DESIGN OF A TRAFFIC SIGNAL CONTROL SYSTEM USING PLC AND HMI

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INTRODUCTION

In the process of national development and modernization, the construction and management of urban traffic infrastructure have increasingly received attention. One of the key factors in ensuring safety, reducing congestion, and improving traffic efficiency is the traffic signal system. Automating this system not only brings practical benefits to urban management but also enables students to approach and apply the knowledge they have learned in practice.

At present, automatic control technology using PLC (Programmable Logic Controller) and HMI (Human Machine Interface) is widely applied in many industrial fields and in daily life thanks to its flexible control capability, ease of supervision, and high reliability.

Due to limited professional knowledge, this project inevitably contains shortcomings. I sincerely look forward to receiving guidance and comments from lecturers and fellow students so that the project report can be further improved.

I would like thank Thai Nguyen University for helping me complete this design on schedule.

Chapter 1: System overview and implementation method

1. System overview

1.1. General introduction to the system

In the context of increasingly rapid urbanization, traffic volume in major cities is rising quickly, creating many challenges in effective traffic management and regulation. One of the important solutions for reducing congestion and traffic accidents is the application of automatic control systems for traffic signals.

The traffic light system using PLC (Programmable Logic Controller) and HMI (Human Machine Interface) is a practical application of automation technology in urban transportation. The PLC is responsible for controlling the operating cycles of the traffic lights accurately, flexibly, and in a manner that can be easily modified according to actual requirements. Meanwhile, the HMI provides a friendly interface that allows operators to monitor the operating status of the system, carry out adjustment operations, or handle faults in an intuitive and convenient way.

The deployment of a PLC-controlled traffic light model combined with an HMI not only improves traffic management efficiency but also opens a modern approach for future smart city solutions.

1.2. Project objectives

1.2.1. General objective

Design, simulate, and build a model of an automatic traffic light system at a four-way intersection with four traffic approaches, using a PLC as the central controller and an HMI screen as the display and control interface.

1.2.2. Specific objectives

Design a PLC control program with stable operation, clear logic, and compliance with traffic safety principles.

Develop an intuitive HMI interface to display the operating status, countdown time, and allow users to adjust signal timing.

Design the system principle diagram, control block diagram, and algorithm flowchart.

Ensure that the model is expandable, easy to maintain, and practically applicable.

1.3. Significance of the project

1.3.1. Practical significance

Helps reduce traffic pressure at complex intersections.

Applies PLC technology in daily life and enhances urban automation capability.

Increases flexibility: the signal timing can be changed easily, the system scale can be expanded, or sensors can be integrated.

Helps learners master the process of designing, programming, and operating industrial control systems.

1.3.2. Educational and research significance

Provides a practical model for students majoring in electrical engineering and automation.

Helps students become familiar with PLC programming and HMI interface design.

Serves as a foundation for subsequent studies such as intelligent control using sensors, artificial intelligence, or IoT connectivity.

1.4. Analysis of technological requirements

a) Technological requirements

Technological requirement: After pressing the Start button (M), green light 1 turns on while red light 2 turns on simultaneously. After 30 s, green light 1 turns off and yellow light 1 turns on for 3 s. Then red light 1 turns on, red light 2 turns off, and green light 2 turns on. After 15 s, green light 2 turns off and yellow light 2 turns on for 3 s. The system then continues to repeat. If the Stop button (D) is pressed at any moment, the system stops and runs again when the Start button is pressed.

b) Analysis of technological requirements for the system

The system includes the following states:

State 1: Press Start -> red light 2 ON and green light 1 ON.

State 2: Green light 1 remains ON for 30 s, then turns OFF; yellow light 1 turns ON.

State 3: Yellow light 1 remains ON for 3 s, then turns OFF; red light 2 turns OFF, and green light 2 and red light 1 turn ON.

State 4: Green light 2 remains ON for 15 s, then turns OFF; yellow light 2 turns ON.

State 5: Yellow light 2 remains ON for 3 s, then turns OFF; red light 1 turns OFF, and green light 1 and red light 2 turn ON. The system automatically repeats the above sequence.

1.5. Some commonly used programmable logic controllers (PLCs) at present

1.5.1. Mitsubishi PLC

Introduction:

Mitsubishi PLC is a PLC product line manufactured by Mitsubishi Electric (Japan), well known for its stability and high reliability, and widely used in industry in Vietnam. The most common series at present is the FX series (FX1N, FX2N, FX3U, FX5U).

Figure 1.1. Mitsubishi Electric is widely used in Vietnam

Advantages:
Compact design and easy installation.
High reliability and stable operation in industrial environments.
Fast processing speed and support for many expansion modules (analog, communication, I/O, HMI, etc.).
GX Works2/3 programming software is easy to use and friendly to learners and automation engineers.
Good compatibility with the company's HMI devices (GOT1000, GOT2000).
Reasonable cost for students and small-to-medium projects.
Disadvantages:
Limited industrial network connectivity in older series (FX1N, FX2N).
Vietnamese documentation is still limited.
No direct display screen on the PLC.

1.5.2. Siemens PLC

Introduction:
Siemens PLC (Germany) is a world-leading automation brand, especially the S7-1200, S7-1500, S7-300, and S7-200 series. It is commonly used in large factories and complex automation systems.

Figure 1.2. Common Siemens PLC series

Advantages:
High processing speed and strong expandability.
Support for many communication standards (Profibus, Profinet, Ethernet).
Integrated and intuitive TIA Portal programming software.
Easy connection with Siemens SCADA, HMI, and inverters.
Abundant documentation and a large user community.
Disadvantages:
Higher price than other PLC lines.
TIA Portal is heavy and requires a high-configuration computer.
Initial installation and configuration are more complex for beginners.

1.5.3. Omron PLC

Introduction:
Omron PLC (Japan) is widely used in small- and medium-scale production lines, especially in industrial machine control systems.

Figure 1.3. Omron PLC widely used in practice

Advantages:
Compact design and easy wiring.
CX-Programmer software is easy to use and supports many programming forms (Ladder, Function Block).
Relatively fast processing speed.
Support for many I/O and communication modules.
Disadvantages:
Fewer advanced features than Siemens or Mitsubishi.
Its address structure differs somewhat from other PLC lines, so beginners can easily be confused.

1.5.4. Delta PLC

Introduction:
Delta PLC (Taiwan) is a popular PLC line in Vietnam because it is low-cost, easy to learn, and suitable for students and small enterprises.

Figure 1.4. Delta PLC from Taiwan is commonly used

Advantages:
Low cost and easy to purchase.
WPLSoft / ISPSoft software interface is simple and easy to operate.
Can be easily connected with Delta HMI.
Relatively good processing speed in basic applications.
Disadvantages:
Lower stability than Mitsubishi and Siemens.
Fewer expansion modules and more difficult integration into large systems.
Limitations in advanced networking and communication features.

1.5.5. Allen-Bradley PLC (Rockwell Automation)

Introduction:
Allen-Bradley PLC (USA) is a professional PLC line widely used in North America and in large-scale factories.

Figure 1.5. Allen-Bradley PLC line from the USA

Advantages:
Very high performance, suitable for complex SCADA systems.
Powerful RSLogix software supporting structured programming and simulation.
Support for many advanced industrial communication protocols.
Disadvantages:
Very expensive and unsuitable for student projects or small systems.
Heavy software and expensive licensing.
Vietnamese documentation is almost unavailable.

1.6. Overview of automatic control systems

1.6.1. Concept of automatic control

Automatic control is a control process in which the input and output variables of a system are adjusted automatically according to predetermined laws without direct human intervention. The purpose of automatic control is to ensure that the system operates stably, accurately, and efficiently.

1.6.2. Basic structure of a control system

A basic automatic control system includes three parts: the controlled object (plant), the controller, and sensors/actuators. The controlled object is the process or device to be controlled (here, the traffic signal system). The controller receives input signals, processes them according to the control algorithm, and issues corresponding commands (PLC). Sensors and actuators receive physical signals such as push buttons or vehicle sensors and act on the signal lights.

1.6.3. Classification of control systems

Open-loop control: there is no feedback from the output, for example a traffic light operating with a fixed time cycle. Closed-loop control: there is a feedback signal, for example a traffic light system controlled according to vehicle density detected by sensors.

