جامعة القاهرة كلية الهندسة
قسم هندسة القوى الميكانيكية
معمل التحكم الأوتوماتيكى

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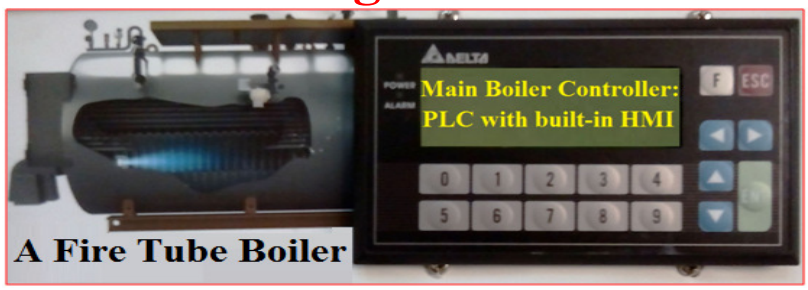
Cataloge for the Training Kit of

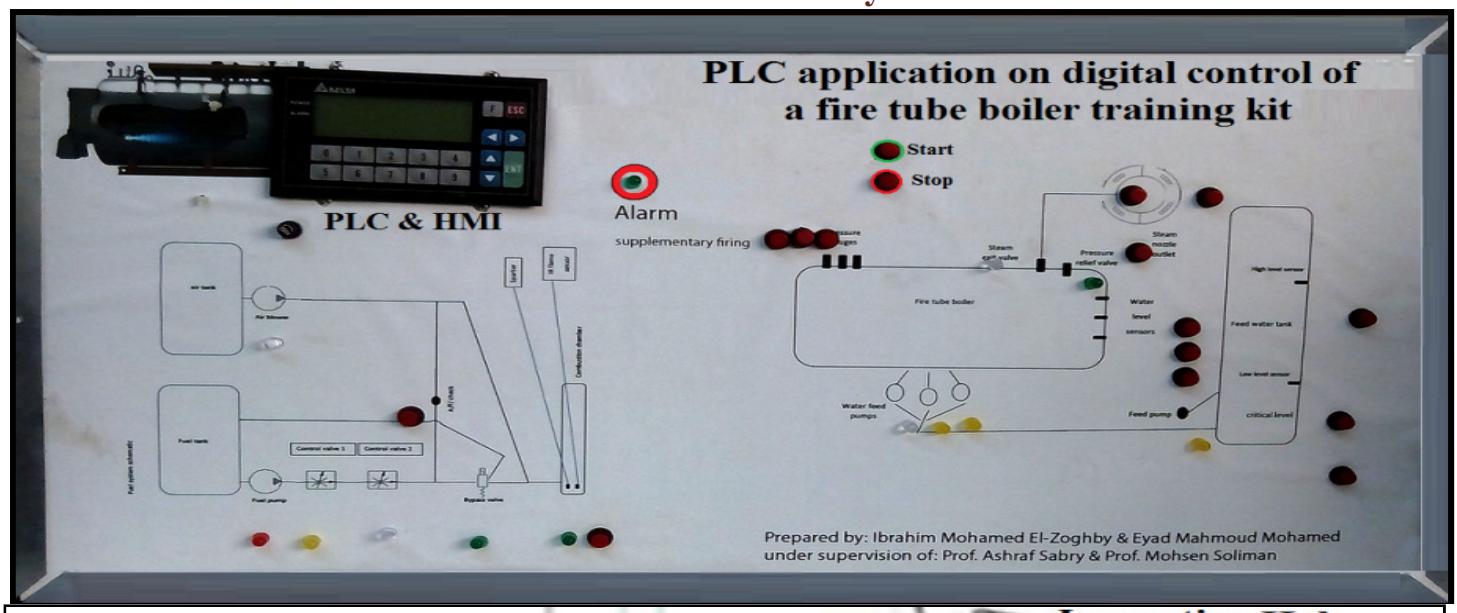
A Fire Tube Boiler with a digital PLC&HMI Control System

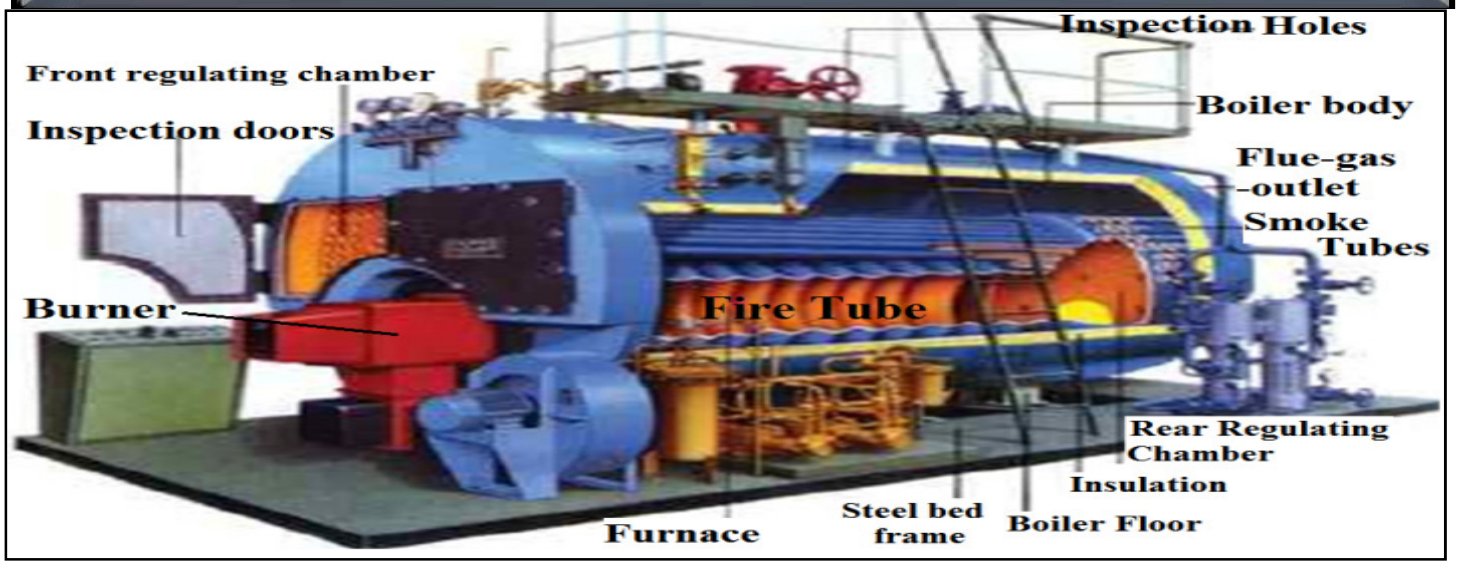


The Training Kit was made by Engs. Ibrahim Mohamed Elzogaby&Eyad Mahmoud Mohamed

Under Supervision of Associate Prof. Mohsen Sayed Soliman, ACC Manager

& Prof. Ashraf SaadEldeen Sabry X-MEP Head

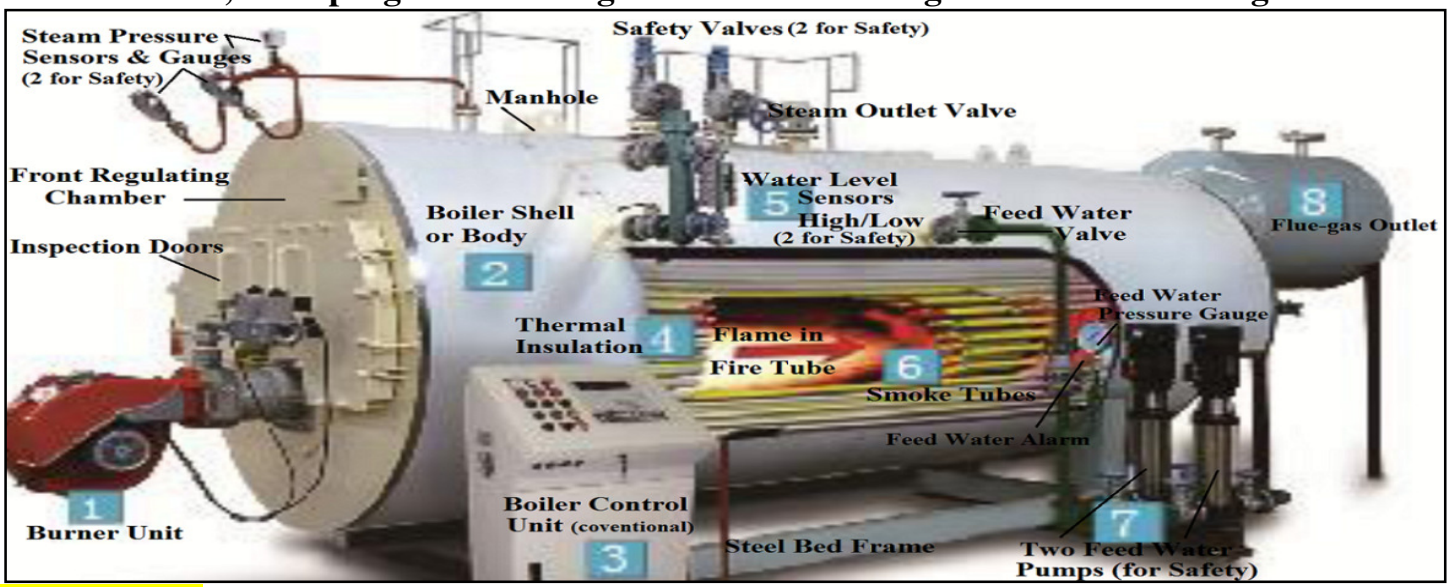




This Catalog was Written & Prepared by

Associate Prof. Mohsen Sayed Soliman, ACC Manager, August 2017

Overview: **This Training Kit is an example for practical application of PLC and HMI (Programmable Logic Controller&Human Machine Interface) Systems in Mech. Power Engg. The Kit represents an introduction for investigation of various types of real control systems which are used in operation processes of a Fire-Tube Boiler System. The real system can include micro-controller or conventional electro-mechanical or Relay type control circuits. The Kit is an effort to design & execute a simplified practical training model which uses both PLC & HMI techniques in order to simulate a real Fire-Tube digital control system. In addition to the task of selecting a specific type of PLC & HMI which are proper for producing this model, another required task was to select & use several types of electric digital switches, Relays, LEDs & input/output I/O devices. Furthermore, in order to practice different aspects of using PLC, the training includes also running and testing practical and real PLC-Simulation software to diagnose possible errors & trouble-shooting of automatic control PLC& HMI systems of sequential programming procedure. Finally the training task includes detailed and carefully prepared documentation procedure report for the SFC, Sequential Function chart, LAD program & wiring of the Fire-Tube Digital Control Training Kit.**



Introduction:

As seen on above fig., a Fire Tube Boiler has many interacting parts. The boiler master control system has many sub-control systems which must work all simultaneously to ensure an accurate, safe, stable & efficient time-variant operation of boiler. They are combustion control appliances, Feed-water& water level control, steam flow & pressure control & blow down control. The boiler operation sequence requirements are permanent& regular adjustments, Automatic sequence & System Interruptions. Modern boiler control is complex & not an ON/OFF system. Recent analogue conventional control systems use micro-processors to perform modulating, multi-points & cross-reference control. This Training Kit is an educational trial multi-steps digital control by PLC& HMI system which uses many parallel &selective branching to do a modified multi-steps sequential boiler operation control levels as shown later.

