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Real Time Control System for Metro Railways Using PLC & SCADA

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Abstract: This paper proposes to adopt SCADA and PLC technology for the improvement of the performance of real time signaling & train control systems in metro railways. The main concern of this paper is to minimize the failure in automated metro railways system operator and integrate the information coming from Operational Control Centre (OCC), traction SCADA system, traction power control, and power supply system. This work presents a simulated prototype of an automated metro train system operator that uses PLC and SCADA for the real time monitoring and control of the metro railway systems. Here, SCADA is used for the visualization of an automated process operation and then the whole operation is regulated with the help of PLC. The PLC used in this process is OMRON (NX1P2-9024DT1) and OMRON's Sysmac studio programming software is used for developing the ladder logic of PLC. The metro railways system has deployed infrastructure based on SCADA from the power supply system, and each station's traction power control is connected to the OCC remotely which commands all of the stations and has the highest command priority. An alarm is triggered in the event of an emergency or system congestion. This proposed system overcomes the drawbacks of the current centralized automatic train control (CATC) system. This system provides prominent benefits like augmenting services which may enhance a network's full load capacity and network flexibility, which help in easy modification in the existing program at any time.

Keywords: Train control system; automation; PLC (programmable logic controller); SCADA (supervisory control and data acquisition)

1 Introduction

Automation has been developed in the context of industrialization to provide various leverages such as process decentralization, virtualization, interoperability, real-time data acquisition, and an important role in mechanization, which provides the human operator with machinery to assist them with the manual requirements of work [1]. Automation reduces power consumption and increases industrial efficiency. Automation assures the improved monitoring and control and also enhances the quality of work performed by control systems [2,3].

Railway systems play a vital role in today's constantly growing transportation sector. Metro railways deliver fast and convenient travels in the metropolitan cities to the daily commuters. The importance of signaling and train control systems in accomplishing these goals cannot be overstated because they ensure the entire safety of train movements, increased efficiency, and lower operational costs [4–7]. Earlier, Track circuits and transmission based systems were used for signaling & train control systems in metro railways. With advancements in telecommunications and information technology, the Communication based train control (CBTC) systems has now been used for railway signaling and train control systems [8,9]. But these CBTC systems have various drawbacks [10–12]. They have a large attack surface. They can be subjected to multiple hacking attacks like network intrusion, data tampering which eventually lead to security hazard [13,14].

Therefore, PLC and SCADA based automation systems can be used in Metro Railways to minimize the failure. PLCs conduct the majority of the control components required to implement system logic [15]. SCADA monitors, regulates, optimizes, and manages generating and transmission systems. Remote terminal units (RTU) are the core component of these systems, which gather data automatically and link directly to sensors, meters, recorders, or process equipment.

It is important to understand how real-world stuff works and therefore to assist the user, PLC code is used with SCADA. Input/output, HMI, signal hardware controller, networks, communication, database, and software are all part of a SCADA system, which are all connected via a PLC program. PLC is capable of altering or modifying the sequence of operations in accordance with the settings of the purpose to prevent failure. Here, SCADA is used for the visualization of an automated process operation and then the whole operation is regulated using PLC. The PLC used here is OMRON (NX1P2-9024DT1) and OMRON's Sysmac studio programming software is used for developing the ladder logic of PLC. Wonderware Intouch SCADA software is used for the visualization of the operation.

This PLC and SCADA based real time monitoring and train control system for the metro railways has various benefits like: This system helps in detecting exact location, avoiding train collisions and opening emergency exit even after the interruption of power system with the use of Programmable Logic Controller. This system overcomes the drawbacks of the current CATC i.e., centralized automatic train control system which comprises of automatic train protection, signaling and operation systems [16–19]. If the communications link between any of the trains is disrupted then the whole system/network will not be affected.

The framework of this paper is organized as follows: Introduction, Prototype of automated metro railways system operator, Operation, results, and Conclusion.

2 Prototype of Metro Railways System

PLC and SCADA are two components that are utilized for Monitoring and Train Control System for the Metro Railways. The communication between SCADA and PLC is via a wired/wireless interface. PLC is a computer with an internal memory\that stores instructions for executing certain operations while scanning the program. The purpose of a PLC is to modify process operations and monitor critical process parameters as needed. PLC receives data/signals from input devices such as sensors, push button switches, contact limit switches, and so on. The information is processed in the input module where logical operations are done on the inputs, and the required response is supplied to the operator via the output module linked device such as a motor, valve, or alarm as shown in Fig. 1.

SCADA monitors and control the system via a centralized OCC (Operation Control Centre) and HMI (Human-Machine interface) that controls the traction system equipment and entire power supply through SCADA. The functional diagram in Fig. 2 shows the working of Metro railways system using PLC and SCADA. To execute its tasks, the PLC requires a regulated power source of 24V DC. IR sensors, stations, and emergencies feed into the PLC, which generates six output signals such as signal/alarm, train running or halting, and door open or close. The PLC's output module will send commands from SCADA to the train. An essential feature is that in the case of an emergency, the alarm will send a status point with the value NORMAL or ALARM.