1.7. Theoretical basis of PLC and HMI

1.7.1. Concept of PLC

PLC (Programmable Logic Controller) is a programmable logic control device developed to replace electromechanical relay control circuits. A PLC executes control commands based on a pre-programmed user program.
The main tasks of a PLC include:
Receiving input signals from sensors, switches, etc.
Processing signals according to the control program.
Outputting control signals to actuators such as lights, relays, motors, etc.

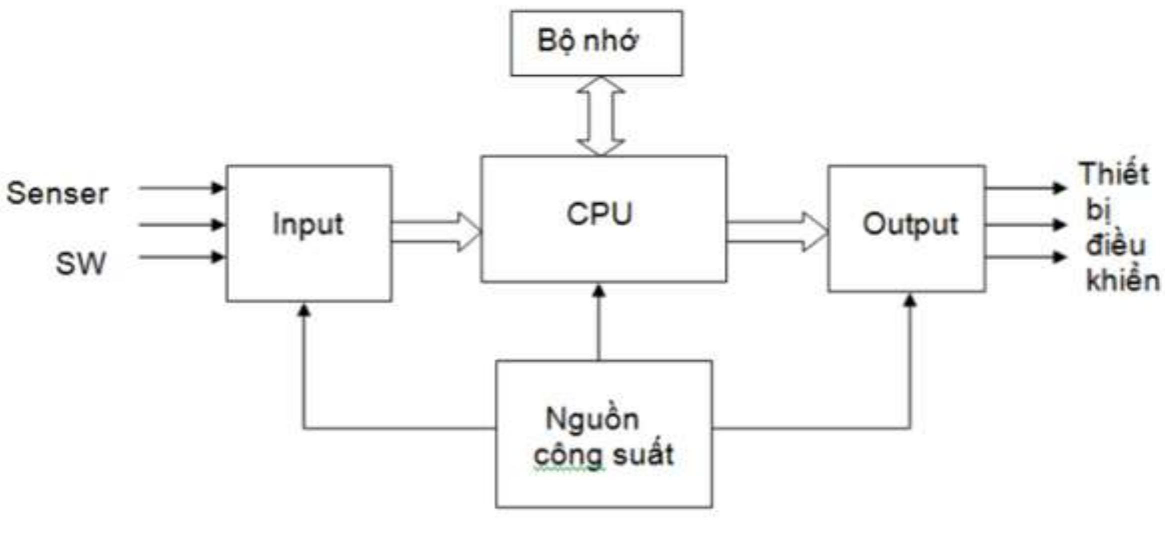


Figure 1.6. Basic operating diagram of a PLC

1.7.2. Basic structure of PLC

Central processing unit (CPU): executes the control program.
Input module: receives signals from sensors, push buttons, etc.
Output module: controls lamps, relays, and peripheral devices.
Memory: stores the program and temporary data.
Power supply unit: supplies power to the entire system.

1.7.3. HMI - Human-Machine Interface

Figure 1.7. GOT2000 HMI image of the system interface

HMI (Human Machine Interface) is a device that allows users to interact directly with the control system. In industry, an HMI helps to:
Observe the operating status of the system.
Adjust operating parameters.
Display warnings, faults, or incidents.
Help operators control the system easily without requiring deep understanding of PLC operation.

1.8. Structure of the traffic light control system

The system includes the following main functional blocks:
Power supply block: provides stable voltage for the PLC and HMI.
Central control block (PLC): executes the control program.

Output signal block: LED lamps simulating red, yellow, and green lights.
HMI interface block: displays information and allows user interaction.

1.9. Control method

The system operates according to a preset cycle. Each direction is assigned a certain green-light interval, followed by yellow and red. The cycle is programmed in the PLC and can be modified via the HMI.

1.10. Design criteria

Ensure safety and avoid signal conflicts.
Provide reasonable timing cycles.
Allow easy observation and adjustment.
Be expandable in the future.

1.11. General structure of an automatic control system

In general, an automatic control system includes three basic components:
Measurement block (sensors): collects physical signals from the actual environment (for example vehicle arrival signals, pedestrian push buttons, light sensors, etc.). These signals are converted into electrical signals and fed into the PLC.
Control block (PLC): is the processing center where the control program is pre-programmed. The PLC performs logical comparisons, time counting, and corresponding control decisions.
Actuation block (control mechanism - traffic lights): receives control signals from the PLC and performs actual actions such as turning red, yellow, and green lights on and off.
In addition, the system also includes the human-machine interface block (HMI), which helps operators observe, monitor, adjust, and intervene when necessary.
The coordinated operation among the above blocks enables the system to operate accurately, stably, and with easy maintenance.

1.12. Traffic light control model at a four-way intersection

The control system is built for a standard four-way traffic intersection with four directions: East-West-South-North. Each direction includes three signal lights:
Red light: movement prohibited.
Yellow light: indicates an upcoming phase transition.
Green light: movement permitted.
Operating principle:
Two opposite directions are allowed to have green lights at the same time (for example East-West, or South-North).
When one pair of directions is green, the other pair must be red to avoid collisions.
After the green interval ends, the system switches to yellow for about 5 seconds, then turns red to transfer the right of way.
The system operates in an automatic cycle programmed in the PLC and can be adjusted via the HMI.

1.13. Block diagram of the system operating principle

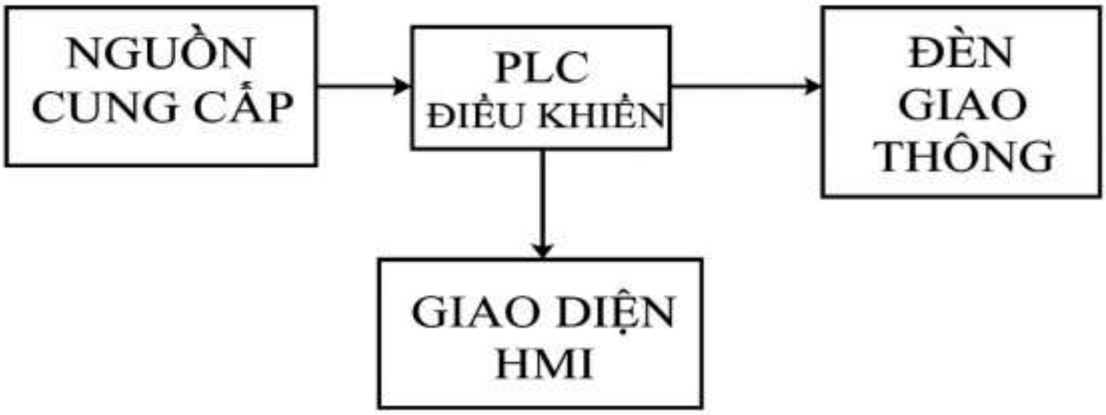


Figure 1.8. Block diagram of the operating principle of the traffic light system

Control principle

Phase	**Priority direction**	**Green light (s)**	**Yellow light (s)**	**Red light (s)**
1	East-West	25	5	25
2	South-North	25	5	25

Figure 1.9. Table of traffic light operating principles

1.14. Design and programming principles

When designing the system, the following principles must be observed:
Logical consistency: two perpendicular directions must not be allowed to have green lights at the same time.
High reliability: the PLC operates continuously, withstands interference, and avoids signal conflicts.
Flexibility: phase times can be changed easily via the HMI without re-downloading the program.
Modularity: the system is divided into independent blocks for convenient maintenance and expansion.

1.15. Overall operation description

When started, the PLC automatically sets all lights to the initial state (all-red condition).
The system then begins the operating cycle:
Phase 1: the East-West direction turns green, while North-South remains red.
After the green interval ends, the yellow light turns on for 5 seconds, then the phase changes to red.
The PLC waits for a short interval to ensure there is no phase overlap.
Phase 2: the North-South direction turns green, while East-West remains red.
The cycle repeats continuously.
The timing of each phase is displayed on the HMI and can be changed to suit actual conditions.

1.16. Advantages and disadvantages of using PLC in traffic light systems

Advantages:
High reliability and stability.
Capable of continuous 24/7 operation.
Flexible programming and easy adjustment.
Easy system expansion and upgrading.
Easy integration with HMI and other I/O modules.
Disadvantages:
Initial investment cost is higher than discrete electronic circuits.

