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Original Research Article

Programmable Logic Controller based mitigation of obsolescence control unit of GHARR-1 Pneumatic Transfer System

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Abstract

Ghana Research Reactor-1 (GHARR-1) is a Miniature Neutron Source Reactor (MNSR) used mainly for Neutron Activation Analysis (NAA), Education and Training. GHARR-1 uses an auxiliary Pneumatic Transfer System (PTS) for the transfer of sample capsules in and out of the irradiation sites. The 90.2 % highly enriched uranium (HEU) core of GHARR-1 was recently converted to a 13 % low enriched uranium (LEU) core. The conversion resulted in the thermal power of GHARR-1 increased from 30 kW to 34 kW whiles maintaining the neutron flux at 1 x 10^{12} n/cm^{2}s. Most of the components used to design the existing one-short conventional NAA controller unit are outmoded and out of stock in the local Ghanaian market, posing threat to future maintenance. To address this situation, a Programmable Logic Controller (PLC) has been used to design a control unit to facilitate the NAA application. This paper outlines the design of a stable +12 /+24 VDC voltage regulated power supply to operate the PLC and control an 8-way solid state relay bank. The relay bank was designed to operate the solenoid valves that open and close a compressed-air to transfer samples into the reactor for irradiation. Function block diagram programming language was used for the design of the PTS controller unit. The paper highlights the simulation results in which electric bulbs were used to represent the solenoid valves to achieve the opening and closing mechanism for the transfer of samples. Implementation of the results obtained from the study would eliminate the difficulty of getting up-to-date components to replace the outmoded ones in the PTS controller.

Keywords: Neutron Activation Analysis, Programmable Logic Controller, Controller Unit, Ghana Research Reactor-1, Simulation, Integrated Circuit

INTRODUCTION

Ghana's Miniature Neutron Source Reactor (MNSR) also known as Ghana Research Reactor – 1 (GHARR-1) is used mainly for Neutron Activation Analysis (NAA) (Akaho, Maaku, Dodoo-Amoo, and Anim-Sampong, 1999; Gao Jijin, 1993). NAA is a nuclear technique used for determining the concentrations of elements in a vast amount of materials. Pneumatic Transfer System (PTS) for Miniature Neutron Source Reactor (MNSR) is an experimental facility of GHARR-1. The basic function of the facility is to transfer samples to the irradiation position of the reactor, and to retrieve activated samples to the lead chamber where the sample is picked up manually onto a gamma detector for counting (Huabai, Gao, Shuping, and Yulun, 1992). Similar facilities have been set-up in MNSR operating organizations, such as: China, (Huabai et al., 1992), Nigeria, (Nigeria Research Reactor-1, 2005), Syria (Chengzhan and Yongchun, 1994), Iran (Faghihi and Mirvakili, 2009) and Pakistan for one-shot

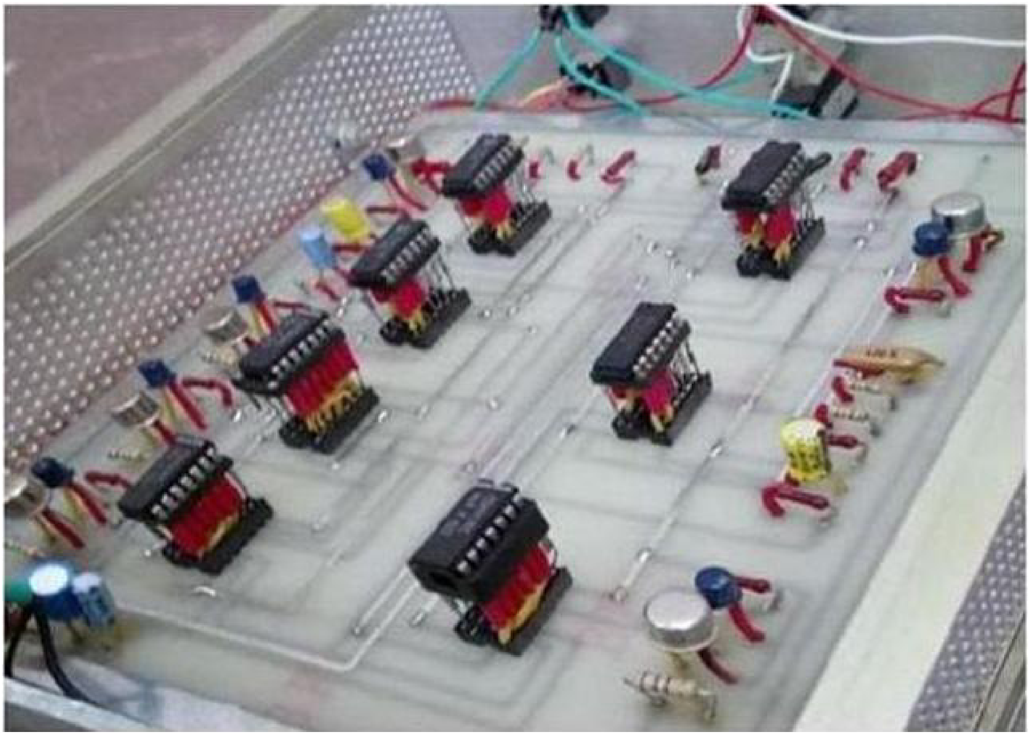

Figure 1. The existing modified PTS controller

conventional NAA. The Syrian Atomic Energy Commission has designed an automatic sample changer for their existing gamma-ray spectrometry system (Sarheel, Nassri, and Ezzuddin, 2018) through a Coordinated Research Project (CRP) by the IAEA. The design did not incorporate the construction of a new controller unit using PLC.A fully automated fast pneumatic transport system for short-time activation analysis has recently been developed at Atomic Institute, Vienna University of Technology for TRIGA Mark II (Ismail, 2010).

The problem associated with the GHARR-1 PTS is that, most of the integrated circuits (ICs) which control a bidirectional diodes circuit, a TRIode for Alternating Current (TRIAC) which operate the PTS solenoid valves for the passage of compressed-air to transfer the samples capsules into the reactor are outmoded or obsolete; resulting in increasing maintenance efforts to sustain acceptable performance. Attempts to procure replacement for the obsolete equivalent ICs of the existing GHARR-1 PTS controller unit from the local Ghanaian market have been unsuccessful due to the different pins configuration. The original controller circuits have been consequently modified in order to accommodate the different pins configuration of the equivalent ICs and to control the solenoid valves, see Figure 1. The original design is becoming out-of-date in comparison with current standards and technology. With ageing of staff of Ghana Atomic Energy Commission (GAEC) and the eminent threat of losing the aging trained staff, it has become imperative therefore to redesign the PTS controller using an industrial computer based PLC to ensure continuous use of the facility. Hence, the present situation poses future maintenance problems. The design of a new PTS control unit was necessitated due to non-availability of the original electronic components on the local market, current technological advancement and the frequency of breakdowns of the controller.