ILO's of Training Kit المخرجات التعليمية المستهدفة من وحدة التدريب:

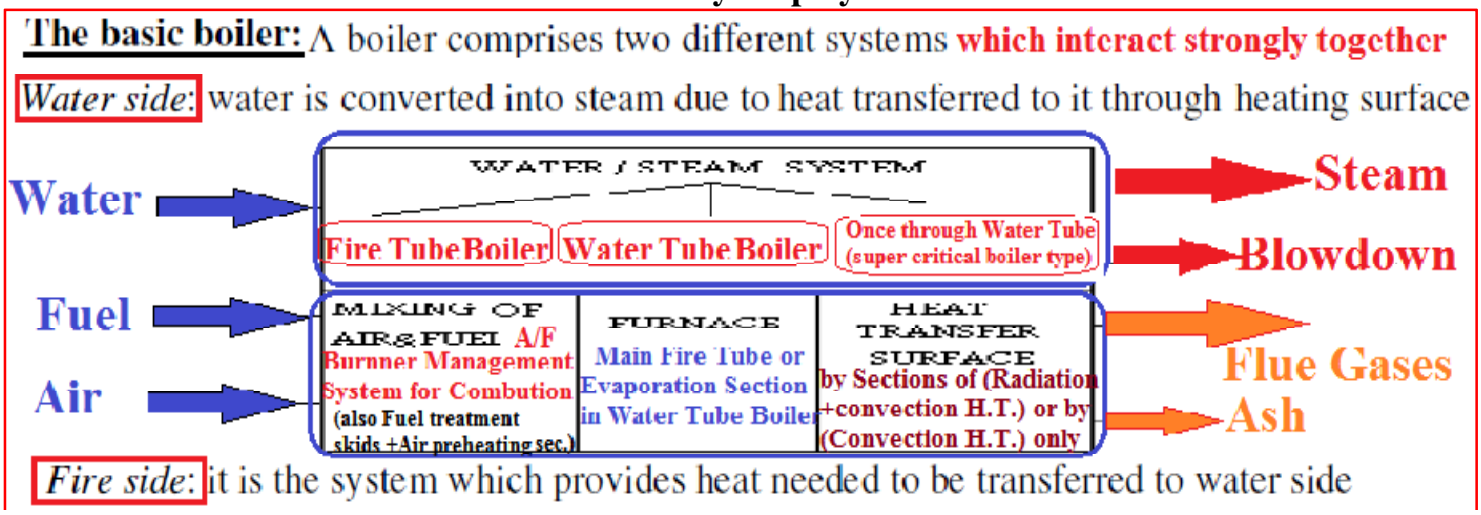
- **دراسة أساسيات ومكوناتPLC والتعرف على إمكانياته وخصائصه التقنية فى عمليات التحكم الإوتوماتيكى ثم تحديد التفاصيل الفنية وعناصرالنوع المناسب لكل منظومة تحكم محددة.**
- **دراسة بعض عناصرالميكاترونيكس الرقمية والتناظرية Input & Output devices for PLC (مثل أجهزة القياس والحساسات والمفاتيح وبعض أنواع أجهزة الخرج Output actuators).**

- تعلم تقنيات وخطوات تصميم برنامج للتحكم المنطقى المتعاقب وممارسة وتنفيذ مخطط لوظائف التشغيل المتعاقب SFC: Sequential Flow Chart
- تنفيذتقنيات البرمجة المتعاقبة Sequential Programming وما تتضمنه من ضرورة وجود برمجة متوازية أوإختيارية Parallel or Selective Branchingحسب متطلبات عملية التحكم.
- تعلم عناصرلغة برمجة أجهزةPLC الخاصة بالمشروع وتعلم برامج ومهارات الكتابة والتوثيق للبرنامج PLC Ladder diagram
- تعلم تقنيات برامج المحاكاة PLC Simulation software لتنفيذ برنامج التحكم بالحاسب الآلى PC لتشخيص أخطاء البرمجة قبل التنفيذ العملى.
- تحديد كافة الحساسات والاجهزة المصاحبة المختلفة لكل من Input and Output devicesالتى يجب توافرها وتعلم كيفية توصيلها بأجهزة PLCلإستكمال منظومة التحكم عند تشغيل PLC.
- تصميم وإنشاء وتنفيذ وتوثيق جهاز تجربة معملية جديدة ووحدة تدريب دائمة بإستخدام جهاز الحاكم المنطقى المبرمج PLCمع كافة المكونات الكهربية والإلكترونية المطلوبة.
- إكتساب Soft skills وخبرة لعمل تقريرهندسى متكامل Technical Engineering Report وتقديم عرض presentation للجهاز ولنتائج المشروع بوسائل عرض سمعية وبصرية حديثة.

Modeling of a real Fire-Tube Control System into a PLC Training Kit:

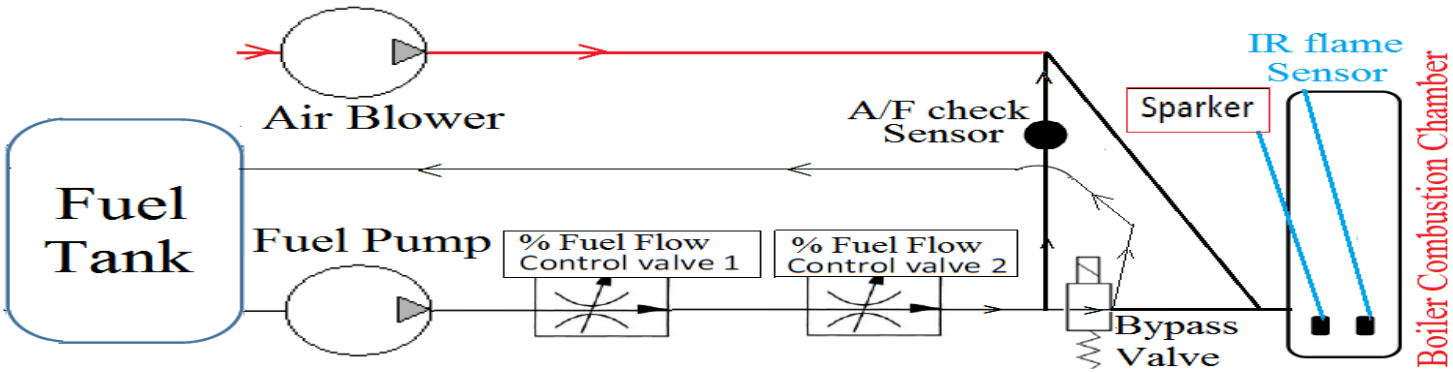
The approach of this Training Kit is to simulate & simplify the boiler real control system. The real system could be an analoge-moulating and multi-point control system which include micro-controller or conventional electro-mechanical or Relay type control circuits. The input components of the control system of a real Fire-Tube Boiler include: IR Photo-cell or Flame-detection Sensor, Liquid Level sensors, ON/OFF Push Buttons, Temperature and Pressure sensors, …etc. The output components for the real control system include: Solenoid Flow Control Valves, Pumps, Motors, Relays, Display LEDs and HMI,….etc.

In order to have a simplified PLC & HMI control system in the Training Kit, we have to assume changing some boiler components or selecting suitable ON/OFF ones to match the digital requirements in the PLC sequential control. All the real input signals are simulated by ON/OFF Push Buttons to get all the PLC-inputs. All real controller outputs to the field devices & actuators are simulated in the Kit by Display LEDs.



Sequence of Operation and the System SFC for the control process

To understand logic behind Inputs & Output of Sequence of operation we remind that the control system we are using is digital control, so a lot of amendments were made on the normal fire tube boiler system components, examples are fuel flow rate control, inlet water flow rate, steam valve opening control and the water level determination which will be all described in details.



Operation of Combustion Fuel Feeding System

The fuel pump is a constant speed fuel pump feeding combustion chamber with fuel from the tank, on the fuel line we can find two control valves, a bypass valve, an A/F ratio checking device a sparker and an IR flame sensor.

To understand how the loop works we need to define and identify the function of each of the pre-mentioned parts in the loop, we will start by the function of the two control valves, the flow of fuel has three levels which are 30%, 60% and 100%.

If the two valves are in off position the flow is 30%, if the first valve is on and the second is off the flow is 60%, if the two valves are switched to ON position the flow rate will be 100%.

The bypass valve has two positions, one sends the fuel back to the tank which is the normal position and the other one occurs when the solenoid is activated which shifts the valve in the position to allow the fuel to mix with air and through to the combustion chamber.

The A/F check device/valve measures the fuel flow rate and adjusts the air flow rate accordingly to get the suitable A/F in the system for complete efficient combustion process and sustainable flame.

IR flame sensor is set in flame zone to sense existence of flame and communicate it to the PLC to stop the sparker from working as soon as the flame is initiated.