Personnel with specialized knowledge are required for programming and maintenance.
If the PLC fails, the entire system may stop operating (if no backup is available).

1.17. Practical applications of automatic traffic light control systems

Intersections in urban areas, industrial zones, and factory gates.
Training models in technical universities.
Testing of priority-control systems for ambulances and police vehicles.
Research and development of intelligent control systems with vehicle-counting sensors.

1.18. Future development trends

Modern traffic light control systems are being developed toward automation and intelligence, combined with:
Traffic flow detection sensors (camera, radar).
Priority control for public-service vehicles.
SCADA or IoT network connection for centralized supervision.
Adaptive control: signal timing changes based on actual traffic density.
This combination forms an intelligent transportation system (ITS), contributing to congestion reduction and accident prevention.

1.19. Chapter 1 summary

This chapter systematized the theoretical basis, technical requirements, and overall solution for the project "Design of a traffic signal control system using PLC and HMI". Specifically:
Problem statement and urgency: presented the context of urbanization, traffic congestion, and the need for automation to improve traffic regulation efficiency, reduce accidents, and optimize travel time.
Project objectives: clearly identified the general and specific objectives of the project (four-way intersection simulation, sequential control algorithm design, HMI interface construction for monitoring and parameter adjustment).
Theoretical basis: explained the concepts of open-loop and closed-loop control systems, PLC structure, scan cycle principle, and the role of HMI in supervision and operation.
Traffic light system analysis: described the three-color control structure (red-yellow-green), phase-based operating principle, safety constraints (not allowing two perpendicular directions to be green simultaneously), and basic scenarios (automatic mode, manual mode, emergency stop mode).
Overall method: presented the system block diagram (power supply -> PLC -> I/O module -> lights -> HMI), cyclic programming principle, input/output signal requirements, and expansion capability (sensors, network connection, priority vehicles).
Comparison of solutions: compared the advantages and disadvantages of the PLC + HMI method with traditional relay circuits and microcontroller-based solutions, and presented the technical basis for selecting PLC at the overall analysis level.

Chapter 2: PLC selection analysis and principle diagram design

A. PLC selection analysis

2.1. General introduction

In modern life, the traffic signal system plays an extremely important role in regulating traffic, ensuring safety, and reducing congestion for vehicles. Today, together with the development of automation technology, traffic light systems no longer operate manually but are fully controlled by programmable logic controllers (PLCs) combined with HMI screens for easy monitoring and parameter setting.
The project "Design of a traffic signal control system using PLC and HMI" is developed with the objective of simulating, controlling, and displaying the operation of a two-direction traffic signal system (N1 and N2). The system can operate fully automatically, ensuring the correct sequence of operation: Green - Yellow - Red, alternately between the two directions.
The system is designed based on the Mitsubishi FX3U PLC, a popular industrial PLC series with flexible expansion capability and easy connection with peripheral devices such as HMI, sensors, switches, and indicator lamps.
In addition, the HMI (Human Machine Interface) is used to supervise operation, adjust light timing, and perform Start/Stop directly on the screen without operation at the control cabinet.

2.2. Analysis of system requirements

To design a suitable traffic signal system, it is first necessary to clearly determine the number of signals, operating sequence, control timing, and operating method. To do this, GX Works2 is used:

Figure 2.1. GX Works2 application used for PLC control programming

2.2.1. Problem description

The traffic signal system includes two perpendicular traffic directions, referred to as direction 1 (N1) and direction 2 (N2).
Each direction has three signal lights: Red - Yellow - Green.
The lights operate alternately, ensuring that the two directions are never green at the same time.
When the Start button (X0) is pressed, the system begins sequential operation.
When Stop (X1) is pressed, all lights turn off and the system stops.
Y0 is the system lamp and turns on when the program is running.
Basic operating sequence:
When N1 green light (Y1) is ON -> N2 red light (Y4) is ON.
After the preset time, N1 yellow light (Y3) turns ON -> indicating an upcoming stop.
Next, N1 red light (Y1) turns ON and N2 green light (Y5) turns ON -> phase transfer to direction N2.
The cycle repeats continuously.

2.2.2. Technical requirements

Fully automatic control using PLC.
The illumination time of each phase can be set or adjusted through the HMI.
Physical push-button Start/Stop operation is available (X0, X1).
The signal lights are controlled via relay outputs (Y0-Y6).
Use a 24 VDC power supply for the PLC and control buttons.

2.2.3. Identification of input/output signals

Type	Address	Symbol	Description
Input	X0	Stop	System stop button
	X1	Start	System start button
	Y0	System lamp	System status lamp
Output	Y2	N1 green light	Permission to move in direction 1
	Y1	N1 red light	Stop in direction 1

	Y3	N1 yellow light	Phase transition for direction 1
	Y5	N2 green light	Permission to move in direction 2
	Y6	N2 red light	Stop in direction 2
	Y4	N2 yellow light	Phase transition for direction 2
Data registers	D0-D13		Signal timing and HMI data transmission

2.4. PLC selection analysis

2.4.1. General introduction to PLC

PLC (Programmable Logic Controller) is a programmable control device that allows users to design logical control algorithms to replace traditional relay, timer, and contactor circuits.

PLC has the following advantages:

Compact size and easy installation.

Stable operation in industrial environments.

Easy program modification, expansion, or repair.

Support for many signal types and communication with peripheral devices.

A basic PLC includes:

Power Supply: provides power to the whole system.

CPU block: processing center that reads the program and executes the control logic.

Input: receives signals from sensors and push buttons.

Output: outputs control signals to external devices (lights, relays, etc.).

Memory: stores the program and temporary data.

2.4.2. Criteria for selecting the PLC for the system

To select an appropriate PLC, the following criteria should be considered:

The required number of input/output (I/O) points.

Signal type (digital or analog).

Module expansion capability when needed.

Communication capability with the HMI.

Price and popularity of the PLC line.

The traffic light system in this project has a total of:

2 digital inputs (Start, Stop)

7 digital outputs (indicator lamp and signal lights)

Therefore, the total number of I/O signals is 9, so a PLC with at least 10-14 I/O is required.

2.4.3. Selection of Mitsubishi FX3U PLC

After comparing common PLC lines such as Siemens S7-200, Omron CP1L, Delta DVP14SS2, and Mitsubishi FX3U, the Mitsubishi FX3U PLC was selected for this project.

Figure 2.2. Mitsubishi FX3U PLC used for the system
Reasons for selection:
Suitable number of I/O: FX3U provides from 14 to 64 I/O depending on the version, satisfying the requirements of a two-direction traffic signal system.
Easy communication with HMI: supports RS-232/RS-485 communication standards for connection with Mitsubishi HMI screens or other brands.
Simple programming: GX Works2 software with Ladder language is easy to understand and commonly used in teaching.
Reasonable price, common components, and easy replacement in practice.
Support for module expansion, allowing integration of priority vehicle sensors, real-time control, or synchronization with other intersections.

Parameter	Value
Supply voltage	24VDC or 220VAC
Number of inputs	8 to 32 digital inputs (X0-X31)
Number of outputs	8 to 32 digital outputs (Y0-Y31)
Output type	Relay or transistor
Program memory	64K steps
Instruction processing time	0.065 us/instruction
Communication ports	RS-232, RS-485, mini USB
Programming languages	Ladder Diagram (LD), Function Block (FB), Instruction List (IL)
Programming software	GX Developer, GX Works2
Operating environment	0-55°C, humidity < 95%
Manufacturer	Mitsubishi Electric (Japan)

Selection conclusion:

With the above technical characteristics, the FX3U PLC fully satisfies the traffic light control requirements of this project.

The PLC can operate stably and reliably, supports HMI connection for time display and parameter adjustment, and makes the system both automatic and easy to operate.

2.5. Design of the system principle diagram

2.5.1. Design objectives

The objective of designing the principle diagram is to identify the method of connection among the elements in the system such as:

PLC (central processing unit)
Control push buttons (Start/Stop)
Traffic signal lights
System status indicator lamp
HMI screen
Power supply

From the principle diagram, it is possible to perform wiring easily, check operation, and program in accordance with the actual operating procedure.

2.5.2. General operating principle

When the Start button (X0) is pressed, the PLC program is activated.

