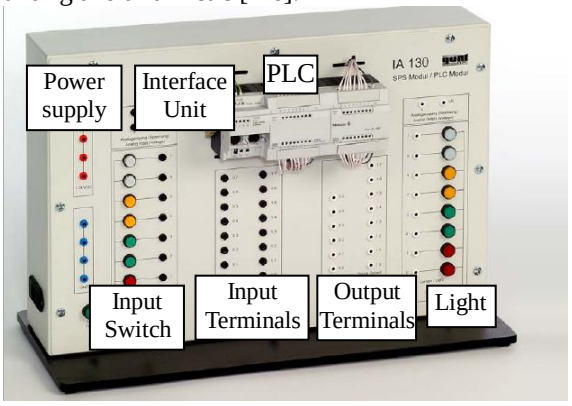


Fig.1: PLC Experimental Setup [2]

A PLC is essentially a computer adapted to the needs of industry. Its inputs and outputs are not designed for humans, but for use in the control of machines. Machine and operator interact solely by way of limit switches, contact switches, or photoelectric switches [2].

In order to write programs, PLC must be connected to a computer via an RS232 interface shown in Figure 1 [2]. Figure 2 shows the block diagram of the complete set up of the PLC. The sensor and load modules in the block diagram are marked as input and output modules respectively in the photograph. The complete set up has the following facilities [5-6].

(1) Programmable Logic Controller (PLC)
(2) Interface Unit
(3) Power supply for PLC input & output module
(4) Power supply for Lamps supply (24V DC)
(5) 24V DC Relay
(6) Two contact relay base
(7) Push button switch
(8) 24V DC Flashing lamps
(9) A Personal Computer (PC)
(10) Sucosoft V5.02 programming software.

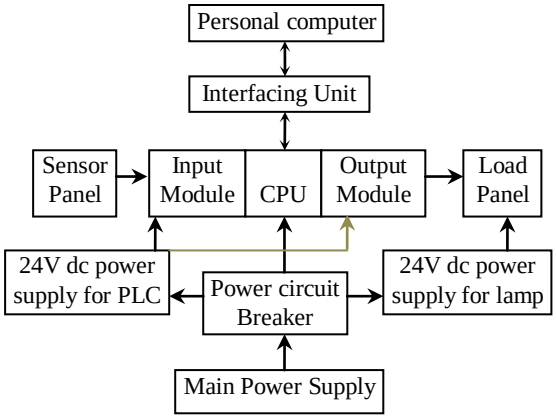


Fig.2: Block diagram of the PLC together with interfacing components

The Sucosoft V5.02 programming software that is used in this study conforms to the international standard IEC 61131-3, and permits programming in the following languages: Statement List (STL), Ladder Diagram (LD), Structured Text (ST) and Function Block Diagram (FBD). In this paper Ladder Diagrams are used that is based on graphical representations with contacts, coils and boxes, as per the circuit diagram [2].

3. PROCES MODEL DEVELOPMENT

The process model of boiler and steam turbine generator can be categorized in to the following basic types of process circuit and their components [1]:

(1) Fuel and Combustion Air Circuit:- It consist of Gas regulator, oil storage tank, fuel valve, force draft (FD) fan, air preheater and burner.

(2) Water Circuit: It consists of demineralized (demi) water storage tank, feed pump, dearator, economizer, condenser and boiler water drums.

(3) Steam Circuit: It consists of main steam line, auxiliary steam header, superheater, atomizing steam line and oil preheater line.

(4) Exhaust Gas Circuit: It consists of furnace, economizer, air preheater and chimney.

