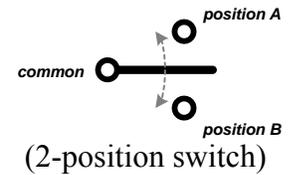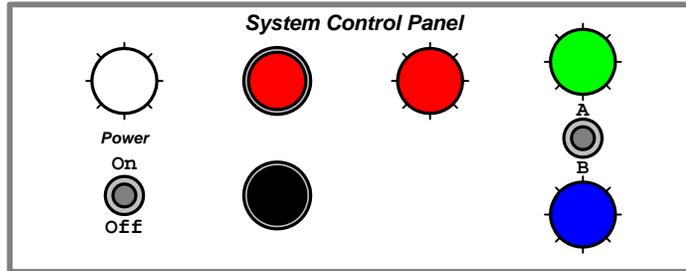**Problem #4)** Design a **reversing, across-the-line (full voltage) motor starter** for a 3Φ Induction motor using discrete components (pushbuttons, contactors, etc.) that also **includes overload protection** for the motor. Note that, although pushbuttons should be utilized for the "Start" and "Stop" buttons, the direction of rotation is to be controlled by a 2-position switch, the position of which at start-up will determine the motor's rotational direction. In other words, once the motor is running, flipping the directional control switch should have no effect on the motor's operation.

Neatly **draw** the schematic for your motor controller in the space below, being sure to show and label all of the required components:

position A

common

position B

(2-position switch)

Problem #5) Figures **5A** and **5B** (last 2 pages) show the wiring diagram of the simple PLC-based motor-control system the ladder-logic program that was downloaded into the PLC. The system was designed to provide start/stop capability, directional control, and overload protection for the motor.

The control panel for the system is shown below:

System Control Panel

Assuming that the PLC is properly supplied with AC power, the key-switch on the front panel of the PLC has been switched to "Run" mode, and the switch SW1 is originally in it's off position:

a) **Specify** the *(Alias) Tag Name* of the instructions aliased to each of the PLC's inputs/outputs, and **describe** and **state the function** of the primary physical devices that are connected to each of the PLC's inputs/outputs. (Complete the tables below)

Instruction	Input	Device Description	Device Function
	0		
SW1	**1**	Single Pole Switch	**Power Switch** – Used to Enable/Disable the Motor Control System
	2		
	3		
	4		
	5		

Instruction	Output	Device Description	Device Function
	0		
oteA	**1**	White Indicator Lamp	**Power Light** – Illuminates to show that the system is enabled
	2		
	3		
	4		
	5		

b) State, in terms of the system's overall operation, what will happen if an operator first flips *switch SW1 to the "ON" position*, then flips *switch SW2 to the "B" position*, and then *presses (and releases) PB2*. **Be specific** and provide all important details.
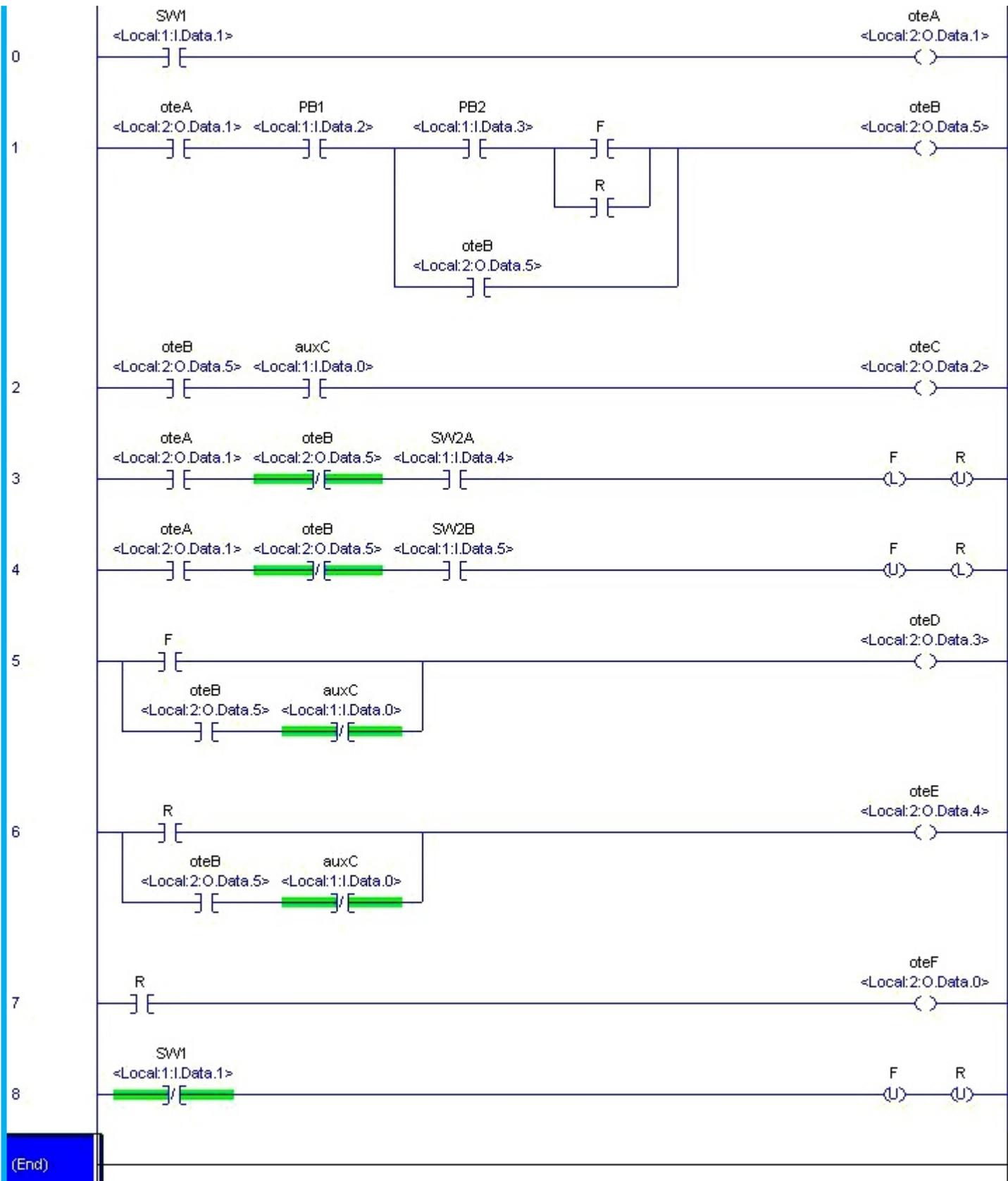
SW1 Switched "On": Input-1 of the PLC goes high, in-turn causing Output-1 to be energized and the White Light to be illuminated.

