International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 7 Issue 12, December - 2023, Pages: 20-29

Design and Implementation of a Fire Detection, Alarm and Suppression System Using Programmable Logic Controller (PLC)

Kalyankolo Umaru[1] and Drici Joseph Felix Tartisious[2]

1Department of Electrical Engineering and Automation, Muni University (MU), Arua –Uganda.
u.kalyankolo@muni.ac.ug
2Department of Electrical and Control Engineering, International University of East Africa (IUEA), Kampala-Uganda
dricijoseph@gmail.com

Abstract: *Industrial and or domestic safety is as much important as the processes carried out in any industry/homes. This is because there is always a tendency for fires to occur due to the existence of fire hazards in industries, domestic and residential settings. Therefore, firefighting system is one of the most important systems in industries and in buildings with multiple occupancy as it protects the facilities, equipment and people against disastrous effects of fire breakouts. Fire detection, alarm and fighting system is a combination of number of devices working together to detect and warn the people through visual and audible appliances when smoke, heat and/or fire are present. It also triggers the suppression system. The alarm used in such system may be activated from flame or smoke detectors and heat detectors. In this project, smoke detectors have been used to detect fire and give an input signal to the programmable logic controller(PLC) which triggers the fire alarm and fire suppression system. Fire alarm system plays the main role in maintaining and monitoring the safety in all kinds of environments and situations. The main objective of this Fire Alarm Control System in Building Automation Using PLC is to make a fire control and suppression system with high reliability and low cost. The system has been designed to cover three zones of protection (three rooms) in which on detection of fire, zone 1 produces audible (buzzer) and visual light emitting diode(LED) alarm, while the LED, direct current (DC) water pump and a buzzer are triggered in zone 2 and a LED, buzzer and Solenoid valve are triggered for zone 3.*

Keywords: smoke detectors, LED, DC water pump, Solenoid valve, Siemens LOGO PLC

I. INTRODUCTION/BACKGROUND

History has proven that early detection of a fire and the signaling of an appropriate alarm remain significant factors in preventing large losses due to fire. [6]

This is because industrial and/or domestic accidents and unsafe working conditions can result in destruction of assets/equipment and temporary or permanent injury, illness, or even death. They also impact on reduced efficiency and loss of productivity. Making the work environment safer was less costly than paying compensation [1].

Hence, well-planned fire prevention activities can save millions of dollars by preventing the destructiveness of fire, as well as saving lives in industry and the public.

This therefore calls for determination and installation of adequate fire protection and detection systems for the protection of the plant buildings, equipment and occupants.

Also adopted building and/or fire codes may require the installation of fire detection and alarm systems. This is because in this current world of advanced technology electronic systems are widely used be it at homes, offices or industries and this is one of the primary reasons for short circuits in homes and commercial applications.

Due to this fire hazard, fighting systems for commercial as well as residential purposes are being implemented. But recently firefighting panels are designed and developed using microprocessors which can breakdown at any time and whose trouble shooting is very difficult and time consuming. So, we have designed and developed this PLC based fire alarm and suppression system in which the PLC is the heart of automation that is being used in the firefighting system.
In this article, a prototype model of 3 rooms in which each room represents a zone of protection was produced. Also, each room consists of two smoke sensors operating in 2oo2 (2 out of 2) topology, and an associated fire alarm and suppression system/devices. Signals from the detectors at any room is detected and monitored using monitoring system installed individually for each room.
The fire alarm and suppression system has components like buzzer for alarming and a DC water pump to represent the sprinkler system and a Solenoid valve for CO_2/Nitrogen gas release and the programmable Logic controller (PLC) is programmed using ladder diagrams.

In this project, on detection of smoke by the smoke detectors in a given room, the PLC triggers the fire alarm and suppression system in that particular room.
Due to the setbacks associated with the microprocessor based systems as outlined below;

- ✓ Microprocessor can breakdown at any time
- ✓ Trouble shooting is very difficult and time consuming [4].
- ✓ Cannot operate in a harsh environment.
- ✓ Limited number of input/output

We have designed and developed a PLC based fire detection, alarm and suppression system in which PLC is the heart of automation. This is due the advantages PLC based system have compared to the microprocessor based systems which to mention but a few;

- ✓ PLC can be used in harsh environments,
- ✓ Flexible (more input and output modules can be added for expansion)
- ✓ Easy to program and troubleshoot
- ✓ Troubleshooting is easy

II. LITERATURE REVIEW

The related literature in the design of an automatic fire detection and fighting system by a few authors was reviewed and discussed.