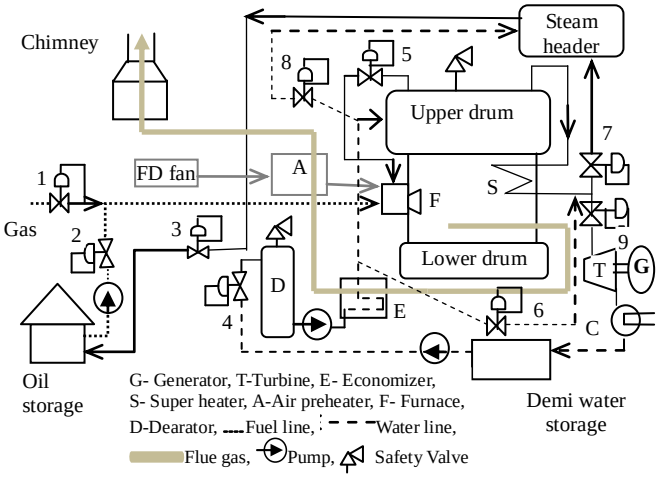


Fig.3: Simplified process schematic diagram [1]

For the control purpose there are few control valves that are numbered in the process schematic diagram. The purpose of the control valves are as follows:

(1) Gas regulator- Maintain the fuel gas pr. fixed.
(2) Oil pressure control- Maintain the oil pr. fixed.
(3) Oil temperature control
(4) Dearator level control
(5) Atomizing steam pressure control- Atomizing the fuel oil for proper combustion.
(6) Main steam line pressure and temperature control
(7) Auxiliary steam pressure control
(8) Auxiliary steam temperature control
(9) Trip and throttle (T&T) valve- control the steam flow to the turbine according to the turbine load demand.

To ensure the safety of the equipment and machinery from high pressure, safety relief valve are used. In the boiler and turbine system pressure relief safety valve are used at the highest pressure position like top of the upper drum and the dearator mentioned in the above schematic diagram in Figure 3. There are many gate valves are used to isolate or bypass a part of the circuit if required that are not shown in the schematic diagram for simplification.

4. PROCES OPERATION DESCRIPTION

Successful operation of a process system depends upon careful installation and initial start up. The safe operation and normal shutdown of a system should be done according to the design of that unit. Before start up there should be a thorough check of the system, like valves, control trip, safety device, and all the mechanical and electrical system that should be in good condition. The power generation from a steam turbine may require three stage of operation: boiler start up, turbine start up and generator synchronization.

4.1 Boiler Start up

In this study we consider D-type, natural circulation, water tube boiler consisting of two drums. The upper and lower drums are connected by convection tube block. The convection super heater is placed before the convection tube block.

For start up of a boiler the following steps have to follow [1]-
(a) Check the water level of upper drum and fuel supply selection position.
(b) Start FD fan and close the combustion chamber to pre purge the boiler. During pre purge the air damper position should keep open 100%.
(c) Ignition energizes and the flame on to energies the main burner and keep the air damper open 12-20%.
(d) Operators have to monitor carefully as the decrease of pressure increase the gas flow rate as well as temp and vice versa.

4.2 Turbine Start & Generator Synchronization

For start up of a steam turbine the following steps have to follow-
(a) Start and run the boiler in its safe operating condition.
(b) Maintain the steam header pressure.
(c) Create vacuum to the condenser to avoid steam back pressure and then steam inject to the turbine.
(d) T&T valve operates manually. The speed of governor increase gradually. A typical speed vs. time of turbine startup characteristics is shown in figure 4 [1].
(e) The critical speed range of the turbine should overcome according to the designer recommendation.
(f) After reach to the normal operating speed then synchronize the generator by connecting VCB.
(g) Give load gradually to the generator according to design specification and demand.

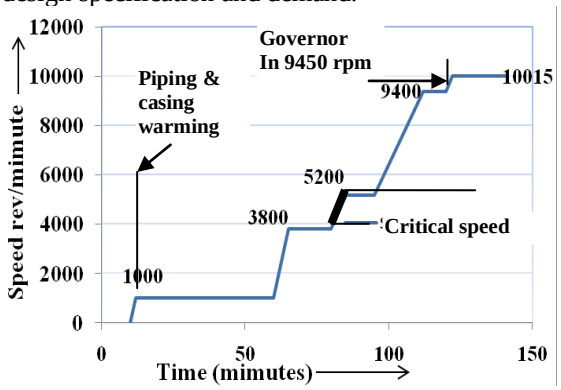


Fig.4: Turbine start up diagram [1]