SW2 Flipped to "B":

PB2 Pressed:

c) Assuming that the operator has performed the steps specified in part (b), **state** what will happen, in terms of the system's overall operation, if *SW2 is flipped to the "A" position* immediately <u>after</u> the operator pressed and released PB2. **<u>Justify</u>** <u>your answer</u>.

d) If the overload relay detects a motor overload while the motor is running, will the system actually shutdown the motor to protect it from damage? **State** and **justify** your answer.

e) If the motor and contactors are located in a separate room from the control panel such that the operator can neither see nor hear those devices, how does the system uniquely inform the operator that an overload has occurred? **State** and **justify** your answer.

f) After the occurrence of an overload, what must be done in order to restart the motor? **State** and **justify** your answer.

g) Why is **Rung 8** included in the ladder-logic program? **State** and **justify** your answer.
(Note – the system will still operate properly if the rung is deleted)

Rung 0:
SW1 <Local:1:I.Data.1> ─┤ ├─ ... oteA <Local:2:O.Data.1> ─( )─

Rung 1:
oteA <Local:2:O.Data.1> ─┤ ├─ PB1 <Local:1:I.Data.2> ─┤ ├─ PB2 <Local:1:I.Data.3> ─┤ ├─ ┬ F ─┤ ├─ ┬ ... oteB <Local:2:O.Data.5> ─( )─
└ R ─┤ ├─ ┘
oteB <Local:2:O.Data.5> ─┤ ├─

Rung 2:
oteB <Local:2:O.Data.5> ─┤ ├─ auxC <Local:1:I.Data.0> ─┤ ├─ ... oteC <Local:2:O.Data.2> ─( )─

Rung 3:
oteA <Local:2:O.Data.1> ─┤ ├─ oteB <Local:2:O.Data.5> ─┤/├─ SW2A <Local:1:I.Data.4> ─┤ ├─ ... F ─(L)─   R ─(U)─

Rung 4:
oteA <Local:2:O.Data.1> ─┤ ├─ oteB <Local:2:O.Data.5> ─┤/├─ SW2B <Local:1:I.Data.5> ─┤ ├─ ... F ─(U)─   R ─(L)─

Rung 5:
F ─┤ ├─ ┬ ... oteD <Local:2:O.Data.3> ─( )─
└ oteB <Local:2:O.Data.5> ─┤ ├─ auxC <Local:1:I.Data.0> ─┤/├─ ┘

Rung 6:
R ─┤ ├─ ┬ ... oteE <Local:2:O.Data.4> ─( )─
└ oteB <Local:2:O.Data.5> ─┤ ├─ auxC <Local:1:I.Data.0> ─┤/├─ ┘

Rung 7:
R ─┤ ├─ ... oteF <Local:2:O.Data.0> ─( )─

Rung 8:
SW1 <Local:1:I.Data.1> ─┤/├─ ... F ─(U)─   R ─(U)─

(End)

Note – be sure to pay careful attention when examining the wiring diagram in order to determine exactly what device is wired to each of the PLC's inputs and outputs.