1. PLC Based Fire Alarm Control System in Building Automation by Rupendra M. Anklekar , Sandesh C. Gharat , Sainath V. Kabadi , jayandra A. Mohite, and Akshay J. Thakare.[4]

In their project published in International journal of creative research thoughts (IJCRT) on the 2nd April 2018, they presented a prototype model of 3 rooms and one water tank in which each room consisted of individual fire or smoke sensor and sub water pump/electric valve, and also the water level sensor for tank and main pump. In their project, the system can detect smoke, heat and are sensed by the detector, followed by the monitoring system which indicates smoke and heat at that particular level. When the sensors from each level are triggered individually, the main buzzer operates and disconnects the AC power supply. Then it runs the emergency exit door motor to escape, the lift comes to ground level and the water pump motor to the affected zone starts to stop the fire.

2. Industrial Fire Fighting System Using PLC with SCADA by Srinivasareddy Allam.

His project for the award of masters of technology in instrumentation engineering in the National Institute of Technology Kurukshetra was to design such equipment by using several proven technologies like PLC and SCADA software.

The detectors are connected in loops and each loop corresponds to a single zone. Depending on the size, the plant is divided into several zones. And each zone may have four to several detectors depending on the size of that particular zone. In some zones water can sprayed to stop fire and as well exhaust fans should be stopped. But in several zones, as there will be some critical equipment, water should not be used. For those zones, sounders are activated so that employees in that zone will take preventive actions [5].

3. Fire alarm system using smoke and heat detectors with PLC by Amna Ahmed Abdalla Ahmed [1].

In his thesis for the award of masters in physics in Sudan University of Science & Technology, Amna Ahmed used smoke and heat detectors as input devices.

He used Mitsubishi PLC as the heart of the system. His output devices were,

- ✓ Heat alarm light indicator (lamp, + or – 24 V).
- ✓ Heat alarm sound indicator (Buzzer, + or – 24 V).
- ✓ Smoke alarm light indicator (Lamp, + or- 24 V).
- ✓ Smoke alarm sound indicator (Buzzer, + or- 24 V).

III. METHODOLGY

This project uses similar technologies as used by the authors whose literature have been discussed.

However, our design consists of three zones of protection with each zone consisting of two detectors for reliability and redundancy purpose.

The system/each zone is activated only and only if both detectors have been triggered, that is using 2oo2 topology (2 out of 2 topology). This eliminates fault alarm resulting from fault in any detector. In case of fault in any detector, the other detector can be used to protect the system until the faulty detector is repaired or replaced (by modifying the loop and program).

- **Input devices are:**
- ✓ Smoke detectors
- **Controller**
- ✓ PLC

- **Output devices**

- ✓ LED to indicate the zones
- ✓ Buzzer
- ✓ DC water pump (for the sprinkler system)
- ✓ Solenoid valve (CO2 release)

On detection of fire, a LED associated with the zone glows and alarm is annunciated to give audible warning to the occupants. At the same time fire suppression system (DC water pump or solenoid valve) is triggered to fight and stop the fire.

As highlighted above, in this project**, 2oo2 (2 out of 2) topology** has been used to implement the system's functionality and it consists of three sub systems:

- ✓ The detection system
- ✓ The monitoring/alarm system and
- ✓ The fire suppression/fighting system