A computer based programmable logic controller (PLC) with a LOGO! Comfort software version (V8) was used for the PTS controller to replace the old controller meant for conventional NAA mode operation (Siemens, 2012). The developed controller unit consists of three basic designed circuits; the PLC device, an eight-way solid state relay bank to replace the existing TRIode for Alternating Current (TRIAC) and a dual regulated voltage high current power supply to operate the PLC and control the solenoid valves. There are two phototransistors fixed at vantage points of the PTS, which communicate with the controller to open or close a solenoid valve for sample transfer and also for counting or analysis of sample by the HPGe detector. The PTS has been partially modified for the purpose of transferring the activated sample capsule directly from the irradiation site onto the detector for counting, see Figure 2. The relocation of the phototransistor from the receiving lead chamber onto the detector will help to reduce greatly the radiation exposure to the operator. It is necessary for the

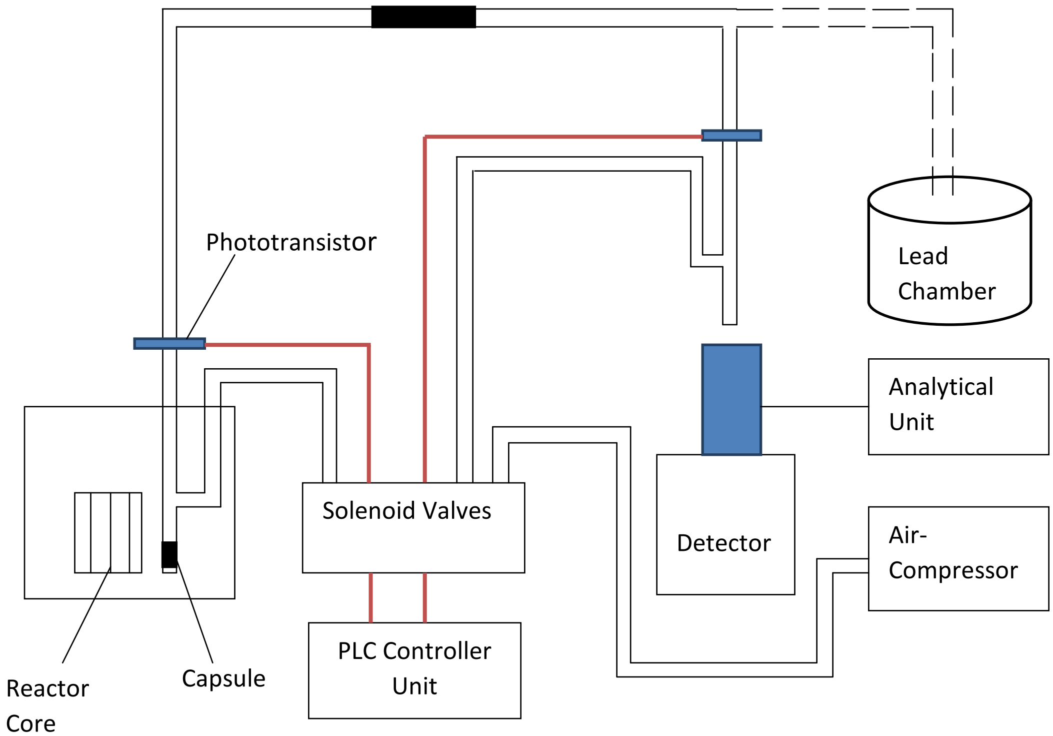

Figure 2. Schematic diagram of PTS with little modification

PTS to be functional during reactor operation because it provides the alternative means of bringing the reactor to sub-criticality by sending cadmium capsules into the reactor in the event of power escalation when the reactor instrumentation and control protection system fails.

MATERIALS AND METHODS

Schematic diagram of the PTS

Figure 2 is a schematic diagram of the PTS with little modification on the phototransistor location (from lead chamber to gamma detector). The system consists of an ejector in which sample capsules are put and air-compressor releasing a compressed-air at an operating pressure of 0.2 MPa to transfer the capsule sample into the reactor for irradiation. The control unit is equipped with a programmable logic controller, software package, and other devices to facilitate optimal analytical procedures. 950 ms were only necessary to transfer the irradiated sample capsule (diameter: 17 mm, length: 56 mm, weight: 500 mg) to the HPGe detector at a distance of 18 meters using a compressed-air (0.2 MPa) as a transport gas.

The pressure in the storage tank or receiver is held higher (between a maximum of 0.6 MPa and a minimum of 0.4 MPa) than the system operating pressure (0.2 MPa) to compensate pressure loss in the pipes. A phototransistor is fixed at an appropriate location on top of the reactor and the other relocated from the lead chamber to the detector to avoid human intervention of picking sample from lead chamber onto the detector as part of this work. The phototransistors have two purposes; the first is to guarantee that the sample capsule has passed a certain point in the system; if that is not the case, the total process will be interrupted. The second is to start specific processes, such as irradiation timer, decay of sample, and measurements or counting of activity.

The detector is a high purity germanium (HPGe) for detection of photons. The analytical unit is a spectrometry system consisting of a high voltage to bias the detector, pre-amplifier to provide an output pulse with an amplitude proportional to the integrated charge output from the detector, main amplifier for amplification and pulse shaping, multi-channel pulse height analyzer sorting successive signal pulses into parallel amplitude channels (Glenn F. Knoll, 2000).

Design Requirements for Safety Systems and Components (SSCs)

Engineering safety features

The International Atomic Energy Agency (IAEA) requires that the design of Safety Systems and Components