4.3 Protection and Control Feature of Boiler and Steam Turbine

In this study the protection and control features of a steam turbine is categorized in three phases: Boiler startup and fuel selection protection, Turbine self and mechanical protection and Generator protection. The protection features of boiler start up and fuel selection are: loss of FD fan, loss of furnace oil (FO) pump, water level in the drum high or low, combustible air pressure high or low, fuel supply pressure or temp high or low compared to the operating range. In first phase, if all the protection features of boiler start up and fuel selection are silent condition only then the boiler will start up after all the alarm are reset condition and the furnace pre purge completed. Otherwise the master and other auxiliary fuel supply valves will be tripped. The second phase covers mainly all the mechanical protection of the steam turbine such as turbine master trip, bearing failure, over speed, governor failure and also the generator circuit breaker open condition. If any protection feature initiates then turbine is tripped and close the trip & throttle (T&T) valve. In the third phase, the closing condition of the T&T valve or any generator protection features according to ANSI will disconnect the generator lockout relay to make the generator excitation off and open the generator circuit breaker. The generator protection features according to the ANSI are: differential current (87G), over voltage (59G), under voltage (27G), over current (51G), ground current (51N), loss of excitation (40G), reverse power (67G) and winding temp high. Here manual operating features are: boiler emergency stop, boiler start switch, interlock reset, turbine trip master, turbine reset master, mechanical trip and mechanical trip reset. Thus the entire cycle is carried out at various phase and each stages is detailed out in the figure 5 [1].

4.4 Boiler and Turbine Protection and Control Logic Diagram

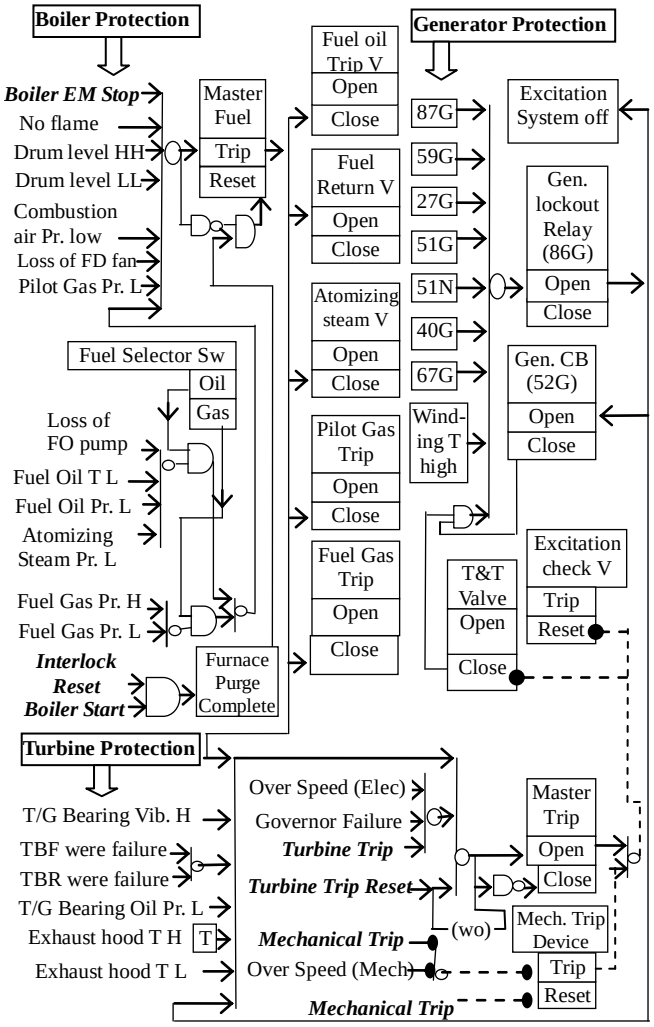


Fig.5: Protection and control logic diagram of Boiler, Steam Turbine and Generator

The no. of protection features in figure 5, are higher than the no of PLC input address that is used in this study. To avoid this problem by ensuring all the protection features a more simplified logic diagram is developed in figure 6.

Here the protection features that are in OR logic operations are represented as a single input.