IV. BLOCK DIAGRAM

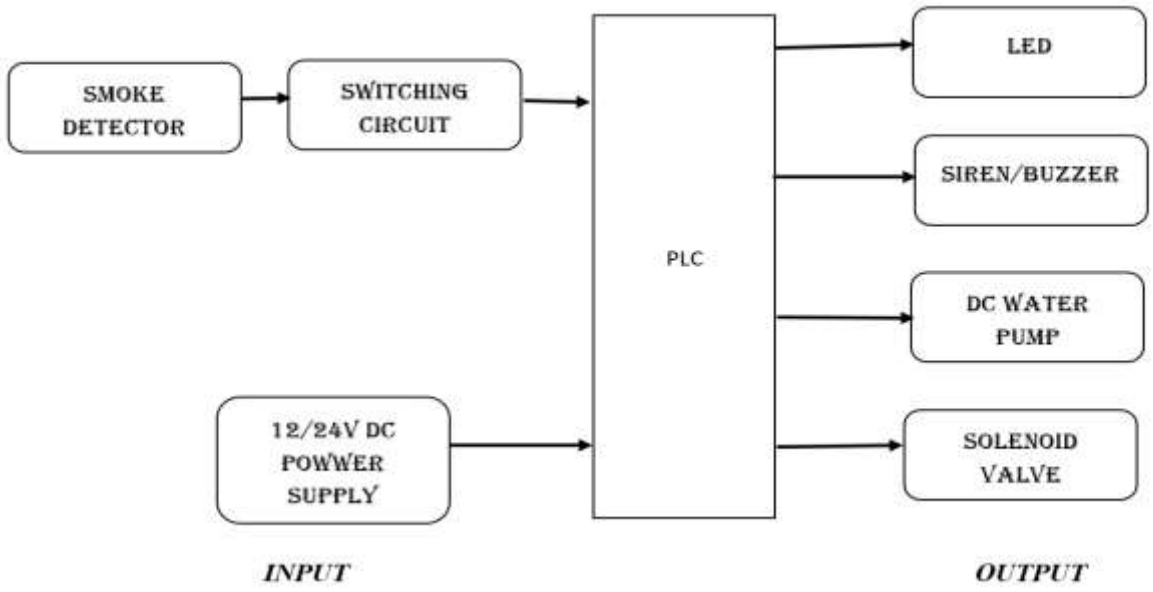

Fig. 1:*Block diagram for the fire alarm and fighting system using PLC*

V. SYSTEM COMPONENTS

- **The smoke detector**

Smoke detectors have been used as fire sensors in this project particularly the MQ-2 modules haven been used as smokes sensors. This module detects smoke as well as gas leakage, the gases it detects include, H_2, LPG, CH_4, CO, Alcohol or propane. It has a detection range of 300-10,000 ppm

Specifications:

- Operating voltage: 5V DC
- Preheat duration: 20 seconds
- Analog output voltage: 0 to 5V

Fig.2: ***MQ-2 smoke detector module***

- **switching circuit**

Since the smoke detector's output voltage is 5V dc, it is not sufficient to trigger the PLC since the operating voltage for the PLC used is 12/24V DC.

Hence, switching device as shown in figure 3 below has been designed to amplify/ switch to 12V DC required by the PLC. The following components were used to design the switching circuit.

- ✓ 1N4007 diode
- ✓ Voltage regulator(L7805cv)
- ✓ 10 micro farad capacitor
- ✓ BC557 Transistor(PNP)
- ✓ 5 pin relay module
- ✓ Resistors (1k ohms)