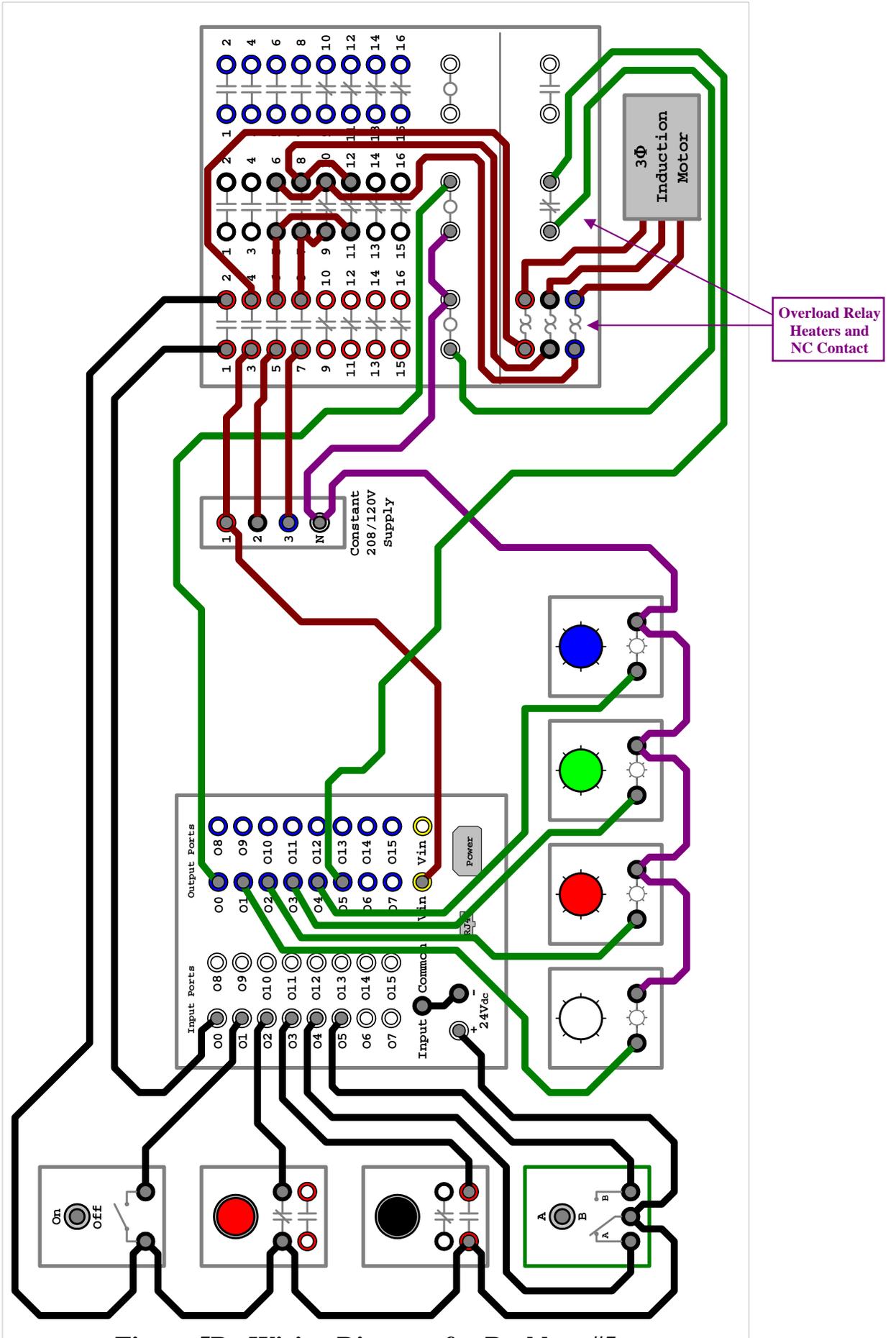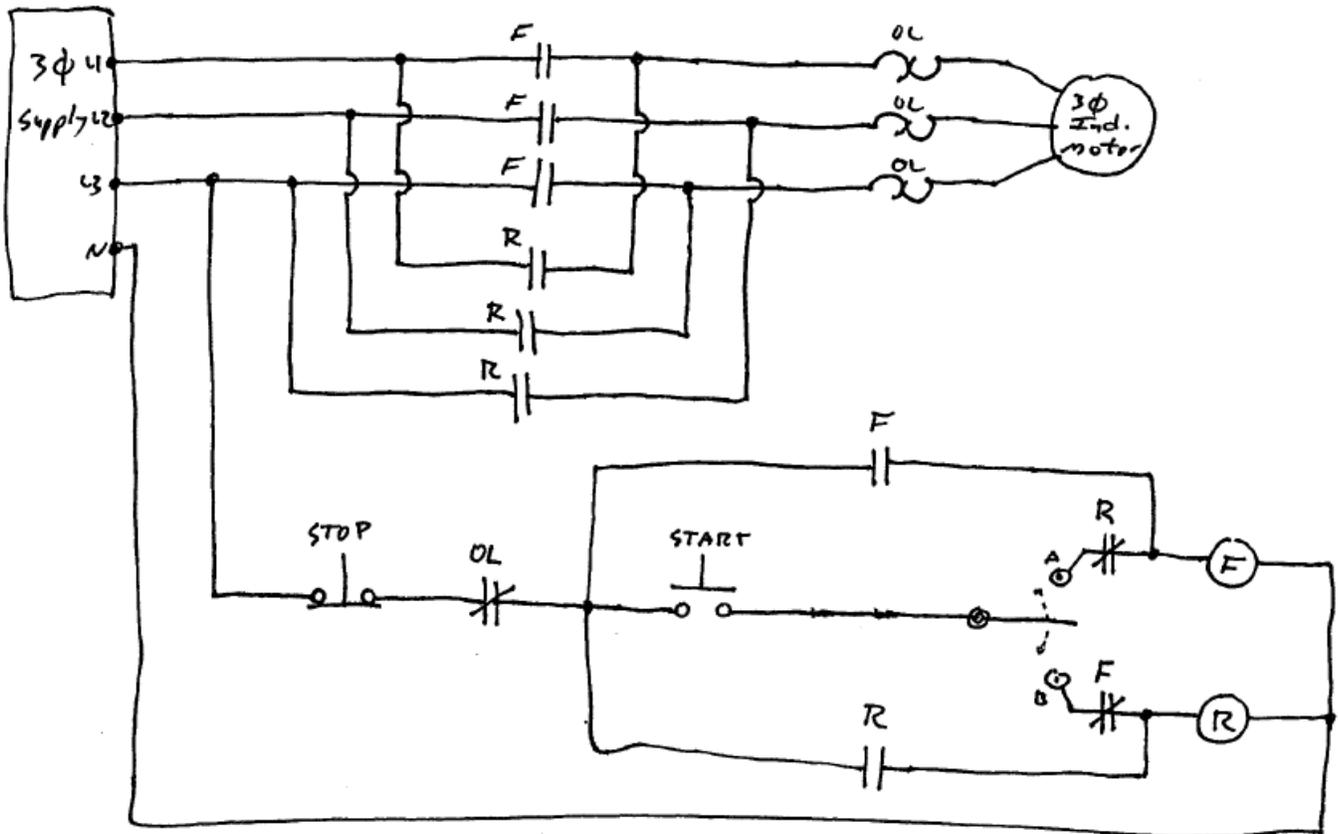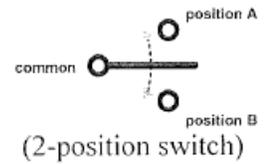**Figure 5A – Ladder Diagram for Problem #5**

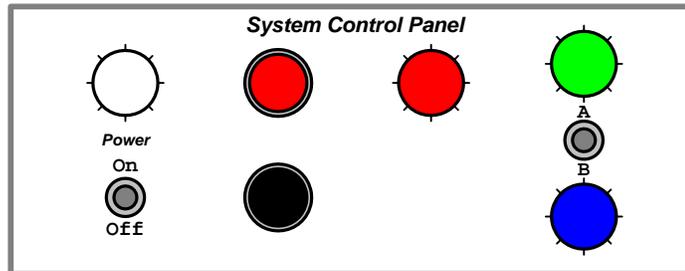**Figure 5B – Wiring Diagram for Problem #5**

Problem #4) Design a **reversing, across-the-line (full voltage) motor starter** for a 3Φ Induction motor using discrete components (pushbuttons, contactors, etc.) that also **includes overload protection** for the motor. Note that, although pushbuttons should be utilized for the "Start" and "Stop" buttons, the direction of rotation is to be controlled by a 2-position switch, the position of which at start-up will determine the motor's rotational direction. In other words, once the motor is running, flipping the directional control switch should have no effect on the motor's operation.