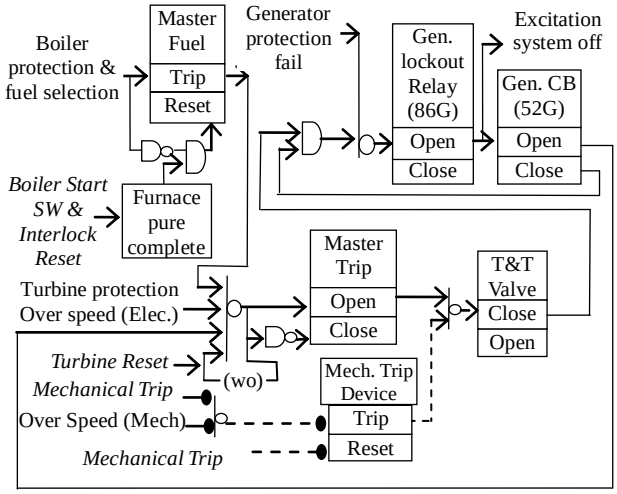


Fig.6: Simlified Protection and control logic diagram of Boiler and Steam Turbine

The typical generator protection diagram is shown in the figure 2. Here current transformer (CT) and potential transformer (PT) are used for metering and protection purpose. Any fault that creates abnormal current or voltage is detected by the specific protective relay from the measured value of CT and PT and give a control signal to the respective circuit breaker to trip.

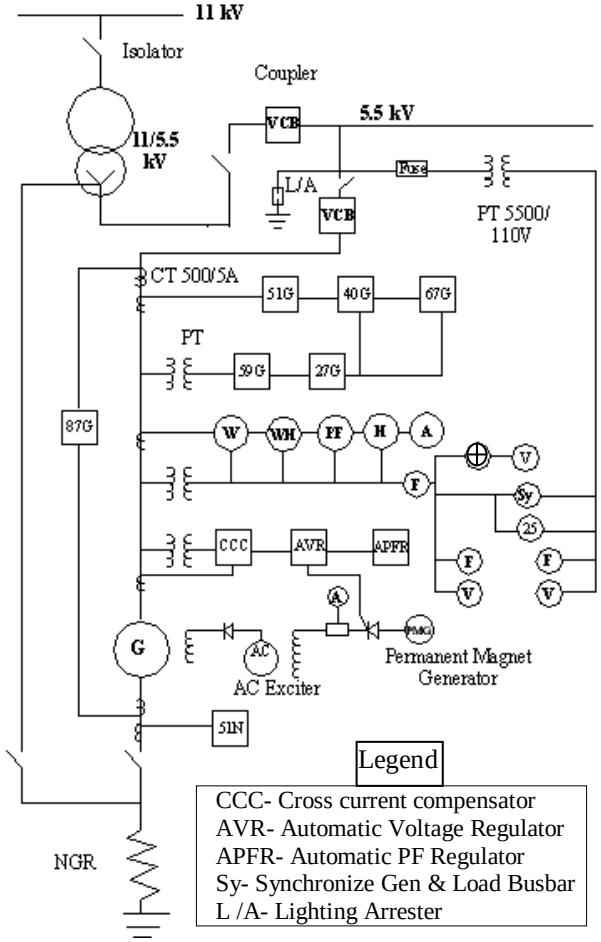


Fig.7: Typical Generator Protection diagram [1]

Lighting arrestors are used to protect the equipment from lighting. Isolator and disconnector are used to isolate a part of the circuit or network. Neutral grounding resistor (NGR) is used to compensate generator grounding current.