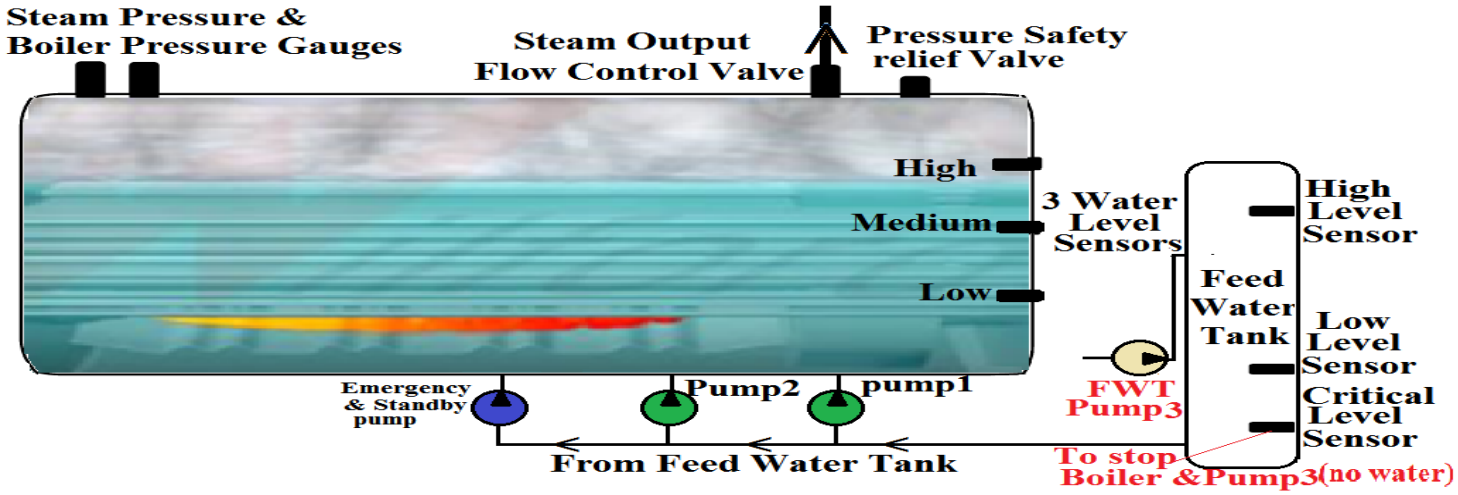
The sparker works as soon as the bypass valve is activated to ignite the fuel air mixture generating the required heat energy for the boiler.

Note: the fuel flow rate percentage is determined according to the steam extracting percentage which will be introduced in the next part.

Boiler Water Level recognition and Boiler Water Level Control System

The system has 3 reference points to determine the water level accordingly, the first one is the Low water level reference point at which the burner cycle bypass valve is activated or deactivated to avoid the burnout of the hot gases tubes.

The 2nd reference point is the medium water level sensor which whenever water is lower that level the feed pump/pumps keep working feeding the system with water, but her comes the important question, when does the pump stop working?! To answer this question the 3rd reference point was introduced which is the high level water reference, whenever the water level reaches the high reference point the pump stops working until the water level reaches the medium level, when the water reaches the medium reference the pump starts working again, and so the loops keep going mainly to always have water level between medium & high levels.



Steam Output Flow Control System

This system has 2 main subsystems,

-Pressure/Temperature determination system.

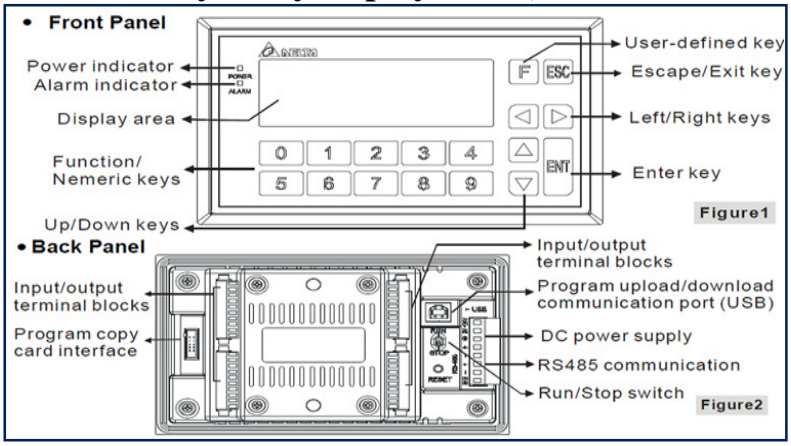
- This system consists of 3 reference point exactly as the previous water level recognition system, the medium and high levels in the water system are replaced by low and high set pressure reference points in which the steam exit valve stays open as long as the pressure value is in between them, the 3rd sensor here is for when the system reaches a set unsafe pressure value in which case the system stops and a relief valve is activated to release the extra pressure keeping the system within safe limits.

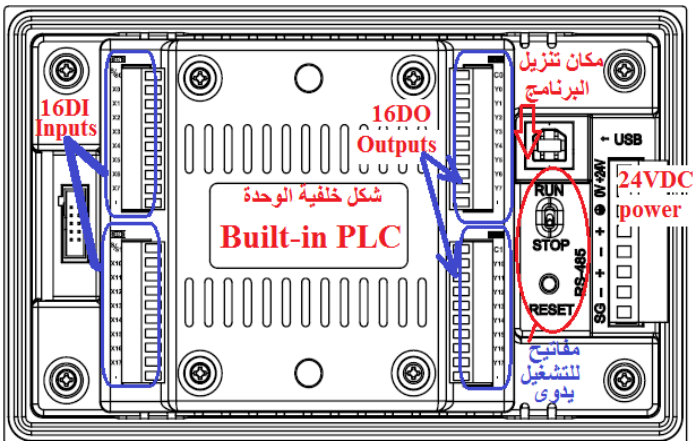
- Steam flow rate control system.

- In this system we use the nozzle governing control system with 3 levels of steam capacity flow rates at 30, 60 and 100%.
- According to the steam exit flow rate the fuel flowa rate and feed water flow rates are adjusted automatically to 30,60 or 100% of their capacity to cope with the steam exit flow rate.
- The mass flow rates of fuel and water shall be calculated through applying an energy balance equation between the energy input from the fuel and inlet water stored energy and the exit steam energy adding to it the energy of the exhaust gases.

Technical data &wiring Diag. of Delta-PLC with built-in HMI(TP04P-32TP1R)used in the Kit:

The Kit uses a 24VDC Delta-PLC with built-in HMI. The PLC has 16 digital inputs&16 digital outputs. All real input IR Photo-cell Sensors, Liquid Level sensors, Limit Switches are modeled in the Kit by15 Push-buttons. A real Temperature sensor (Thermistor) is also used as one input. All real output control signals to Relays, hydraulic or any electric-mechanical actuators are modeled by many display LEDs, 3-DC motors and an alarm Buzzer (all 16 outputs are used).

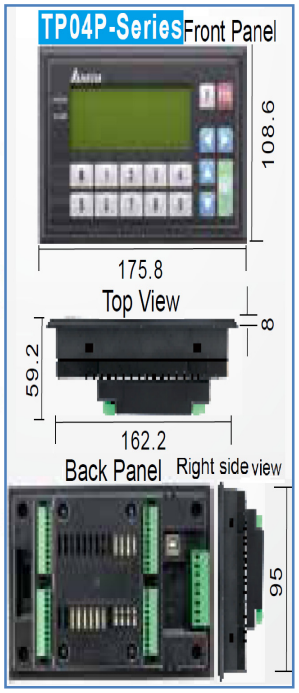




What is TP04P-32TP1R Delta TP series products. TP04P is composed of a text panel and a PLC. It supports abundant instructions. The capacity of the program memory it supports is 8K steps. TP04P features the same program download port shared by both PLC and TP editing software: WPLSoft/ISPSoft and TPEditor. It also offers various graphical objects for developing the program. The user can also obtain higher efficiency by purchasing additional extension cards, which increase the program portability and save the program download time. Please ensure to use TP series with Delta power supply module, DVPPS01, DVPPS02 or DVPPS05.

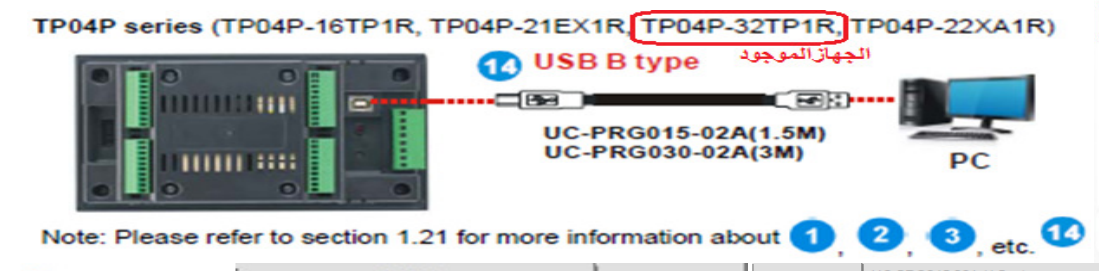
EN ✓ TP04P is an OPEN-TYPE device. It should be installed in a control cabinet free of airborne dust, humidity, electric shock and vibration. To prevent non-maintenance staff from operating TP04P, or to prevent an accident from damaging TP04P, the control cabinet in which TP04P is installed should be equipped with a safeguard. For example, the control cabinet in which TP04P is installed can be unlocked with a special tool or key.

EN ✓ DO NOT connect AC power to any of I/O terminals, otherwise serious damage may occur. Please check all wiring again before TP04P is powered up. After TP04P is disconnected, Do NOT touch any terminals in a minute. Make sure that the ground terminal ⏚ on TP04P is correctly grounded in order to prevent electromagnetic interference.