Neatly **draw** the schematic for your motor controller in the space below, being sure to show and label all of the required components:

(2-position switch)

Problem #5) Figures **5A** and **5B** (last 2 pages) show the wiring diagram of the simple PLC-based motor-control system the ladder-logic program that was downloaded into the PLC. The system was designed to provide start/stop capability, directional control, and overload protection for the motor.

The control panel for the system is shown below:

Assuming that the PLC is properly supplied with AC power, the key-switch on the front panel of the PLC has been switched to "Run" mode, and the switch SW1 is originally in it's off position:

a) **Specify** the *(Alias) Tag Name* of the instructions aliased to each of the PLC's inputs/outputs, and **describe** and **state the function** of the primary physical devices that are connected to each of the PLC's inputs/outputs. (Complete the tables below)

Instruction	Input	Device Description	Device Function
auxC	**0**	**NO Auxiliary Contact from Main Contactor**	**Signals to the PLC that the Main Contactor dropped-out, most likely due to an Overload**
SW1	**1**	Single Pole Switch	**Power Switch** – Used to Enable/Disable the Motor Control System
PB1	**2**	**NC Pushbutton**	**Used to "Stop" the motor**
PB2	**3**	**NO Pushbutton**	**Used to "Start" the motor**
SW2A	**4**	**2-Pole Switch (in position A)**	**Sets system for "Forward" motor operation**
SW2B	**5**	**2-Pole Switch (in position B)**	**Sets system for "Reverse" motor operation**

Instruction	Output	Device Description	Device Function
oteF	**0**	**Field Coil (Directional Contactor)**	**Controls the Directional Contactor that determines the motor's direction of rotation**
oteA	**1**	White Indicator Lamp	**Power Light** – Illuminates to show that the system is enabled
oteC	**2**	**Red Indicator Lamp**	**Motor Energized Indicator Illuminates when Main Contactor actuates**
oteD	**3**	**Blue Indicator Lamp**	**Forward Operation Indicator (Also ON with Green during Overload)**
oteE	**4**	**Green Indicator Lamp**	**Reverse Operation Indicator (Also ON with Blue during Overload)**
oteB	**5**	**NC OL Contact & Main Field Coil**	**Controls the Main Contactor that (de)energizes the motor**

b) State, in terms of the system's overall operation, what will happen if an operator first flips *switch SW1 to the "ON" position*, then flips *switch SW2 to the "B" position*, and then *presses (and releases) PB2*. **Be specific** and provide all important details.

SW1 Switched "On": Input-1 of the PLC goes high, in-turn causing Output-1 to be energized and the White Light to be illuminated.

SW2 Flipped to "B": Input-5 becomes TRUE, causing (on Rung 4):
- the R-bit to be Latched   (R = 1)
- the F-bit to be UnLatched   (F = 0)

This causes (on Rungs 5, 6 & 7):
- the oteD-bit to be Reset   (oteD = 0)
- the oteE-bit to be Set   (oteE = 1)
- the oteF-bit to be Set   (oteF = 1)

which:
- switches-OFF Output-3 (Blue "Forward" Light OFF)
- switches-ON Output-4 (Green "Reverse" Light ON)
- switches-ON Output-0, Energizing the Directional Contactor's Field Coil, in-turn setting the motor for Reverse Operation

PB2 Pressed: Input-3 becomes TRUE, causing (on Rung 1):
- the oteB-bit to be Set   (oteB = 1)

which:
- switches-ON Output-5, Energizing the Main Contactor's Field Coil, in-turn Energizing the motor in Reverse

Additionally, when the Main Contactor's Contacts actuate, the NO Auxiliary Contact wired to Input-0 closes and Input-0 becomes TRUE, causing (on Rung 2):
- the oteC-bit to be Set   (oteC = 1)

which:
- switches-ON Output-2 (Red "Motor Energized" Light ON)

c) Assuming that the operator has performed the steps specified in part (b), **state** what will happen, in terms of the system's overall operation, if *SW2 is flipped to the "A" position* immediately <u>after</u> the operator pressed and released PB2. **Justify** your answer.

If SW2 is flipped to the "A" position after PB2 has been pressed-and-released, there will be <u>no change</u> in the motor's operation.

Even though the switch has physically changed position, causing Input-5 to become FALSE and Input-4 to become TRUE, the <u>oteB-XIOs</u> on Rungs 3 & 4 become FALSE whenever the motor is energized, thus preventing the state of both the R & F bits from being changed.

But, it is worth noting that the R-bit will be Unlatched and the F-bit will be latched immediately after the motor is Stopped.

d) If the overload relay detects a motor overload while the motor is running, will the system actually shutdown the motor to protect it from damage? **State** and **justify** your answer.

> **<u>Yes</u>, the system will shutdown (de-energize) the motor if an Overload is detected.**
>
> **The Overload Relay's NC Contact is wired in-series with the Main Contactor's Field Coil. Thus, when the OL Contact "opens" during an overload, the field coil will be de-energized, causing the Main Contactor's contacts to drop-out, in-turn de-energizing the motor.**

e) If the motor and contactors are located in a separate room from the control panel such that the operator can neither see nor hear those devices, how does the system <u>uniquely</u> inform the operator that an <u>overload</u> has occurred? **State** and **justify** your answer.

> **The system indicates that an Overload has occurred <u>by switching-OFF the Red Lamp and simultaneously illuminating both the Blue and Green Indicator Lamps</u>.**
>
> **When an Overload occurs and the Main Contactor's contacts drop-out, the auxiliary contact that is wired to Input-0 opens, causing Input-0 to become False.**
>
> **But Output-5 is still ON (oteB = 1).**
>
> **Thus the parallel paths around both the F-XIC and the R-XIC on Rungs 5 & 6 will make both of their rung conditions TRUE, causing both the Blue and Green lamps to be switched ON, while the auxC-XIC on Rung 2 will cause that rung to become FALSE, switching OFF the Red lamp.**

f) After the occurrence of an overload, what must be done in order to restart the motor? **State** and **justify** your answer.