Figure 3. Block diagram of the PTS control unit

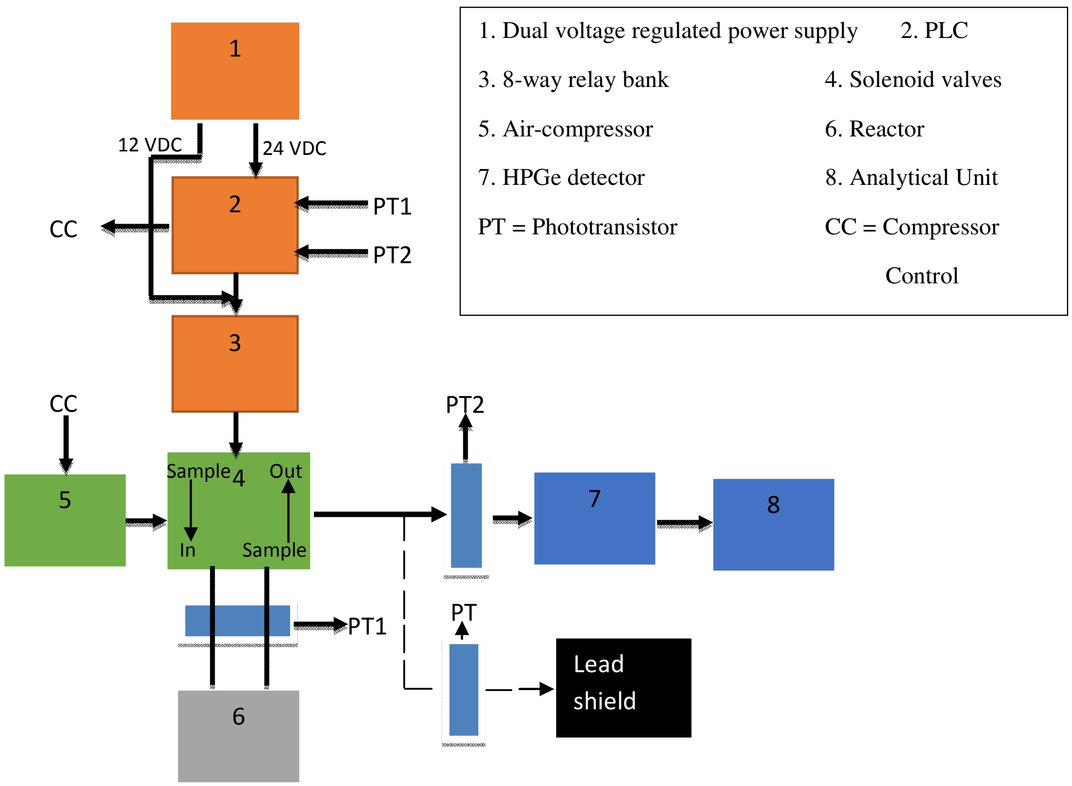

Figure 4. Flow chart for the PTS

(SSCs) of Research Reactors (RRs) follow a certain criteria so not to compromise the safety operations of RRs (IAEA, 2005; IAEA Specific Safety Guide No.SSG-39, 2016).

The PTS control unit designed, satisfies the design requirements as follows:

Pre-design appraisal

i. The PTS control unit designed satisfies the surveillance requirements, as well as decommission and disposal aspects will not interfere with the Reactor under normal operation.
ii. Provisions have been made for the inspection, periodic testing and maintenance (including simulation of the program) to verify that the engineering safety features continue to function or in a state of readiness to perform the functions and will be reliable and effective upon demand.
iii. Surveillance test points have been provided as means to measure the AC and DC voltages using externally connected testing devices. Potentiometers (POTs) have been provided for recalibration of the +12 and +24 DCV power supply.
iv. Under the design for testability, provision has been made for the PTS control unit to be put under real conditions by exposing the sensors (the phototransistors) of the system to actual process variable rather than simulation.

Safety Considerations for the design of an Experiment or Modification* (IAEA SPECIFIC SAFETY GUIDE No. SSG-24, 2012*)

The design of the controller unit for modification on the existing PTS demonstrates that:
i. the designed PTS control unit can fulfil the task for which it is intended

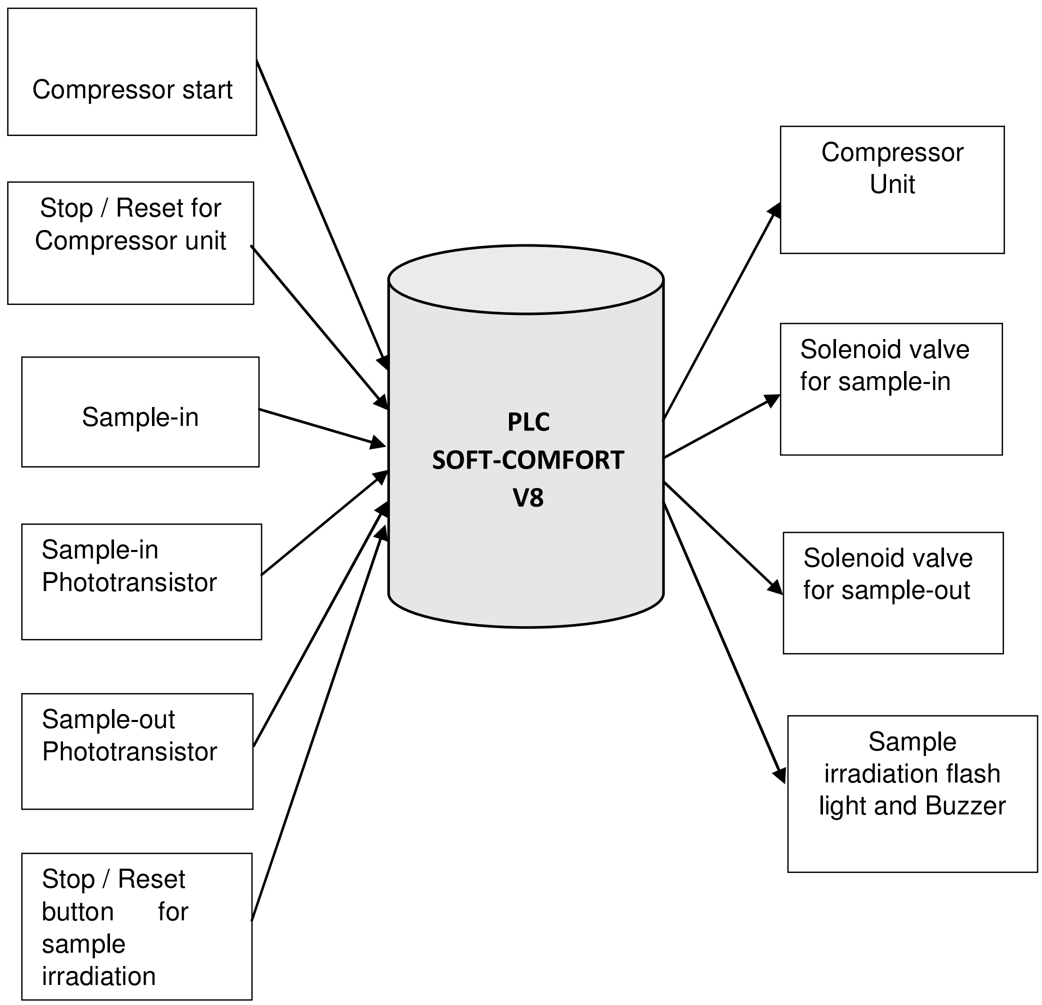

Figure 5. Context analysis diagram

ii. it can be installed and operated without compromising the safety of the Research Reactor
iii. the unit can be removed or decommissioned without compromising the safety of the RR.

PLC Control Unit

The illustration of components for the designed control unit is shown in Figure 3. The control unit consists of three main components, these are: high current dual voltage regulated power supply, PLC device and an 8-way relay bank of which five relays are used. The designed power supply has a dual voltage of +24 VDC and +12 VDC and could be regulated from its internal reference voltage minimum of 1.25 to a safe maximum voltage of 30 VDC at a safe operating current of 5 Amps. Two high current power transistors, 2N3055 and MJ 2955 were used alongside LM 317 voltage regulator which is capable of supplying 1.5 A (Texas Instrument, 2014). The +24 VDC operates the PLC and the +12 VDC controls the output switching system to operate the relay bank. The relay bank has eight +12 VDC relays that are controlled by the PLC output to supply a 220 VAC to operate the solenoid valves. Figure 4 shows a block diagram of a complete system flow of the PTS.The context analysis diagram shown in Figure 5 depicts the PLC software controlling five inputs and four outputs.