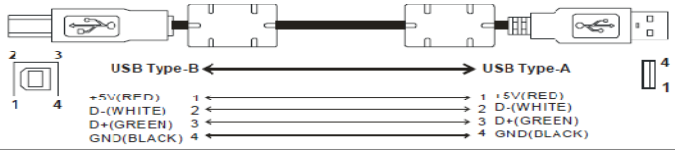
Delta PLC/HMI Cable Selection Guide

Cables for PLC Programming & Serial Communication

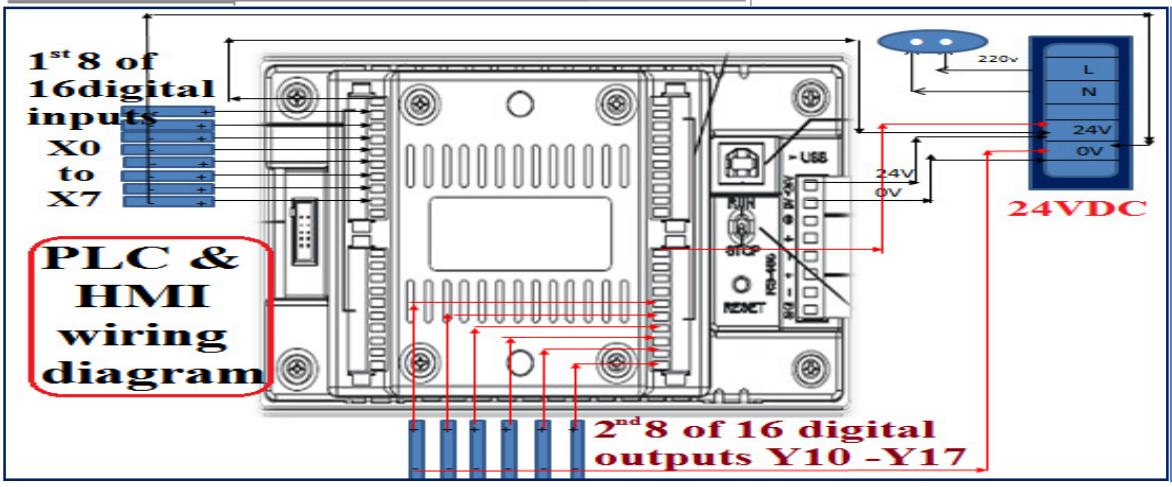


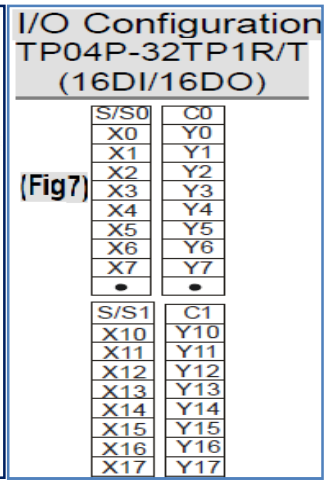
14 USB Type-B	Cable	Machine
CPU	USB Type-B ↔ USB Type-A	connected
TP	UC-PRG015-02A (1.5 m) (Figure 19)	PC
	UC-PRG030-02A (3 m) (Figure 19)	
Adapter	Module/Interface card	

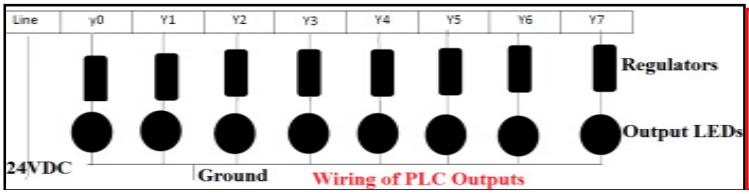
Figure 19	UC-PRG015-02A (1.5 m) UC-PRG030-02A (3 m) UC-PRG050-02A (5M) (only for DOP)	USB Type-B ↔ USB Type-A

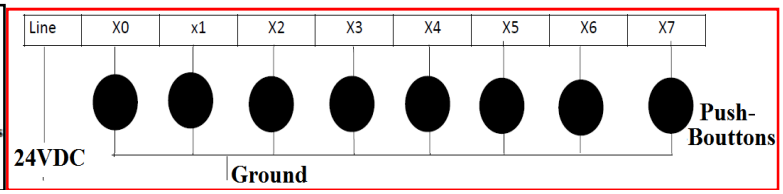


◆ Note: UC-PRG050-02A is used for transferring input signals between the interface panel and the controller. The cable is used exclusively for all-electric injection molding machines.









DC-power Supply

Signal Conditioning

The output of the sensors cannot be given directly to the PLC as the input voltage to the PLC should be 24V. Hence they are given through signal conditioning circuits which condition the input signals and in turn give it as an input to the PLC . For safety purposes the input are given directly to the PLC .They are given through relay circuits . The relay consists of 3 terminals-common. NO and NC . the 24V which is to be inputted into the PLC will be available in the common terminal .

▪ Function Specifications

Model / Spec.	TP04P series
PLC program capacity	8k steps
Screen type/Display color	STN-LCD/Monochromatic
Driver	Delta automation products
Function/Numeric keys	0~9, ESC, F, Enter and Up/Down/Left/Right keys
Alarm LED indicator (Red)	Power indication (Blinking for three times)/Communication error alarm/User program indication
Backlight	Automatically turning off the backlight: 1~99 minutes (0: The backlight is not turned off.) (The life span of the backlight is about 50,000 hours at a temperature of 25°C)
Contrast adjustment	Set by software, 10 levels of adjustment
Language/Font	ASCII: (Code page 850) Alphanumeric code (including European characters) Taiwan: Traditional Chinese fonts China: Simplified Chinese fonts
Resolution	192 × 64 dots
Display range	101.8 mm (W) × 35.24 mm (H); 4.1" (diagonal)
Font size	ASCII. 5 × 8, 8 × 8, 8 × 12, 8 × 16
Display text	5×8 dots: 38 characters × 8 rows | 8×12 dots: 24 characters × 5 rows 8×8 dots: 24 characters × 8 rows | 8×16 dots: 24 characters × 4 rows
Program upload/download communication port USB (COM1)	Transmission method: Virtual communication port Data length: 7 or 8 bits, Stop bits: 1 or 2 bits, Parity: None/Odd/Even Baud rate: 9,600 bps~115,200 bps USB: USB (Type B) terminal
Extension communication port RS485 (COM2) RS485 (COM3)	Asynchronous transmission method: RS-485 Data length: 7 or 8 bits, Stop bits: 1 or 2 bits, Parity: None/Odd/Even Baud rate: 9,600 bps~115,200 bps RS-485: 8 PIN-removable terminal block
Download & Monitoring method	Download program to TP through virtual COM port

Model / Spec.	TP04P series
Extension interface	Slot for a program copy card
Panel components	**Description**
Alarm LED indicator (Red)	Status 1: when turning on the power, this LED will start blinking slowly and when the power is ON, this LED will be off. Status 2: when the user-defined conditions are met, LED will blink every 1 second along with an alarm sound.
Power LED indicator (Green)	When the power is ON, this LED will be ON.
Display area	LCD module; it is used to display current program status.
Numeric keys	Keys 0~9 can be used for inputting constants. Users can also define the keys by themselves.
Function keys	Users can define the keys.
Enter key (ENT)	If the input value is correct, press the key to confirm the setting. Users can define the key in the user page.
Arrow keys	Up: for increasing the setting value or go to the previous page Down: for decreasing the setting value or go the next page Left/Right: for selecting the position of the setting value Users can redefine functions of the arrow keys in the user page.

Training kit

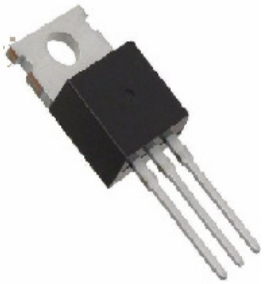
- The kit consists of metal black painted casing with dimensions of 1*0.5*0.2 meters.
- The kit has 0.5*0.3 opening at the back with a door supplied by two hinges for connections adjustments in the future.
- The front face of the kit is transparent polycarbonate with dimensions of 1*0.5 meters on which all will be mounted.
- The board has the system components on it which are (PLC – power supply – switches – LEDs – fuses)

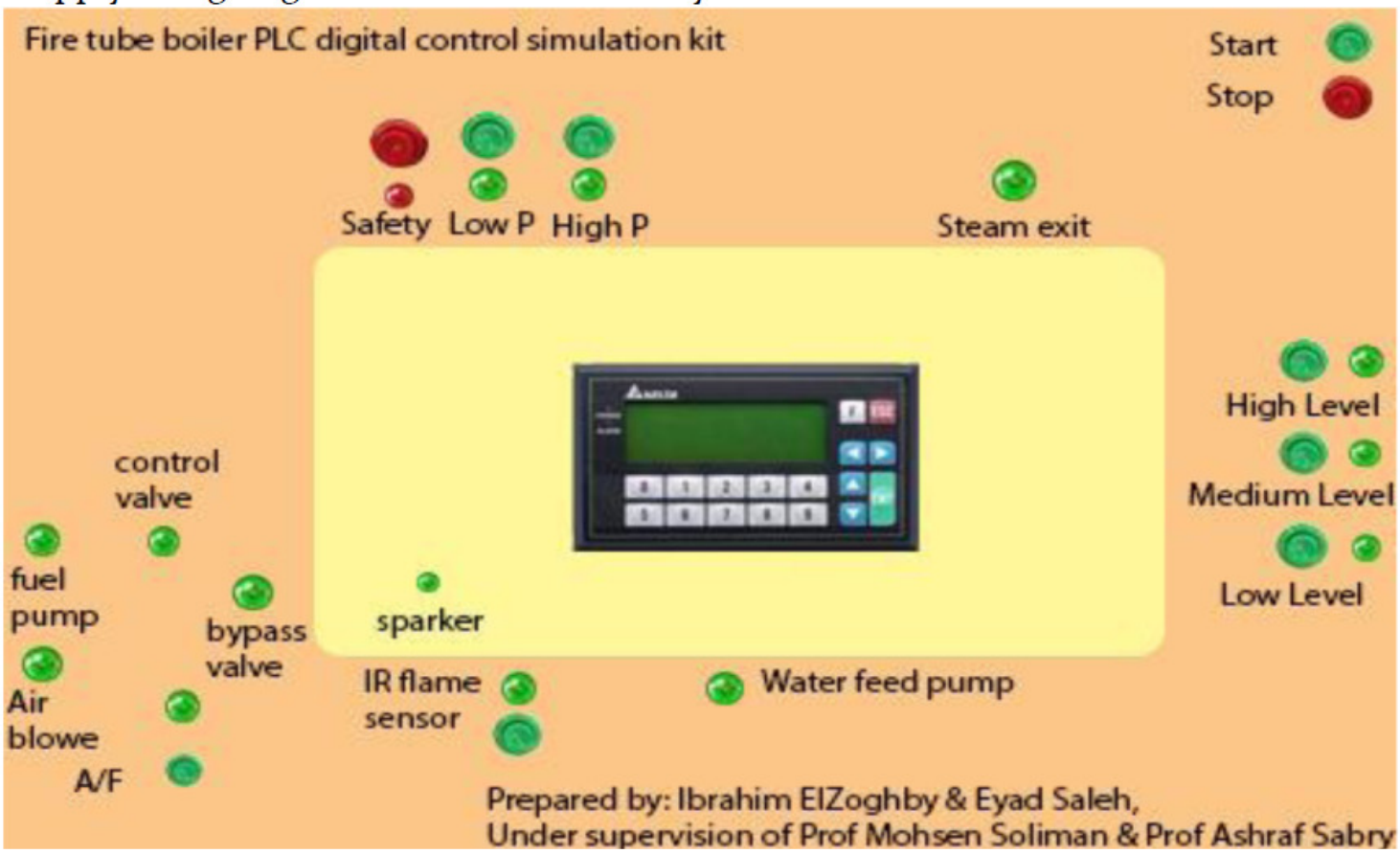
a) Buttons (Switches)
The (on/off) push button switches continuous signal type running on 24 volts DC, simulating the existence of sensors and acting as inputs in the system.

b) Fuse 1 A fuse used before the PLC as a safety circuit for the system to avoid any burn components.

c) LEDs
They are 5 V LEDs used to simulate the existence of outputs in the system, and connected to the PLC output terminals.

d) Regulators
Used to reduce the voltage coming from the power supply and going to the LEDs so that they don't burn out.