Schematic diagram for the switching circuit

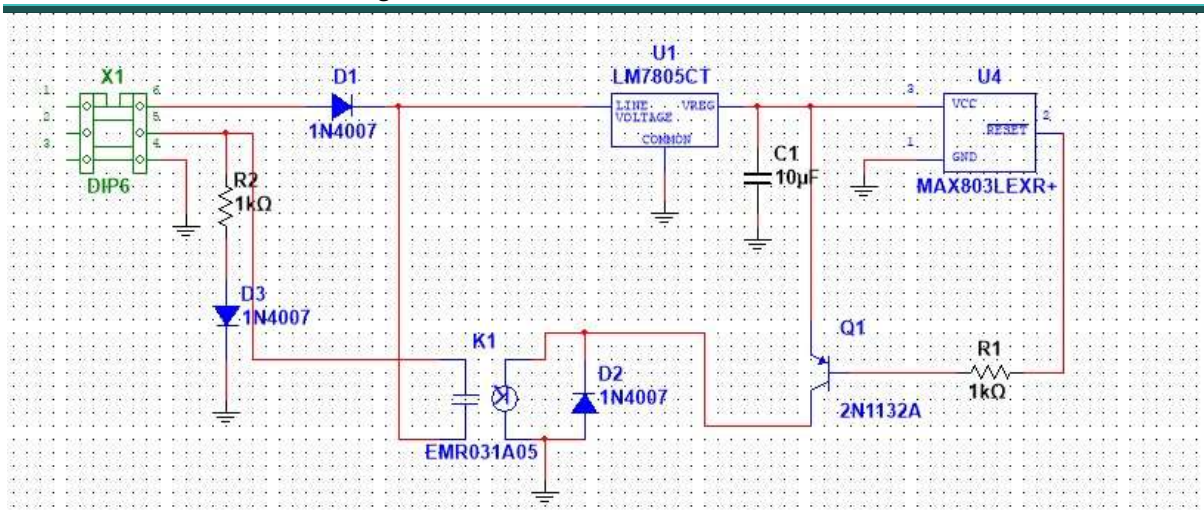

Fig.3: ***Schematic diagram for the switching circuit***

Fig.4: ***sensor and switching circuit (input devices) prototype***

- **The PLC**

A programmable logic controller (PLC) is the heart/brain of the system. It as a central processing unit (CPU) that is able to accommodate an application program and input/output modules. The fire, alarm and firefighting process are executed by instructions stored in a PLC memory. The PLC memory stores the values of timers, relays, sequencers, and counters. The PLC offers certain advantages such as reliability, low cost, and can be re-programmed.

Hence, the automated system used the PLC as its main control unit and with its non-volatile memory having the ladder logic prewritten on it. The ladder logic was written using LOGO soft comfort 8.2 software.

Siemens LOGO PLC was used in this project. It has 8 inputs (I1 to I8 and 4 outputs. The output has relay contacts (Q1, Q2, Q3 and Q4) This PLC has operating voltage of 12/24V DC. The PLC gets its input signal from the sensor and switching circuit.

According to the program, the PLC switches/ activates the output relay on detection of smoke. This triggers the output device in the associated zone/room.

Fig.5: ***Siemens LOGO PLC and program uploading***

- **Output devices**

On detection of fire, the PLC triggers/switches the following output devices.

- ✓ LED to indicate the zones
- ✓ Buzzer
- ✓ DC water pump (for the sprinkler system)
- ✓ Solenoid valve (CO2/ foam powder release)

VI. DESIGN AND IMPLEMENTATION

Smoke detectors sense the smoke produced by an outbreak of fire and outputs 5V DC in its **DO** (digital output) pin. The 5V DC generated by the smoke detector is amplified by the switching circuit. This generates 12V DC voltage to be fed in to the input port of the PLC.

Each room/zone has two smoke detectors installed in it and the PLC has been programmed using **2oo2 (2 out of 2 topology).** That is, once both detectors in each room are activated, the PLC triggers/activates the fire alarm and fighting system in the associated room/zone. The PLC has been programed using ladder diagram and LOGO soft comfort 8.2 software has been used.

On detection of fire in room/zone 1, the LED and buzzer goes on to give a visual and audible alarm. The LED for each room/zone has been marked to indicate the fire status of the associated zone/rom.

For room/zone 2, the LED, buzzer and a DC water pump go on. Again the LED here indicates the room/zone and the DC water pump represents the sprinkler system used for fire suppression.

Lastly, on detection of fire in room/zone 3, the LED showing the room number, buzzer and a solenoid valve are activated. The Solenoid operated valve (SOV) is activated to release halon gases, carbon dioxide or powder. Water is not used for firefighting in room 3 because this room/zone is considered to be a computer or electronic room/zone.

VII. Ladder programming

The ladder diagram shown in figure 6 and 7 was written using LOGO soft comfort 8.2 software based on the requirement of the system as described below:

- ✓ Activation of smoke detectors SD1 and SD2 triggers the PLC to activate fire alarm and LED for room 1
- ✓ For room/zone 2, activation of SD3 and 4 triggers the PLC to switch on and LED for room 2 and a Dc water pump which supplies the sprinkler system.
- ✓ Also, SD 5 and 6 trigger the PLC to activate an LED for room 3 and a solenoid valve to release halon gases or carbon dioxide/powder for fire in computer or electronic room.
- ✓ The system keeps on alarming and the firefighting system continues to be on after being triggered by fire unless the system is reset manually.
- ✓ Hence a reset pushbutton has been provide in input I7 to manually reset the system after being triggered

