Course Code and Title: EEE 402: Control Systems Section 1 Group 1
Semester and Year: Summer – 2024
Open Ended Design Lab Experiment to Control the Speed of a Permanent Magnet DC motor using a PLC (Programmable Logic Controller).

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Lab Manual Part:

Objective:

The objective of this open-ended lab is to control the speed and direction of a permanent magnet DC motor using pulse width modulation (PWM).

Abstract:

This project aims to control the speed and direction of a permanent magnet DC motor using a Programmable Logic Controller (PLC). We will create a logic diagram using 'Totally Integrated Automation Portal V10.' The setup includes physical input and output ports, with push buttons controlling inputs and outputs connected to 'RUN/STOP' and 'CW/CCW' ports using banana plug jacks. We will monitor the hardware outputs in 'Monitoring Mode' to better understand PLC-based motor control in real-life applications.

Equation:

Now,

RPM = K *V * I

V = K * ($RPM/$ I)

This equation shows the relationship between the applied voltage and rpm of a DC motor.

where the motor's constant (K) divided by the current (I) yields the proportionality constant. The This experiment's goal is to control a PMDC motor's speed with a PLC and then analyze the outcomes.

Equipment:

1. PMDC motor module
2. (PLC) Programmable Logic Controller
3. Connecting wire

Procedure:

The ladder diagram.

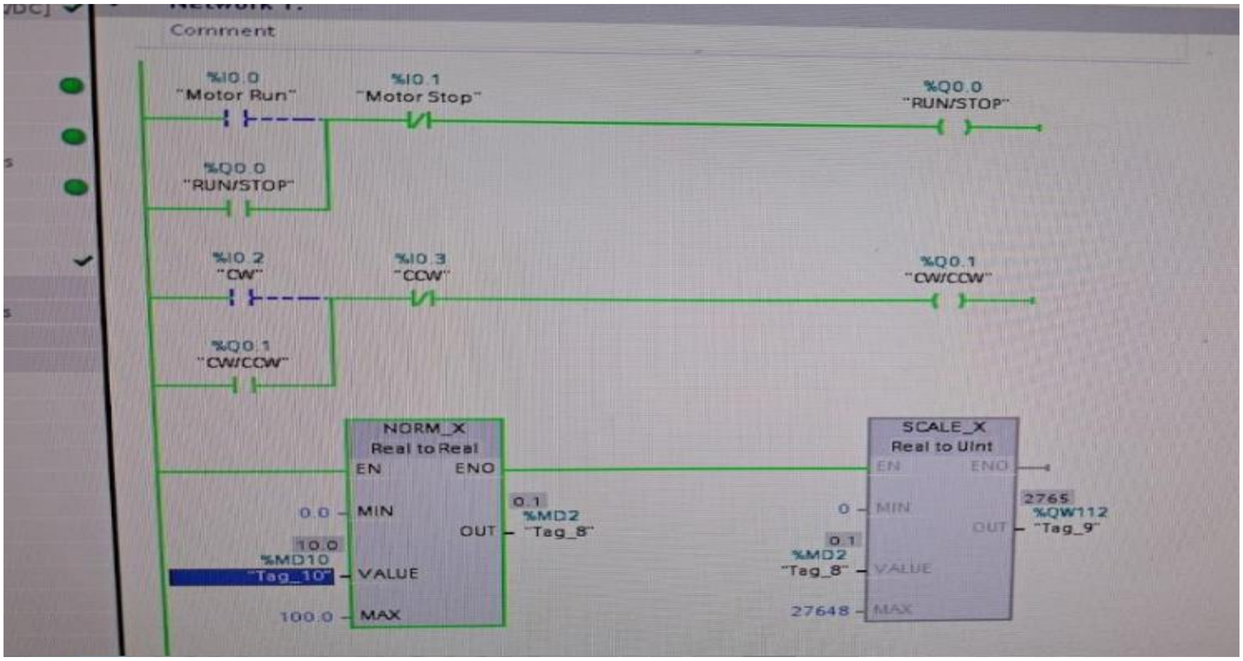

Figure 1: Ladder logic diagram.

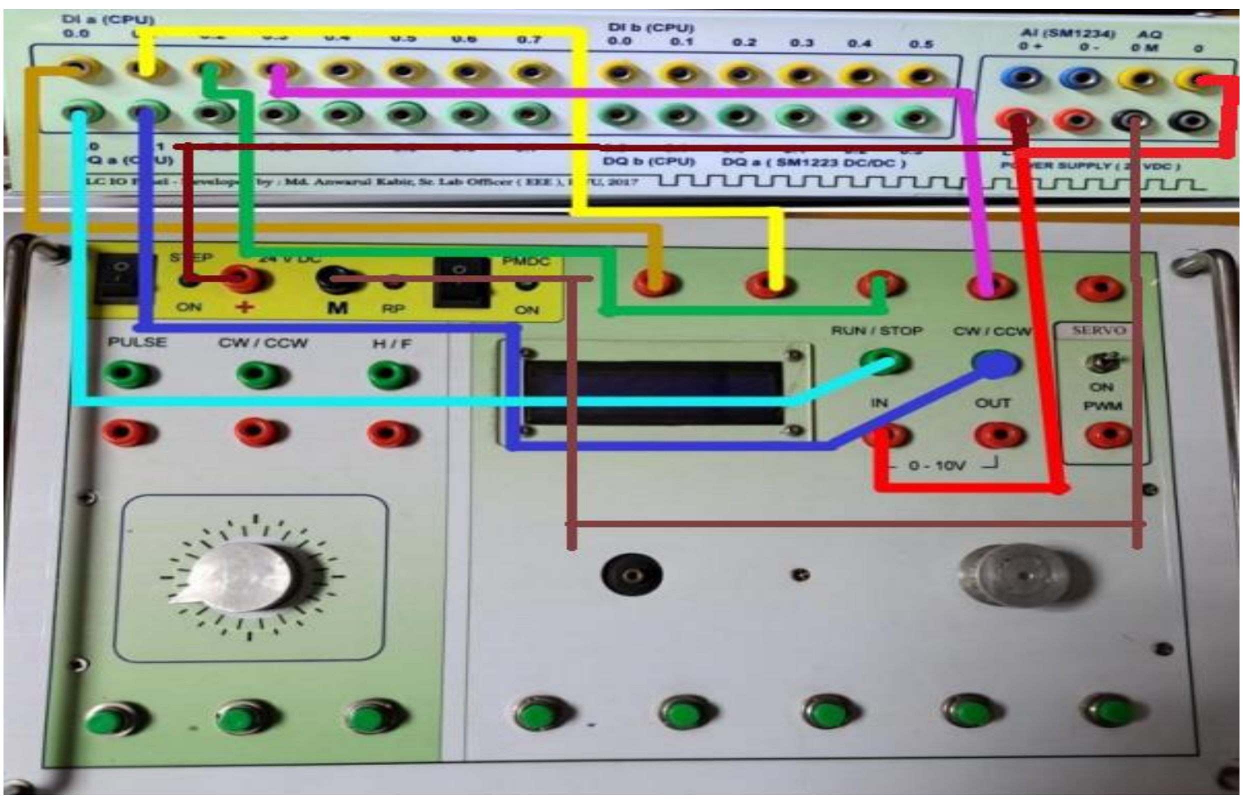

Figure 2: Connection between PLC and module ports

System Components:

1. Input side: I0.0, I0.1, I0.2, I0.3
2. Output side: Q0.0, Q0.1
3. Controller Side: NORM_X, SCALE_X

Description of System Components:

1) (I 0.0) is normally open (NO) and used to Run the DC motor.
2) (I0.1) is normally closed (NC) used to Stop the DC motor.
3) (Q 0.0) is used as a latch to Run the system by pressing the button once.
4) (Q 0.0) is used to rotate the DC motor and show the speed and direction.
5) (I 0.2) is normally open (NO) used to rotate the DC motor in CW.
6) (I0.3) is normally closed (NC) used to change the rotation of the DC motor.
7) (Q 0.1) is used as a latch to Run the system by pressing the button once.
8) Set value and to transfer date from PC to PLC NORM_X is used.
9) Make PLC receive the Set Value and perform according to that was inputted, SCALE_X is used.

Module connection with PLC:

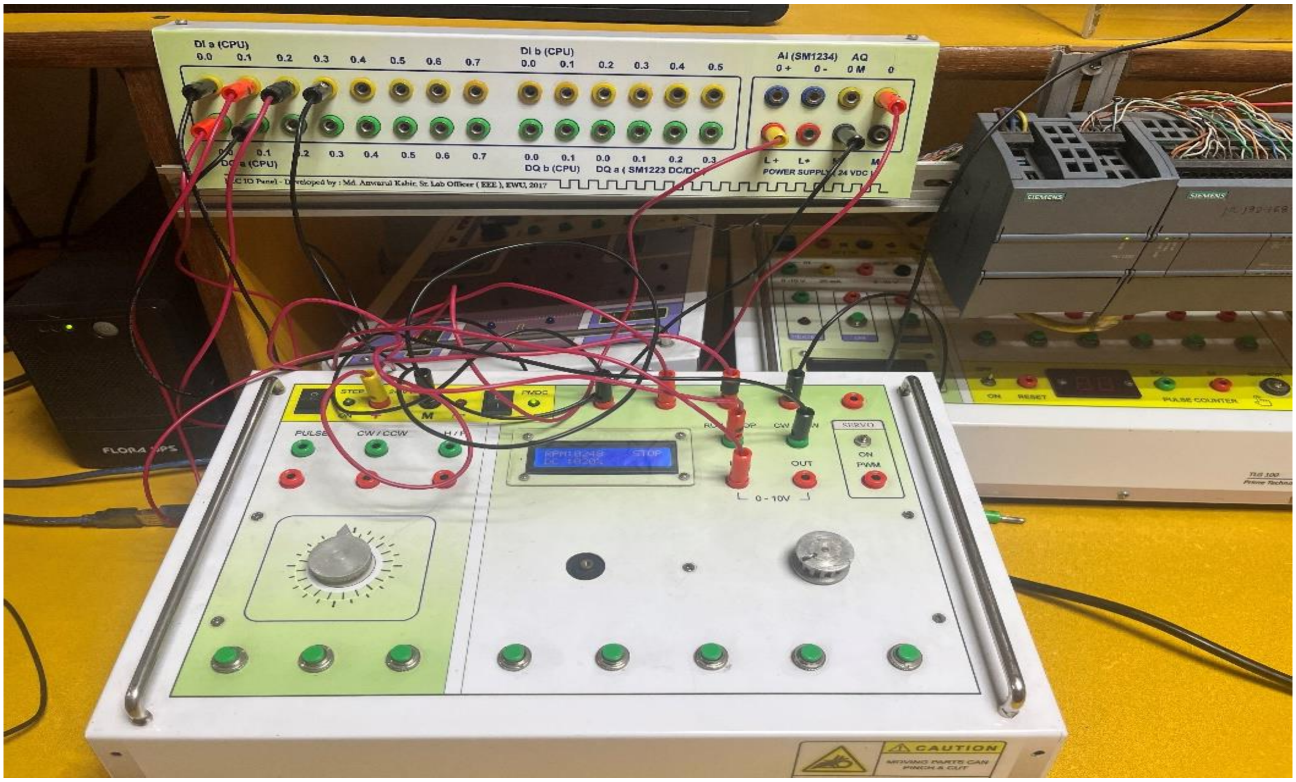

Figure 3: Connection between PLC and module ports

Ladder Diagram:

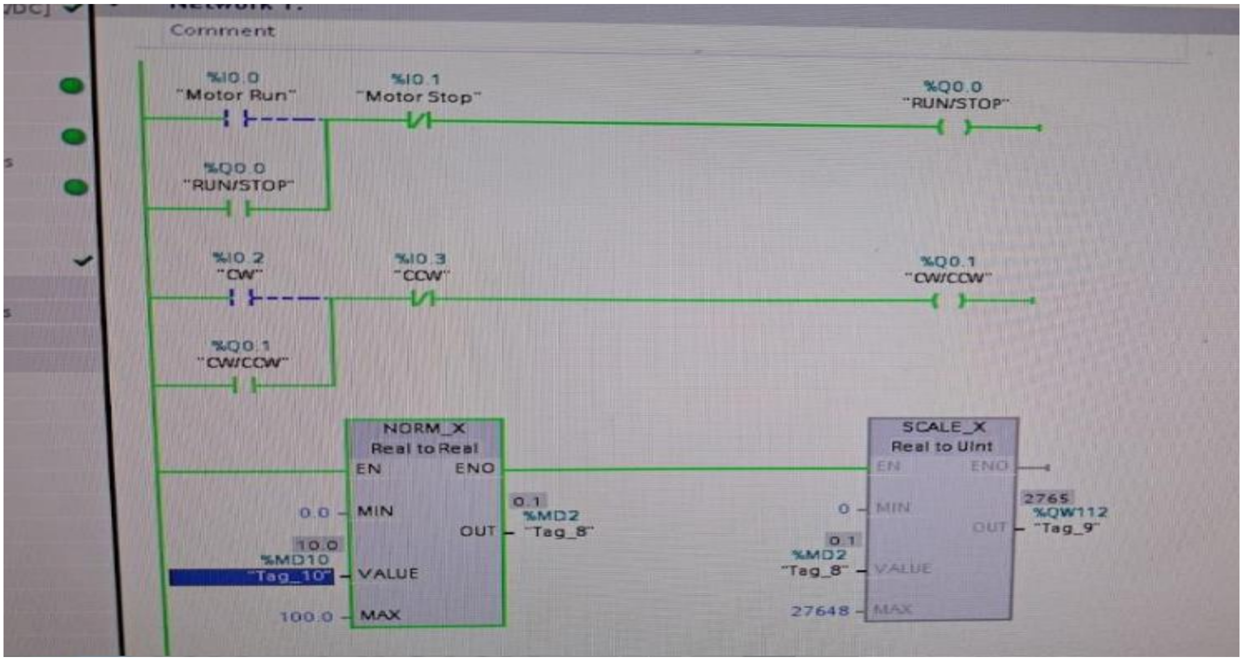

Figure 4: Ladder logic diagram for 10V input voltage and CW direction

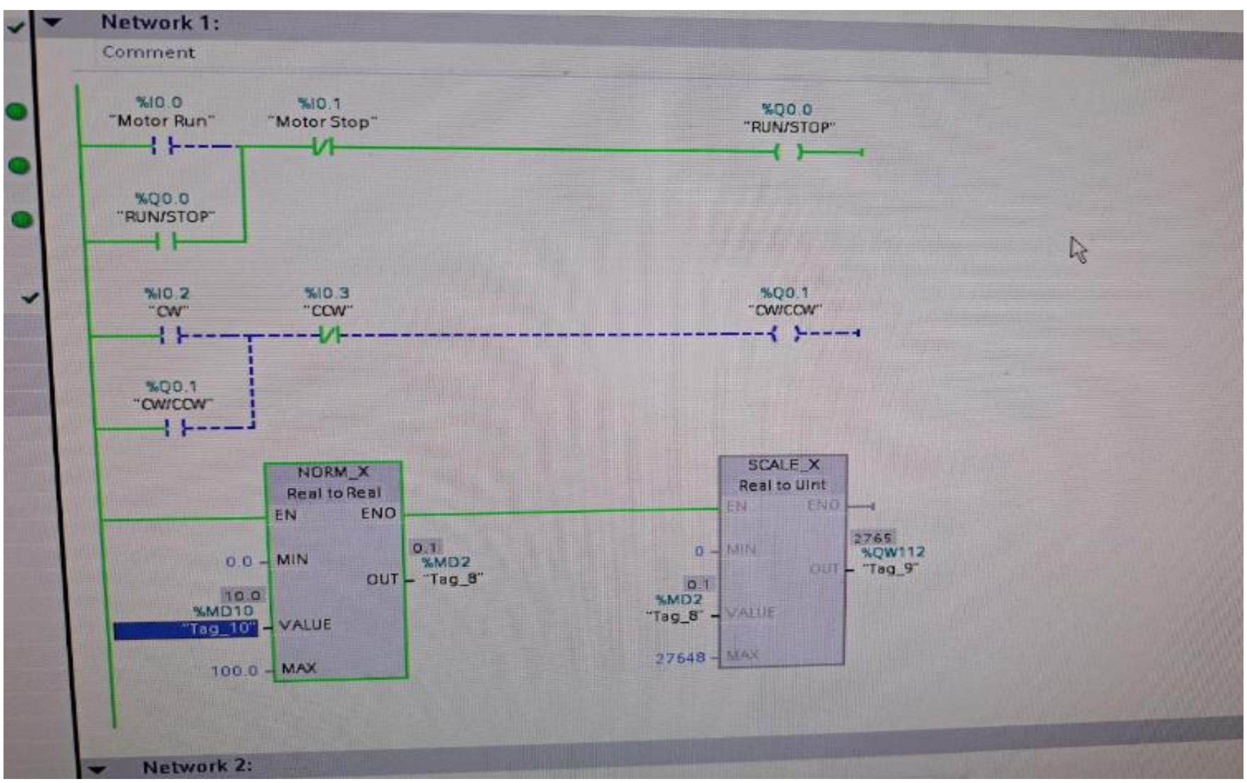

Figure 5: Ladder logic diagram for 10V input voltage and CCW direction

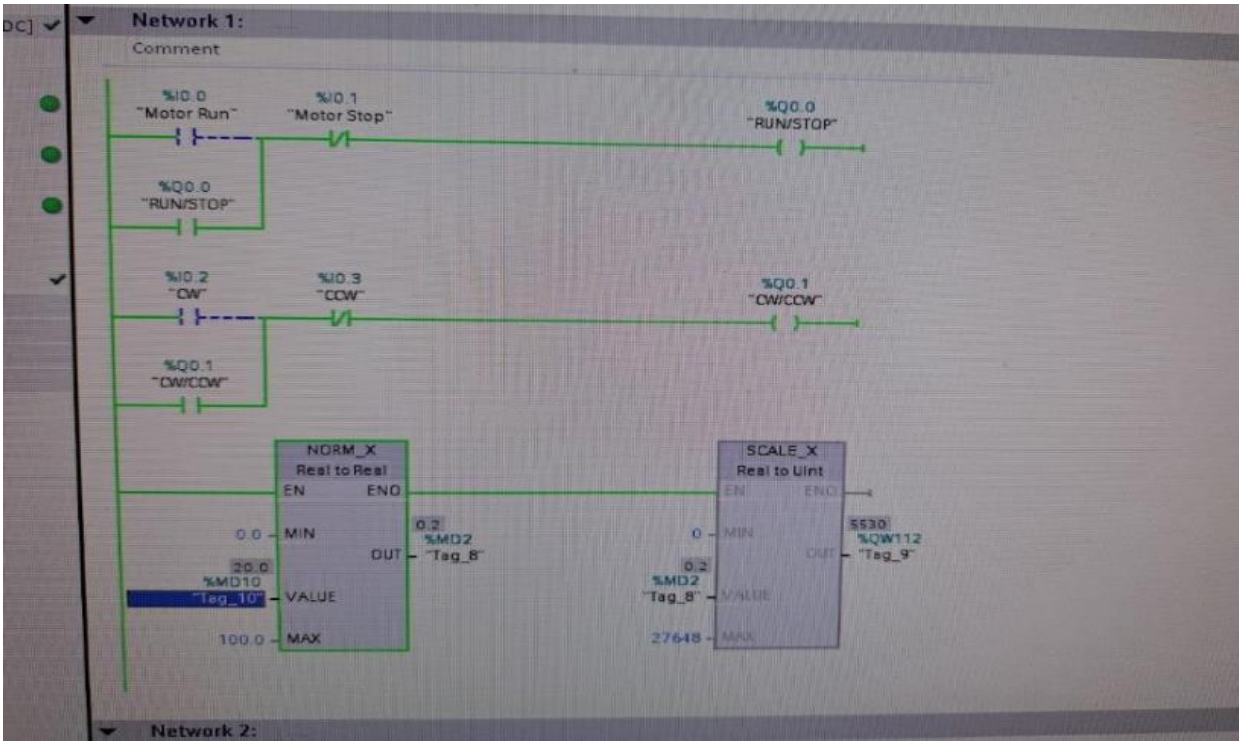

Figure 6: Ladder logic diagram for 20V input voltage and CW direction

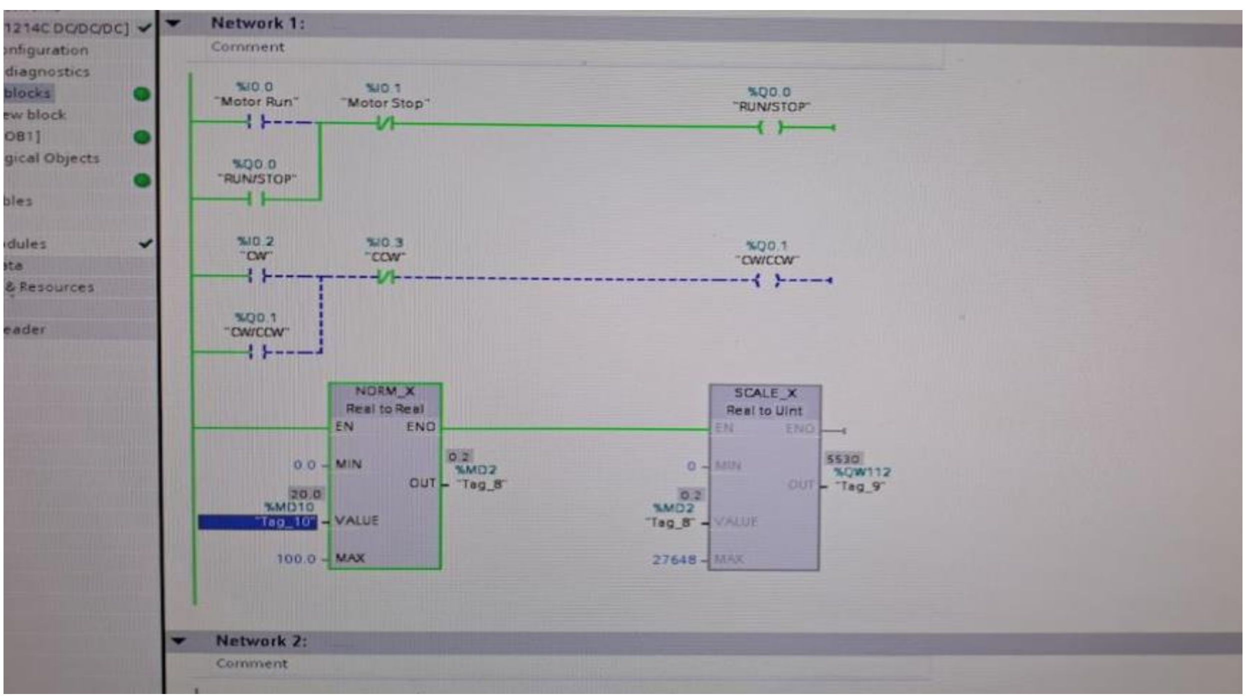

Figure 7: Ladder logic diagram for 20V input voltage and CCW direction