RESULTS AND DISCUSSIONS

Figure 6 shows the schematic diagram of the pneumatic transfer system control unit. The wiring starts from the dual voltage regulated high current power supply through the PLC, terminal block (T_1) to the relay bank. The relay bank connects through the terminal block (T_2) and (T_3) to the solenoid valves. I_1 to I_6 are the input switches used, and Q_1 to Q_3 are the outputs of the PLC used to control five (5) relays on the relay bank. Q_4 connects directly to an irradiation flash light and a buzzer which flashes and beeps during sample irradiation. Function block diagram

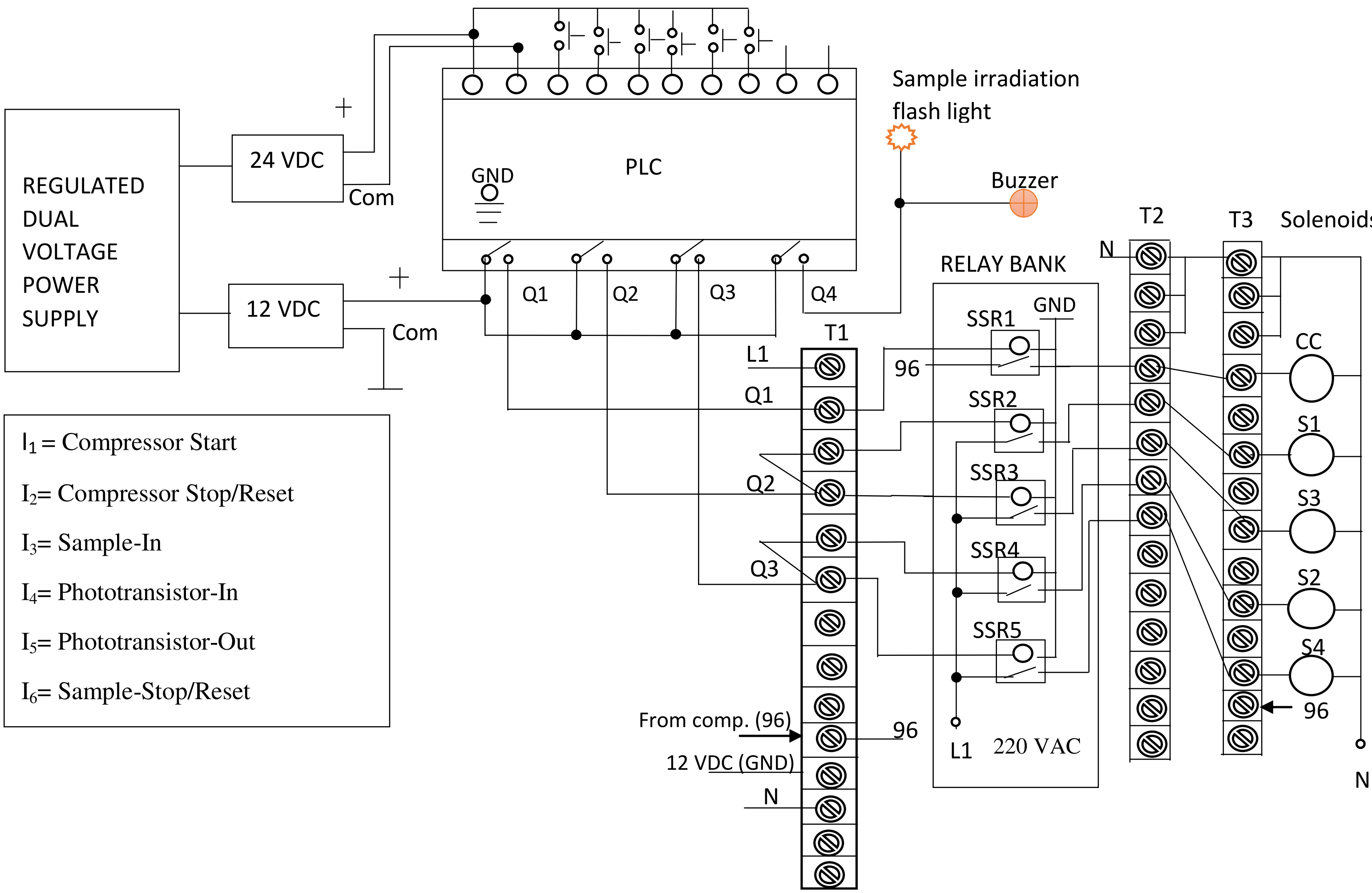

Figure 6. Schematic diagram of the designed PTS controller unit

(FBD) programming language is used for the design as shown in Figure 7. The PLC software program is designed to control the air compressor during sample irradiation through a timer B006. When a momentary switch I_1 start-button is depressed, timers B006 and B012 start working per the preset time allotted to the timers. The timer B012 has a special function of ensuring that the maximum pressure of the air compressor is built-up to 0.6 MPa, after which the 'sample-in' start-button could be operated. The air-compressor contactor coil Q_1 is energized by a 220 VAC, enabling a 3-phase 415 VAC to be connected across the compressor motor, see Figure 8. The irradiation timer B007 starts to count down as per the pre-set value and stop when irradiation period is over. The flash light flashes whiles the buzzer beeps when the irradiation is in

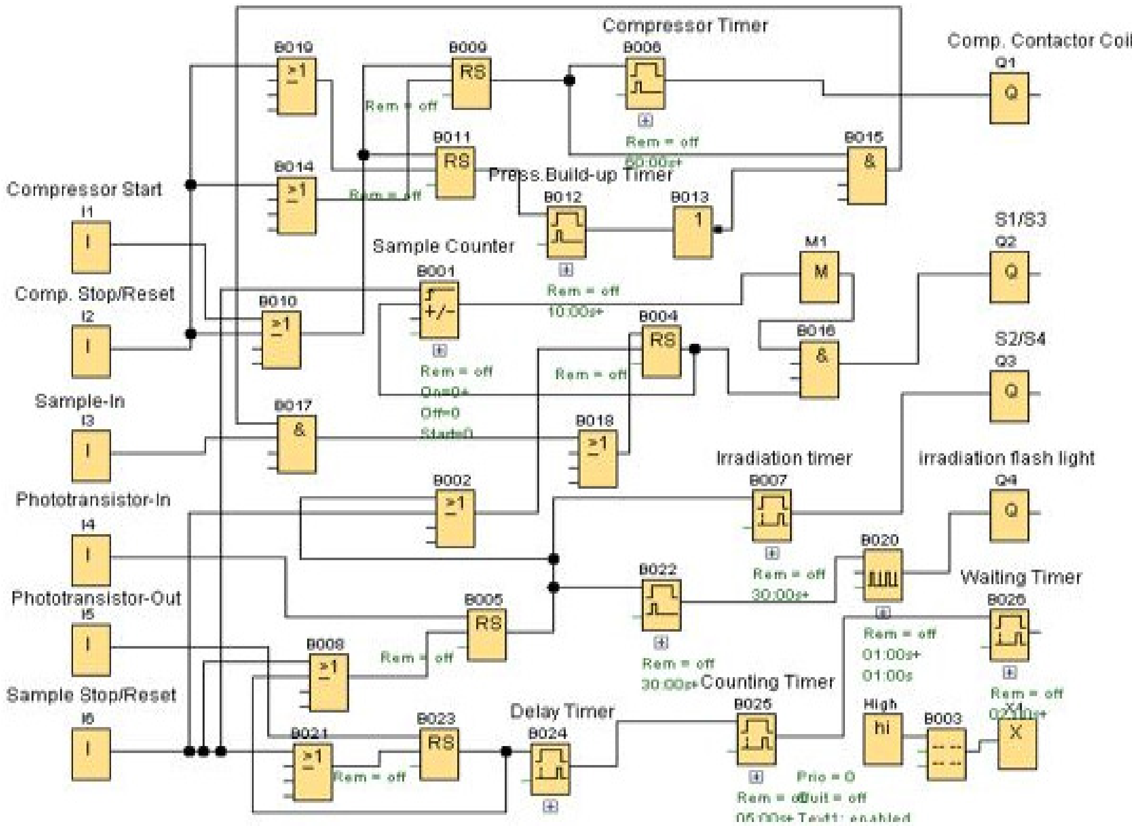

Figure 7. Newly designed function block diagram for conventional one-shot activation analysis