> **In order to restart the motor, the Overload Relay must be allowed time to cool-down.**
>
> **Once the relay cools-down, the NC OL Contact will either automatically re-close (if the relay allows such) or the NC OL Contact can manually be reset (re-closed).**
>
> **Note that, once the NC OL Contact re-closes, the motor will automatically restart without requiring the operator to press the "Start" button (PB2) because Output-5 remains ON. This is <u>potentially dangerous</u>… for safety purposes, an auxC-XIC could be placed in-series with the "hold-in" oteB-XIC on Rung 1, causing the rung to become FALSE and Output-5 to be switched-Off during an Overload. But, this would also affect the manner in which Rungs 5 & 6 operate, thus requiring further changes in the program.**

g) Why is **Rung 8** included in the ladder-logic program? **State** and **justify** your answer.
  (Note – the system <u>will</u> still operate properly if the rung is deleted)

> **Without Rung 8, when SW1 is "opened" (switched OFF) to completely shut-down the system, either the Green Lamp or the Blue Lamp will remain illuminated (depending on the position of SW2, and if set for reverse, the Directional Contactor would remain energized.**

Note – unless otherwise specified within each problem statement, assume that if a push-button is pressed, it is held-in for less than ½-second and then released. Furthermore, if a button is pressed, it will be released before any additional buttons are pressed.

Problem #5) Design a **reversing, series-resistance (soft-starting) motor starter** for a 3Φ Induction motor using discrete components (pushbuttons, contactors, etc.) that also **includes overload protection** for the motor. Note that two separate pushbuttons should be utilized to "Start" the motor; one for starting the motor in the "forward" direction and the other for starting the motor in the "reverse" direction.

NEATLY **draw** the schematic for your motor controller in the space below, being sure to show and label all of the system components. (Use a straight-edge when drawing all of the system wires)

Problem #6) The following schematic diagram depicts a simple PLC-based control system that is used to control the operation of three 24V$_{DC}$ indicator lamps.

The ladder diagram for the program loaded into the PLC is shown on the last page.

a) Assuming that no bits were previously latched and the PLC is switched to run mode, if **Pb-A is pressed and released**, describe the operational state of the system.

b) Assuming that no bits were previously latched and the PLC is switched to run mode, state the **set of steps** (button presses) that are required to **illuminate** (turn-on) only the **Blue** indicator lamp.

c) Assuming that steps described in part (b) were completed and only the Blue indicator lamp is illuminated, state the **set of steps** (button presses) that are required to **turn-off** the **Blue** indicator lamp such that no lamps are illuminated.

d) Assuming that no bits were previously latched and the PLC is switched to run mode, state the **set of steps** (button presses) that are required to **illuminate** (turn-on) only the **Green** indicator lamp.

e) Assuming that steps described in part (d) were completed and only the Green indicator lamp is illuminated, state the **set of steps** (button presses) that are required to **turn-off** the **Green** indicator lamp such that no lamps are illuminated.

f) Assuming that no bits were previously latched and the PLC is switched to run mode, state the **set of steps** (button presses) that are required to **illuminate** (turn-on) **all three indicator lamps**.

g) Assuming that steps described in part (f) were completed and that all three indicator lamps are illuminated, state the **set of steps** (button presses) that are required to **turn-off** all three lamps.
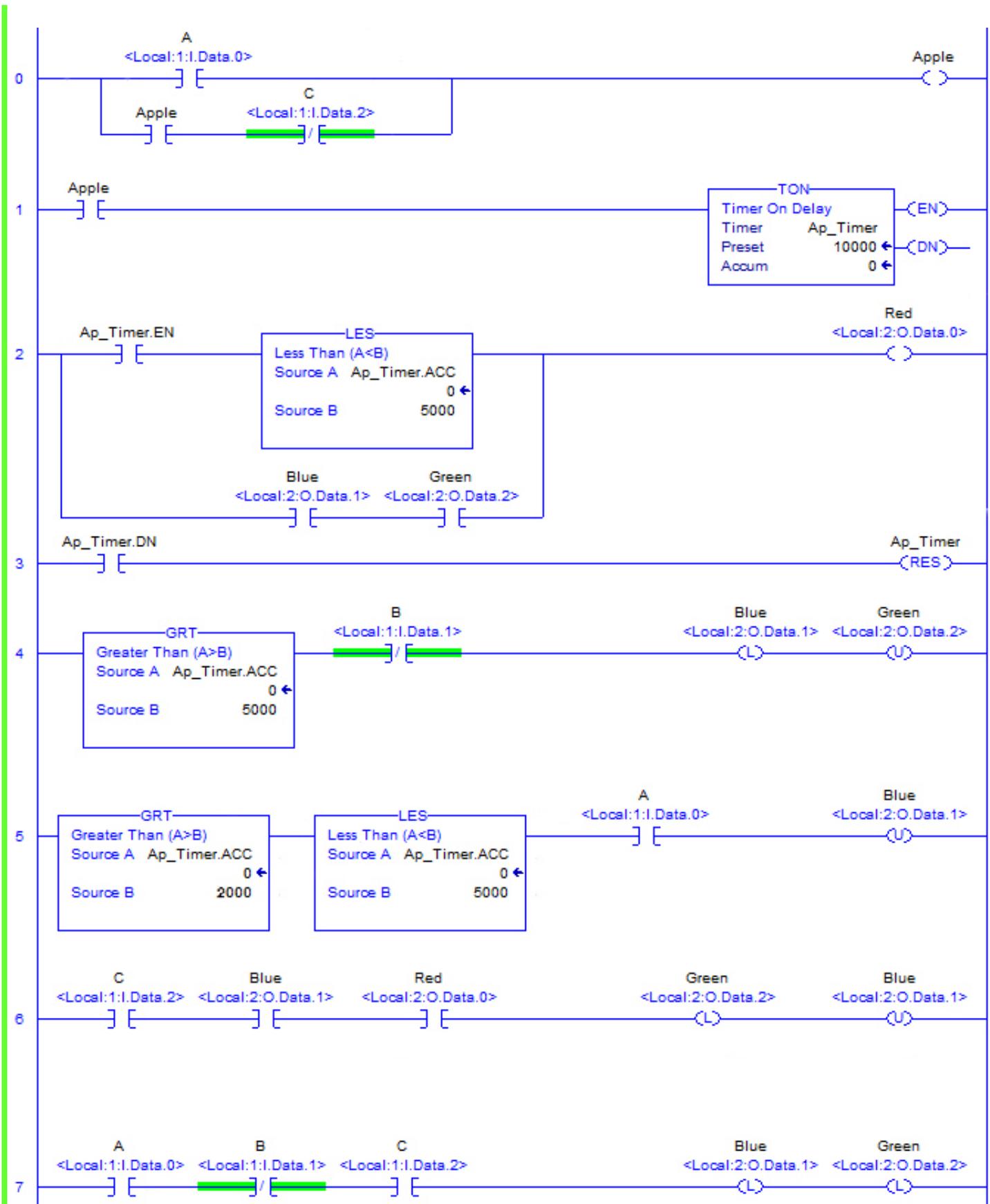
Figure 6 – Ladder Diagram for Problem #6