Ladder Diagram " ISPsoft " In This project we used ISPsoft to be the ladder diagram program used .

ISPSoft V2.0 Highly Accessible Programming Software

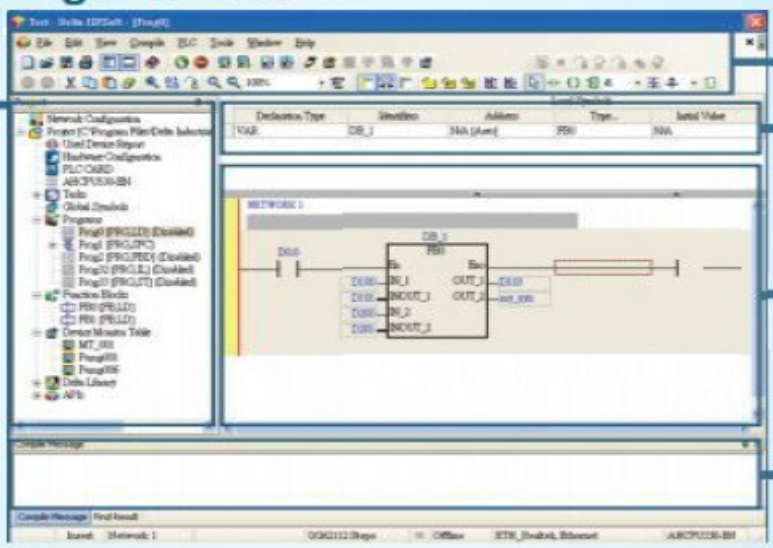
Fully Integrated Interface

Advanced Programming Interface + Visualized Hardware Configuration + Simplified Network Configuration

Advanced Programming Interface

Project Management Window

- **New functions:** Network configuration, hardware configuration and PLC card
- Supports 5 programming languages (LD/FBD/SFC/IL/ST)
- **Function Blocks:** Symbols can be introduced in call-by-value or call-by-reference types. Function blocks can be called in function block for up to 32 levels
- **Monitor Table:** It can be stored and managed separately. Multiple monitor tables can be stored in a single project
- **User Library:** Users can design frequently used instructions for specific applications in different industries
- **Task:** Supports cyclic, I/O interrupt, timer interrupt, external interrupt, etc. Software will provide the usable tasks for different CPU



يوجد 4 برامج إضافية لإستخدام PLC&TextPanel ضمن عمليات شبكة تحكم مركبة ومتقدمة

DELTA_IA-PLC_ISPSoft-V3-02_SW_20160801.zip

3 برامج إضافية مع كتالوجاتها

DELTA_IA-TP_TPEditor-V1-89_SW_20170208.zip

DELTA_IA-PLC_TP-USB-Driver_SW_20150824.zip

DELTA_IA-PLC_COMMGR-V1-07_SW_20161214.zip

DELTA_IA-PLC_ISPSoft_UM_EN_20160518.pdf كتالوج البرنامج الأساسى

Delta_WPLSoft_V2.30.zip برنامج رابع إضافى مع الوحدة

كل البرامج مع كتالوجاتها موجودة على موقع معمل التحكم الأوتوماتيكى ACC

We must install USB-driver for TP-data cable in order to do communications between PLC & PC

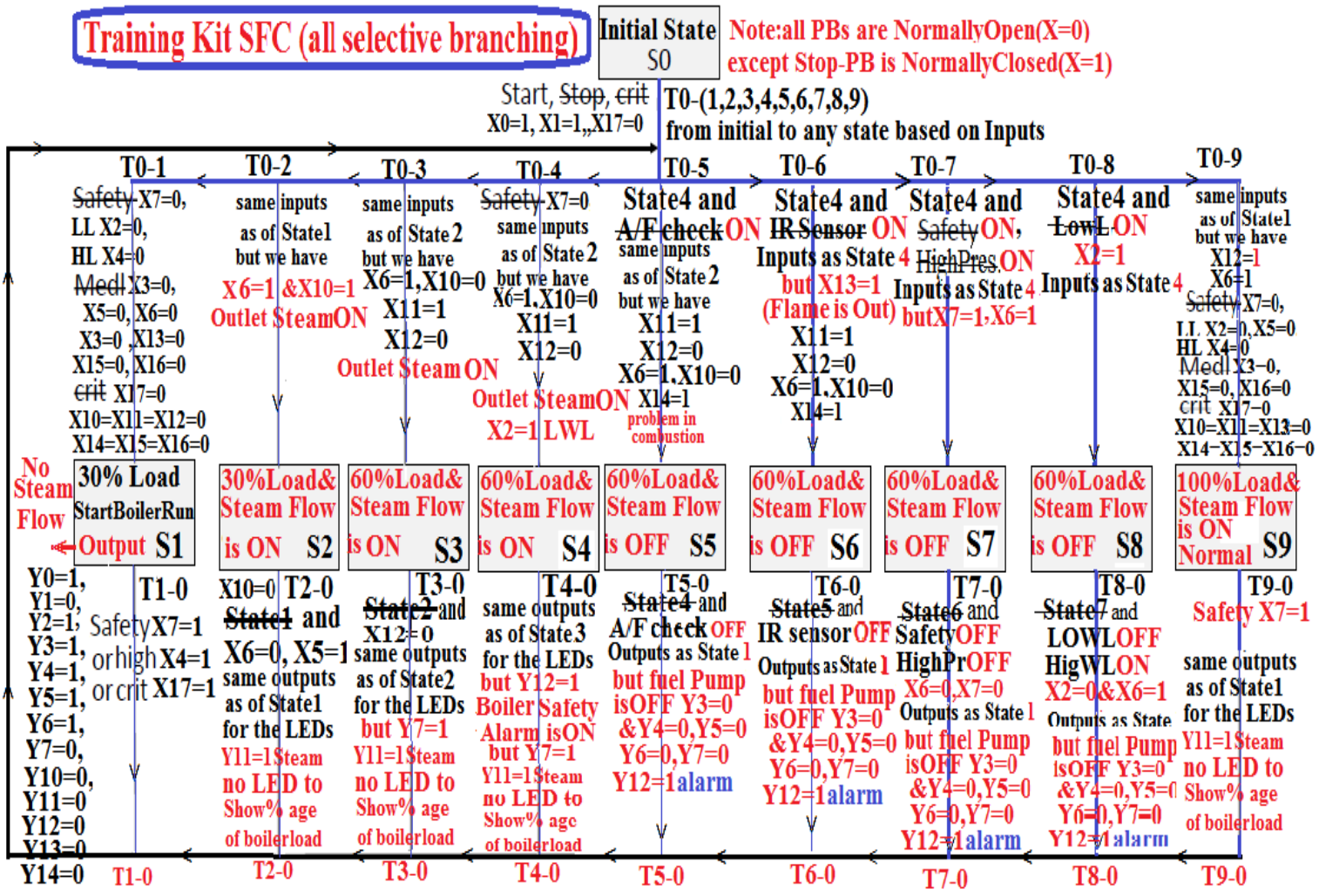
Details of all Inputs and Outputs of the Training Kit

PB of Inputs	PLC inputs in LAD		
Start	P0	NO-PB	X00
Stop	P1	NC-PB	X01
Water level (in Boiler Shell)			
Low	P2	NO-PB	X02
Medium	P3	NO-PB	X03
High	P4	NO-PB	X04
Pressure Steam or Water (same)			
Low	P5	NO-PB	X05
High	P6	NO-PB	X06
Safety	P7	NO-PB	X07
Nozzle (Boiler% Load of Full Load)			
1st Load 30%	P8	NO-PB	X10
2nd Load 60%	P9	NO-PB	X11
3rd Load 100%	P10	NO-PB	X12
IR sensor	P11	NO-PB	X13
A/F check	P12	NO-PB	X14
Resevoir (Feed Water Tank)			
Low Level	P13	NO-PB	X15
High Level	P14	NO-PB	X16
Critical level	P15	NO-PB	X17