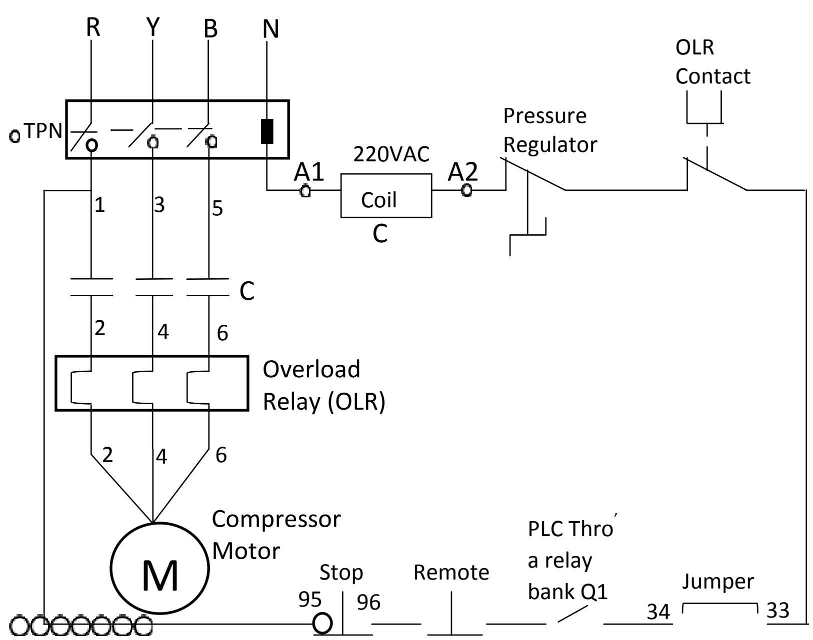

Figure 8. Schematic diagram for a remote control of air compressor system by PLC

progress. The momentary button I_2 could be pressed to interrupt the operation when a problem is detected and reset later to resume operation. The delay timer B024 (td), counting timer B025 (ti) and waiting timer B026 (tw) come into play when the phototransistor-out on top of the HPGe detector detects the sample. Momentary switches