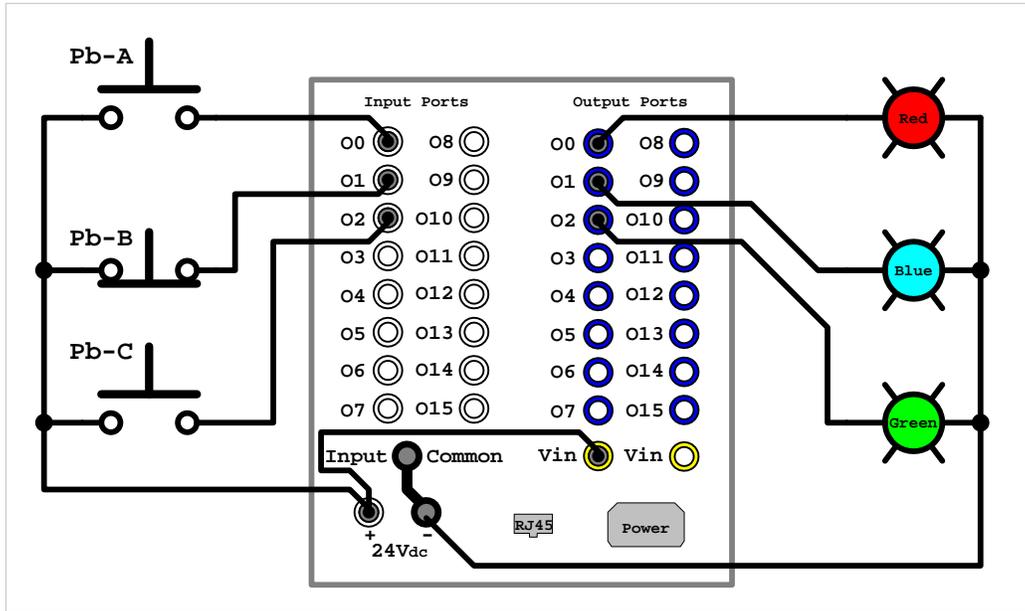**(The Answers for Version II are <u>NOT</u> Available)**

Instructions: Part "B" of this exam is composed of a set of "take-home" problems that must be completed individually, under "open-book" conditions, with absolutely <u>no</u> assistance from any other person.

Problem #5) Design a **forward/reverse, series-resistance (reduced-voltage) motor starter** with **overload protection** for a 3Φ Induction motor using discrete components (pushbuttons, contactors, etc.).

Notes: a) Two separate pushbuttons should be utilized to initially energize (Start) the motor; one for starting the motor in the "forward" direction and the other for starting the motor in the "reverse" direction.

b) A single delay timer should be utilized to automatically bypass the starting resistors (without requiring a second button-press) after the motor has been initially energized in either direction.

c) Although the contactors may contain any type of auxiliary contactors (NO or NC), <u>only normally-open contacts may be chosen for the main contacts</u> utilized in the "power" portion of the circuit.

d) The control circuit must prevent the operator from changing the direction of the motor without first stopping the motor once it has been energized.

<u>NEATLY</u> **draw** the schematic for your motor controller in the space below, being sure to show and label <u>all</u> of the system components. (Use a <u>straight-edge</u> when drawing all of the system wires)

Problem #6) The following schematic diagram depicts a simple PLC-based control system that is used to control the operation of three 24V_DC indicator lamps.

The ladder diagram for the program loaded into the PLC is shown on the last page.

Note – for parts (b) ⇨ (g), due to human error, there is no way to guarantee that two or more pushbuttons can be pressed (or released) at the <u>exact</u> same instant in time. For example, if an operator is instructed to press (or release) pushbuttons Pb-A and Pb-C at the exact same time, you may assume that the NO contacts within the two pushbuttons will close (or open) roughly within 100msec of each other, but which pushbutton's contacts close (or open) first may vary.

a) Assuming that no bits were previously latched and the PLC is switched to run mode, if **Pb-A is quickly pressed and released** (in less than 1 second), describe the **operational state of the system** in terms of the indicator lamps (i.e. – what does the operator see happening with respect to the three indicator lamps?).

b) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **only the Blue indicator lamp is illuminated** (turned-ON). (The **Blue** lamp should remain ON <u>constantly</u> and the **Red** and **Green** lamps should remain OFF)

Be very specific. State any required conditions, important timing requirements or visual indicators that must be followed when preforming the steps.