The implementation process was entirely based on the ladder diagram shown below

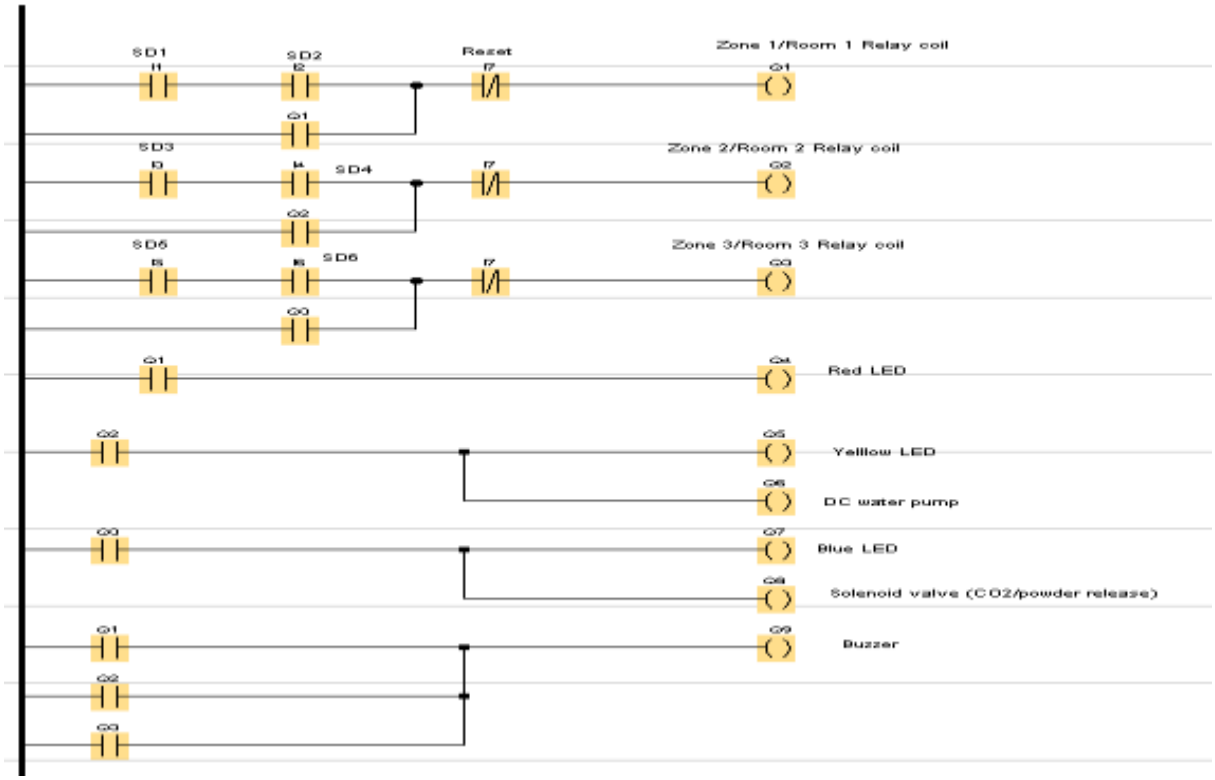

Fig. 2: ***Ladder diagram before simulation***

VIII. Simulation of the system

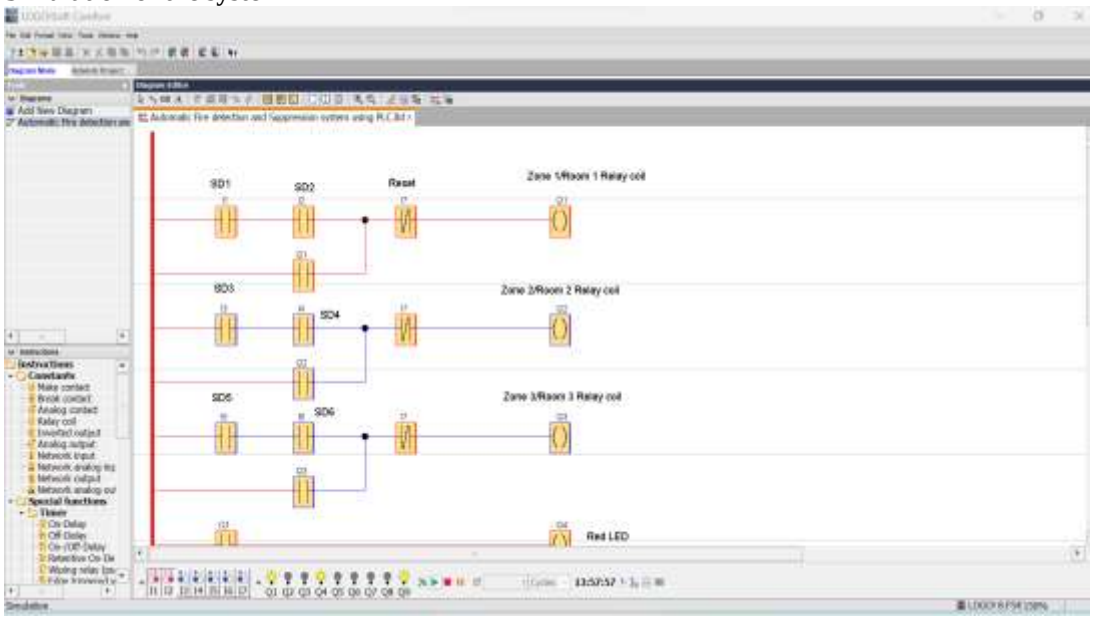

Fig. 3: ***Ladder diagram during simulation***

IX. Results and Discussions

As mentioned before, MQ-2 smoke detectors were used as sensors. These sensors output 5V DC. This is not sufficient to trigger the PLC used here as its operation voltage for the PLC used is 12/24V DC. Hence a switching circuit was used to amplify/switch the 12V DC required by the PLC.

The input signal from the sensor and switching circuit is fed to the PLC input. In this project, I1 to I6 were used for the sensors and I7 is a reset pushbutton.

The PLC switches/triggers the output devices on according to the program uploaded in it. The Ladder diagram was programmed in the PC (personal computer) and uploaded to the PLC using a LAN cable.