4.5 Process Flow Diagram

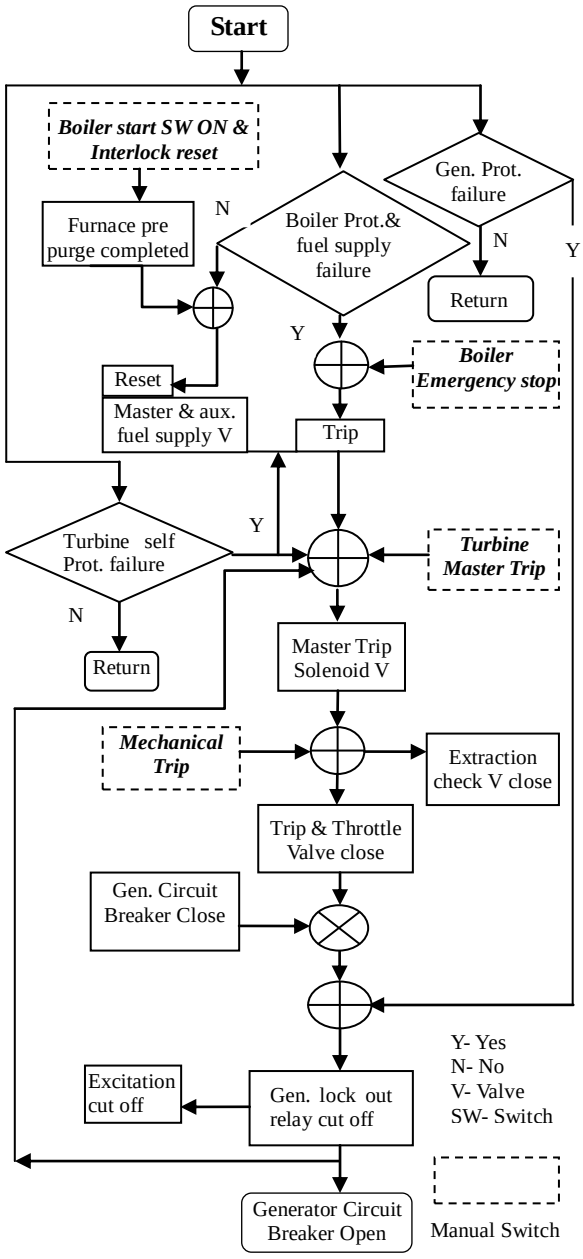


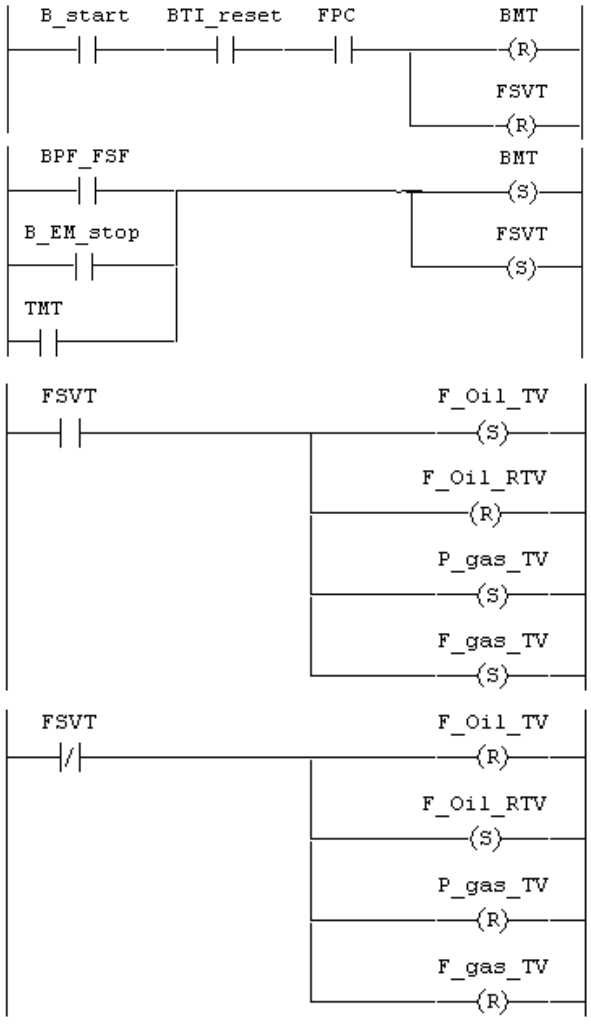
Fig.8: Flow chart of Protection and control of Boiler, Steam Turbine and Generator

4.6 Program Development

Automation software of PLC is programmed in **Sucosoft V5.02 programming software** and this software is the simulation software of the **Moeller** PLC. The Ladder Diagram (LD) PLC programming language used easy to understand. LD is based on graphical representations with contacts, coils and boxes, as per the circuit diagrams. Indicator lights are used as outputs where as push button switches are used as inputs [3].