The light control process operates in a closed cycle as follows:

Stage 1: N1 green light (Y2) ON, N2 red light (Y4) ON. Duration: T1 (stored in register D0).
Stage 2: N1 yellow light (Y3) ON, N2 red light (Y6) ON. Duration: T2 (stored in D1).
Stage 3: N1 red light (Y1) ON, N2 green light (Y5) ON. Duration: T3 (stored in D2).
Stage 4: N1 red light (Y1) ON, N2 yellow light (Y6) ON. Duration: T4 (stored in D3).

At the end of the cycle, the system returns to stage 1 and repeats continuously until Stop (X1) is pressed, at which point all lights turn off and the system stops.

2.5.3. System block diagram

The general block diagram includes the following main parts:

220VDC power supply block: supplies power for the PLC, push buttons, and relay modules controlling the lights.

PLC FX3U: receives control signals, processes the program, and outputs commands to control the lights.

Start/Stop push buttons: start or stop the control program.

Signal lamps: receive control signals from the PLC via outputs Y0-Y5.

HMI screen: communicates with the PLC through the communication port to display signal timing and operating status and to allow parameter modification.

2.5.4. PLC address connection table

Type	Address	Symbol	Function description	Notes
Input	X1	Stop	System stop push button	NC
	X0	Start	System start push button	NO
	Y0	System lamp	System indication	
Output	Y2	N1 green light	Permission to move in direction 1	Relay module
	Y1	N1 red light	Stop indication for direction 1	Relay module
	Y3	N1 yellow light	Phase transition indication for direction 1	Relay module
	Y5	N2 green light	Permission to move in direction 2	Relay module
	Y6	N2 red light	Stop indication for direction 2	Relay module
	Y4	N2 yellow light	Phase transition indication for direction 2	Relay module
Data registers	D0-D13		Registers storing phase times	HMI link

2.5.5. Principle wiring diagram design

220VDC power is supplied to the PLC.

Terminal X0 is connected to the Start push button (normally open, NO type).

Terminal X1 is connected to the Stop push button (normally closed, NC type).

Outputs Y0-Y6 are connected to a relay module to control the 220V signal lamps.

The intermediate relays supply 24V power to the red, yellow, and green lamps of the two directions N1 and N2.

The HMI screen is connected to the PLC via the RS-232 port (COM port) to display signal timing, operating status, and allow adjustment of each phase time.

2.6. Description of each block operation

a) Power supply block: supplies 220VDC for the PLC and control devices. In addition, the system uses an intermediate relay module to control the 24V lamps, ensuring safe isolation between the control circuit and the power circuit.

b) Central control block (PLC): receives control signals from the Start/Stop push buttons, processes them according to the Ladder program, and controls outputs Y0-Y6 corresponding to each lamp. The PLC also exchanges data with the HMI via the communication port.

c) HMI display block: used to display lamp status (Green - Yellow - Red), display the countdown time for each phase, allow the operator to change lamp timing (write directly to registers D0-D13), and perform Start/Stop directly on the screen.

d) Actuation block: includes the traffic signal lamps for the two directions. Each direction has three lights (Red, Yellow, Green). These lamps are controlled through the relay module receiving signals from the PLC.

e) Control push-button block: the Start and Stop push buttons allow the operator to manually control the system when necessary. These buttons are wired to PLC inputs X0 and X1.

2.7. Logic operation diagram

The operating cycle can be described by the following state table:

Stage	**N1 red**	**N1 yellow**	**N1 green**	**N2 red**	**N2 yellow**	**N2 green**	**Note**
1	0	0	1	1	0	0	N1 moves, N2 stops
2	0	1	0	1	0	0	N1 transition to N2
3	1	0	0	0	0	1	N1 stops, N2 moves
4	1	0	0	0	1	0	N2 transition to N1

The cycle is repeated continuously.

2.8. Analysis of the detailed control principle

The traffic signal system has the function of regulating lanes and ensuring that vehicles pass safely and in accordance with traffic regulations.

To achieve this, the PLC program must control the green-yellow-red lights sequentially and accurately, while ensuring that the two directions are never green at the same time.

2.9. Description of the control sequence

When the system is turned on (Start), the PLC initializes memory variables and turns on the system lamp Y0 to indicate operation.

The PLC reads the signal timing values from registers D0 -> D3, then uses timers T0 -> T3 for alternating control.

When a timer completes (for example, T0 times out), the PLC automatically transfers to the next stage.

The cycle repeats continuously until the operator presses Stop (X1).

During operation, the HMI displays:

Countdown time for each phase (for example: "Green remaining 12 seconds").

Operating status (RUN / STOP).

Allows changing the D0-D3 values using the "Settings" button directly on the screen.

2.10. Electrical safety

To ensure safety for operators and equipment:
The entire power circuit (220V lamps) is isolated through intermediate relays.
The control cabinet enclosure must be grounded (GND).
The control signal wires use 24VDC to avoid electric shock.
A 2P-6A main circuit breaker is used for protection in the event of a fault.

B. Principle diagram design

2.11. General introduction

In automatic control systems, the principle diagram plays a particularly important role. It is a drawing that shows the electrical, signal, and control-logic relationships among the system elements.
For the project "Design of a traffic signal control system using PLC and HMI", building the principle diagram helps to:
Determine the overall hardware structure of the system.
Serve as the basis for designing the actual wiring circuit and PLC control programming.
Help operators and maintenance personnel clearly understand the operating principle of the system, making repair and expansion more convenient.
The principle diagram fully presents the main functional blocks including: the power block, the central control block (PLC), the signal input/output block (sensors, push buttons, signal lamps), and the HMI display and interaction block.

2.12. Block-type principle diagram

a) Overall block diagram: the overall block diagram of the traffic light control system is presented as follows.
The system is divided into five main blocks: power supply block, central control block (Mitsubishi FX3U PLC), input block, output block (signal lights), and display/setting block (HMI).
b) Description of functional blocks:
Power Supply block: receives 220VAC mains power. Through the PS1 power supply unit, it is converted into 24VDC to supply the PLC, HMI, and control elements. The signal lights operate at 220VAC and are controlled through intermediate relays.
Central control block (Mitsubishi FX3U PLC): is the "brain" of the system. It receives signals from the push buttons (Start, Stop, Reset) and outputs control signals to Y0-Y11 to switch the lights on and off. It executes the traffic light control algorithm according to the cycle.
Input signal block: includes Start, Stop, and Reset push buttons. The signals are fed into PLC ports X0 and X1.
Output signal block: the traffic lights are controlled through intermediate relays. PLC outputs Y0-Y6 send signals to the relays, which then switch the lights according to the cycle. Each direction has three lights (Red, Yellow, Green). The 220VAC supply passes through relays controlled by the PLC.
HMI display block: directly connected to the PLC through the communication port. It displays lamp status, countdown time, and allows the operator to change the mode.
c) General operating principle:
When power is supplied, the power indicator lamp turns on and the HMI displays the start-up interface.
The operator presses Start (X0) -> the PLC begins the cycle.
Direction 1 green light (Y2) turns on, direction 2 red light (Y4) turns on.
After D0 seconds, the yellow light (Y3) turns on for 2-3 seconds, then the phase changes.
Direction 2 is then allowed to move -> Y5 turns on, Y1 turns on to stop direction 1.
The cycle repeats continuously.
When Stop (X1) is pressed -> all lights turn off, only the system lamp remains on to indicate the stopped state.
d) Remarks on the block-type principle diagram:
The circuit structure is simple, easy to understand, and suitable for a model application or a small real system.
The FX3U PLC ensures high reliability, fast processing speed, and easy programming in GX Works2.
HMI increases interactivity and the aesthetic quality of the model.
Clear functional division makes maintenance and expansion convenient.
The design ensures electrical safety thanks to 24VDC and 220VAC isolation.

2.13. Detailed wiring diagram design

This section presents the detailed electrical wiring among the devices, including three main parts: power supply, control, and load.