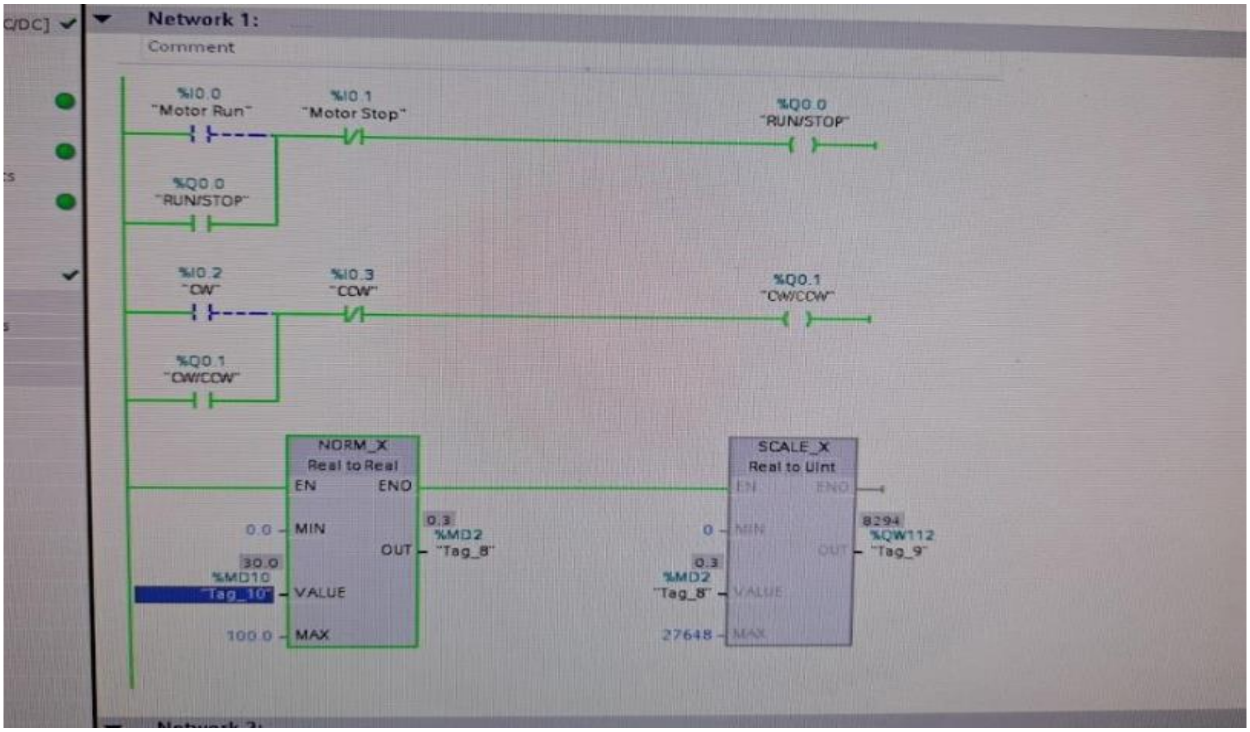

Figure 8: Ladder logic diagram for 30V input voltage and CW direction

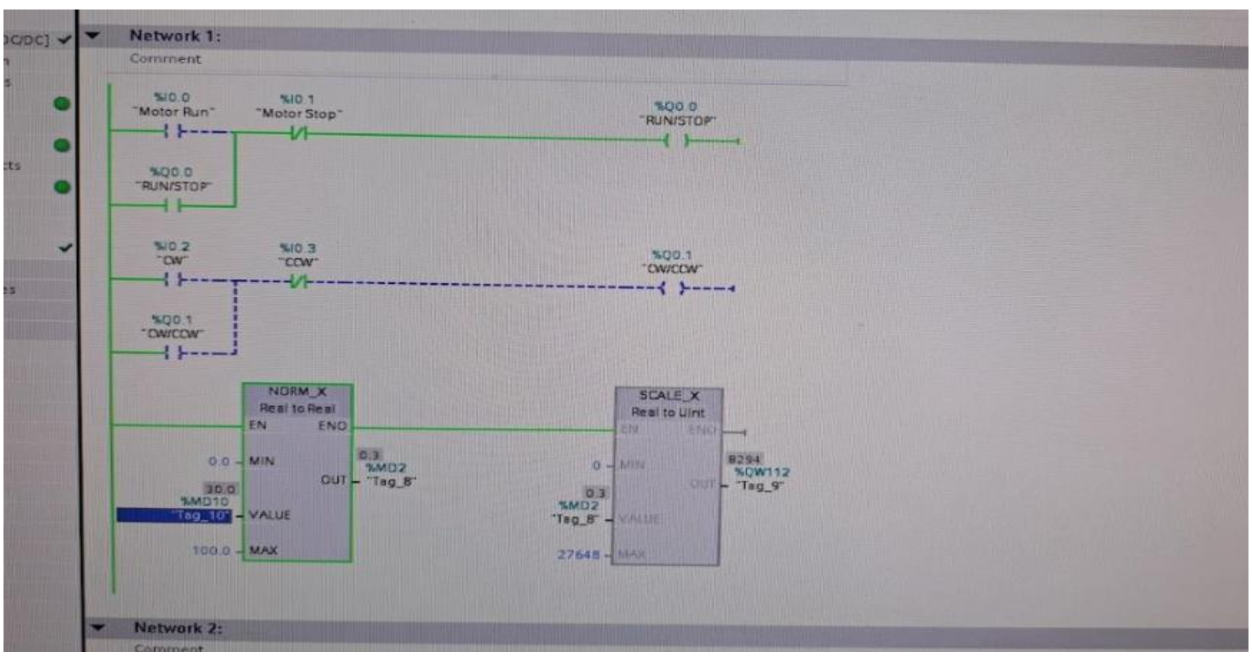

Figure 9: Ladder logic diagram for 30V input voltage and CCW direction

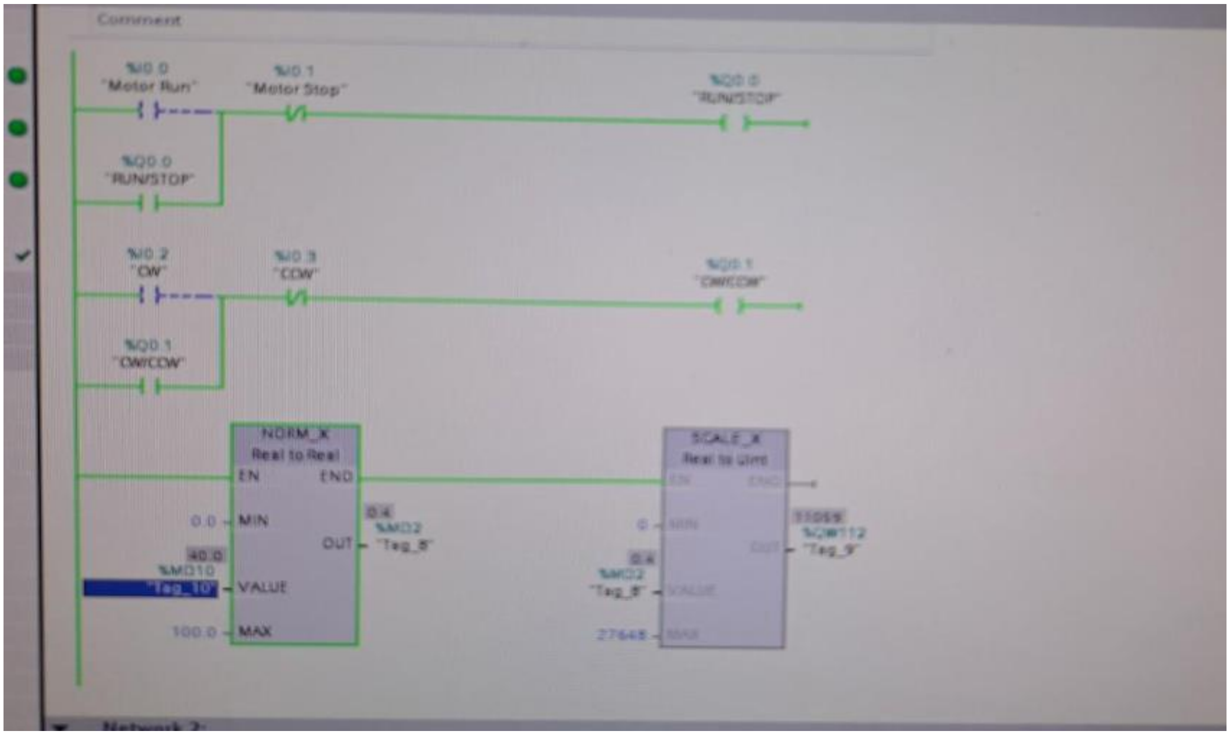

Figure 10: Ladder logic diagram for 40V input voltage and CW direction

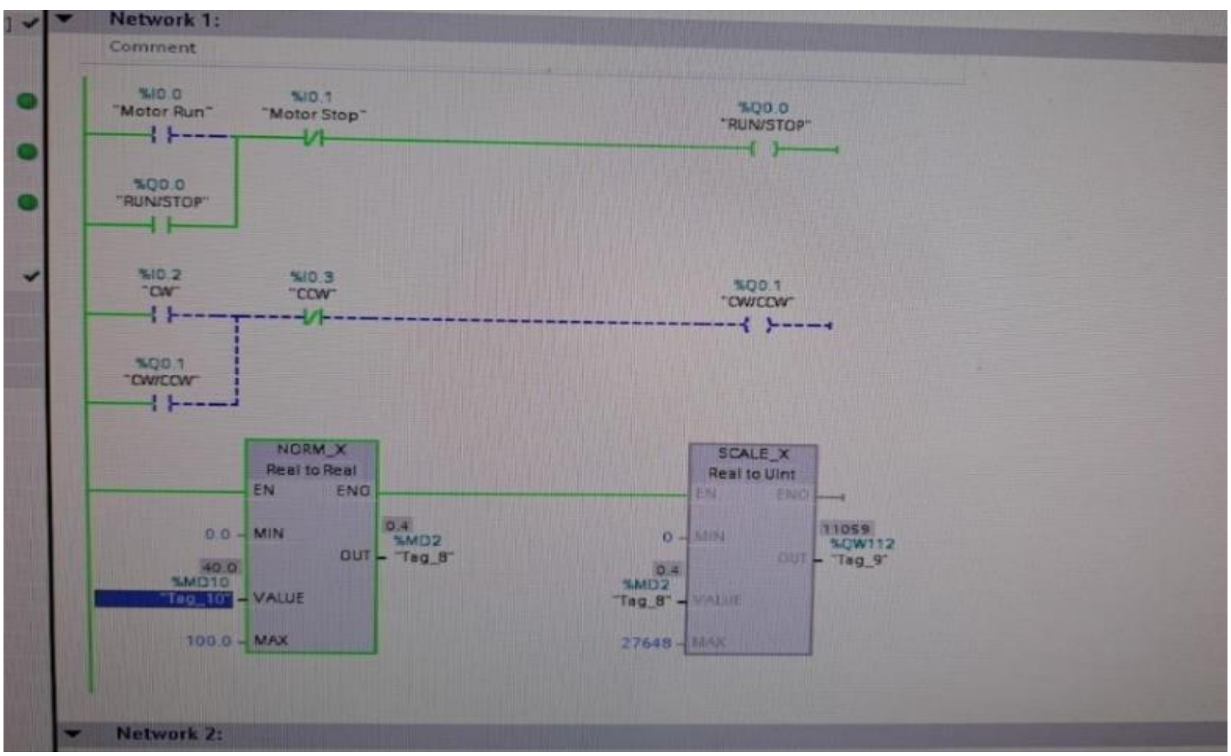