For example: "When the Red light turns-on, immediately press and release pushbutton…"

c) Assuming that steps described in part (**b**) were completed and only the Blue indicator lamp is illuminated, state the **exact set of steps** (button presses) that are required to **turn-off** the **Blue** indicator lamp such that no lamps are illuminated. (**All lamps** should constantly remain **OFF**)

d) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **only the Green indicator lamp is illuminated** (turned-ON). (The **Green** lamp should remain **ON** constantly and the **Red** and **Blue** lamps should remain **OFF**)

e) Assuming that steps described in part (**d**) were completed and only the Green indicator lamp is illuminated, state the **exact set of steps** (button presses) that are required to **turn-OFF** the **Green** indicator lamp such that no lamps are illuminated. (**All lamps** should remain **OFF**)

f) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **all three indicator lamps are continuously illuminated** (turned-ON).

g) Assuming that steps described in part (**f**) were completed and that all three indicator lamps are continuously illuminated, state the **exact set of steps** (button presses) that are required to **turn-OFF** all three lamps. (**All lamps** should remain **OFF**)

Figure 6 – Ladder Diagram for Problem #6

Problem #5) Design a **forward/reverse, series-resistance (reduced-voltage) motor starter** with **overload protection** for a 3Φ Induction motor using discrete components (pushbuttons, contactors, etc.).

Notes: a) Two separate pushbuttons should be utilized to initially energize (Start) the motor; one for starting the motor in the "forward" direction and the other for starting the motor in the "reverse" direction.
  b) A single delay timer should be utilized to automatically bypass the starting resistors (without requiring a second button-press) after the motor has been initially energized in either direction.
  c) Although the contactors may contain any type of auxiliary contactors (NO or NC), only normally-open contacts may be chosen for the main contacts utilized in the "power" portion of the circuit.
  d) The control circuit must prevent the operator from changing the direction of the motor without first stopping the motor once it has been energized.

  NEATLY draw the schematic for your motor controller in the space below, being sure to show and label all of the system components. (Use a straight-edge when drawing all of the system wires)
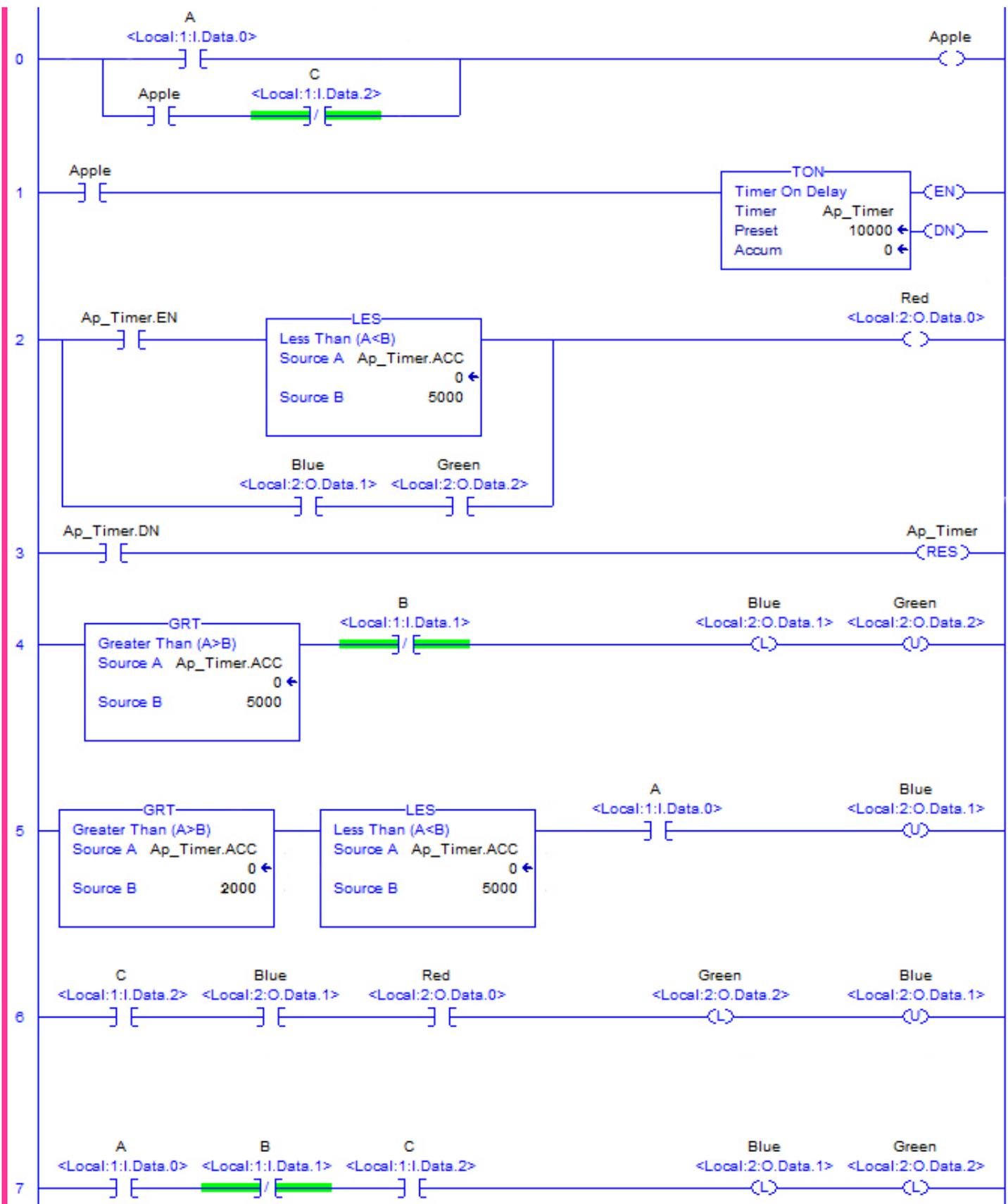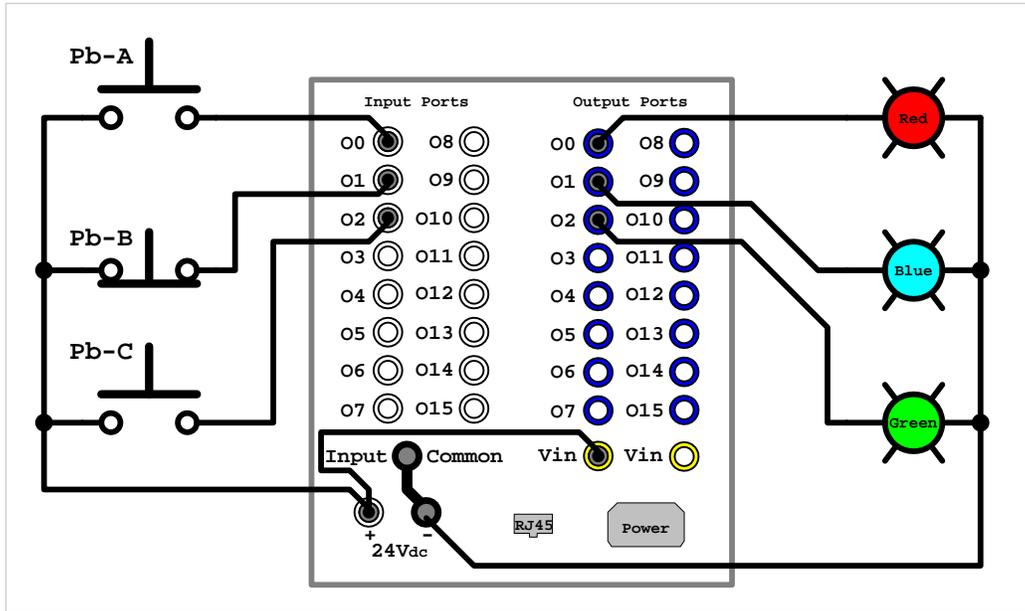
Problem #6) The following schematic diagram depicts a simple PLC-based control system that is used to control the operation of three 24V$_{DC}$ indicator lamps.