Power circuit:

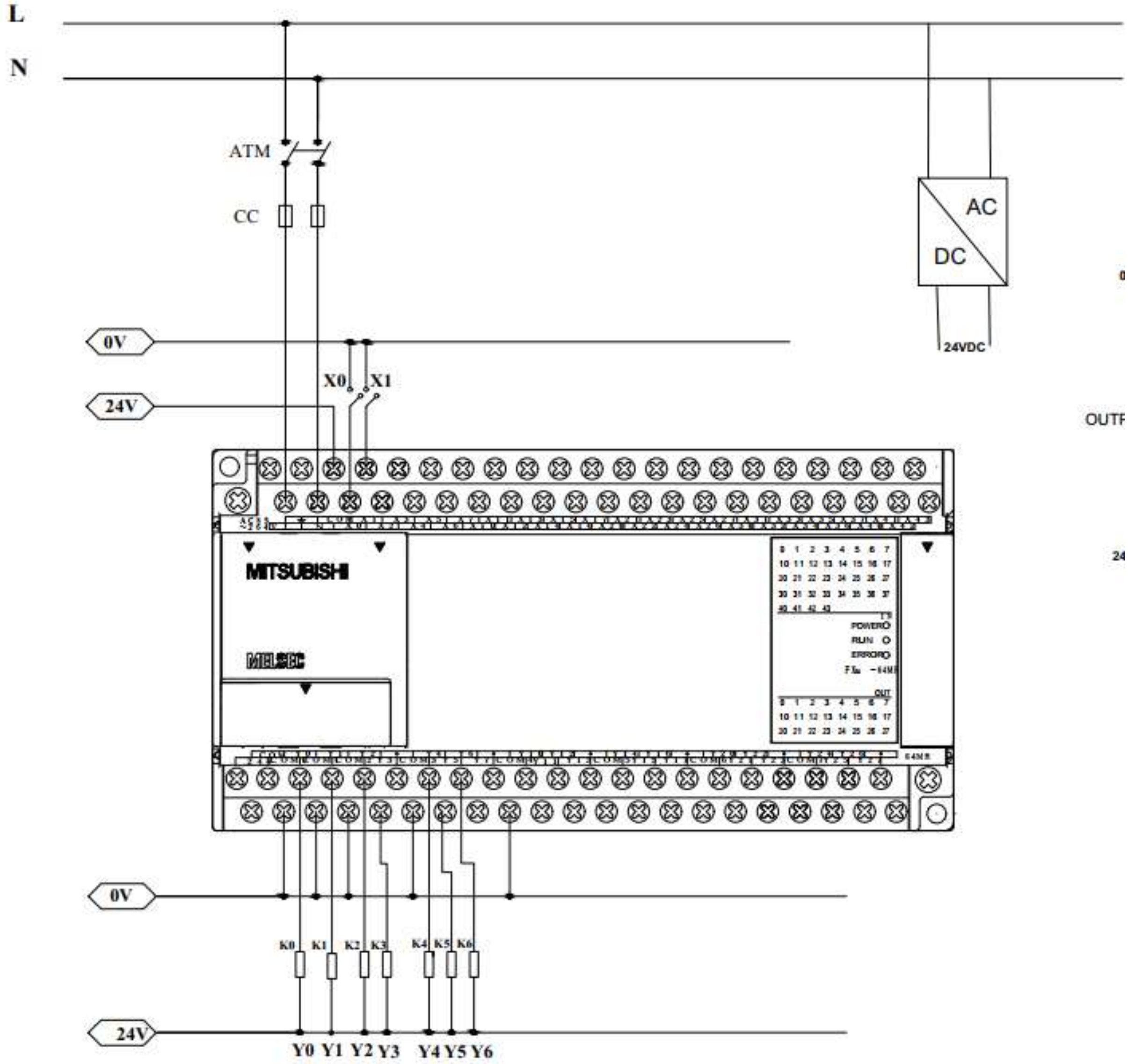
The 220VAC source is fed through the main fuse, after which:

One branch supplies the 24VDC power supply unit -> this provides power for the PLC and HMI.

The other branch is supplied through intermediate relays to control the signal lamps.

PLC outputs only provide 24VDC signals, so intermediate relays (R1-R8) are required.

The relay coils are controlled by 24VDC from the PLC, while the relay contacts switch the 220VAC lamp circuit.



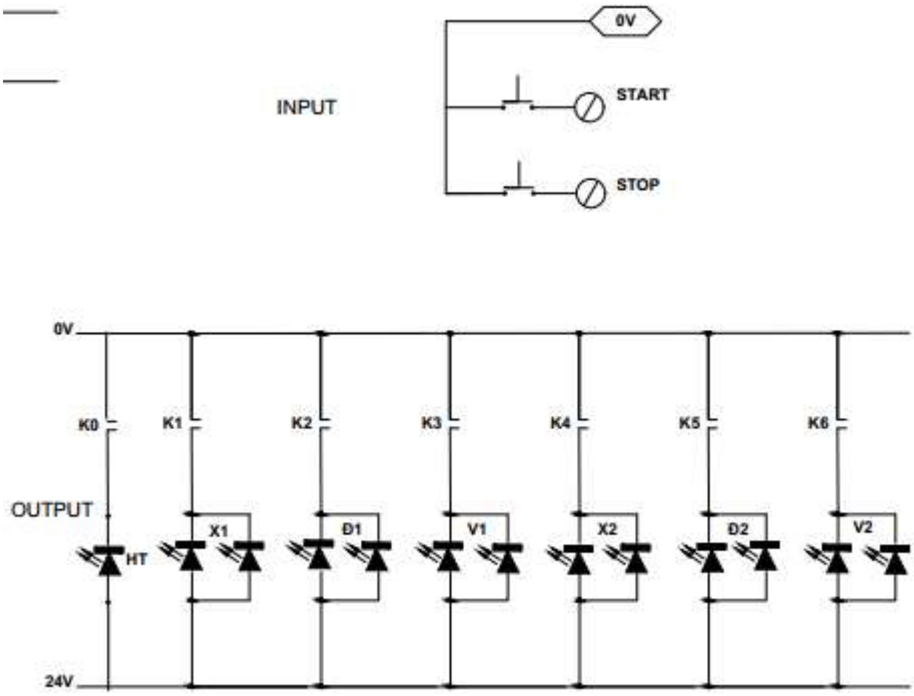


Figure 2.3. Power circuit diagram of the traffic light system

2.14. Description of system operation

After power is supplied to the system:
The operator presses Start and the PLC starts the cycle.
The red light for direction 1 and the green light for direction 2 turn on according to the preset sequence.
After the set time (for example 20 seconds), the yellow light turns on for 3 seconds as a warning before phase transition.
The cycle repeats for the remaining directions.
The HMI displays the countdown clock, the name of the active direction, and the system status.
If Stop is pressed, all lights turn off or return to the safe condition (yellow flashing).
If Reset is pressed, the system returns to the initial cycle.

2.15. Technical requirements in design

Control voltage: 24VDC; load voltage: 220VAC.
Ensure safe isolation between the control circuit and the power circuit.
Provide protective fuses for each load branch.
Grounding wire and metal equipment enclosures must be connected to ground.
Use symbols and wire numbering according to TCVN 6610-1 or IEC 60445.
Use intermediate relays to protect the PLC from the inrush current of the lamps.
The design should be neat, easy to maintain, and easy to expand.