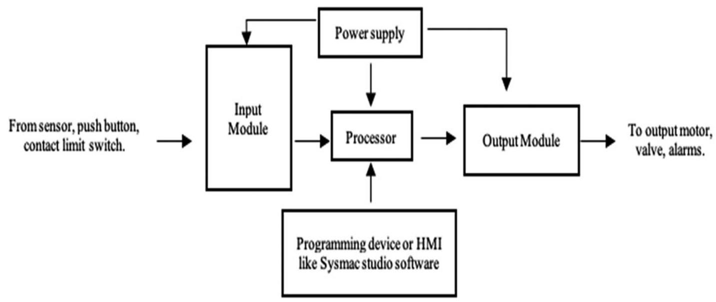

Figure 1: PLC block diagram

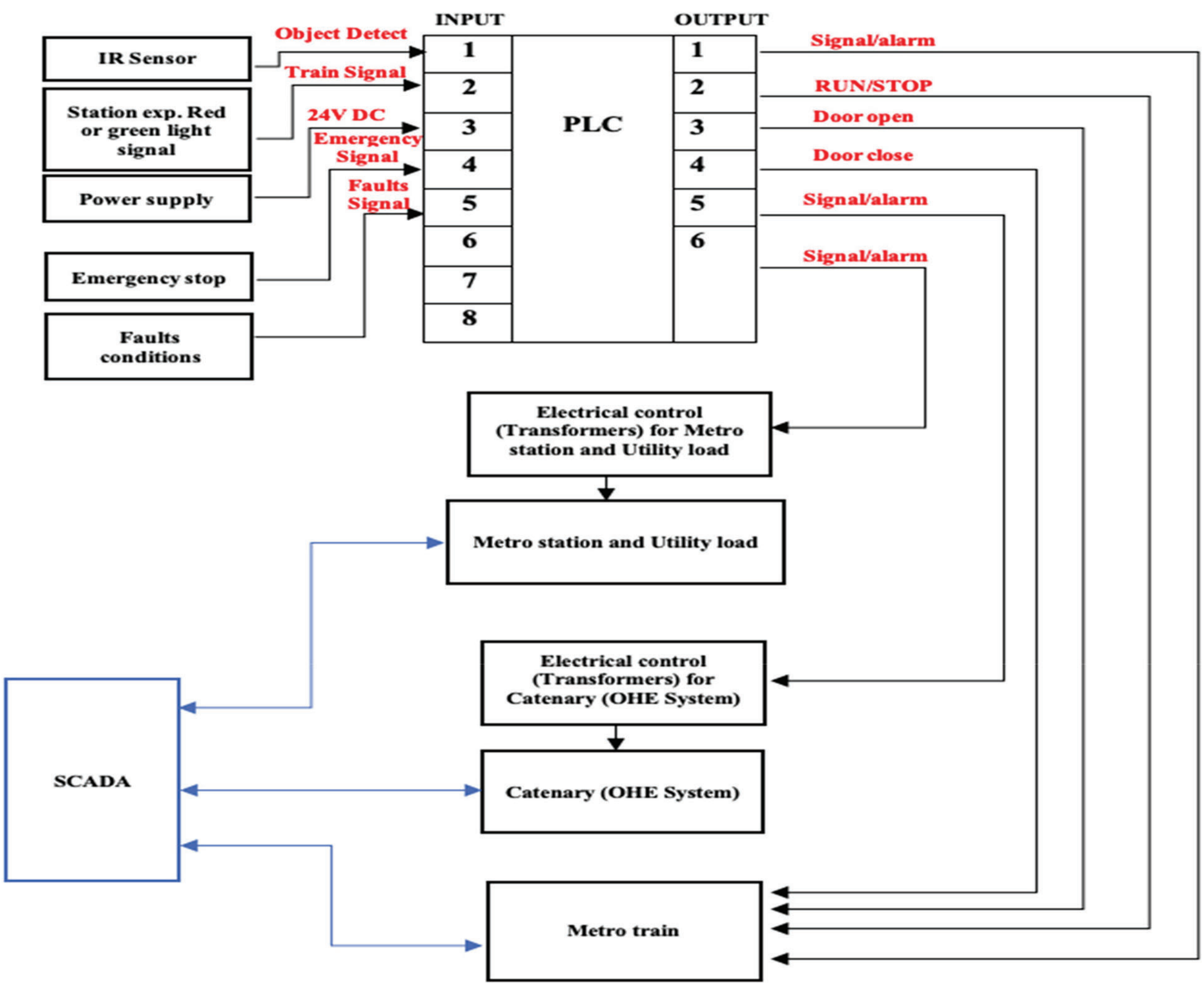

Figure 2: Functional block diagram of metro railways using PLC and SCADA

The prototype of the automated metro railways system operator has four main applications. OCC is the main application of this automated metro train system operator prototype. An operator sits in front of the HMI and controls the metro train system. Each station is linked to the OCC through a remote connection. It has command of all stations and handles all commands such as emergency and congestion with highest priority. CCTV function, Metro stations and metro platform view, and Electrical control are other sub-applications of the system (traction power control and power supply system). Sub application are CCTV function, Metro stations view (Metro train system), Metro platform view, and Electrical control (traction power control and power supply system).

Fig. 3 shows the functioning of the Main application and sub-application and Fig. 4 shows the block diagram and OCC runtime window in SCADA Wonderware Intouch software from where the operator may command and monitor. The IR and reflecting sensors on the RTU are used to scan the programs. If there is a problem with the process, the RTU sends a message to the Master Terminal Unit (MTU), which then sends signals or alerts to the operator on the screen.

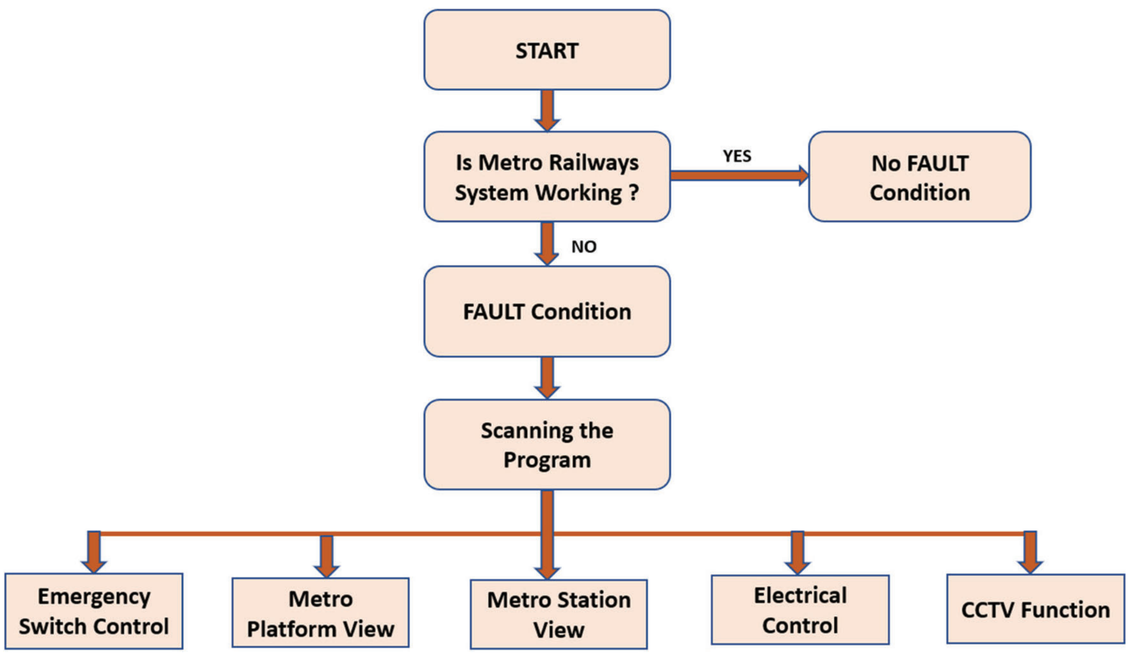

Figure 3: Functioning of main application

3 Operation

The operation of the entire system is shown using the flow charts listed below:

3.1 Metro Platforms View Sub-Application

The driver of the trains controls the metro platforms, and the operator of any platform can manage the traffic of the metro station. This flowchart in Fig. 5 and Tab. 1 shows the working of Metro platforms view sub-application. Here, t is timing tag of process/tag of slider.

3.2 Metro Stations (Traction SCADA System) View Sub-Application

In this flowchart in Fig. 6, functioning of Metro stations (traction SCADA) view sub-application is shown. Metro train starts moving when the switch is turned ON. The LED in the control panel view indicates the proper location of the metro train. This system can track, control and recognize the location of the train even after a power outage or other breakdown. The emergency light will turn ON in case of any fault station and an alert message is displayed by the OCC in the relevant metro station on the HMI or operation display.

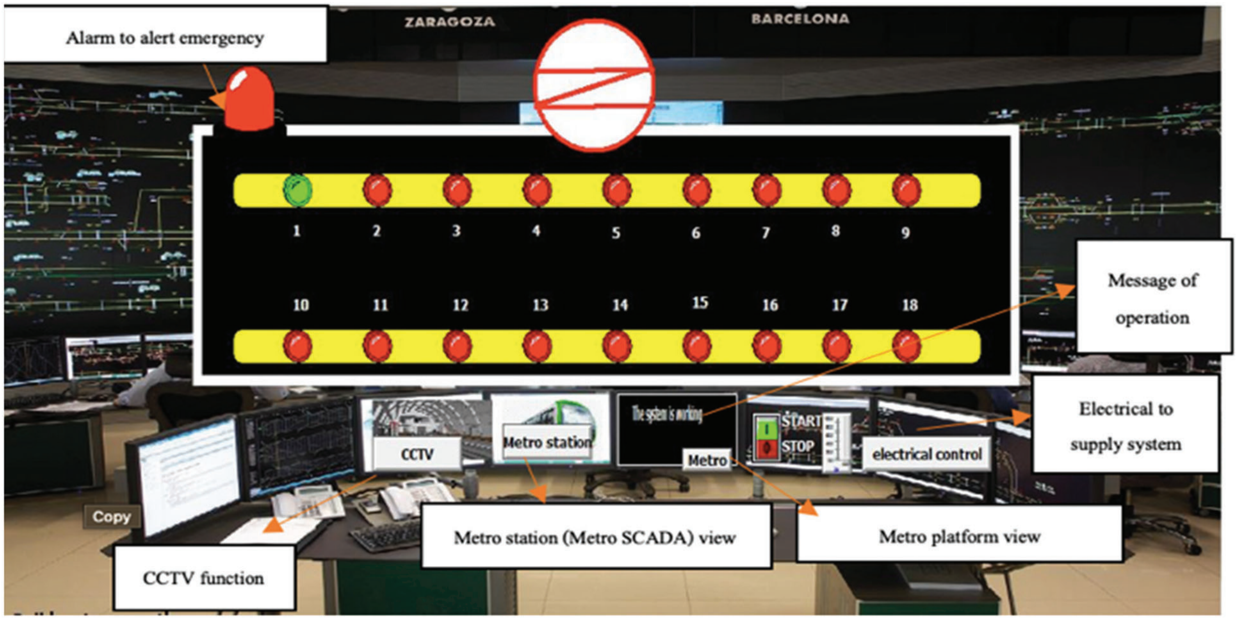

Figure 4: Operational control center runtime window in SCADA Wonderware Intouch software