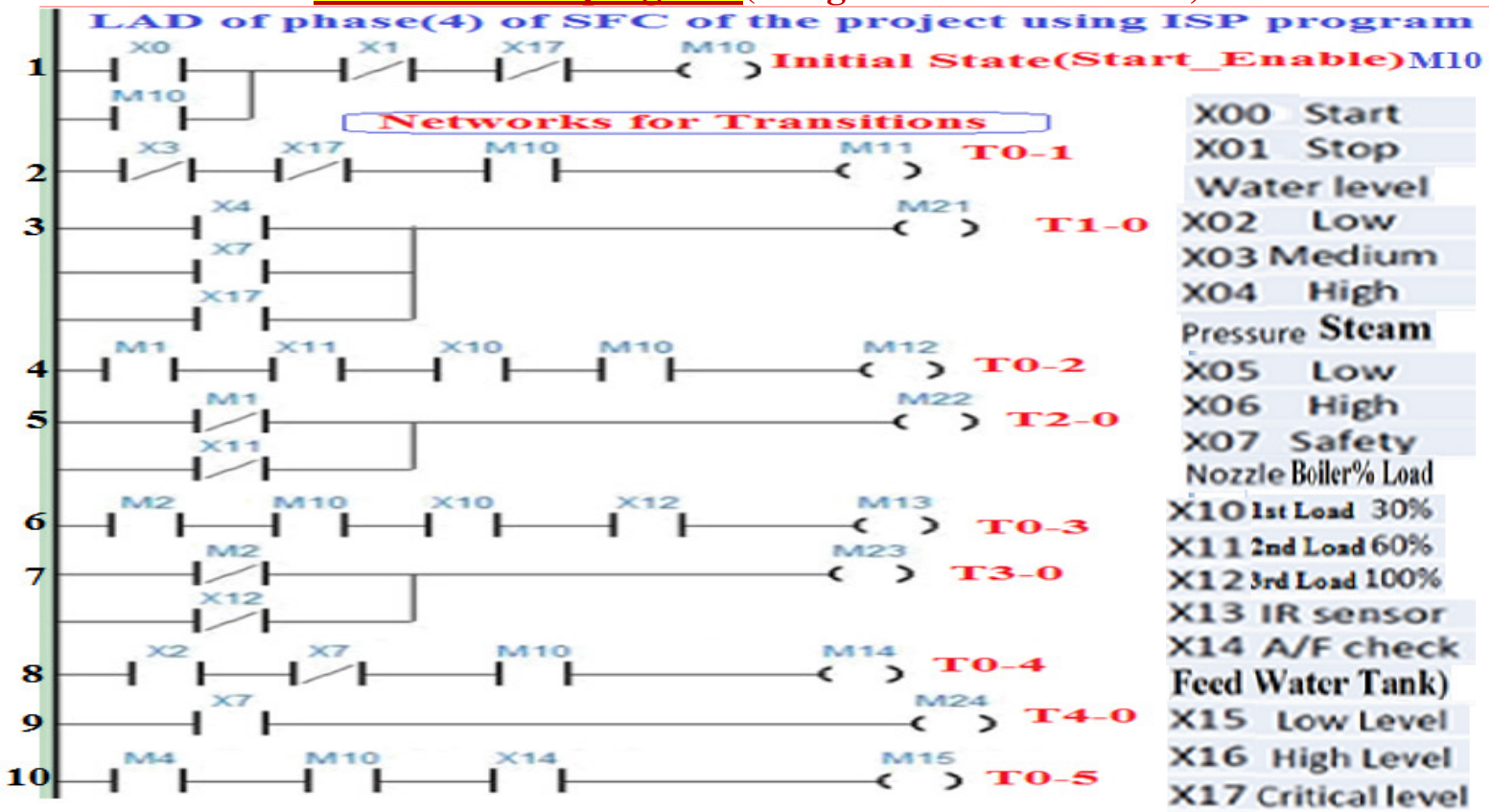
All outputs are LEDs	PLC Output on LAD	
Boiler Feed Water Pump1	P40	Y00
Boiler Feed Water Pump2	P41	Y01
Feed Water Tank Pump3	P42	Y02
Fuel Pump for Burner	P43	Y03
Air Blower for Burner	P44	Y04
Spark Ignition for Burner	P45	Y05
Fuel By-Pass Valve of Load	P46	Y06
Fuel Flow Control Valve1	P47	Y07
Fuel Flow Control Valve2	P48	Y10
Steam Output Flow Valve	P49	Y11
Boiler Safety Alarm	P50	Y12
Boiler Feed Pump Alarm	P51	Y13
Boiler Relief Valve ON	P52	Y14

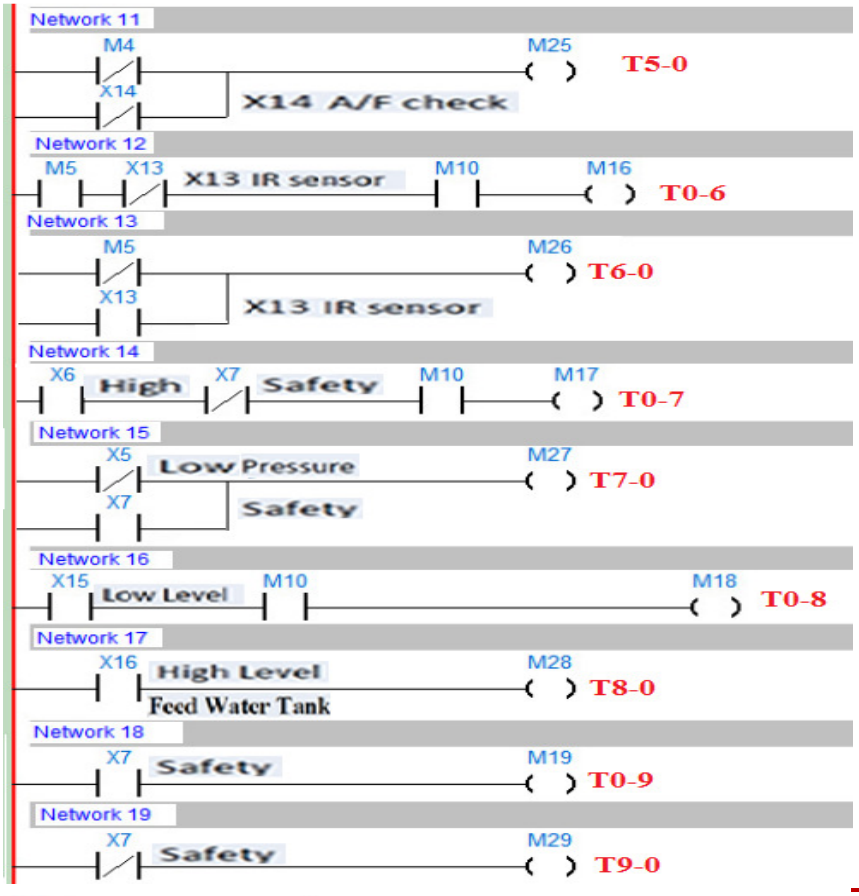
To understand LAD & SFC we have to see following Table

Name of State	Address of Relay	Name of Transition	Address of Relay	Name of Transition	Address of Relay
State 0	M0	--	--	--	--
State 1	M1	T0-1	M11	T1-0	M21
State 2	M2	T0-2	M12	T2-0	M22
State 3	M3	T0-3	M13	T3-0	M23
State 4	M4	T0-4	M14	T4-0	M24
State 5	M5	T0-5	M15	T5-0	M25
State 6	M6	T0-6	M16	T6-0	M26
State 7	M7	T0-7	M17	T7-0	M27
State 8	M8	T0-8	M18	T8-0	M28
State 9	M9	T0-9	M19	T9-0	M29
Start Enable	M10	--	--	--	--

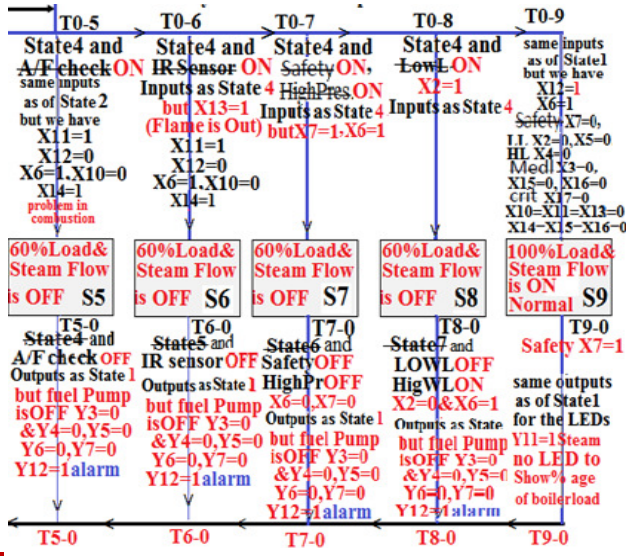


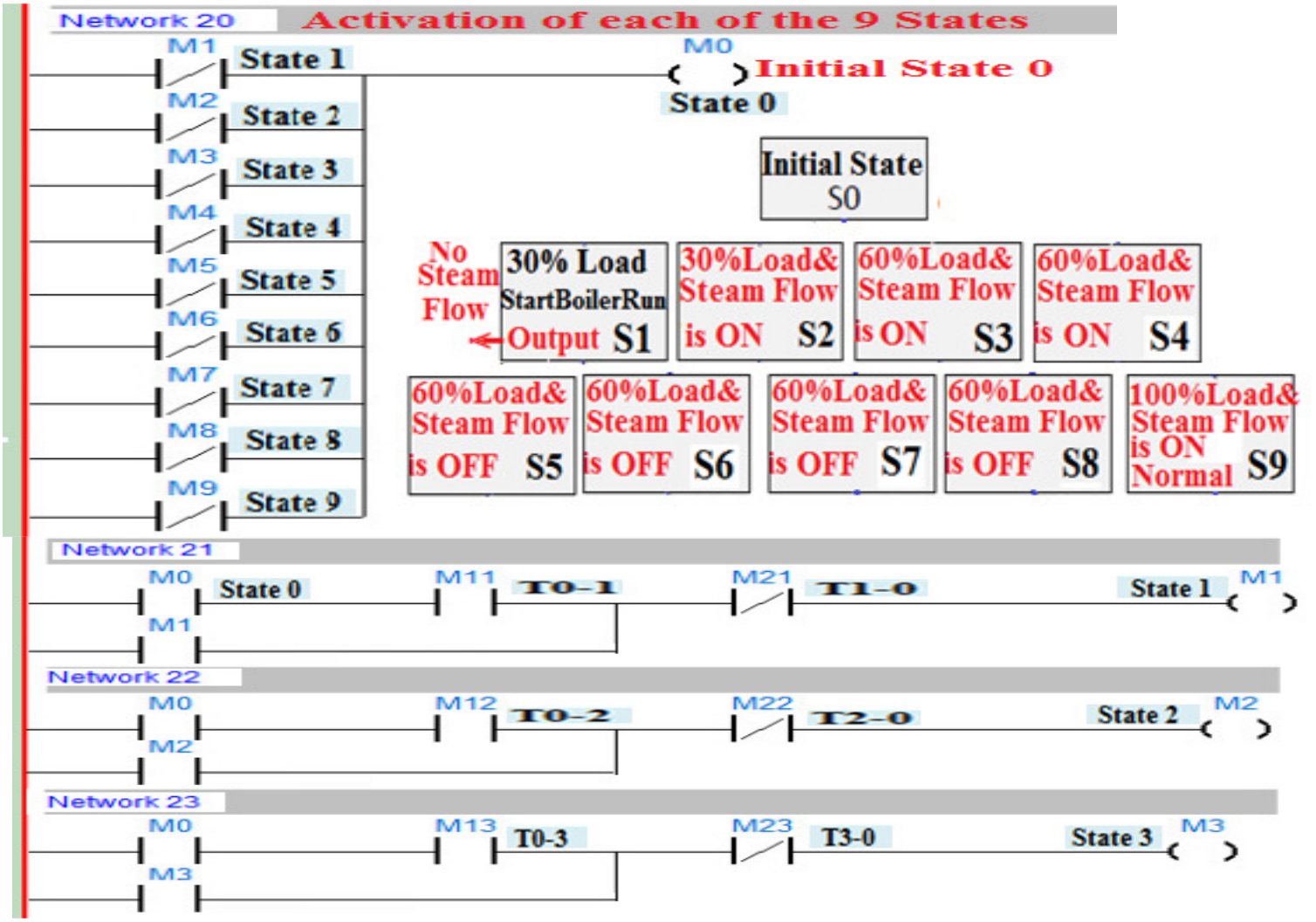
The Final LAD program (using ISP Software V3.02)