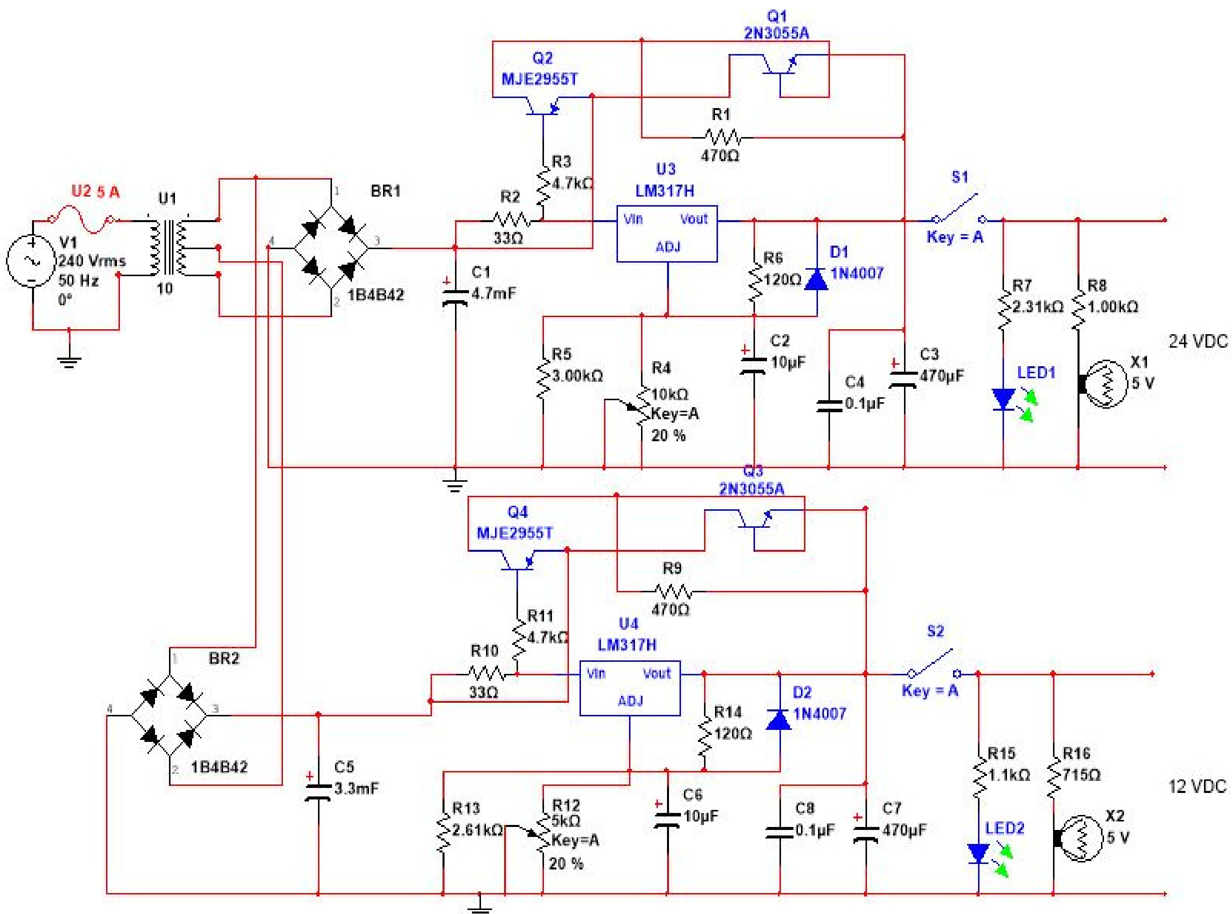

Figure 9. Dual voltage regulated power supply - +12/+24 VDC

Table 1. List of used circuit components

24 VDC		**12 VDC**	
Component ID	Part Number	Component ID	Part Number
IC U3	LM 317 TO-220	IC U4	LM 317 TO-220
Transistor Q1	2N3055 Metallic	Transistor Q3	2N3055 Metallic
Transistor Q2	MJE 2955	Transistor Q4	MJE 2955
Resistor R1	470 Ohms 0.5Watts	Resistor R9	470Ohms 0.5 Watts
Resistor R2	33 Ohms 5 Watts	Resistor R10	33 Ohms 5 Watts
Resistor R3	4.7 K 0.5 Watts	Resistor R11	4.7 Ohms 0.5 Watts
Resistor R4	10 K Potentiometer	Resistor R12	5 K Potentiometer
Resistor R5	3 K 0.5 Watts	Resistor R13	2.61 K 0.5 Watts
Resistor R6	120 Ohms 0.5 Watts	Resistor R14	120Ohms 0.5 Watts
Resistor R7	2.31 K 0.5 Watts	Resistor R15	1.1 K 0.5 Watts
Resistor R8	1 K 0.5Watts	Resistor R16	715 Ohms 0.5 Watts
Capacitor C1	4700 µF / 50 V Electrolytic	Capacitor C5	3300 µF / 63 V Electrolytic
Capacitor C2	10 µF / 50 V Electrolytic	Capacitor C6	10 µF / 50 V Electrolytic
Capacitor C3	470 µF / 50 V Electrolytic	Capacitor C7	470 µF / 50 V Electrolytic
Capacitor C4	104 Ceramic	Capacitor C8	104 Ceramic
Diode D1	IN4007	Diode D2	IN4007
Rectifier BR1		Rectifier BR2	
Transformer U1	15-0-15 Center Tapped 2 Amps Step Down Transformer		

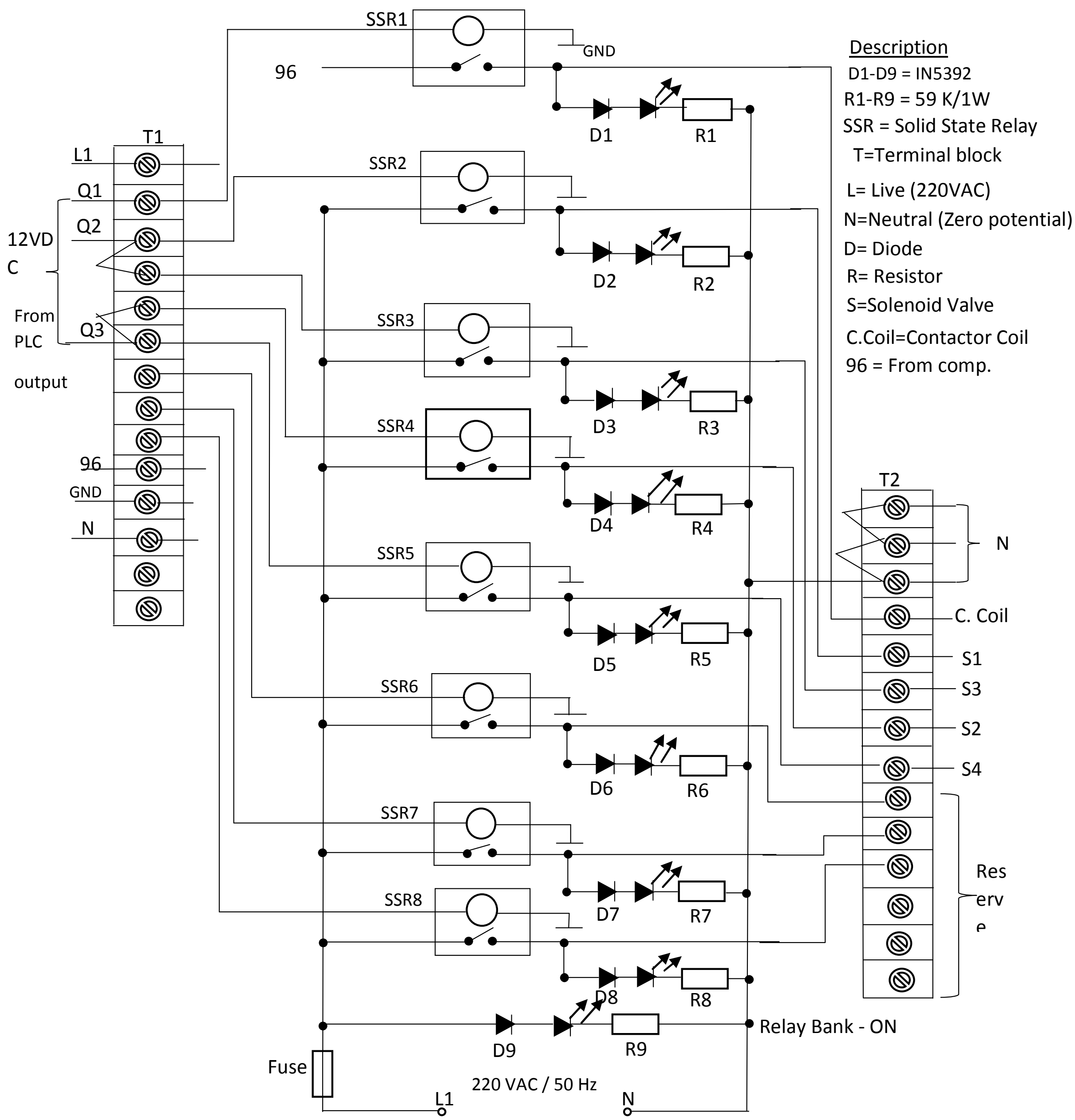

Figure 10. The designed 8-way relay bank to operate the solenoid valves

are used to represent the phototransistors (sensors). A High Current Dual Voltage regulated power supply (+12 / +24 VDC) has been designed to operate the PLC and the relays in the relay bank. A center tapped (15-0-15 CT) transformer U_1 converts the 240 VAC to 30 VAC and 15 VAC respectively and rectified by a separate full-wave rectifier (bridge type) D_1 and D_2. The output of the rectifiers are filtered (smoothing) by capacitors C_1 and C_4, shown in Figure 9. Table 1 shows the list of components used for the power supply. Figure 10 shows an 8-way solid state relay (SSR) bank designed to operate the solenoid valves. A 220VAC is connected across the solenoid valve (S) through the Solid State Relay (SSR) contacts to operate it using the Soft Comfort V8.0 of LOGO! Siemens software.