The ladder diagram for the program loaded into the PLC is shown on the last page.

Note – for parts **(b)** ⇨ **(g)**, due to human error, there is no way to guarantee that two or more pushbuttons can be pressed (or released) at the <u>exact</u> same instant in time. For example, if an operator is instructed to press (or release) pushbuttons Pb-A and Pb-C at the exact same time, you may assume that the NO contacts within the two pushbuttons will close (or open) roughly within 100msec of each other, but which pushbutton's contacts close (or open) first may vary.

a) Assuming that no bits were previously latched and the PLC is switched to run mode, if **Pb-A is quickly pressed and released** (in less than 1 second), describe the **operational state of the system** in terms of the indicator lamps (ie – what does the operator see happening with respect to the three indicator lamps?).

The Red Light will be flashing O<small>N</small> and O<small>FF</small> in the following pattern:

5 seconds O<small>N</small> → 5 seconds O<small>FF</small> → repeat
↰   ←   ←   ↲

b) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **only the Blue indicator lamp is illuminated** (turned-O<small>N</small>). (The **Blue** lamp should remain O<small>N</small> <u>constantly</u> and the **Red** and **Green** lamps should remain O<small>FF</small>)

Assuming that everything is O<small>FF</small>:

- **Press-and-Release Pb-A** [as described in part (a)]   → **Red Light F<small>LASHING</small>**
- **When Right Light goes O<small>FF</small>, Press-and-Release Pb-B** → **Blue Light O<small>N</small>**
- **While Right Light goes O<small>FF</small>, Press-and-Release Pb-C** → **Red Light O<small>FF</small>**

c) Assuming that steps described in part (**b**) were completed and only the Blue indicator lamp is illuminated, state the **exact set of steps** (button presses) that are required to **turn-off** the **Blue** indicator lamp such that no lamps are illuminated. (**All lamps** should constantly remain OFF)

Assuming Blue is already ON:

- **Press** (and-Hold) **Pb-A** → **Red Light FLASHING**
- **Hold Pb-A until Blue OFF (2+ seconds) then Release** → **Blue Light OFF**
- **Press-and-Release Pb-C** → **Red Light OFF**

d) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **only the Green indicator lamp is illuminated** (turned-ON). (The **Green** lamp should remain ON constantly and the **Red** and **Blue** lamps should remain OFF)

Assuming that everything is OFF:

- **Press-and-Release Pb-A** → **Red Light FLASHING**
- **When Right Light goes OFF, Press-and-Release Pb-B** → **Blue Light ON**
- **Press-and-Hold Pb-A** → (Red Light still FLASHING)
- **Press-and-Hold Pb-C** → **Green Light ON**
  → **Blue Light OFF**
- **Release Pb-A 1st and then Release Pb-C** → **Red Light OFF**

e) Assuming that steps described in part (**d**) were completed and only the Green indicator lamp is illuminated, state the **exact set of steps** (button presses) that are required to **turn-OFF** the **Green** indicator lamp such that no lamps are illuminated. (**All lamps** should remain OFF)

Assuming Green is already ON:

- **Press** (and-Hold) **Pb-A** → **Red Light FLASHING**
- **When Right Light goes OFF, Press-and-Release Pb-B** → **Blue Light ON**
  → **Green Light OFF**
- **Press-and-Release Pb-C** → **Red Light OFF**
- **Press-and-Hold Pb-A until Blue OFF, then Release** → **Blue Light OFF**
- **Press-and-Release Pb-C** → **Red Light OFF**

f) Assuming that no bits are initially latched and that the PLC is switched to run mode, state the **exact set of steps** (button presses and releases) that are required such that **all three indicator lamps are continuously illuminated** (turned-ON).

Assuming that everything is OFF:

- **Quickly Press-and-Release Pb-A,B,C all at same time** → **All Lights ON**

g) Assuming that steps described in part (**f**) were completed and that all three indicator lamps are continuously illuminated, state the **exact set of steps** (button presses) that are required to **turn-OFF** all three lamps. (**All lamps** should remain OFF)

If all lights are ON, they can't be turned OFF because Apple is reset (Apple = 0) and Ap_Timer is disabled, preventing Rungs 4,5 & 6 from Unlatching Blue or Green, which is required before Red can be turned OFF.