Table 1: Metro platform view description

Label	Description
1. t = 0	The traffic light is red. the trains are stopped and the passengers move out/in of the train and pantograph is not collect the power yet.
2. 20 > t >= 15	The doors are closed.
3. For t >= 20	The doors are closed and pantograph collects the power and electrical signal on overhead system is ON. Train starts running.
4. 100 >= t >= 20	Traffic light is green. The train starts moving forward.

3.3 Traction Power Control and Power Supply System (Electrical Control)

This flowchart in Fig. 7 shows the functioning of Electrical control view sub-application. Metro rail lines must be electrified with 25 kV, single phase, 50 Hz for overhead equipment to deliver electrical energy to locomotives or trains for operating the motor. The substation, feeding post, and other equipment at the control post and switching station make up the power supply system. A catenary i.e., the overhead equipment (OHE) is used to deliver power to a metro train equipped with a pantograph in metro rail traction systems. Transformer1(T1) is a stepdown transformer for metro stations and Utility load, transformer2(T2) is a stepdown transformer for the catenary, and transformer3(T3) is a step-up transformer for 132 kV incoming line from generating station.

The system is turned on by pressing the button ON S0. The power control and power supply system where t is timing tag of process or the tag of slider is shown here (see Tab. 2).

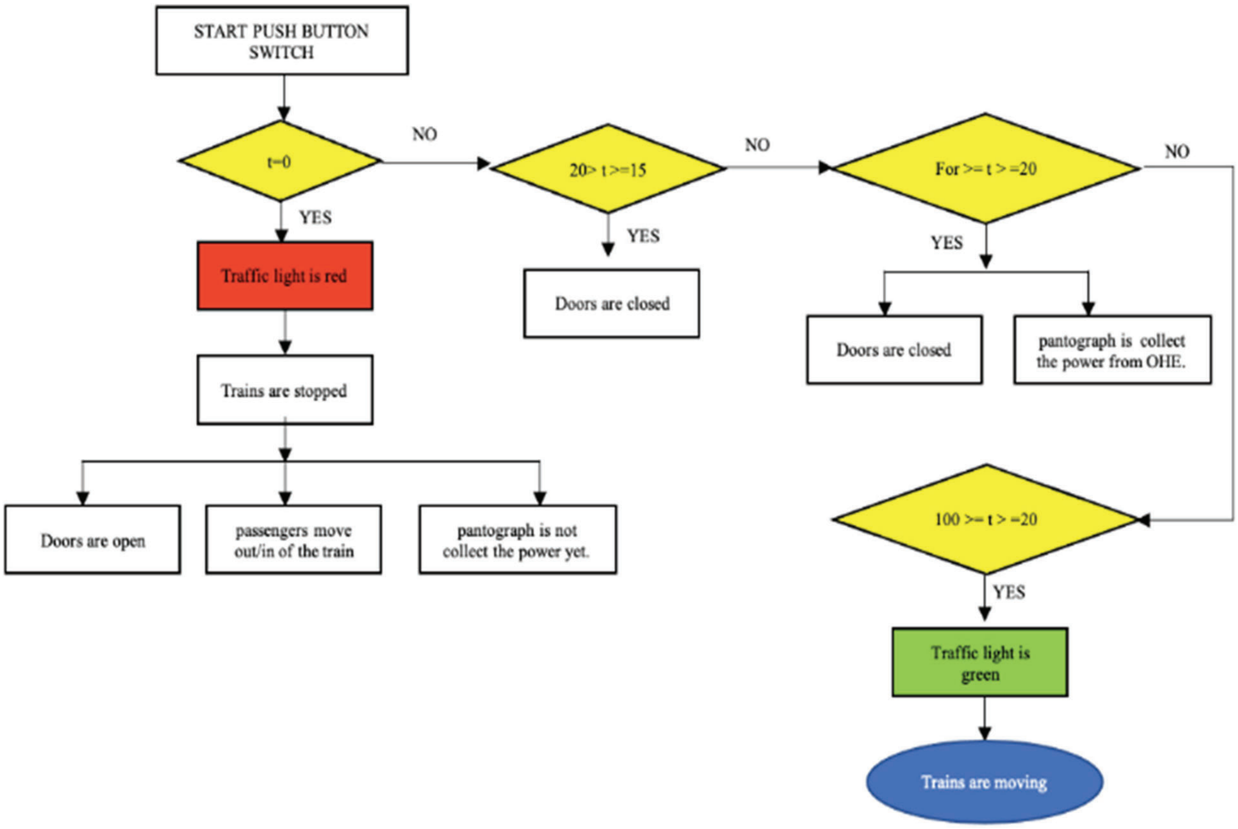

Figure 5: Working of metro platforms view sub-application

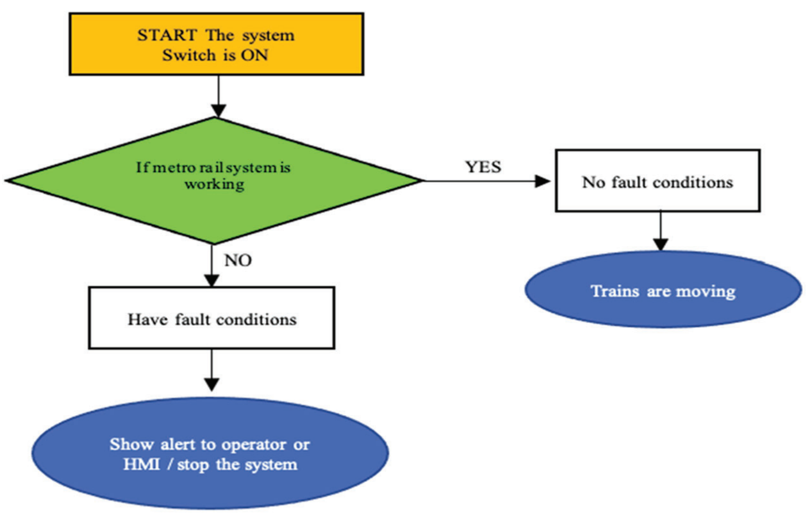

Figure 6: Working of metro stations (traction SCADA system) view sub-application

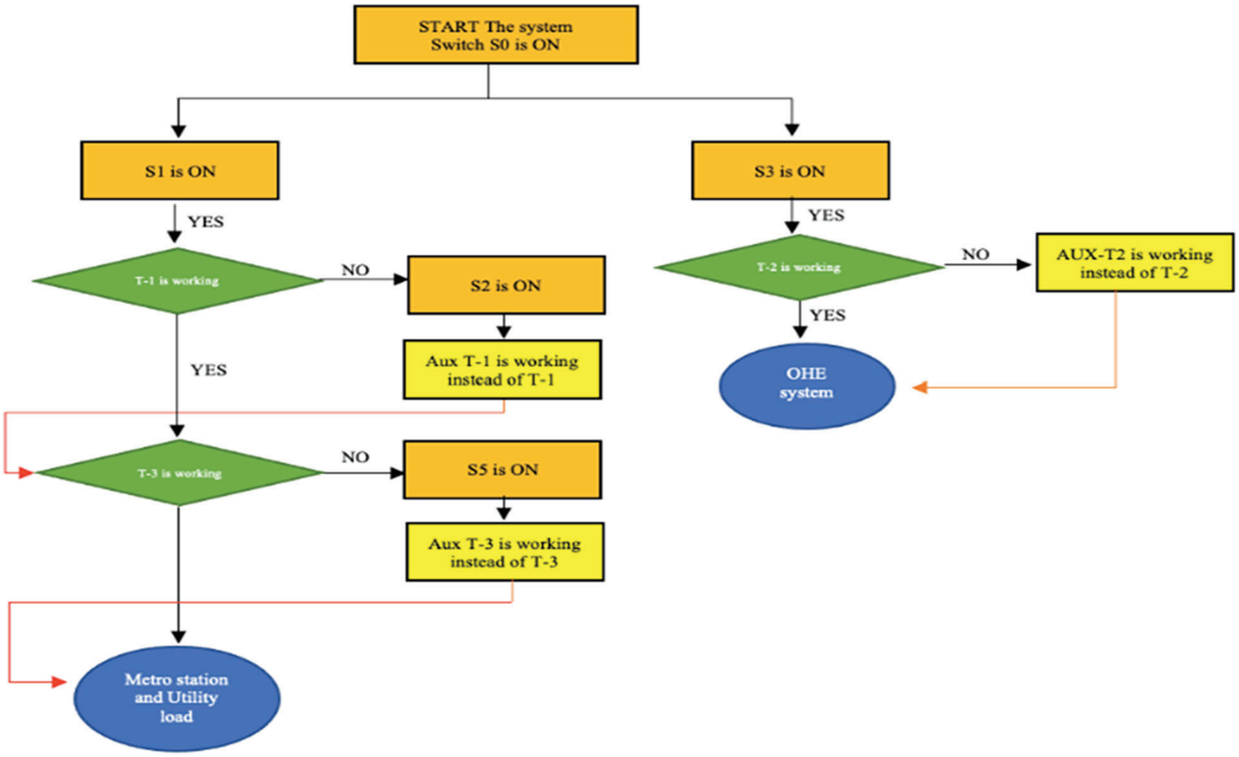

Figure 7: Working of traction power control and power supply system

Table 2: Electrical control view description

Label	Description
1. S0 is ON	Power supply is ON.
2. T1 and S1 are ON	Power supply (132 kV/33 kV) is fed to the stepdown transformer (T1), then fed to the step-up transformer (T3), and then fed to metro stations and utility load.
3. For 50 <= t1 < 100	Transformer (T1) is damaged.
4. S2 is ON	When transformer1 (T1) is damaged, the Auxiliary transformer1 (Aux-T1) is operated, and the power supply is fed to the stepdown transformer on standby (132 kV/33 kV). If transformer3 (T3) is also not working, the power supply is running through the Auxiliary transformer3 (Aux-T3 step-up transformer 33 kV/415 kV) and then fed to metro stations and utility load.