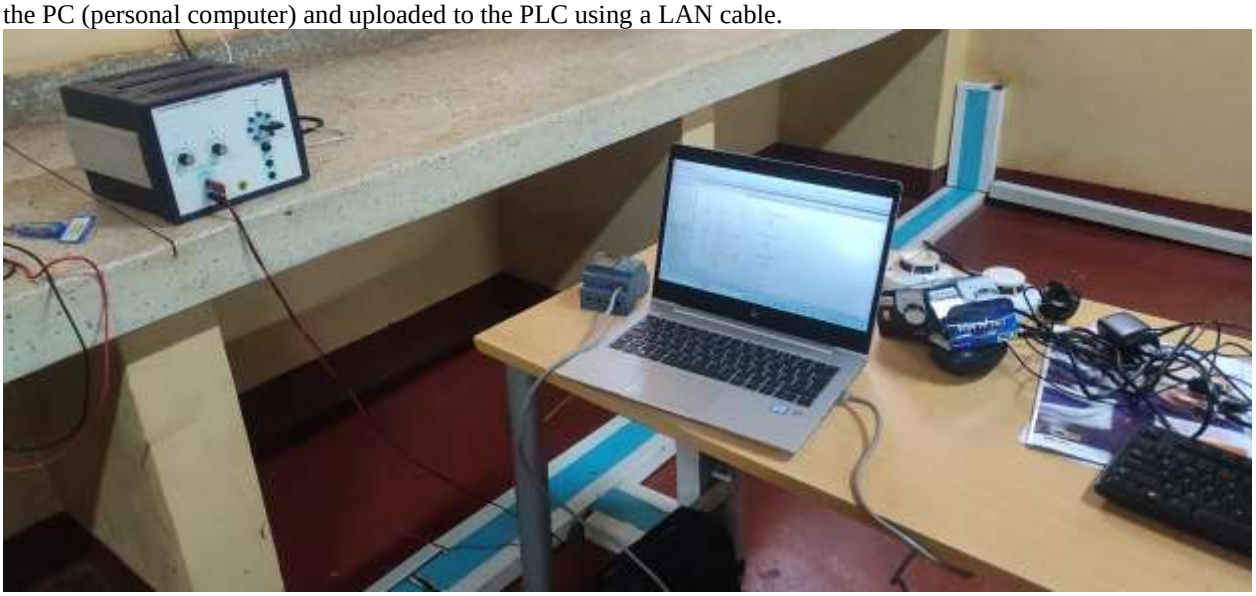

Fig. 8: ***Uploading the program from PC to the PLC***

The output devices connection/wiring

- The output devices for room/zone 1 have been connected to Q1
- The LED and DC water pump in zone 2 have been connected to Q2
- The LED and Solenoid valve as in zone 3 have been connected to Q3
- Note the buzzer is connected in parallel to Q1, Q2 and Q3.

The full system after connection/wiring

Fig. 9: The fully wired system

X. Conclusion

In this project, we have been able to design and implement an automatic fire detection, alarm and suppression system using Siemens LOGO PLC.

Due to the unavailability of highly sensitive and 12/24 DC smoke detectors, the smoke detector circuit has been modified using MQ-2 smoke detector module and switching circuit.

The system was tested and gives satisfactory response/result. LEDs indicate the zone in which fire occurs. More so, a fire suppression/fighting device of an associated zone gets activated on detection of fire/smoke.

The system provides the following functionalities

- ✓ Prevents fire outbreak through early detection of fire.
- ✓ Annunciating/ giving audible and visible alarm/indication on the occurrence of fire (fire monitoring function).
- ✓ Activation of firefighting system to extinguish the fire

In this way, the system keeps constant surveillance on the fire security of the zones of protection/facility. This saves an industrial, commercial and residential facilities from the disastrous effects of either unnoticed or delayed manual action during fire outbreak.

XI. Recommendations

As discussed above, due to the unavailability of 12/24V DC smoke detectors, MQ-2 smoke detector module and a switching/amplification circuit was used to give the desired 12/24V DC voltage required by the PLC input. This makes the sensor circuit more complex.

However, there exists compact 12/24V DC conventional smoke detectors in the market. By using these type of sensors, the sensor circuit is simplified and its output voltage can be directly input to the PLC.

More so, sensitivity of MQ-2 smoke detector module is low, low range and it requires more heating time on its first usage. Hence, to have a highly reliable and fast acting system, high range/highly sensitive smoke, heat and fire detectors are recommended.

In this project, LEDs have been used to indicate the zone where fire breaks out. However, by using addressable smoke detectors instead of the convectional detectors, it would be easy to identify the zone and the detector that is activated. This helps in quick troubleshooting in case of faults in the sensor circuit and precise location of fire can be located.

Other sensors like, heat, flame and flammable gas detectors can be incorporated in the system to allow it to detect all kinds of fire/ fire hazards.

HMI and/SCADA systems should be incorporated to the system to allow user interface/interaction with the system.

All the above recommendations allows the system to be used in all kinds of settings, be it residential and commercial buildings industrial facilities

XII. REFERENCES

[1] Fire alarm system using smoke and heat detectors with PLC by Amna Ahmed Abdalla Ahmed.

[2] https://www.ijrte.org/wp-content/uploads/papers/v7i6/F2266037619.pdf

[3] Fire Alarm Control System in Building Automation Using PLC by Vilas K Jadhav, Shekhar R Tapase, Dhanashri G Bhor, Sanketkumar P Ingale

[4] PLC Based Fire Alarm Control System in Building Automation by Rupendra M. Anklekar , Sandesh C. Gharat , Sainath V. Kabadi , jayandra A. Mohite, and Akshay J. Thakare

[5] Industrial Fire Fighting System Using Plc with SCADA by Srinivasareddy Allam

[6] https://www.ifsta.org/sites/default/files/Chapter14_FICE8.pdf

[7] https://www.govinfo.gov/content/pkg/GOVPUB-C13 da3a767b5157f28656d4fa685b015121/pdf/GOVPUB-C13-da3a767b5157f28656d4fa685b015121.pdf

[8] Programmable Logic controllers by W. Bolton-fourth edition