2.16. System principle diagram

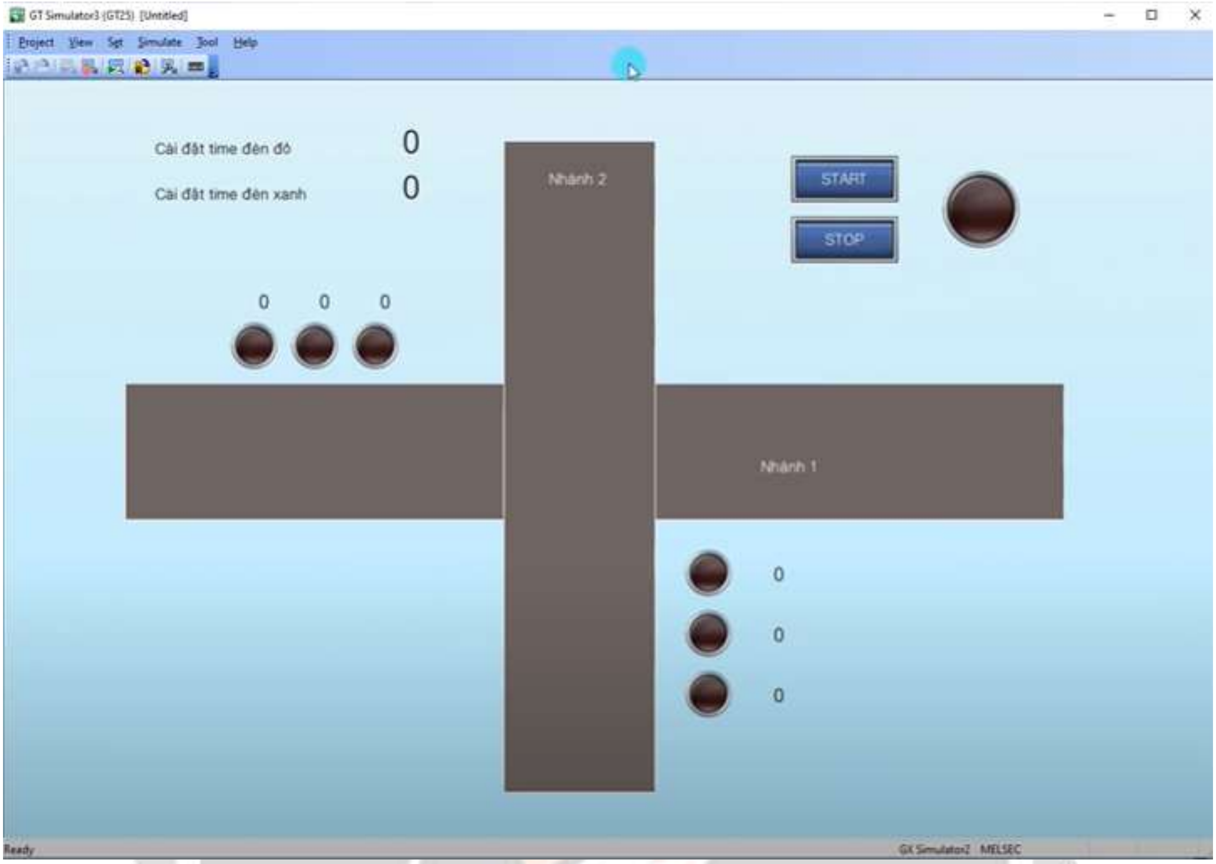


Figure 2.4. HMI screen describing the operation of the traffic light system

2.17. Conclusion of the principle diagram design section

Through the above design, a complete principle diagram model of the traffic light system has been established, including:

PLC control block as the center.

HMI display block for observation and operation support.

Input/output signal blocks that enable flexible system operation.

C. Chapter 2 conclusion

In Chapter 2, the following tasks were performed:

Analysis of the requirements of the traffic light control system.

Selection of Mitsubishi FX3U PLC as the central controller.

Design and detailed description of the principle diagram and system block diagram.

Presentation of the general operating principle and selection of auxiliary devices.

The result of Chapter 2 is the completion of the hardware design, ensuring that the system can operate stably, is easy to assemble, easy to program, and easy to expand.

Chapter 3: Control algorithm design

1. Control algorithm design

3.1. Control objectives

The system is designed to control traffic lights at an intersection with two directions (N1 and N2).
Each direction has three lights: red, yellow, and green, which are automatically controlled in a preset cycle by the Mitsubishi FX3U PLC.
In addition, the operator can start, stop, and adjust the illumination time of each light through the HMI screen.

3.2. Analysis of control requirements

The traffic light control system must satisfy the following requirements:
Automatic control:
The signal lights change according to the preset time cycle (red - green - yellow).
The timing of each phase can be adjusted via the HMI.
Manual operation (if necessary):
Each light can be controlled individually (for testing or fault handling).
There are Start, Stop, and Reset buttons.
Display and supervision:
Display the countdown time of each phase.
Display the operating status of the system (Automatic, Stop, Fault).
Safety requirement:
Two green lights must never be on at the same time.
Phase transition must include a yellow warning light.

3.3. Development of the control flowchart

The control algorithm is described by a flowchart.
Below is the text description; the flowchart can be drawn according to the following steps:
3.3.1. General algorithm
Start -> Initialize the system.
The PLC checks input signals.
All lights OFF -> only the red light ON.
Press Start -> the system runs in automatic mode.
Operating cycle:
Direction 1 green light ON for time T1.
Direction 1 yellow light ON for 3 seconds.
Direction 2 green light ON for time T2.
Direction 2 yellow light ON for 3 seconds.
Repeat the cycle.
Press Stop -> stop the program, all red lights ON.
Press Reset -> return to the initialized state.
3.3.2. Detailed control flowchart
The algorithm flowchart can be drawn with the following blocks:
Start
Check Start push button
Phase 1 (Direction 1 green light)
Time counting -> timeout -> switch to yellow phase
Phase 2 (Direction 2 green light)
Repeat cycle
Check Stop or Reset push button

3.4. Operating principle

Phase	Branch (N1)	Branch (N2)	Time (s)
1	Green (Y2)	Red (Y4)	D1 (Set_Time_Green)
2	Green (Y2)	Red (Y4)	D2 (Set_Time_Yellow)
3	Red (Y1)	Green (Y5)	D1 (Set_Time_Green)

4	Red (Y1)	Green (Y5)	D2 (Set_Time_Yellow)

After phase 4 ends, the system returns to phase 1 and continues repeating.
The timing values D0-D2 can be changed directly on the HMI, allowing users to flexibly adjust the operating cycle.

3.5. Memory structure and role of registers

Address	Registers	Function
D0	Set_Time_Red	Set the red-light duration
D1	Set_Time_Green	Set the green-light duration
D2	Set_Time_Yellow	Set the yellow-light duration
D3	Time_N1_Red	Timer for red light of branch 1
D4	Time_N1_Green	Timer for green light of branch 1
D5	Time_N1_Yellow	Timer for yellow light of branch 1
D6	Time_N2_Red	Timer for red light of branch 2
D7	Time_N2_Green	Timer for green light of branch 2
D8	Time_N2_Yellow	Timer for yellow light of branch 2
D9	SET_T1	Set green-light timing variable of branch 1
D10	SET_T2	Set red-light timing variable of branch 2
D11	SET_T3	Set combined green/red-light timing variable
D12	SET_T4	Set red/red-light timing variable
D13	SET_T5	Repeat cycle

Registers D3-D8 are used to display the actual countdown values on the HMI screen in each phase.

3.6. PLC internal variables

Variable	Type	Function
D0	Data register	Timing value for direction 1
D1	Data register	Timing value for direction 2
M0	Intermediate bit	Status flag for phase 1
M1	Intermediate bit	Status flag for phase 2
M10	Intermediate bit	System running flag
T0, T1	Timer	Timing for phases 1 and 2
T2, T3	Timer	Timing for yellow phases

3.7. System start and stop conditions

When X0 (Start) = ON -> set M0 = 1, allowing the system to operate.
When X1 (Stop) = ON -> reset M0 = 0 and turn off all lights (Y0-Y6).
In stop mode, the timers are paused and the system waits for a new start command.

3.8. PLC-HMI communication

Protocol: RS-485 or RS-232.
Baud rate: 9600 bps.
Device: Mitsubishi FX Series.
HMI tags correspond to D0, D1, M10, etc., for data read/write.

3.9. Simulation and program testing

The program is tested using simulation software:
GX Works2 Simulator to run the PLC Ladder program.
GT Designer 3 to simulate the HMI.
Testing steps:
Download the program to the virtual PLC.
Run the Start simulation -> observe the lights.
Check timing and operating logic.
Check HMI display.

Results:
The phases operate in the correct sequence.
There are never two green lights on at the same time.
Timing can be changed from the HMI.

3.10. Remarks

The control algorithm is simple, easy to understand, and ensures that the two traffic directions do not conflict with simultaneous green lights.

The timing parameters are flexible and can be set directly via the HMI, allowing the operator to easily change the operating cycle according to actual conditions.