Figure 11: Ladder logic diagram for 40V input voltage and CCW direction

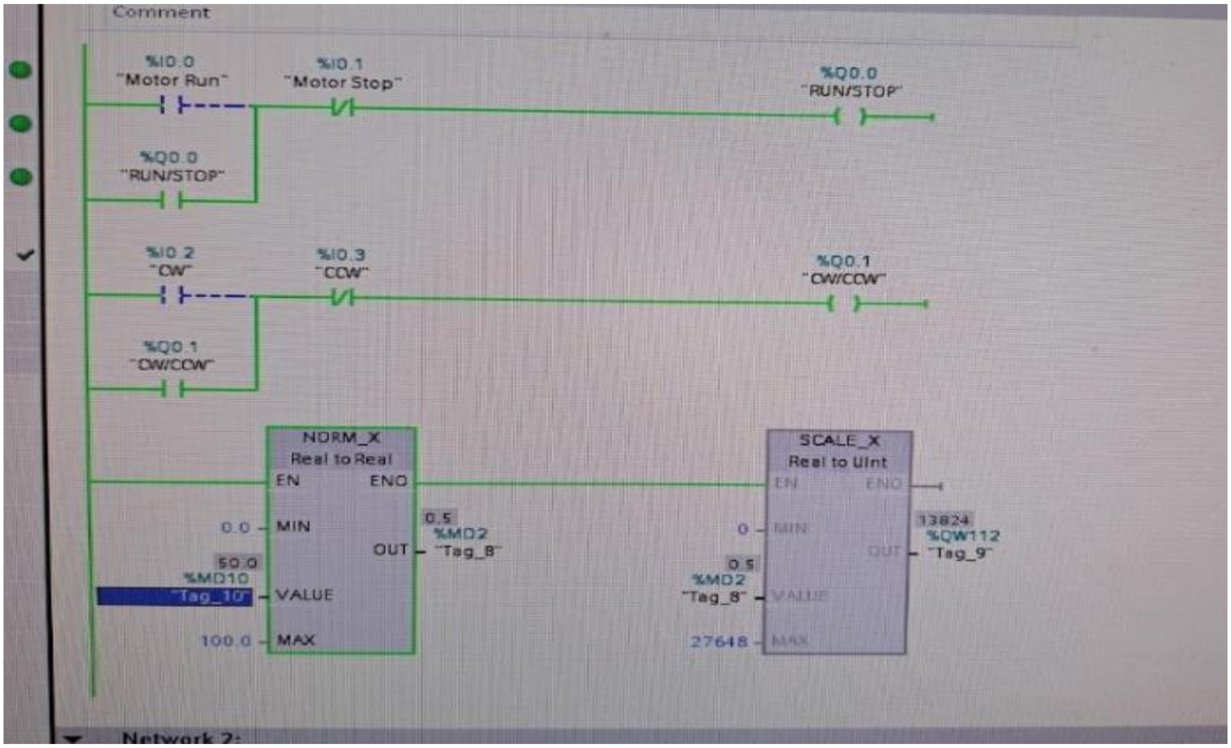

Figure 12: Ladder logic diagram for 50V input voltage and CW direction

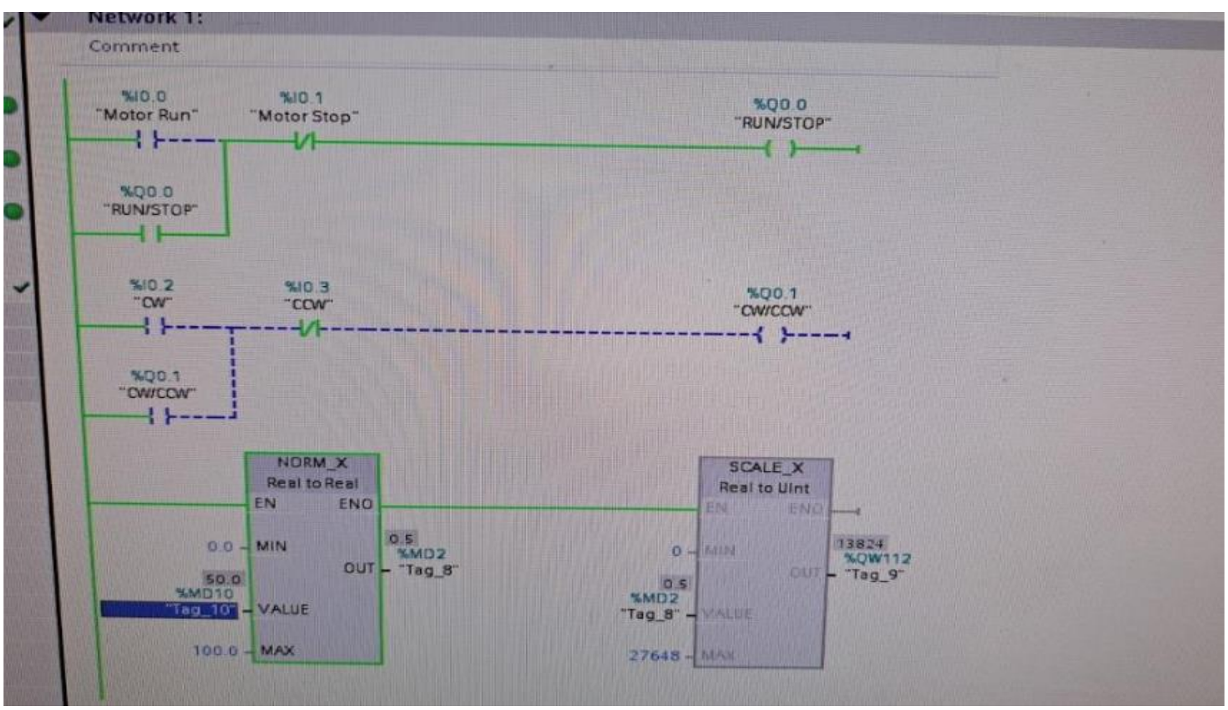

Figure 13: Ladder logic diagram for 50V input voltage and CCW direction

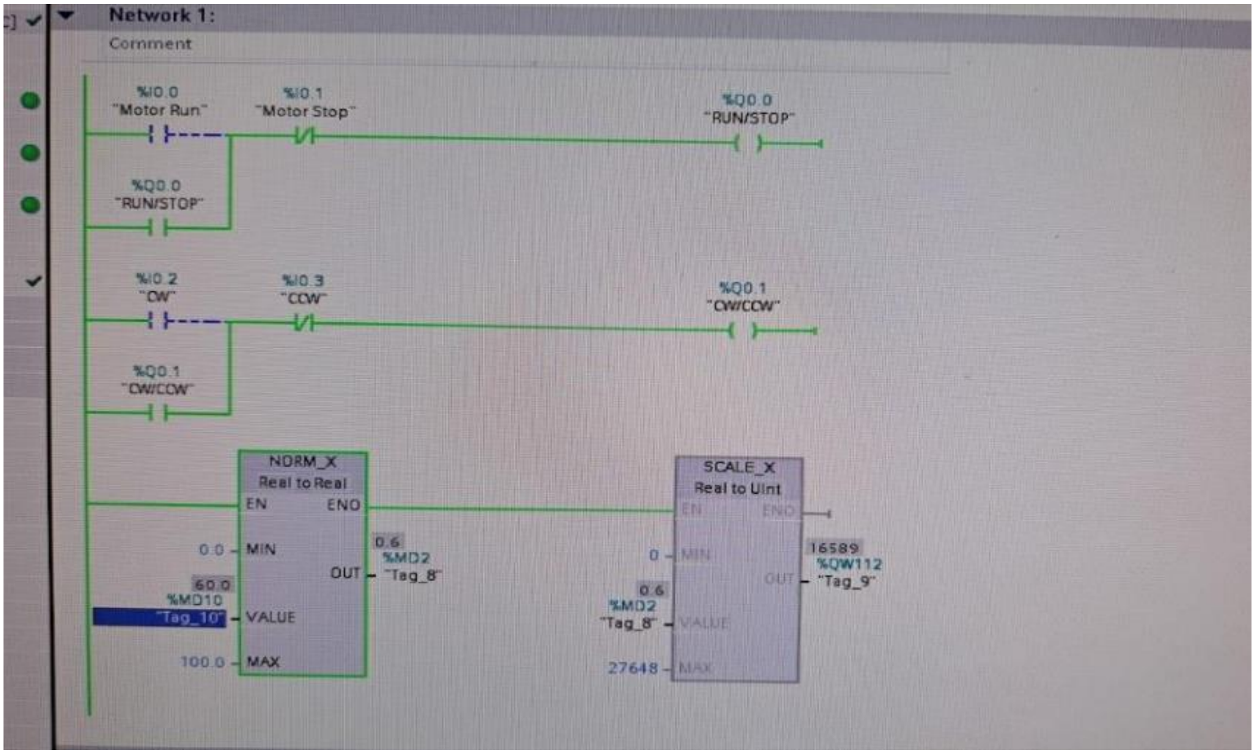

Figure 14: Ladder logic diagram for 60V input voltage and CW direction

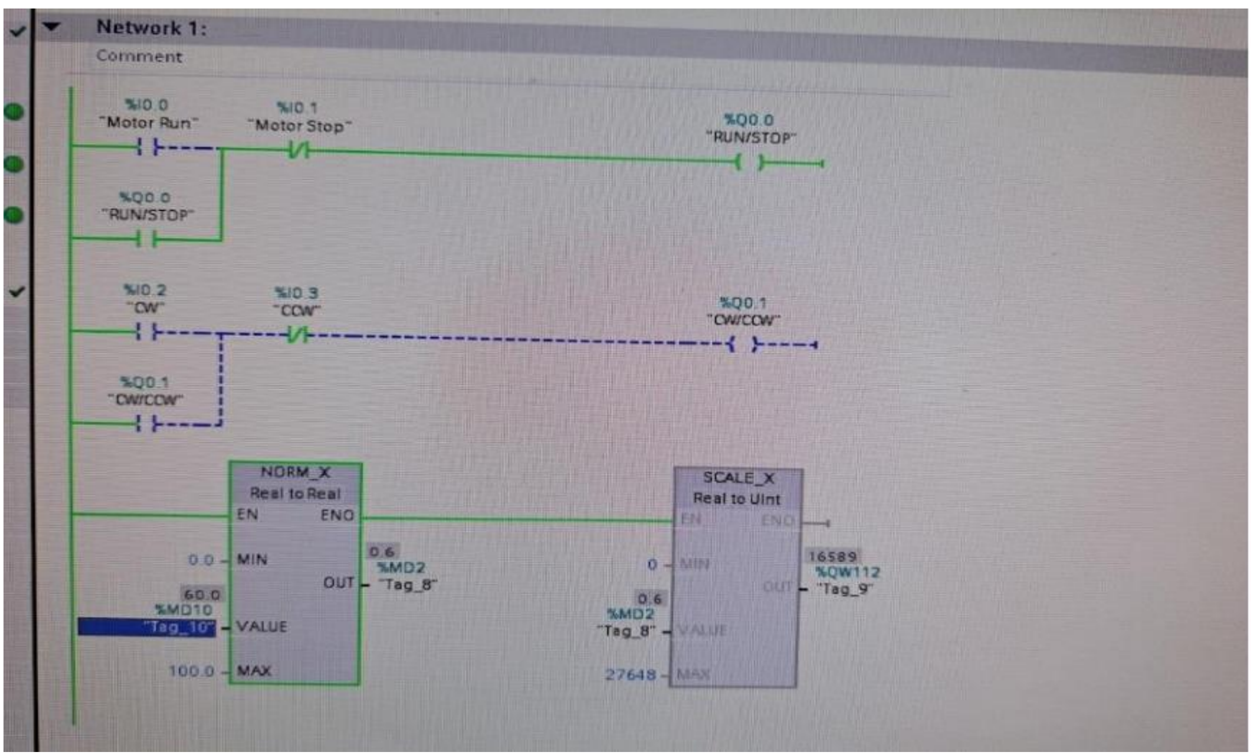