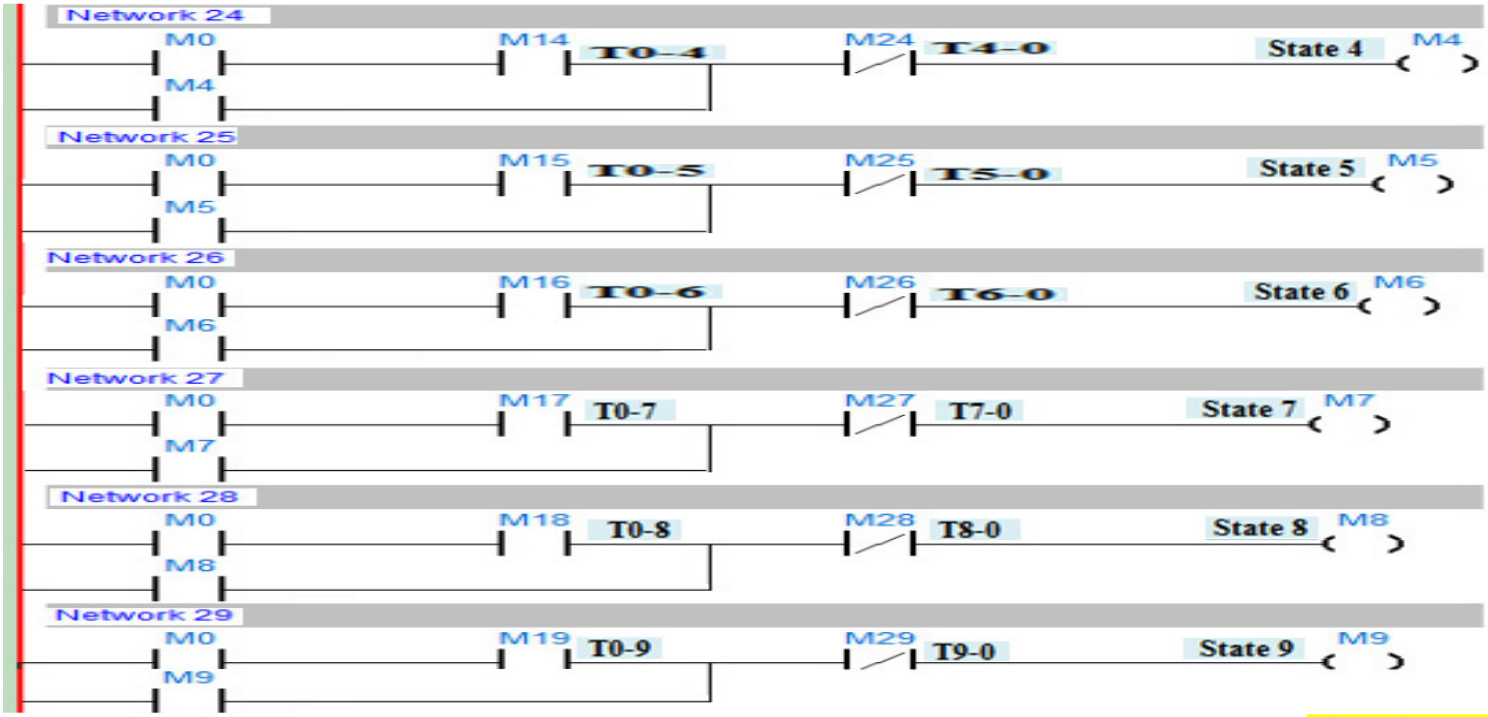




Name of Transition	Address of Relay	Name of Transition	Address of Relay
--	--	--	--
T0-1	M11	T1-0	M21
T0-2	M12	T2-0	M22
T0-3	M13	T3-0	M23
T0-4	M14	T4-0	M24
T0-5	M15	T5-0	M25
T0-6	M16	T6-0	M26
T0-7	M17	T7-0	M27
T0-8	M18	T8-0	M28
T0-9	M19	T9-0	M29

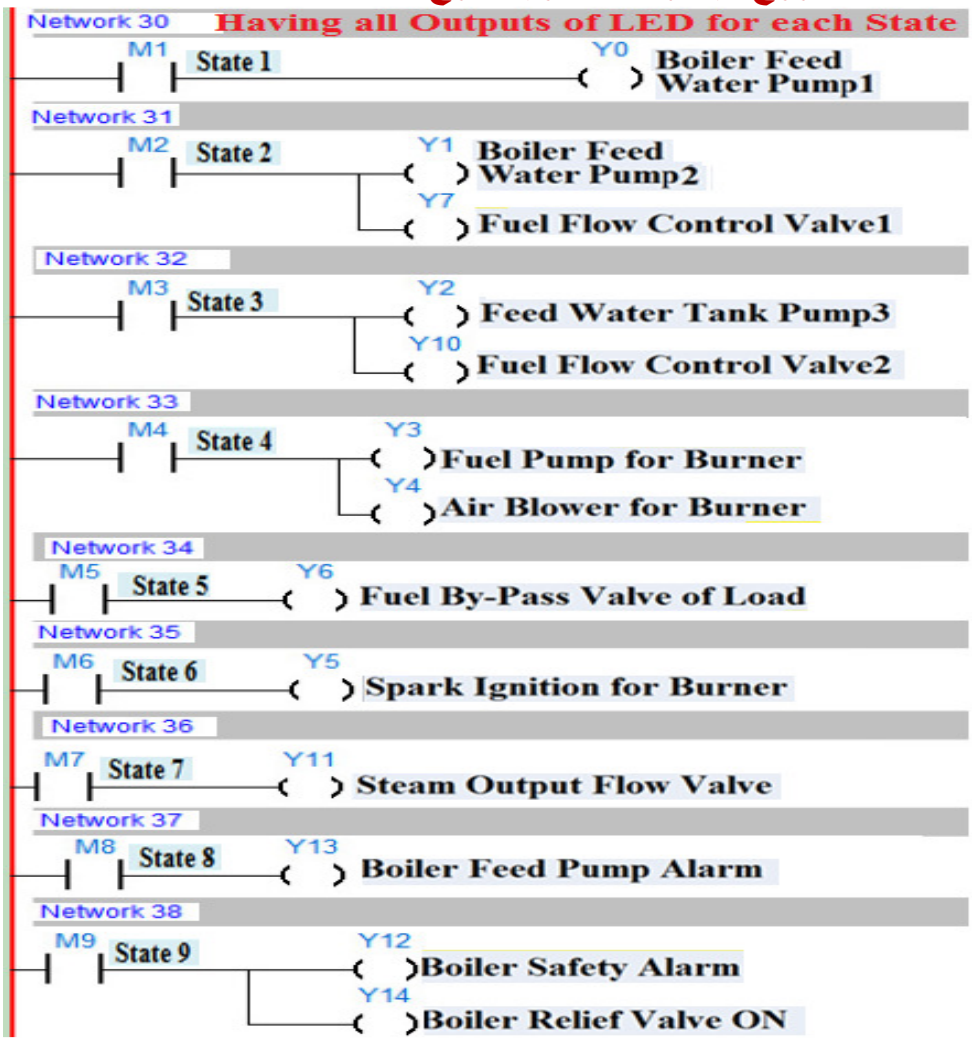


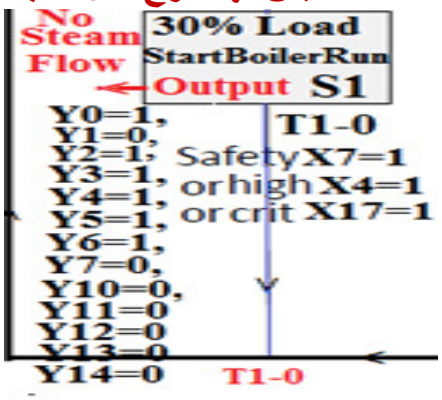


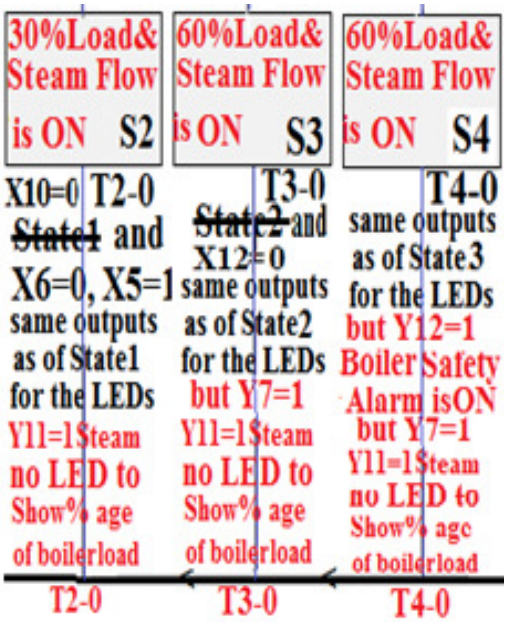


ملاحظة هامة:

يجب مراجعةSFCمع LADلأن هناك عدم تطابق فى الخرج outputs المفروض فى كلState (مثال فى أول حالة)
ويوجد حالات ليس لها خرج مثل نسبة% للحمل عند خروج البخار كما لا يوجد خرج لحالة IR-flame detector