5. S3 is ON	Stepdown transformer2 (T2, 132 kV/25 kV) is ON and the power supply is fed to catenary overhead electrical lines (OHE) through which the metro train is connected.
6. For 50 <= t2 < 100	Transformer2 (T2) is damaged.
7. S4 is ON	Auxiliary Transformer2 (Aux-T2) is ON and the power supply (132 kV/25 kV) is fed to the catenary (OHE).

3.4 CCTV

A sophisticated intrusion detection system (IDS) will be placed at the platform, with comprehensive CCTV or video surveillance coverage of stations, parking, and public spaces. Internal security monitoring systems such as the Automatic Train Supervision (ATS) system, SCADA, Passenger Information System (PIS), and Public Address System (PA) can be implemented to minimize reaction time from personnel. A smart interface is provided to the control room operator using this CCTV approach. They can make quick and effective judgements for running the metro system and delivering the required services. This flowchart shows the functioning of CCTV view sub-application in Fig. 8.

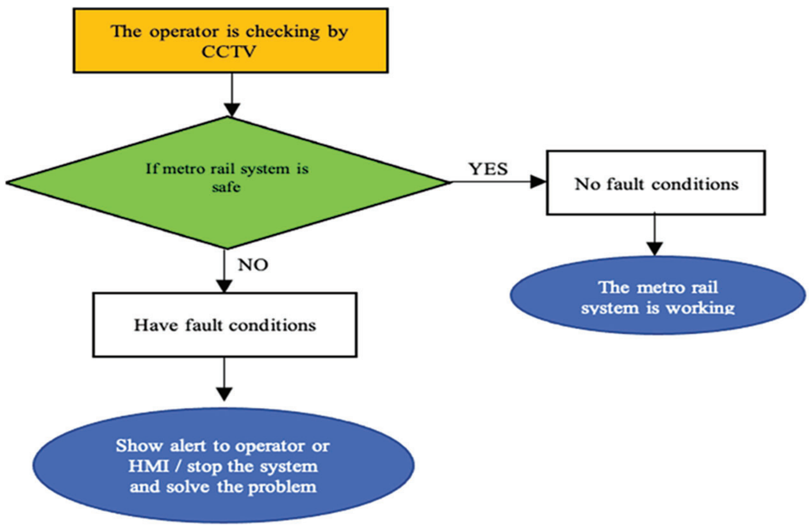

Figure 8: Flowchart for the working of CCTV

4 Results and Discussion

A SCADA Wonderware Intouch software window of every operation is shown with the ladder logic program of PLC in this section.

4.1 Operational Control Center (OCC)

Fig. 9 shows the OCC runtime window in SCADA Wonderware Intouch software from where the operator may command and monitor. The IR and reflecting sensors on the RTU are used to scan the programs. If there is a problem with the process, the RTU sends a message to the Master Terminal Unit (MTU), which then sends signals or alerts to the operator on the screen.

4.2 Metro Platforms of Sub-Application

All the cases of metro platforms view sub-application are shown here with the help of SCADA system and PLC ladder logic (see Figs. 10–12).

Fig. 13 shows the Metro stations (traction SCADA) of sub-application. Metro train starts moving when the switch is turned ON. The LED in the control panel view indicates the proper location of metro train. This system can track, control and recognize the location of the train even after a power outage or other breakdown. The emergency light will turn ON in case of any fault station and an alert message is displayed by the OCC in the relevant metro station on the HMI or operation display (see Fig. 14).