Figure 15: Ladder logic diagram for 60V input voltage and CCW direction

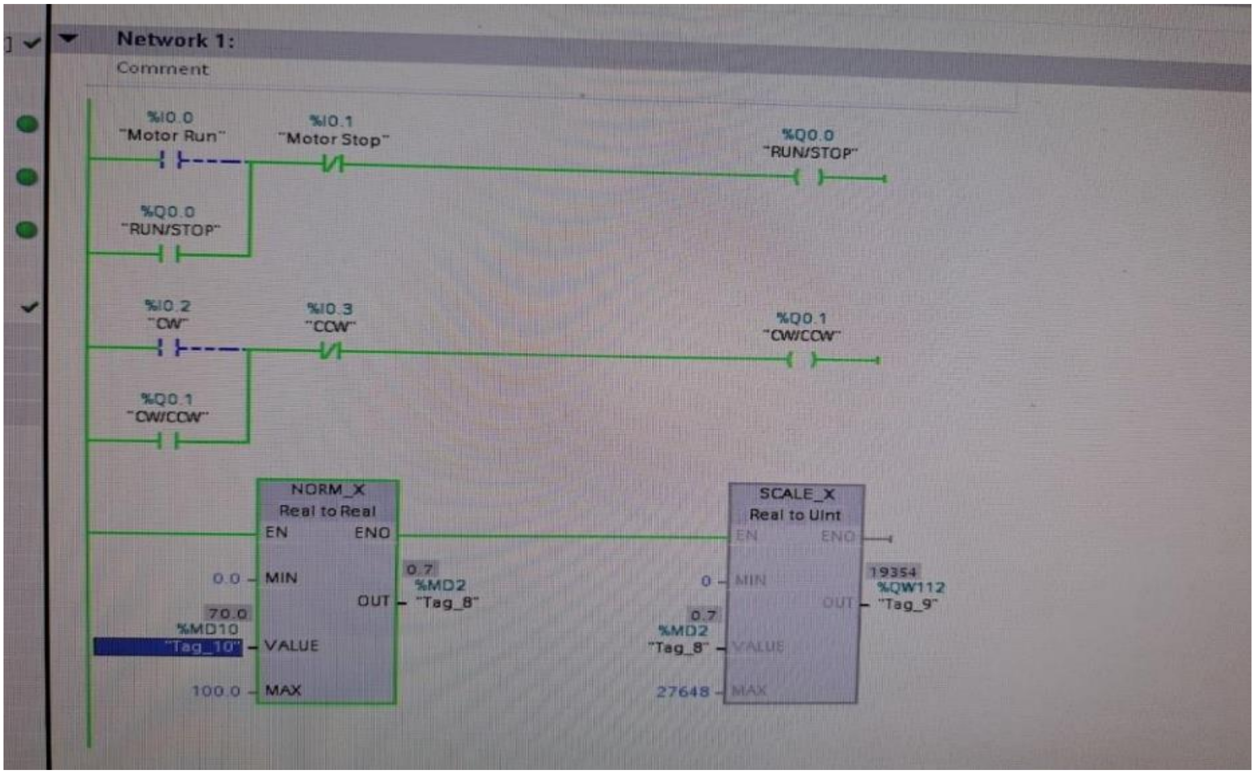

Figure 16: Ladder logic diagram for 70V input voltage and CW direction

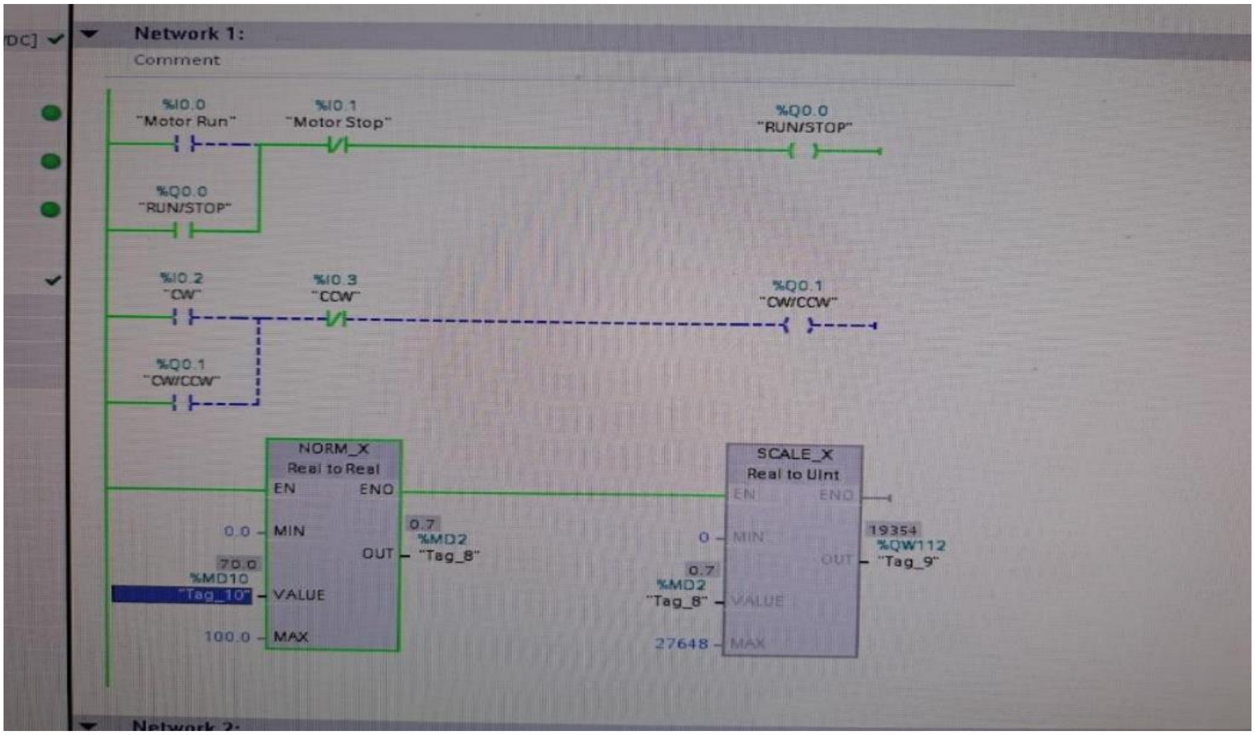

Figure 17: Ladder logic diagram for 70V input voltage and CCW direction

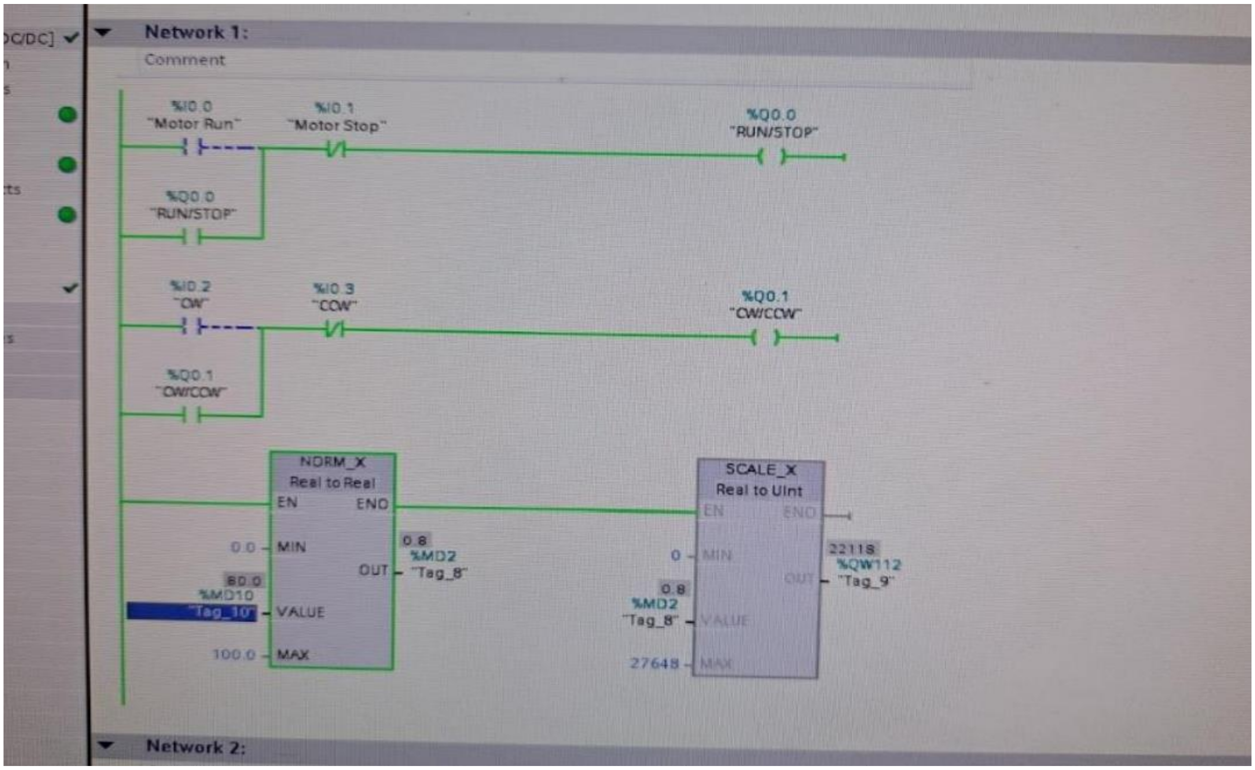

Figure 18: Ladder logic diagram for 80V input voltage and CW direction

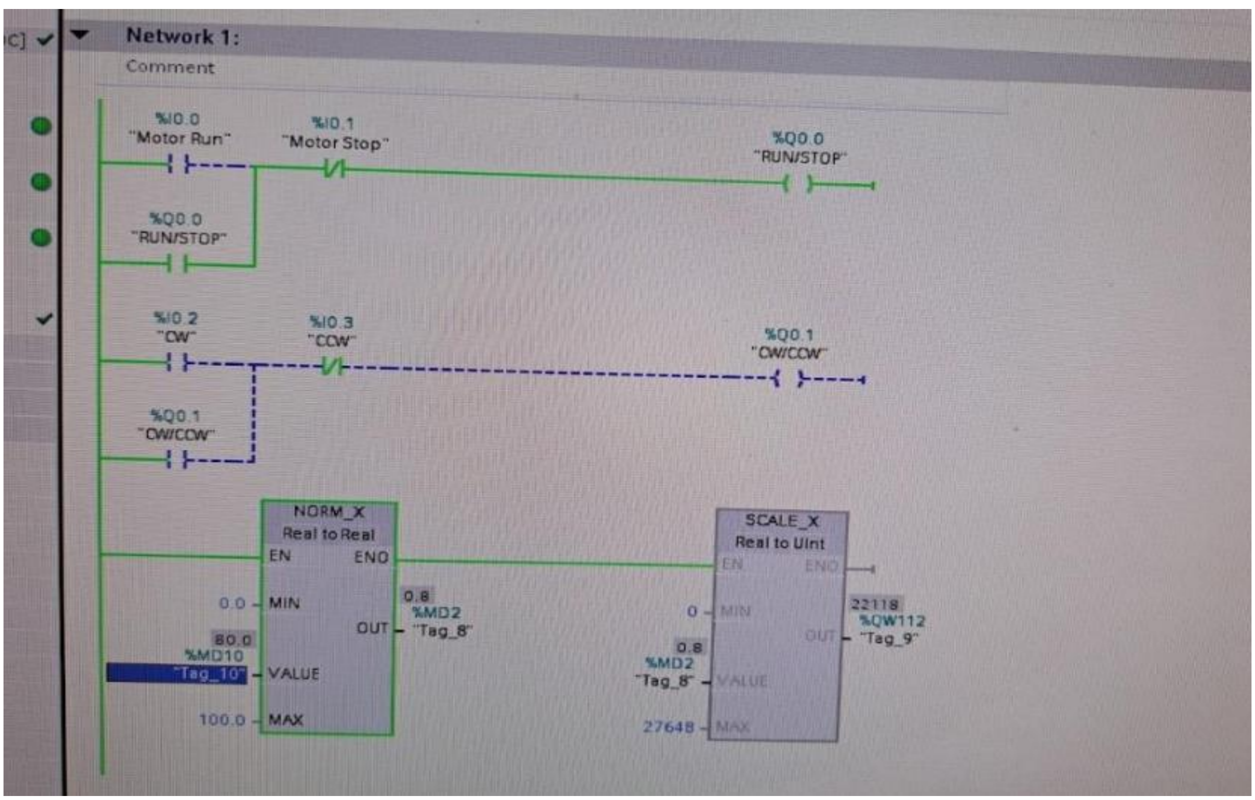