Simulation of PTS controller designed program

The design consists of six inputs (I_1 -1_6) and four outputs (Q_1-Q_4). Compressor start-button (I_1) is depressed and the compressor contactor coil energized. Timer B006 is set to keep the compressor (Q_1) running till the operation of the reactor is over, see Figure 11. Solenoid valves

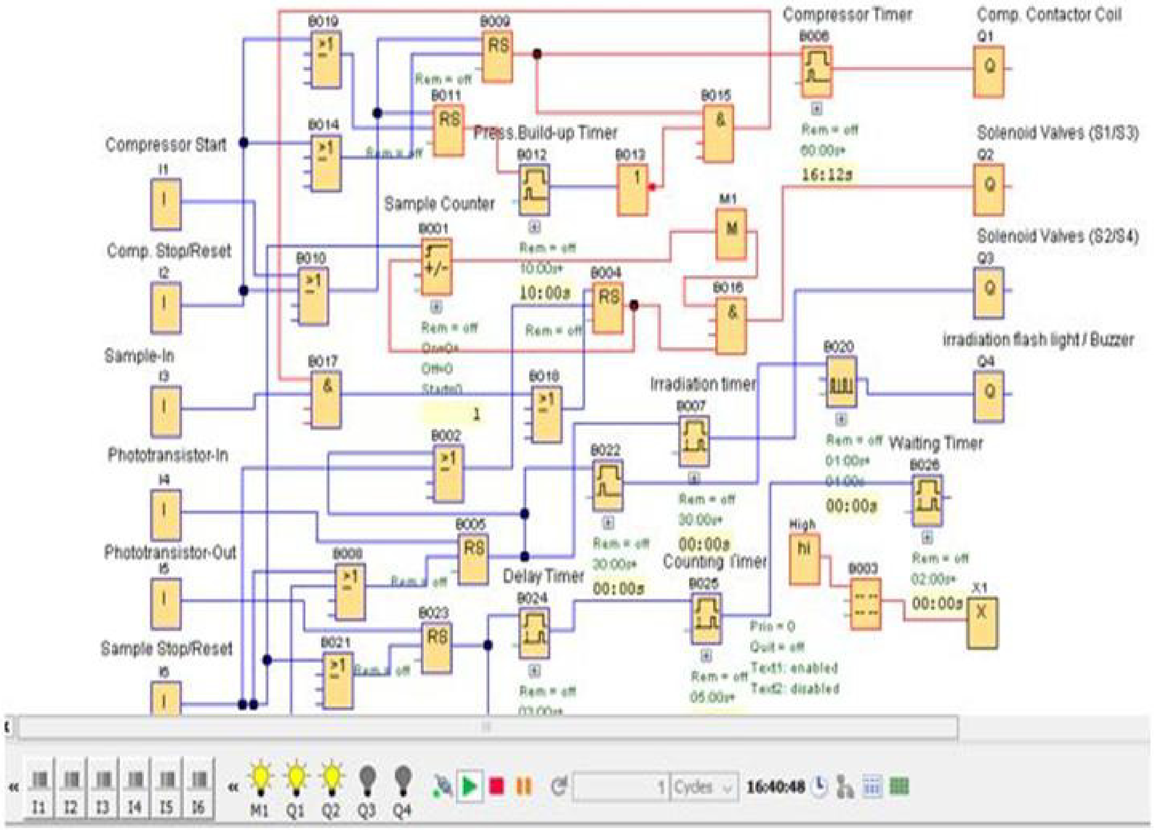

Figure 11. Energized compressor contactor coil and solenoid valves

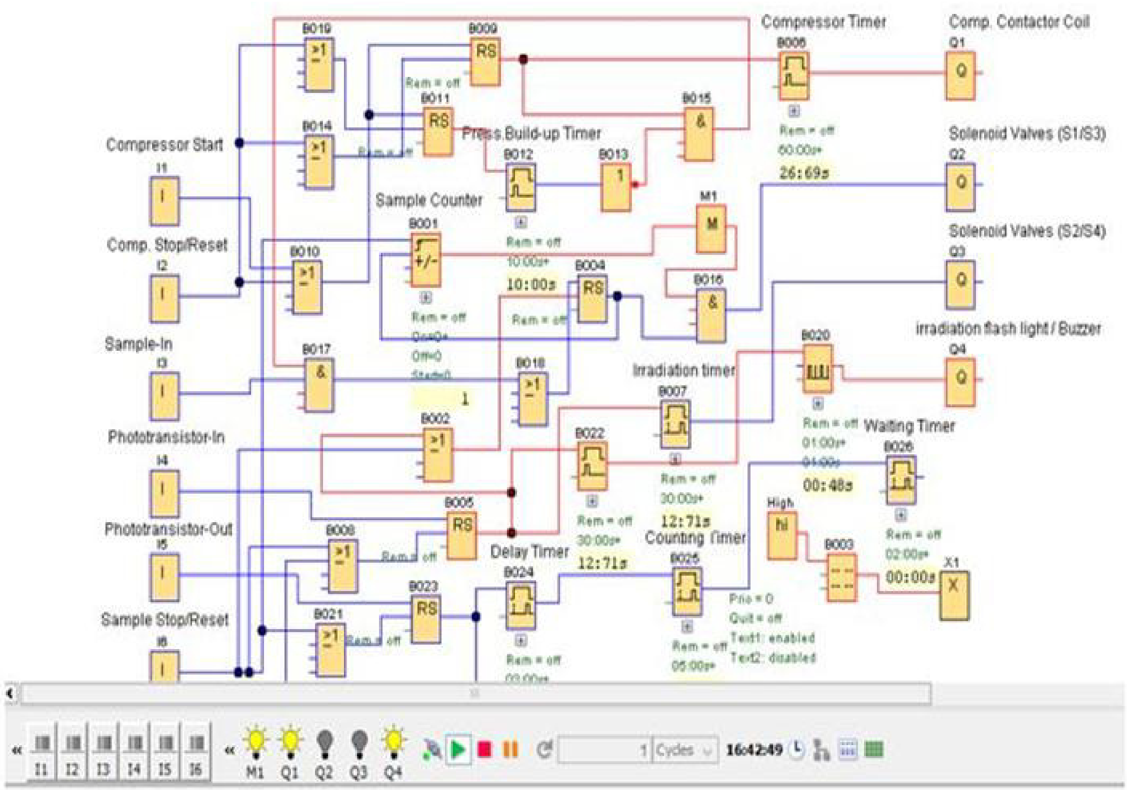

Figure 12. Irradiation light flashes up and buzzer beeps

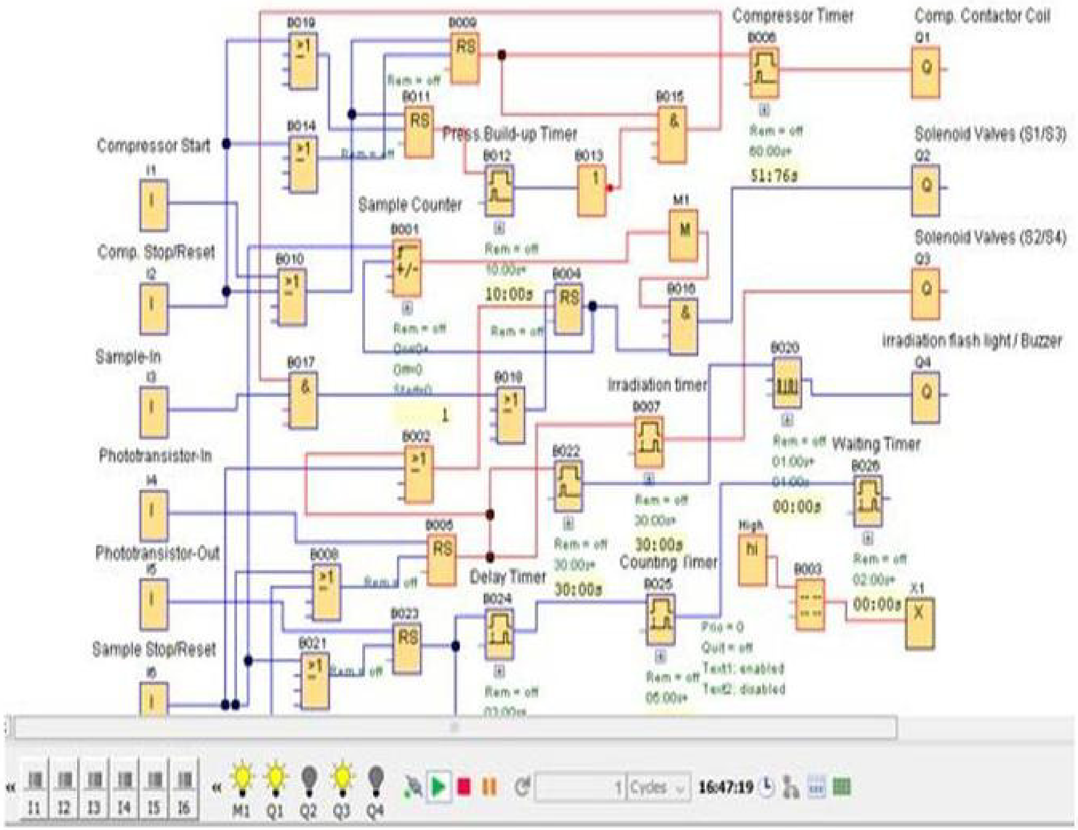

Figure 13. Solenoid valves S2/S4 energized, the sample is out of the irradiation site

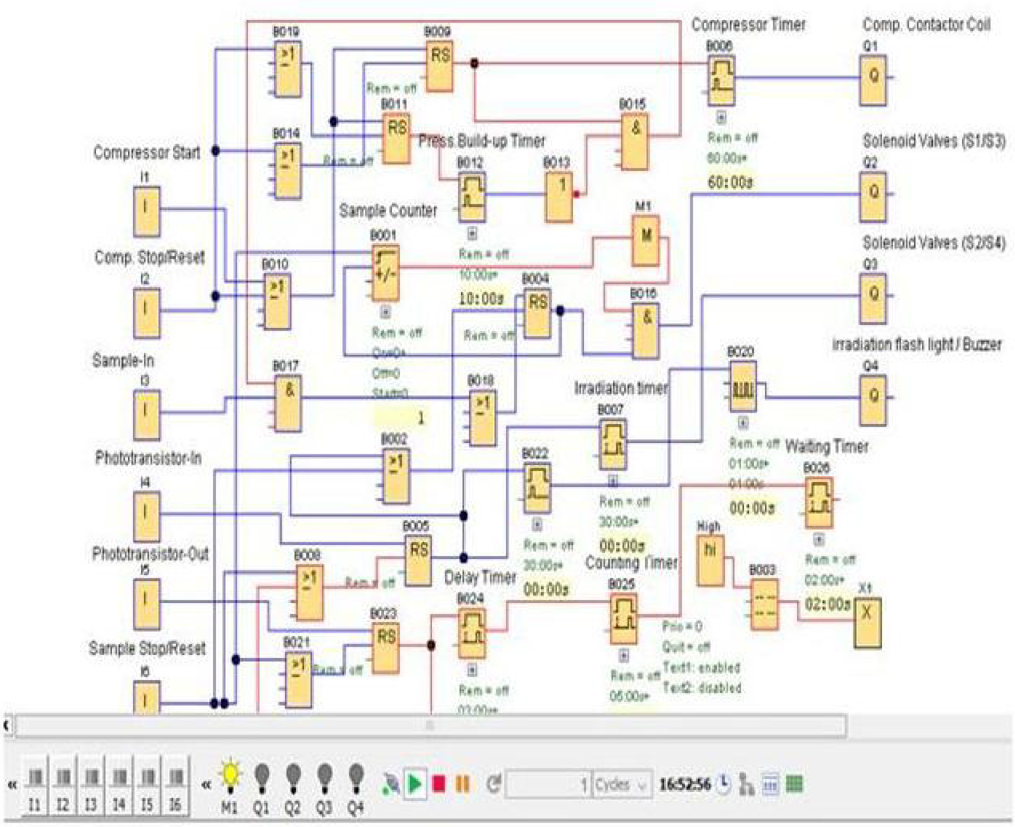

Figure 14. Completion of irradiation and Counting

(S_1/S_3) are activated when a sample-IN button (I_3) is depressed. The pressure build-up timer B012 enables the air pressure to get to the required level before the sample-IN button could be operated. The Phototransistor-IN on top of the reactor detect the sample (pressing the button I_4) and close the output Q_2 of solenoid valves S_1 / S_3. The output Q_4 in Figure 12 flashes up with associated beeps from a buzzer to indicate that sample irradiation is in progress. Irradiation timer B007 starts per the preset time. The output Q_3 in Figure 13 is energized to indicate that solenoid valves S_2 / S_4 are opened and the compressed-air transferred the sample onto the gamma detector for counting after the irradiation. Phototransistor-OUT on top of the gamma detector detects the sample and closes output Q_3 of solenoid valves S_2 / S_4. Delay timer (t_d) B024, counting timer (t_c) B025 and waiting timer (t_w) B026 start in that sequence. Figure 14 shows that the irradiation and counting processes are over. M_1 is a flag to ensure connectivity.

CONCLUSION