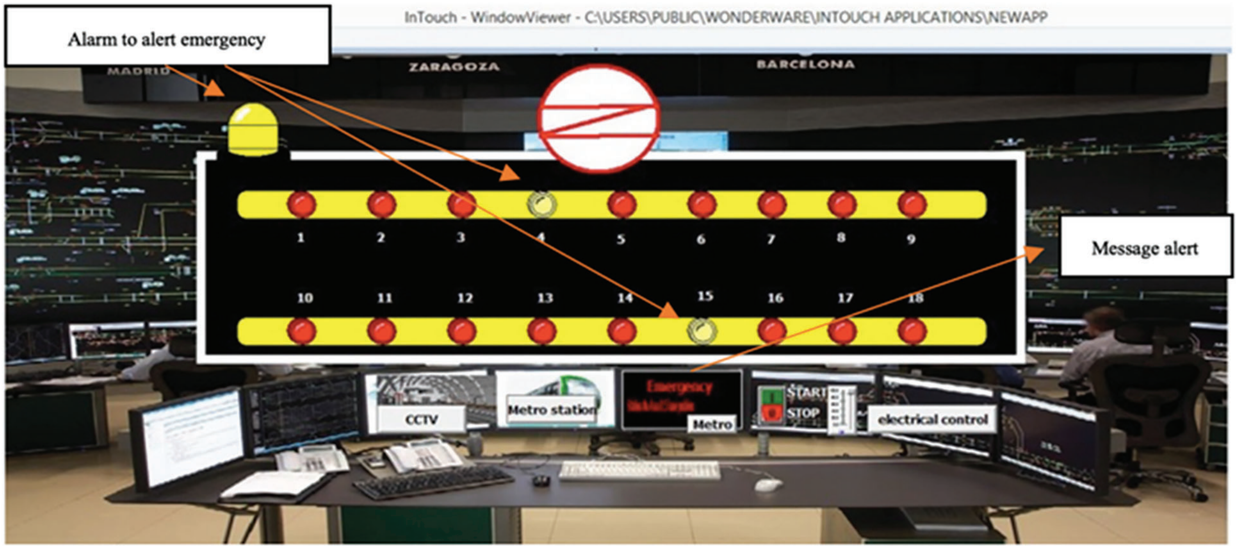

Figure 9: OCC of main application with failure in the system

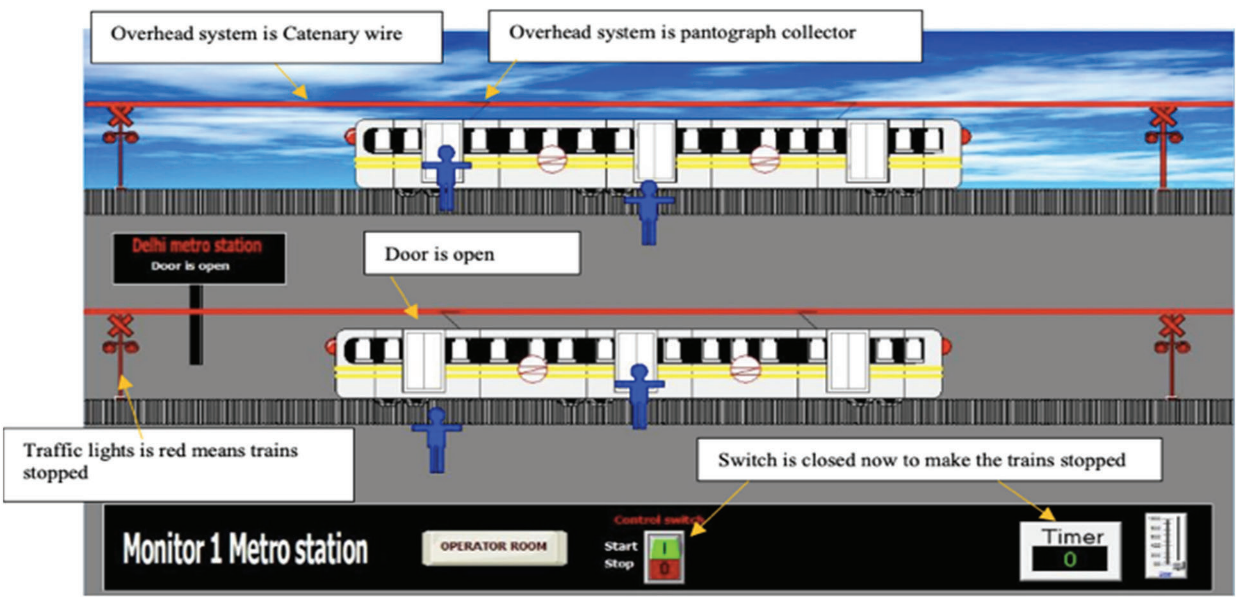

Figure 10: For t = 0, doors are open

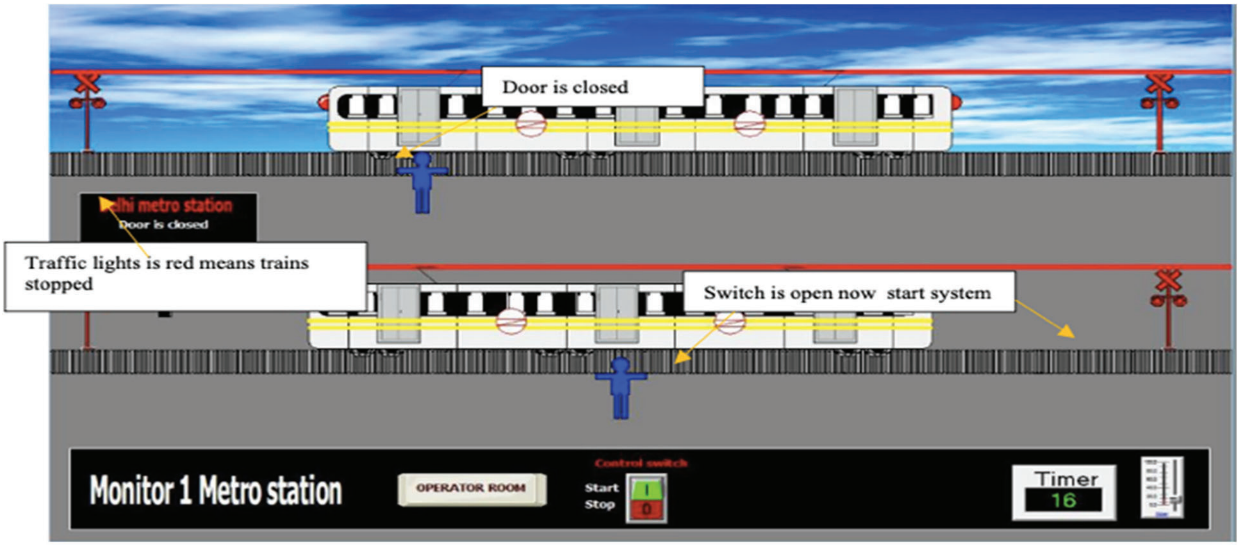

Figure 11: For 20 > t >= 15, doors are closed

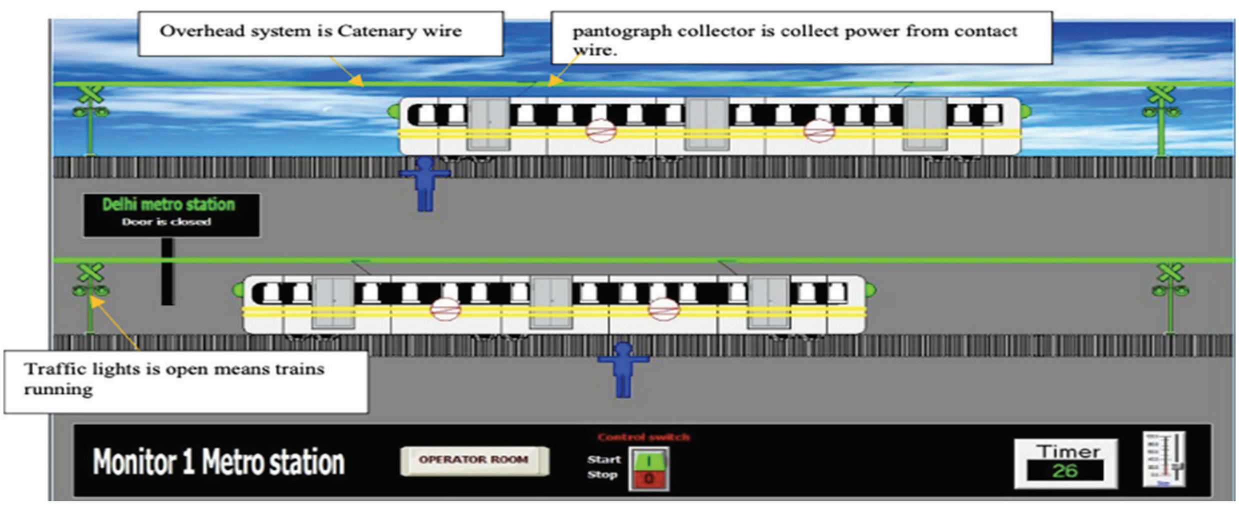

Figure 12: For 100 >= t >= 20, traffic light is green. The train starts moving forward