Figure 19: Ladder logic diagram for 80V input voltage and CCW direction

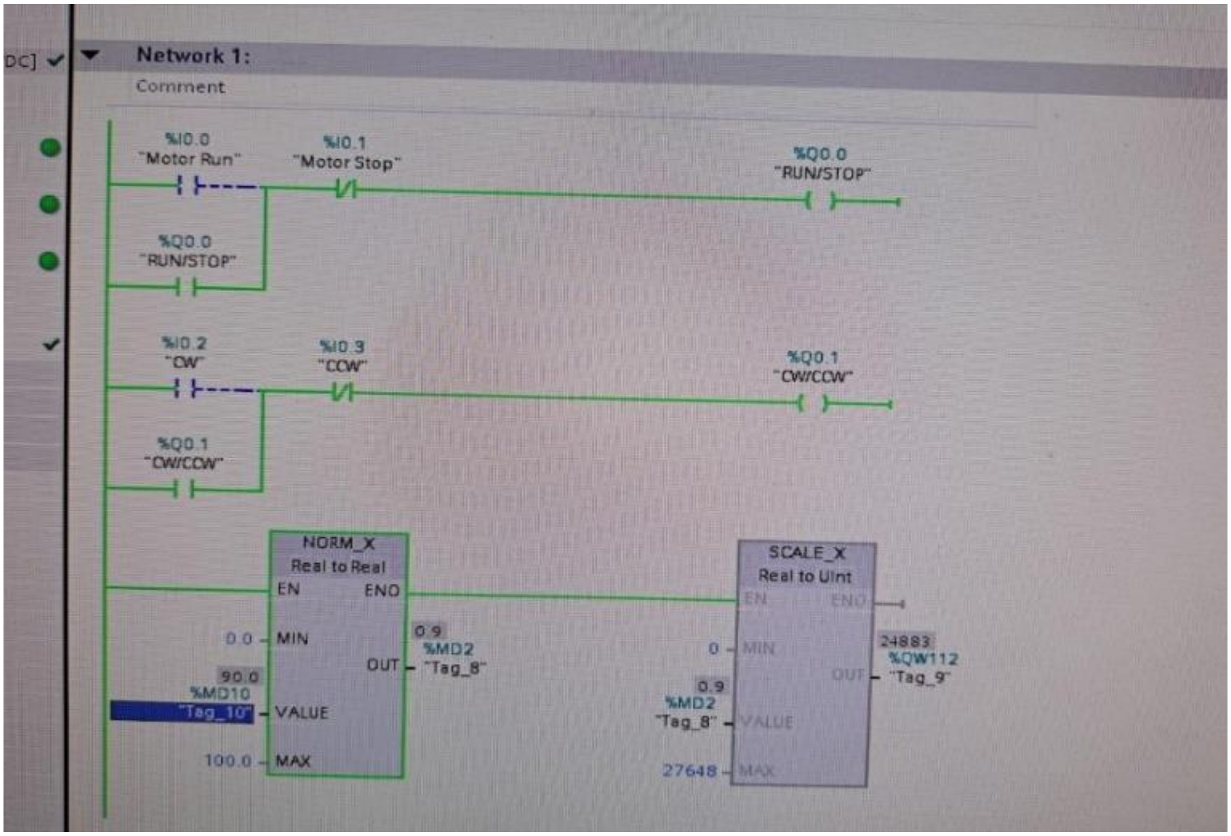

Figure 20: Ladder logic diagram for 90V input voltage and CW direction

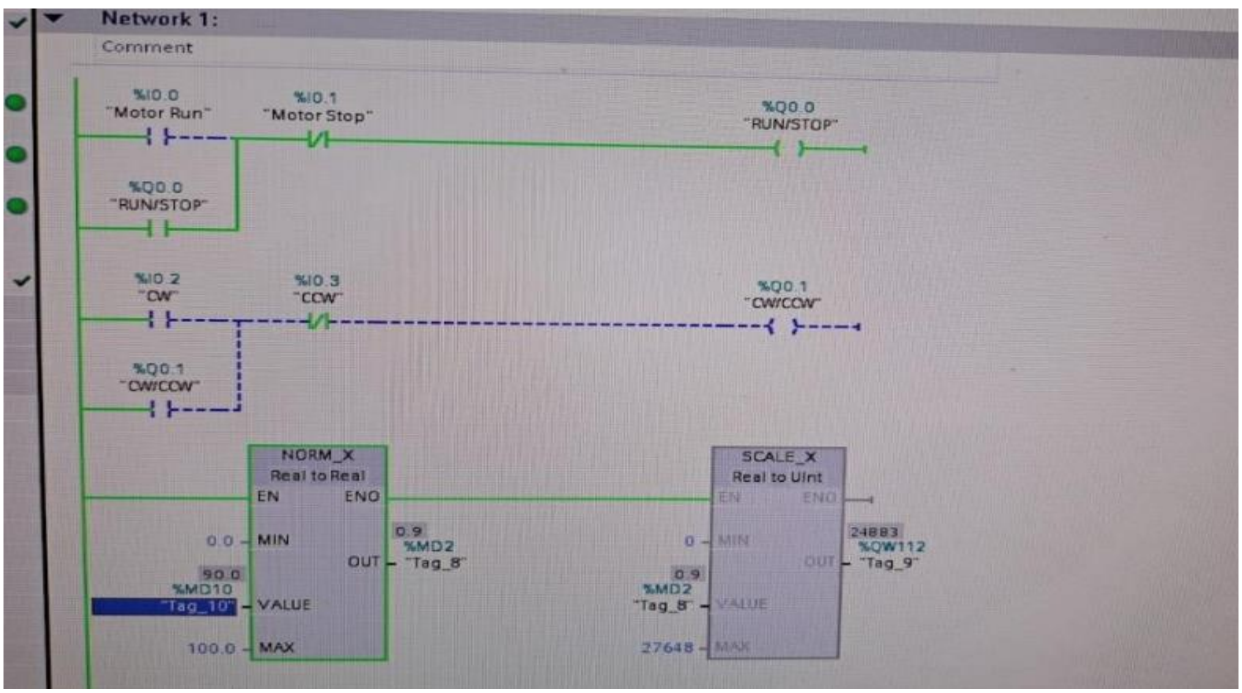

Figure 21: Ladder logic diagram for 90V input voltage and CCW direction

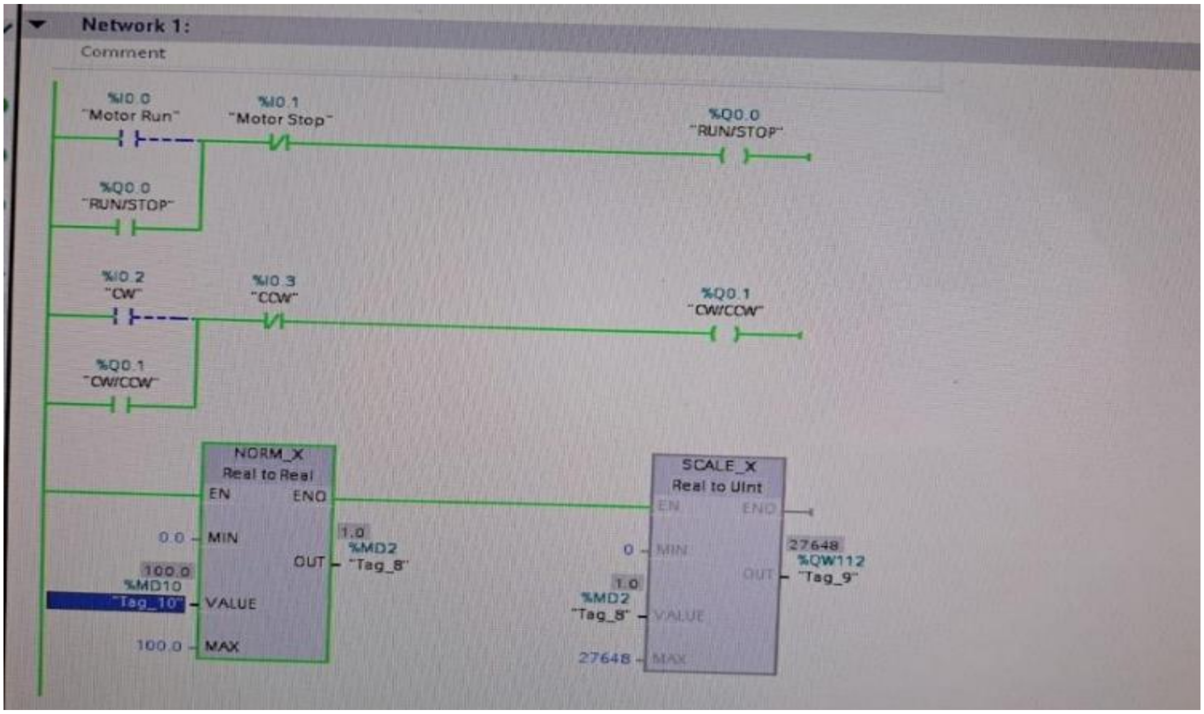

Figure 22: Ladder logic diagram for 100V input voltage and CW direction 100V