The design of pneumatic transfer system controller unit to facilitate neutron activation analysis using PLC to transfer sample capsule into and out of the reactor irradiation sites has been developed. Function Block Diagram (FBD) programming method was used for the design. The computer simulation results show that the LOGO! Soft Comfort software (from Siemens Company, Inc.) is capable of effecting NAA application. It was observed during the simulation that, the PLC is able to start and control the air-compressor machine remotely from the PTS room. Two solenoid valves open for a compressed-air to transfer sample capsule into the reactor for irradiation when the sample-IN button is depressed. Phototransistors (on top of the reactor and on the detector) control the solenoid valves and the movement of the samples. The study has shown that the computer based PLC control unit for PTS can be used to replace the existing one to enhance NAA application at GHARR-1. This approach would ensure the facility's maintainability in the future.

Data Availability Statement

Logo 8 Siemens Programmable Controller Logic (PLC)

The PLC used for this study is LOGO! Base Module 12/24 RCE Controller, 8 digital inputs and 4 relays (10Amps) outputs (6ED1 052-1MD00-0BA8) from Siemens Industrial Automation Products Ltd. LOGO! Soft Comfort V8.0 is LOGO! Programming software used for the study. It runs under Windows (including Windows XP, Windows 7, and Windows 8), Linux, and Mac OS X.Additional support is available on the Siemens LOGO! Web site, (http://www.siemens.com/logo)

Power supply design

The power supply was designed using Multisim version 12.0 from National Instruments. The program could be retrieved from (www. ni.com/Multisim). 2N3055 (NPN), MJ2955 (PNP), (2015). Complementary Silicon Power Transistors (6th revision)". Retrieved from http://www.onsemi.com/pub_link/.Collateral/2N3055-D.PDF) Semiconductor Components Industries, LLC.

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Conflict of Interests

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