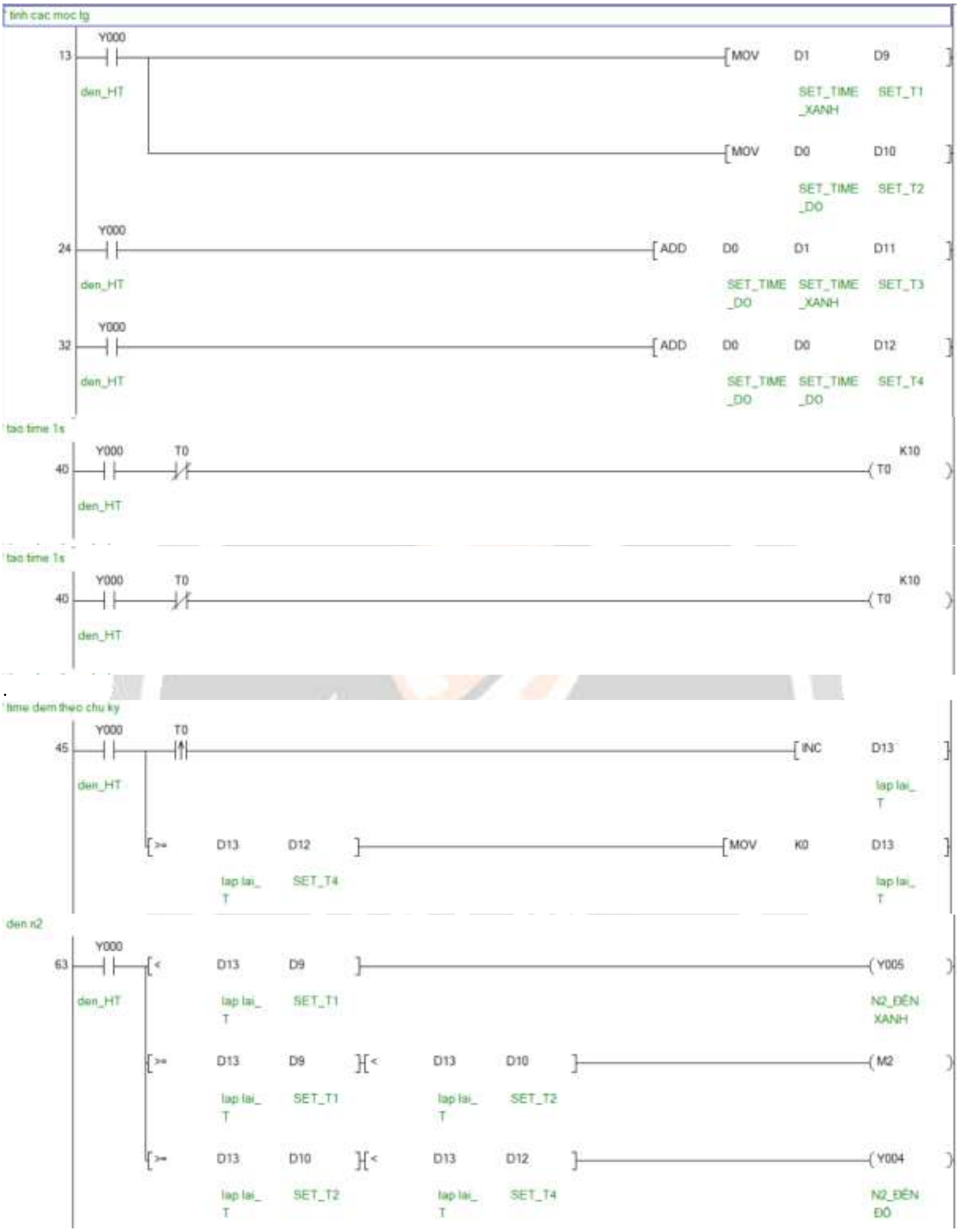
Chapter 4: Control programming using PLC and HMI

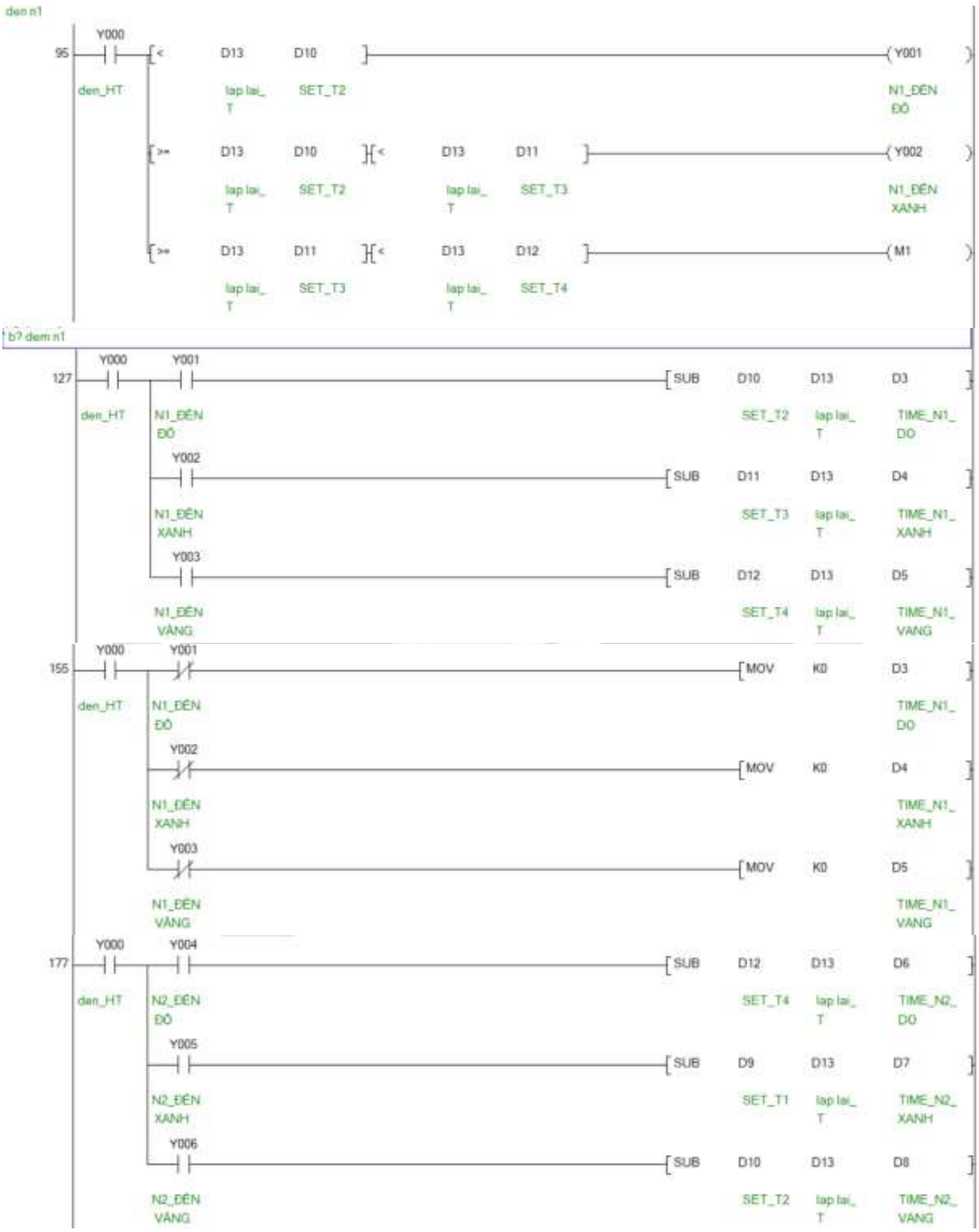
In Chapter 3, addresses were assigned to the push buttons, limit switches, and actuators.