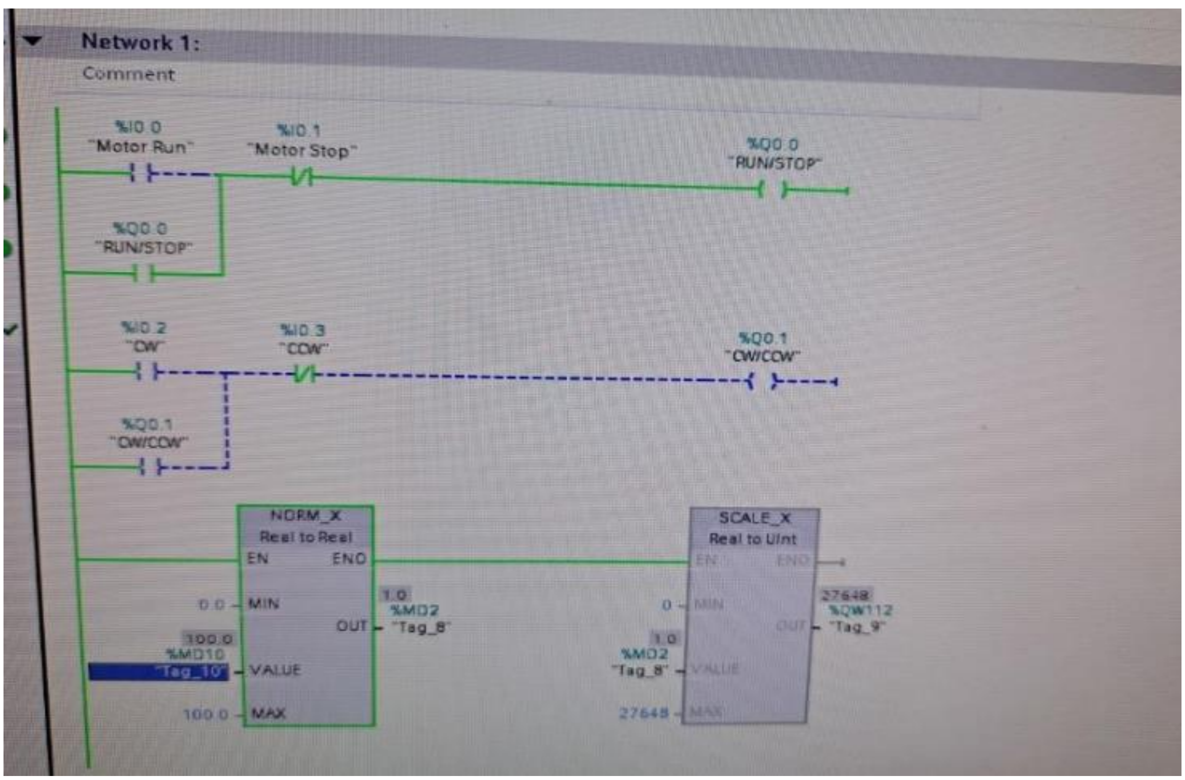

Figure 23: Ladder logic diagram for 100V input voltage and CCW direction

Description of ladder diagram

To control the PMDC motor, we use four push buttons. Buttons I0.0 and I0.1 are designated to turn the motor ON and OFF, respectively, while buttons I0.2 and I0.3 control the direction of rotation—clockwise and anticlockwise. Both outputs are latched to allow continuous operation.