Name	Typ	Ini	Address	
B_start	BOOL		%I0.0.0.0.0	Boiler start switch
BTI_reset	BOOL		%I0.0.0.0.1	B&T interlock reset
FPC	BOOL		%I0.0.0.0.2	Furnace purge complete
BPF_FSF	BOOL		%I0.0.0.0.3	Boiler prot.& fuel fail
B_EM_stop	BOOL		%I0.0.0.0.4	Boiler Emergency stop
TMT	BOOL		%I0.0.0.0.5	Turbine Master trip
TPF_GF	BOOL		%I0.0.0.0.6	Turbine prot.& Gov.fail
TMR	BOOL		%I0.0.0.0.7	Turbine Master reset
Mech_trip	BOOL		%I0.0.0.1.0	Mechanical trip
Mech_TR	BOOL		%I0.0.0.1.1	Mechanical trip reset
MPF	BOOL		%I0.0.0.1.2	Mechanical prot. fail
OS_Elec	BOOL		%I0.0.0.1.3	Over speed electrical
OS_mech	BOOL		%I0.0.0.1.4	Over speed mechanical
BMT	BOOL		%Q0.0.0.0.0	Boiler Master trip
FSVT	BOOL		%Q0.0.0.0.1	Fuel supply valve trip
MTSV	BOOL		%Q0.0.0.0.2	Master trip sol. valve
GLR_Open	BOOL		%Q0.0.0.0.3	Gen lockout relay open
TTV_close	BOOL		%Q0.0.0.0.4	T&T valve close
ECV_close	BOOL		%Q0.0.0.0.5	Extraction check valve
G_Ex_off	BOOL		%Q0.0.0.1.0	Gen. excitation off
G_CB_open	BOOL		%Q0.0.0.1.1	Gen. CB open
GPF	BOOL		%Q0.0.0.1.2	Gen. prot. fail
F_Oil_TV	BOOL	False		Fuel oil trip valve
F_Oil_RTV	BOOL	False		Fuel oil return trip v
P_gas_TV	BOOL	False		Pilot gas trip valve
F_gas_TV	BOOL	False		Fuel gas trip valve

Fig.9: The Process Variable Declaration for PLC System.



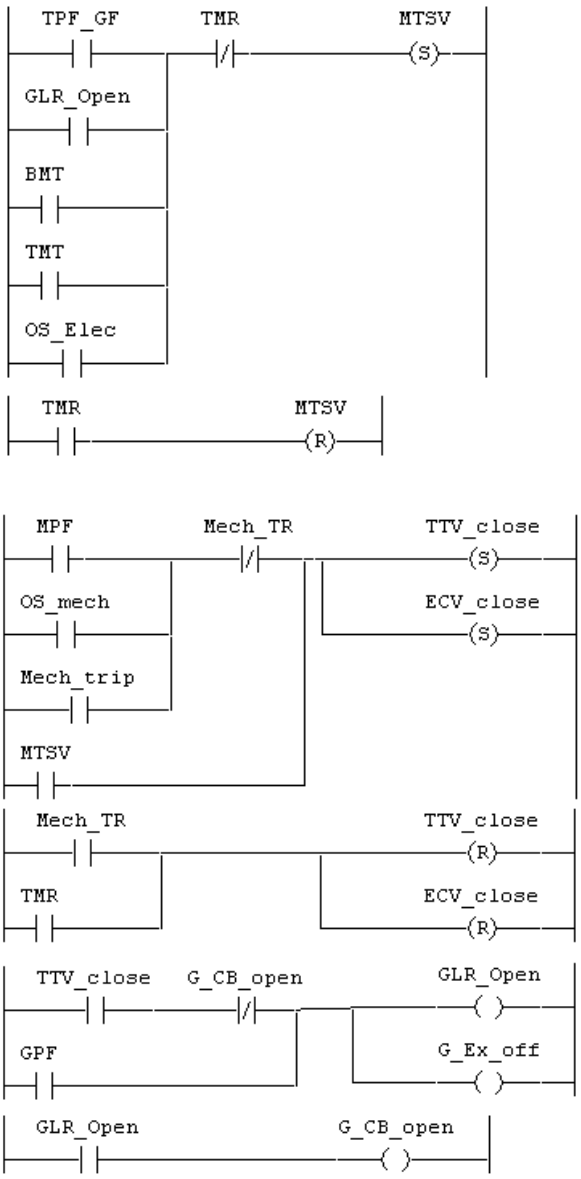


Fig.10: Ladder Logic Program of Boiler, Turbine and Generator Protection and Control System