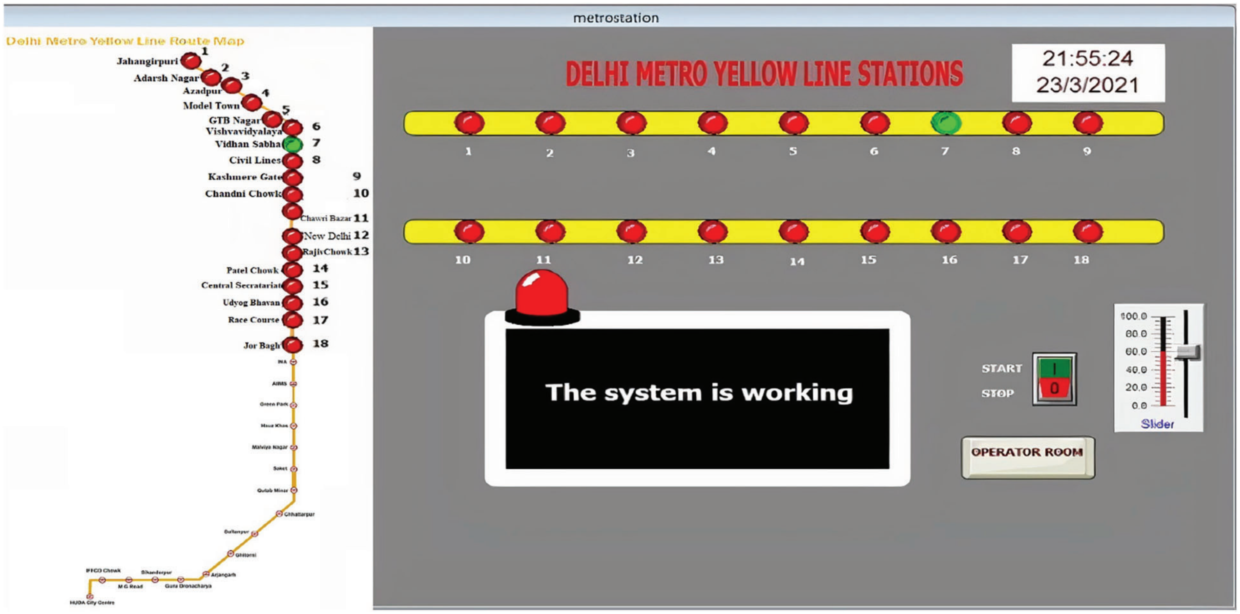

Figure 13: Metro stations (traction SCADA) of sub-application

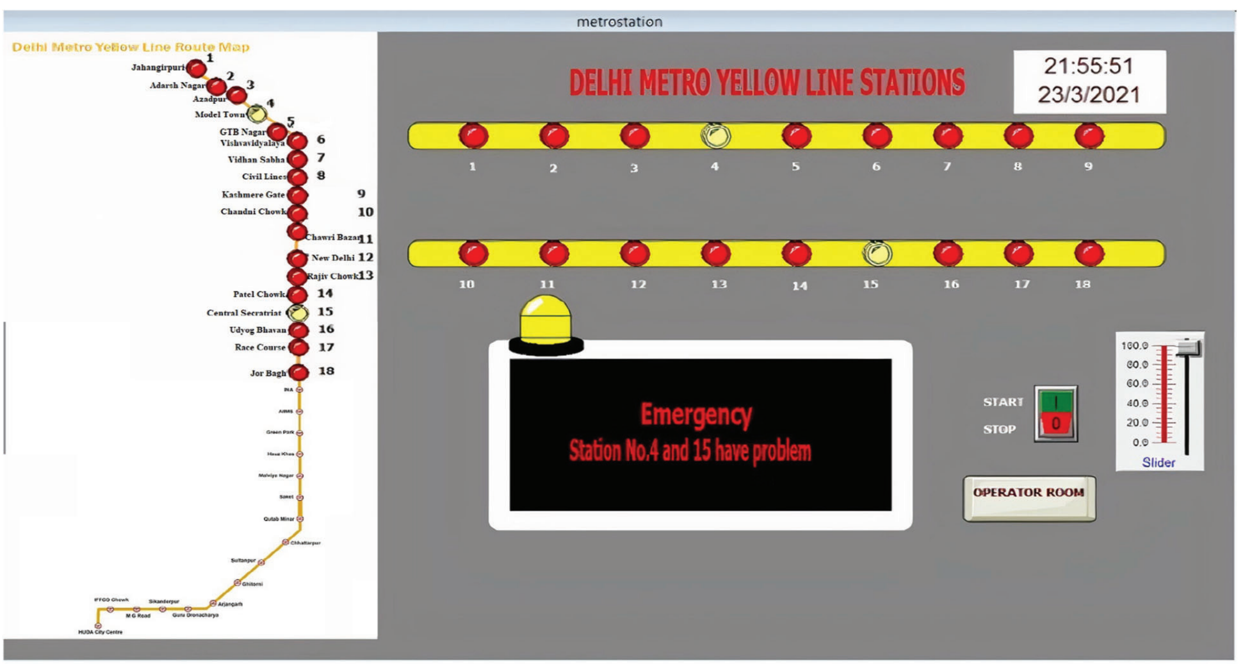

Figure 14: Metro stations (traction SCADA) of Sub-application (failure)

4.3 Electrical Control (Traction Power Control, And Power Supply System) View Sub-Application

Here, the functioning of Electrical control view sub-application is shown. Metro rail lines must be electrified with 25 kV, single phase, 50 Hz for overhead equipment to deliver electrical energy to locomotives or trains for operating the motor. The substation, feeding post, and other equipment at the control post and switching station make up the power supply system. A catenary i.e., the overhead equipment (OHE) is used to deliver power to a metro train equipped with a pantograph in metro rail traction systems. Transformer1(T1) is a stepdown transformer for metro stations and Utility load, transformer2(T2) is a stepdown transformer for the catenary, and transformer3(T3) is a step-up transformer for 132 kV incoming line from generating station.

(1) No Fault Condition: For running the system, a power supply of (132 kV/33 kV) is fed to the stepdown transformer (T1), then fed to the step-up transformer (T3), and then fed to metro stations and utility load. (see Fig. 15).

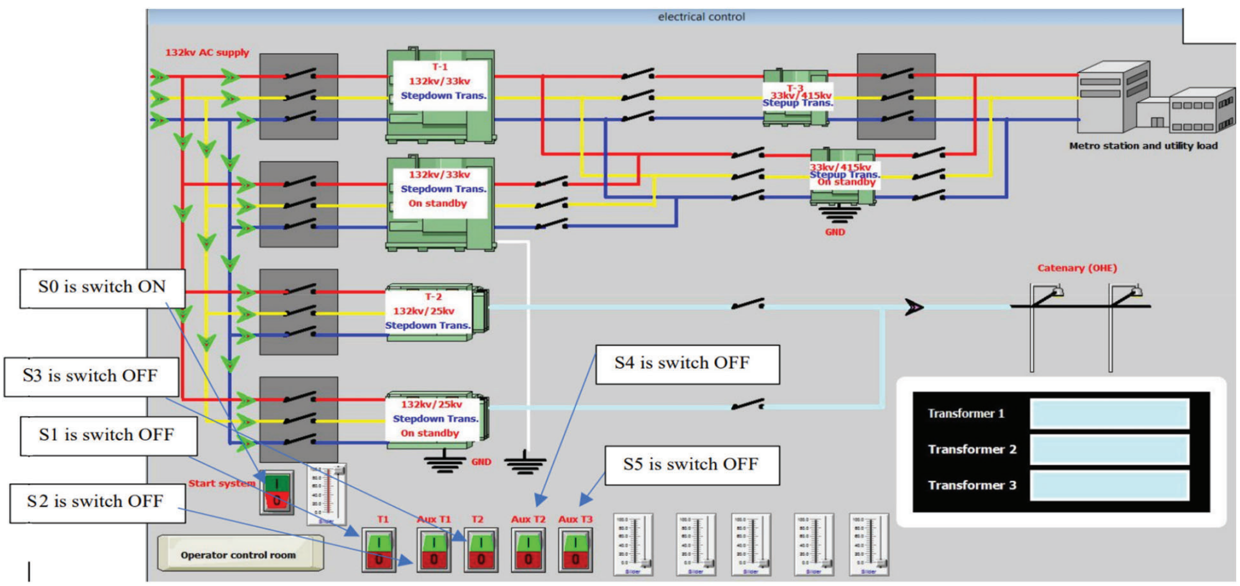

Figure 15: S0 is ON, Power Supply is ON (No fault Condition)

(2) For 50 <= t1 < 100: When transformer1 (T1) is damaged, the Auxiliary transformer1 (Aux-T1) is operated, and the power supply is fed to the stepdown transformer on standby (132 kV/33 kV) (see Fig. 16).