To adjust the output value for the PLC module, SCALE_X and NORM_X must be configured. The desired motor speed is normalized by NORM_X within the range of 0 to 1. The output from NORM_X is then scaled by SCALE_X to a value between 0 and 27,648.

Based on the scaled output, the PLC generates a specific binary voltage. In our setup, with a power source of 10V, the PLC converts it to 100V.

Experimental Data Analysis

RPM values for variable Voltages:

Voltage [V]	Set value [V]/DC [%]	Clockwise (CW) [rpm]	Counterclockwise (CCW) [rpm]

Theoretical data sheet:

At DC 100% motor, no- load maximum rpm is, M=1300 and the rated voltage is, Vc=18 volts. We applied the voltage between 1 to 10 (applied voltage=Va) volts for this experiment. The estimated speed equation will be,

Clockwise Speed= $\left(\frac{M}{V_c}\right)$ ×Va----- (i)

Counterclockwise speed= $\left(\frac{\text{clockwise speed}}{\text{clockwise voltage}}\right)$ × Counterclockwise voltage ------ (ii)

RPM values for variable Voltages according to theory:

Voltage [V]	Set value [V]/DC [%]	Clockwise (CW) [rpm]	Counterclockwise (CCW) [rpm]

Error calculation:

Error = $\left(\frac{\text{Experimental Value} - \text{Theoretical Value}}{\text{Theoretical value}}\right) \times 100\%$

Voltage [V]	Set value [V]/DC [%]	Error (%) of Clockwise	Error (%) of Clockwise

Post Lab Questions:

1) Briefly explain the working principle of a Permanent Magnet DC (PMDC) motor.
2) What is NORM_X and SCALE_X?
3) Calculate the error.

Experiment Part

Output from PMDC motor module:

Figure 24: Input and Output setup of module and PLC for 10V input voltage and CW direction

Figure 25: Input and Output setup of module and PLC for 10V input voltage and CCW direction

Figure 26: Input and Output setup of module and PLC for 20V input voltage and CW direction

Figure 27: Input and Output setup of module and PLC for 20V input voltage and CCW direction

Figure 28: Input and Output setup of module and PLC for 30V input voltage and CW direction

Figure 29: Input and Output setup of module and PLC for 30V input voltage and CCW direction

Figure 30: Input and Output setup of module and PLC for 40V input voltage and CW direction

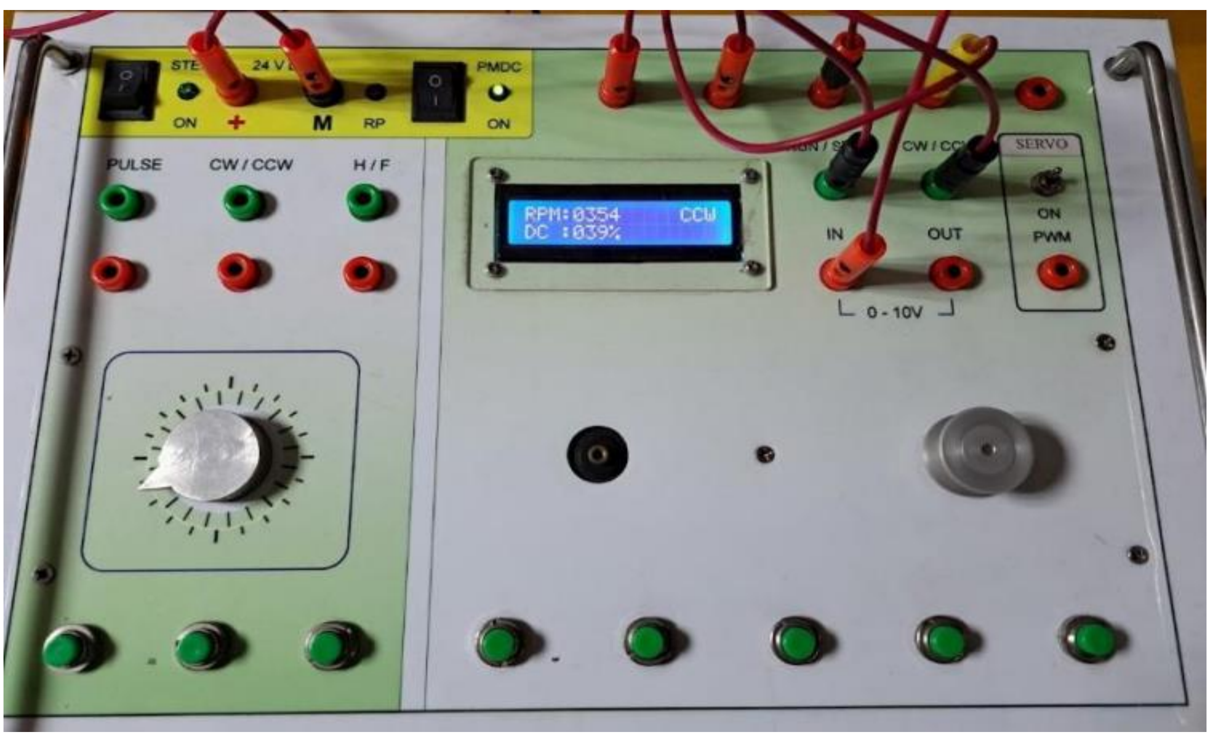

Figure 31: Input and Output setup of module and PLC for 40V input voltage and CCW direction

Figure 32: Input and Output setup of module and PLC for 50V input voltage and CW direction

Figure 33: Input and Output setup of module and PLC for 50V input voltage and CCW direction

Figure 34: Input and Output setup of module and PLC for 60V input voltage and CW direction

Figure 35: Input and Output setup of module and PLC for 60V input voltage and CCW direction

Figure 36: Input and Output setup of module and PLC for 70V input voltage and CW direction

Figure 37: Input and Output setup of module and PLC for 70V input voltage and CCW direction

Figure 38: Input and Output setup of module and PLC for 80V input voltage and CW direction

Figure 39: Input and Output setup of module and PLC for 80V input voltage and CCW direction

Figure 37: Input and Output setup of module and PLC for 90V input voltage and CW direction

Figure 38: Input and Output setup of module and PLC for 90V input voltage and CCW direction

Figure 39: Input and Output setup of module and PLC for 100V input voltage and CW direction

Figure 40: Input and Output setup of module and PLC for 100V input voltage and CCW direction

Theoretical data sheet

RPM values for variable Voltages:

Voltage [V]	Set value [V]/DC [%]	Clockwise (CW) [rpm]	Counterclockwise (CCW) [rpm]
1	10	91	95
2	20	165	178
3	30	266	269
4	40	347	354
5	50	407	434
6	60	504	508
7	70	564	563
8	80	604	604
9	90	627	633
10	100	635	636

Comment: It is observable that with the increase in voltage the rpm increases.

RPM values for variable Voltages according to theory:

Voltage [V]	Set value [V]/DC [%]	Clockwise (CW) [rpm]	Counterclockwise (CCW) [rpm]
1	10	72.22	72.22
2	20	144.4	144.4
3	30	216.67	216.67
4	40	288.8	288.8
5	50	361.11	361.11
6	60	433.33	433.33
7	70	505.55	505.55
8	80	577.77	577.77
9	90	650	650
10	100	722.22	722.22

Error calculation:

Voltage [V]	Set value [V]/DC [%]	Error (%) of Clockwise	Error (%) of Counter clockwise
1	10	26	31.5
2	20	14.3	23.3
3	30	22.8	24.2
4	40	20.2	22.6
5	50	12.7	20.2
6	60	16.3	17.2
7	70	11.6	11.4
8	80	4.6	4.5
9	90	3.5	2.6
10	100	12.1	11.9

Comment: Due to friction and heat loss, we notice some differences from the expected values. Also, the module we used is not a perfect voltage source and doesn't supply a precise voltage. These fluctuations cause variations in the motor's RPM.

Post lab question answers:

1. A Permanent Magnet DC (PMDC) motor uses permanent magnet to create magnetic field. When a voltage is applied to the armature winding, a current flow through it. This current creates a magnetic field that interacts with the magnetic field produced by the permanent magnets on the rotor. This interaction generates a torque that causes the rotor to rotate.
2. NORM_X: It is a function block which can be used to normalize a value within a certain range. The input value can be scaled to 0 to 1 from its original value by mentioning minimum and maximum.

   SCALE_X: This function block is used to scale a normalized. For instance, the output of the NORM_X function can be sent to the SCALE_X function, then the SCALE_X function can convert this normalized value to a new desired range.

3. Error calculation:

$$\text{Error} = \left(\frac{\text{Experimental Value} - \text{Theoretical Value}}{\text{Theoretical value}}\right) \times 100\%$$

Voltage [V]	Set value [V]/DC [%]	Error (%) of Clockwise	Error (%) of Counter clockwise
1	10	26	31.5
2	20	14.3	23.3
3	30	22.8	24.2
4	40	20.2	22.6
5	50	12.7	20.2
6	60	16.3	17.2
7	70	11.6	11.4

8	80	4.6	4.5
9	90	3.5	2.6
10	100	12.1	11.9

Conclusion:

In this lab, we explored the control of a PMDC motor using a PLC. By designing and conducting an experiment, we were able to observe how different PLC settings affect the motor's speed. Through theoretical analysis, practical experimentation, and data analysis, we gained valuable insights into how to effectively control the motor’s speed. This process allowed us to better understand the relationship between PLC settings and motor performance, while also highlighting the role of factors like friction and voltage fluctuations.