To program the entire system, addresses must be assigned to the status variables and timer variables as follows:

Push button	X000: Stop
	X001: Start
Indicator lamp	Y000: System lamp
	Y001: N1 red light
	Y002: N1 green light
	Y003: N1 yellow light
	Y004: N2 red light
	Y005: N2 green light
	Y006: N2 yellow light
D0-D13	Time counters

4.1. PLC control program


tinh cac moc tg
13
Y000
den_HT
MOV D1 D9
SET_TIME _XANH SET_T1
MOV D0 D10
SET_TIME _DO SET_T2
24
ADD D0 D1 D11
SET_TIME _DO SET_TIME _XANH SET_T3
32
ADD D0 D0 D12
SET_TIME _DO SET_TIME _DO SET_T4
tao time 1s
40
T0
K10
T0
tao time 1s
40
time dem theo chu ky
45
INC D13
lap lai_ T
>= D13 D12
lap lai_ T SET_T4
MOV K0 D13
den n2
63
< D13 D9
Y005
N2_ĐÈN XANH
>= D13 D9 < D13 D10
M2
>= D13 D10 < D13 D12
Y004
N2_ĐÈN ĐỎ


den n1
95
Y000
den_HT
< D13 D10
lap lai_T SET_T2
Y001
N1_ĐÈN ĐỎ
>= D13 D10 < D13 D11
lap lai_T SET_T2 lap lai_T SET_T3
Y002
N1_ĐÈN XANH
>= D13 D11 < D13 D12
lap lai_T SET_T3 lap lai_T SET_T4
M1
b? dem n1
127
Y000
den_HT
Y001
N1_ĐÈN ĐỎ
SUB D10 D13 D3
SET_T2 lap lai_T TIME_N1_DO
Y002
N1_ĐÈN XANH
SUB D11 D13 D4
SET_T3 lap lai_T TIME_N1_XANH
Y003
N1_ĐÈN VÀNG
SUB D12 D13 D5
SET_T4 lap lai_T TIME_N1_VANG
155
Y000
den_HT
Y001
N1_ĐÈN ĐỎ
MOV K0 D3
TIME_N1_DO
Y002
N1_ĐÈN XANH
MOV K0 D4
TIME_N1_XANH
Y003
N1_ĐÈN VÀNG
MOV K0 D5
TIME_N1_VANG
177
Y000
den_HT
Y004
N2_ĐÈN ĐỎ
SUB D12 D13 D6
SET_T4 lap lai_T TIME_N2_DO
Y005
N2_ĐÈN XANH
SUB D9 D13 D7
SET_T1 lap lai_T TIME_N2_XANH
Y006
N2_ĐÈN VÀNG
SUB D10 D13 D8
SET_T2 lap lai_T TIME_N2_VANG

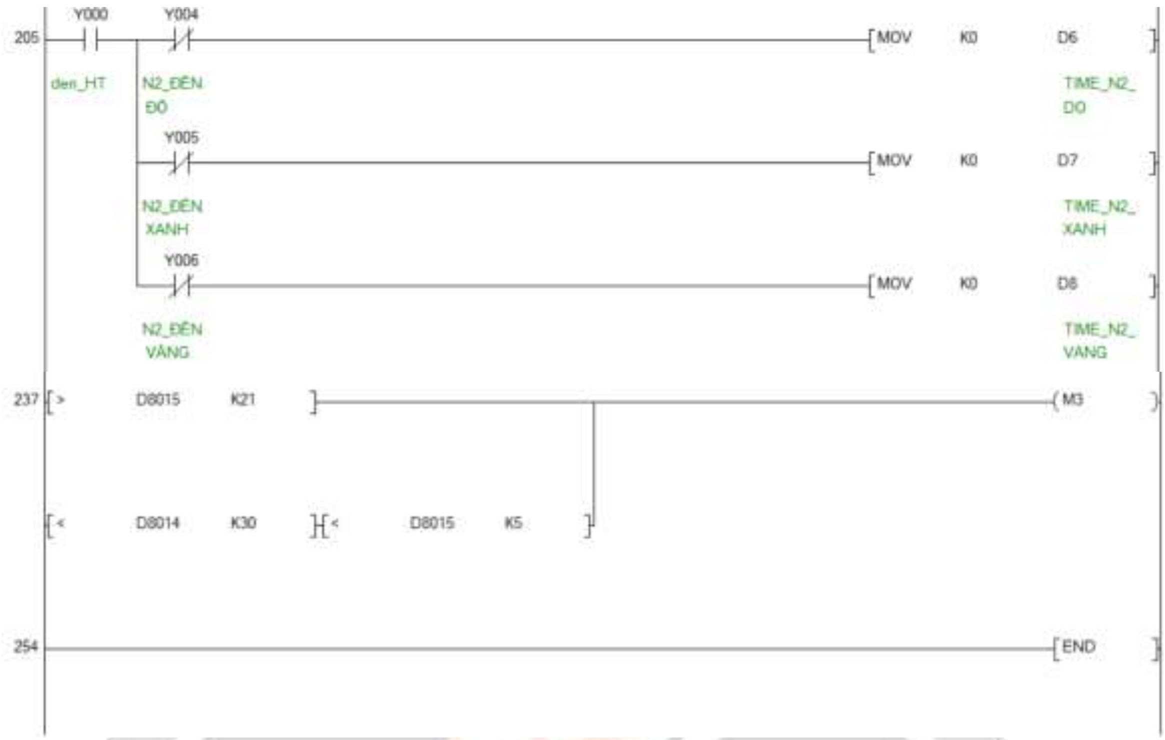


Figure 4.1. PLC programming code diagram for traffic light control

4.2. HMI control program

4.2.1. Programming in GT Designer 3

Figure 4.2. HMI interface image describing traffic light operation

4.2.2. Control program in GT Simulator 3

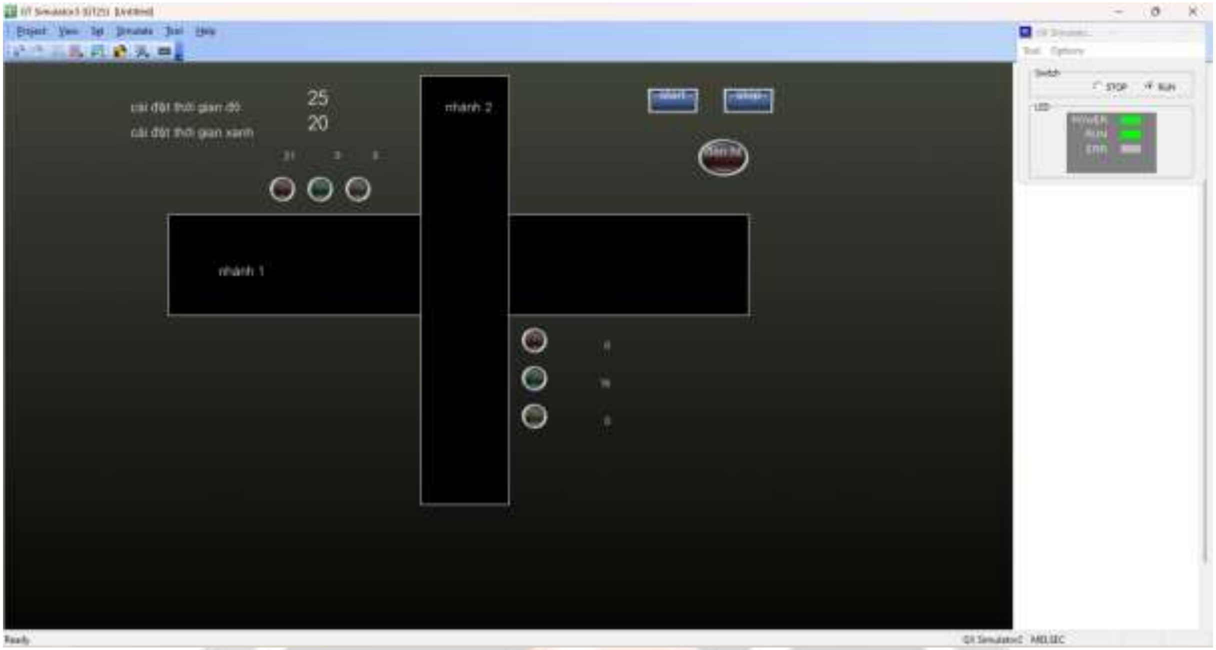


Figure 4.3. HMI image for setting the operating time of the traffic lights

Chapter 5: Principle explanation and result verification

5.1. Principle explanation

This section presents the explanation of the control principle of the designed traffic light system, including the sequence of operation of each phase, the role of the PLC in processing control logic, the HMI in supervision and adjustment, and the coordination between the hardware and software blocks in the complete system.

5.2. Result verification

The obtained results show that the designed system satisfies the proposed requirements.

The traffic light phases operate in the correct sequence, and no conflict occurs between the two directions.

Signal timing values can be modified via the HMI and are updated correctly during system operation.

The PLC program operates stably in simulation, and the HMI interface supports convenient supervision and operation.

Therefore, the proposed design is feasible for training models and can be further expanded for practical applications.