(3) For 50 <= t2 < 100: Stepdown transformer2 (T2, 132 kV/25 kV) is ON and the power supply is fed to catenary overhead electrical lines (OHE) through which the metro train is connected. If transformer2(T2) gets damaged, then Auxiliary transformer2 (Aux-T2) provides the power in case of transformer2(T2). Switch ON S0, S2, and S4 means the system is working.

(4) When Stepdown transformer3(T3) gets damaged, then Auxiliary transformer3 (Aux-T3) provide the power in case of transformer3(T3). Switch ON S0, S4, and S5 means the system is working (see Fig. 17).

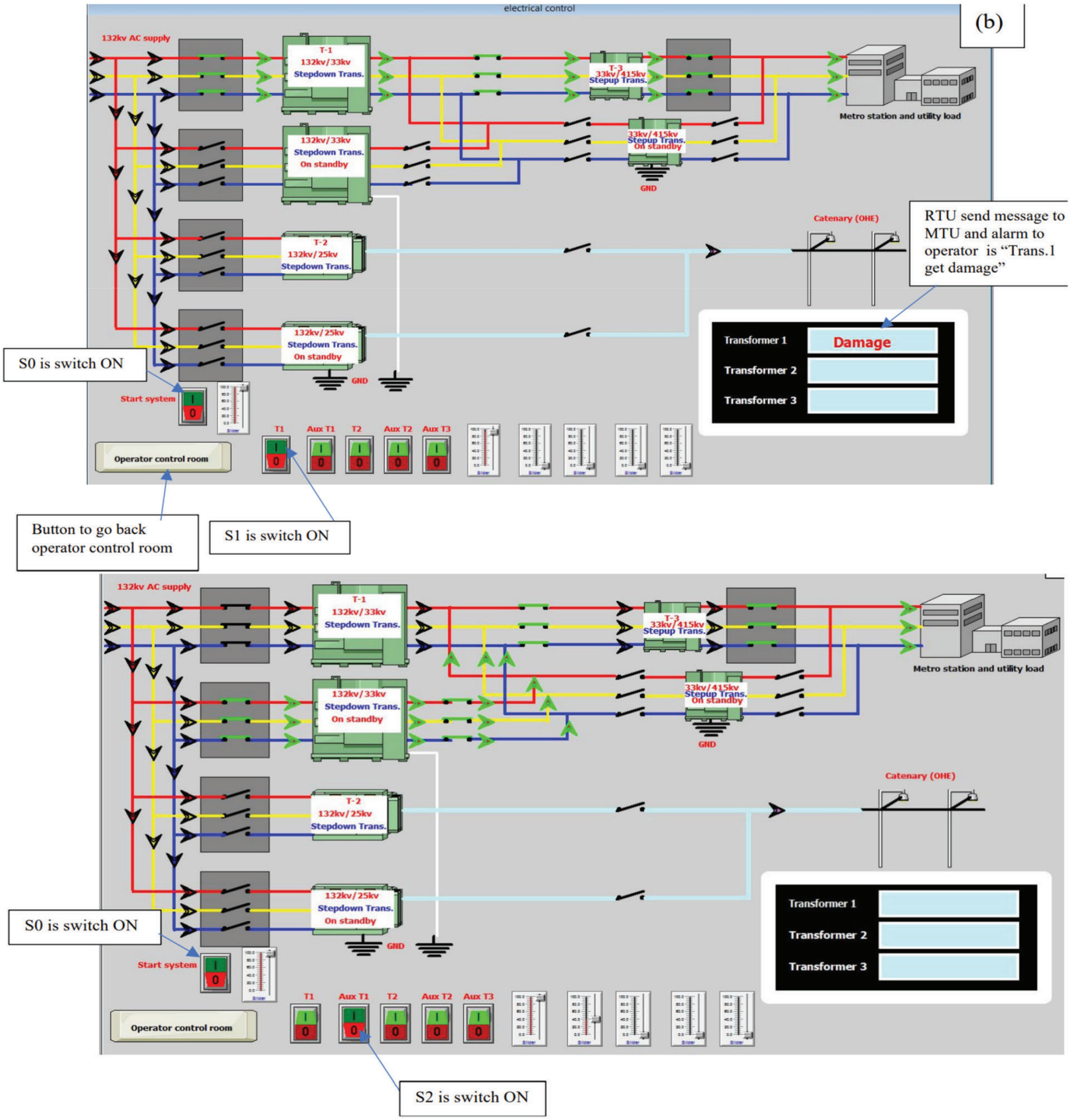

Figure 16: For 50 <= t1 < 100, When Transformer (T1) is damaged, then Aux-T1 is operated