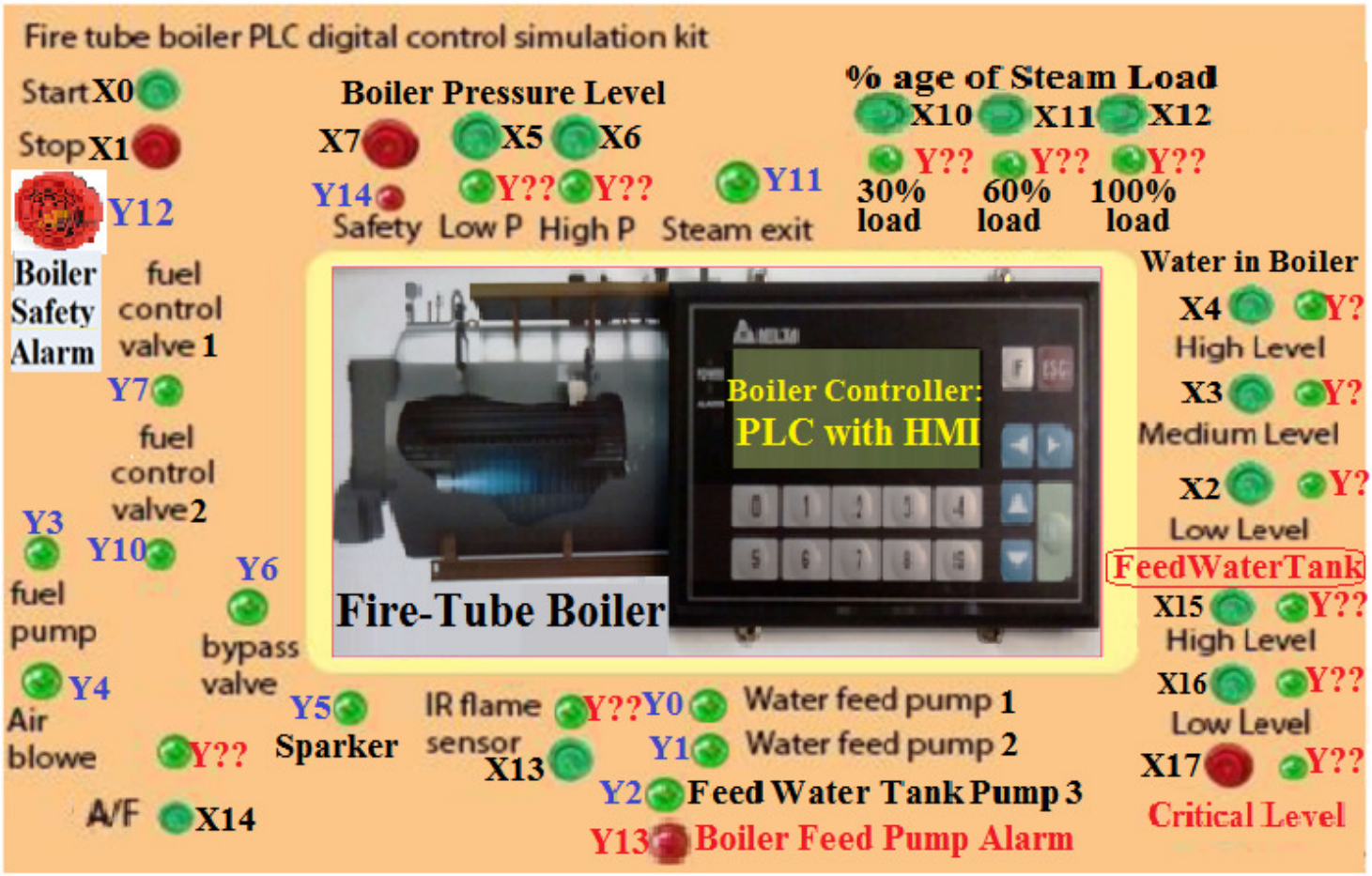


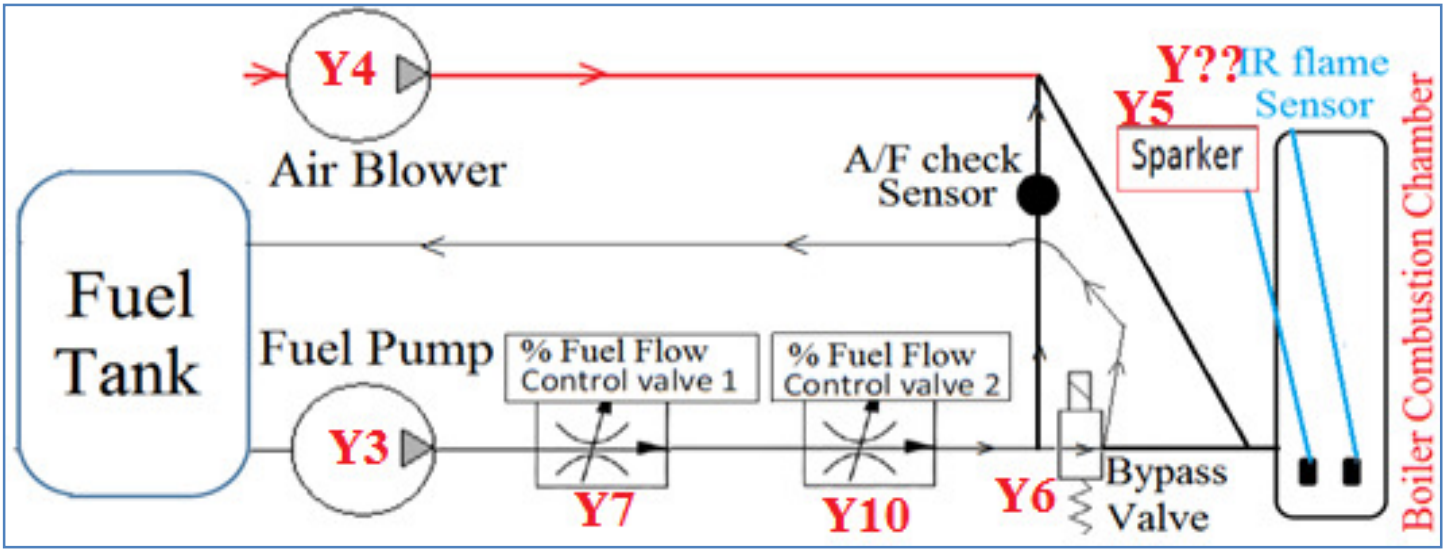


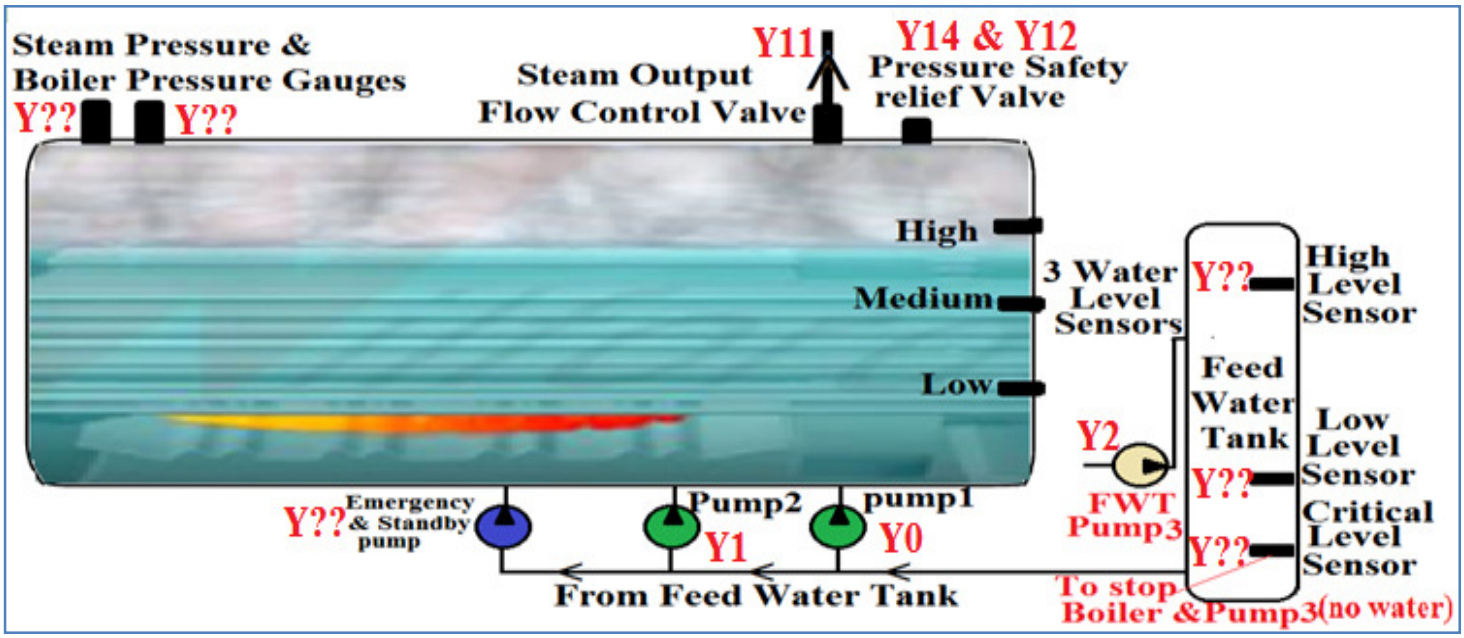
End of LAD diagram

Modifications & Recommendations for Future Work

We have to review the matching between SFC & LAD to correct for the Inputs and the outputs. We have also to re-do the Front Control Panel of the Boiler as shown below. The new Front Control Panel of the Boiler needs to add many LEDs to shown the outputs for many of the operation conditions of the Boiler (such as % age of Steam load, Boiler Low/High pressure level, Water Level in the Boiler, A/F check, Feed Water Tank Level,….).







Recommendations

- Using the HMI text panel with the PLC for having wider range of inputs and outputs and for viewing the details of operations of the PLC.
- Introducing analogue control in the process as it will give more feasibility on the control process and increase the accuracy of system.
- Introducing the instructions list as coding language alongside the ladder diagram.

References

Programmable Logic Controllers by William Bolton (5th edition)
http://s1.downloadmienphi.net/file/downloadfile5/192/1388863.pdf

Programmable Logic Controllers by William Bolton (6th edition)
https://books.google.com.eg/books?id=sDqnBQAAQBAJ&pg=PA1&dq=programmable+logic+control&hl=en&sa=X&redir_esc=y#v=onepage&q&f=false

https://en.wikipedia.org/wiki/Programmable_logic_controller

https://en.wikipedia.org/wiki/Fire-tube_boiler

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