4.6 Program Execution

The ladder logic program execution by Sucosoft V5.02, Moeller PLC software requires the following steps [3]-

(a) Program development in pou editor
(b) Topology configaration.
(c) Program code generation.
(d) Program transfer from computer to PLC
(e) Test and commissioning
(f) Program run

After following the above mentioned steps then the PLC become ready to run the program. PLC executes the program successfully after pressing the start switch. PLC always scan its input address and give an output signal according the instruction of the program. If the process sequences may need changed or modification only change in the program will sufficient for successful program execution.

5. COPERISON WITH THE EXISTING INSTRUMENTATION SYSTEM

The present instrumentation system of Steam Turbine Generator (unit-1) of Eastern Refinery Ltd., Chittagong consists of three major subsystems- the burner management system, governor system and generator protection system. The proposed control system will be better with following aspects compared to the present control system by Ebara Power Engineering Company Ltd. (EPECL), Japan.

(1) Low Cost: One single programmable logic controller is enough for control and operation.

(2) Correcting Errors: With PLC control, any change in operation or sequence is as simple as retyping the logic. Correcting errors in PLC is extremely short and cost effective that is not possible with existing control system by EPECL for the end user.

(3) Testing: A Programmable Logic Control program can be tested and evaluated in a lab before its real time of operation. The program can be tested, validated and corrected which saving very valuable time

6. CONCLUSION

The most important aspect of any power plant is the boiler and turbine protection and control. Several techniques can be implemented to control the boiler and turbine in power plant. The method that has to be used relies on various objectives like superior quality, increased efficiency, high profit and other such points depending upon the purpose. With the prime objective of catering to these necessities and the needs of the industrial sector, significance has been given here to automation. The proposed operation and control feature will provide better flexibility in customization of operation and control with minimum effort. When running a PLC program, a visual observation on the screen of each operation at every point is also possible which will make troubleshooting and decision making really quick, easy and simple. The Paper has furnished itself to study the integral parts of the entire process involved, their implementation and the problems that may show up have also been given their due importance.

7. ACKOWLEDGEMENT

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8. REFERENCES

[1] EBARA POWER ENGINEERING COMPANY LTD., 3MW STG Operation Manual, Eastern Refinery Ltd., Chittagong.

[2] GUNTE, Equipment for Engineering Education, http://www.usdidactic.com/html/p3562.htm (04/06/2011)

[3] Sucosoft S40 V5.02, Moeller PLC Software.

[4] K. Gowri Shankar "Control of Boiler Operation Using PLC- SCADA", *International Multi Conference of Engineers and Computer Scientists 2008 Vol II, IMECS 2008,* Hong Kong , March 19-21, 2008.

[5] P.K. Shadhu Khan, Abdullah-Al-Noman and Rajib Kumar Dey, "PLC Based Operation of Three Natural Gas Generator Models- A Learing Aid for Undergraduate Students" *Third International Conference on Power Systems,* Kharagpur, INDIA December 27-29, 2009.

[6] Erickson, K.T., "Programmable logic controllers" Potentials, IEEE, vol. 15, p. 14, March 1996.

[7] Gulpanich, S. Tipsuwanporn, V. Suesut, T. Tirasesth, K., "Implementation programmable logic controller for Thailand Industries," Computational Intelligence for Modeling, Control and Automation, 2005 and International Conference on Intelligent Agents, vol. 2, p. 234, November 2005.

[8] Wen Tan, Horacio J. Marquez, and Tongwen Chen, "Multivariable Robust Controller Design for a Boiler System" *IEEE Transactions on Control System Technology, VOL. 10, NO. 5,* September, 2002.