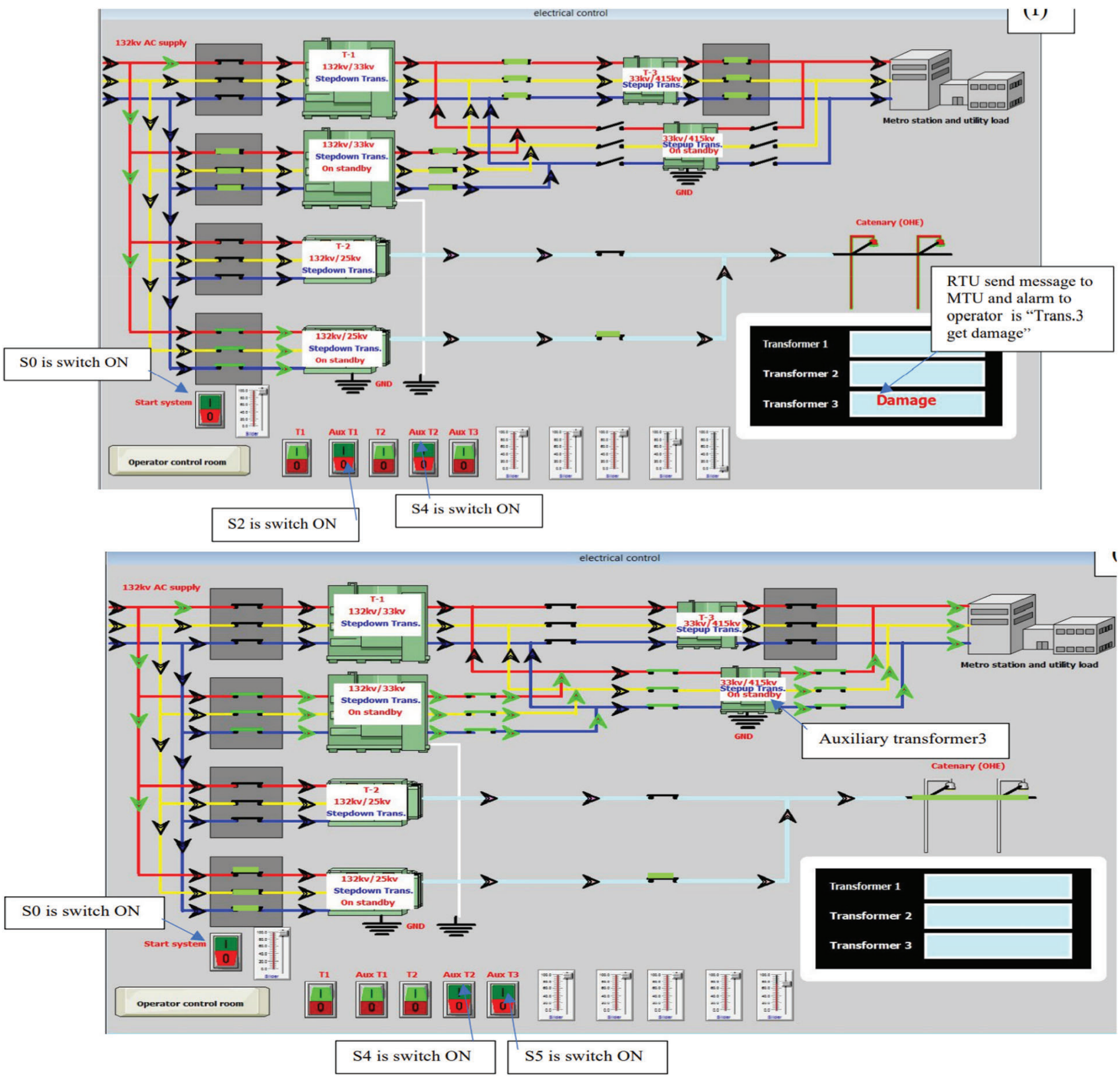

Figure 17: When T3 gets damaged, then Aux-T3 provides the power in case of T3

4.4 CCTV

The SCADA Wonderware Intouch software window of CCTV operation is shown in Fig. 18.

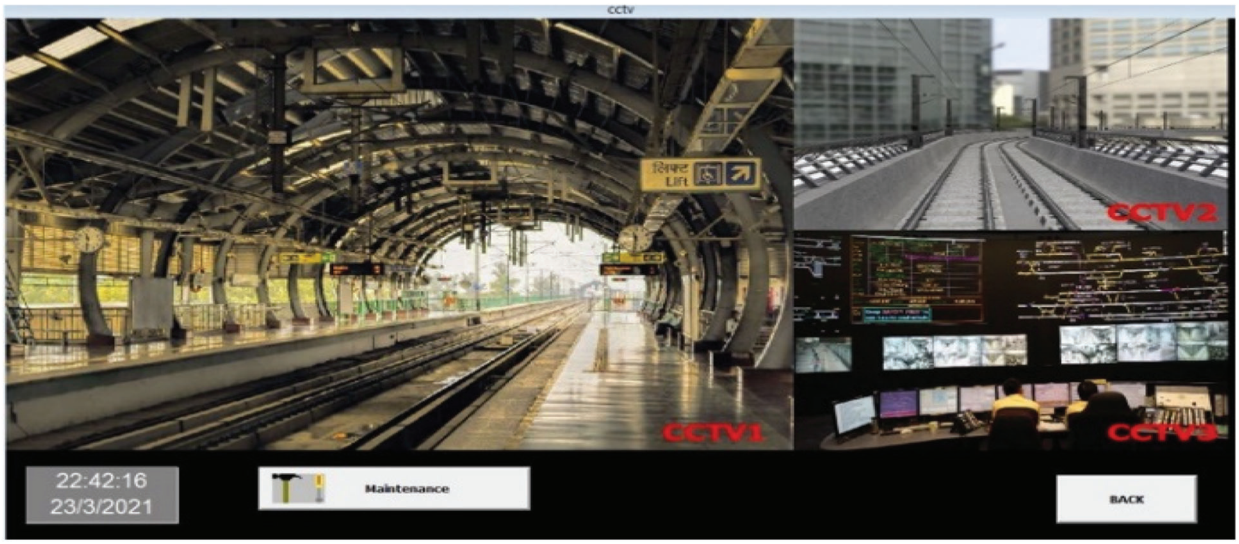

Figure 18: CCTV of sub-application

5 Performance Evaluation

Industrial Control Systems (ICS) and SCADA systems play a critical role in the management and regulation of Critical Infrastructure. SCADA systems are bringing us closer to the real-time application world. SCADA systems increase the efficiency of a control system operation while also providing improved protection for the equipment it uses. Furthermore, it increases employee productivity. SCADA frameworks use an established monitoring platform, advanced communication system, and sensors to provide required information and timely alerts/warnings to observing stations. The designed SCADA system offers continuous access and visualization of all the data in a more efficient and timely manner. It also provides a centralized and thorough display of parameters. The use of "Wonderware Intouch" software facilitates the gathering and visualization of data. The data collecting procedure in the proposed SCADA system is primarily centered on creating adequate communication links between the SCADA server (master station) and numerous PLCs and sensors that measure and send the readings of a variety of valuable parameters. The proposed system decreases the false error percentage in comparison to the traditional systems (Fig. 19). Tab. 3 shows the key features and contribution of the developed platform.

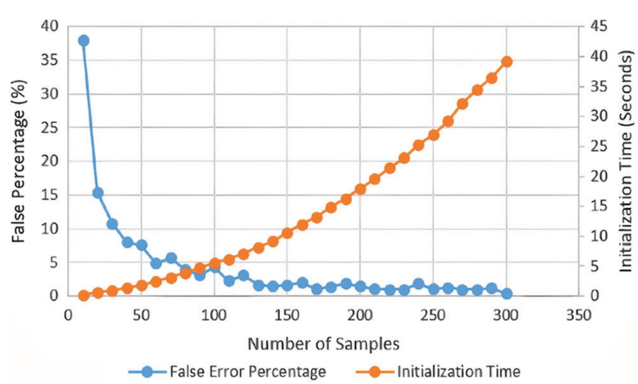

Figure 19: Initialization time and false error percentage of the proposed system

Table 3: Key features and contribution of the developed platform

S. No.	Aspect	Contribution
1	System installation	Easy installation and system equipment can be added to traditional power switches with few modifications and wiring.
2	Cost	Using a single central unit PLC that implements the load sharing algorithm and sends control commands to the basic switching parts saves cost. Using open source software in the SCADA visualization platform saves money. Eliminates the need to purchase extra network units or pay for a service subscription by using a secure remote access platform.
3	Interoperability	Helps in safe and uninterrupted monitoring, control and signalling of the metro railways movement.
4	Operation sustainability	Good operation sustainability by having a self-restoration capability after a power interruption.
5	Convenience	Provides remote access, and features all system parameters in a single SCADA web interface.
6	Security	Uses a hierarchical authentication scheme for the management and visualization of controlling railways assets in SCADA system.
7	Extendibility	Proposed method is extendible by configuring more devices, switches and screens in the SCADA software.
8	Equipment Maintenance	Predictive maintenance practices could be scheduled on the basis of monthly performance evaluations. The power quality indices at different nodes of the railway system can be used to solve malfunctioning issues.

6 Conclusion

In this paper, a PLC and SCADA based Real time monitoring and train control system for the Metro Railways has been used in to minimize the failure. Here, SCADA is used for the visualization of an automated process operation and then the whole operation is regulated using PLC. The PLC used here is OMRON (NX1P2-9024DT1) and OMRON's Sysmac studio programming software is used for developing the ladder logic of PLC. Wonderware Intouch SCADA software is used for the visualization of the operation. This system helps in detecting exact location, avoiding train collisions and opening emergency exit even after the interruption of power system with the use of Programmable Logic Controller. This system overcomes the drawbacks of the current CATC system comprising of automatic train protection, signaling and operation systems.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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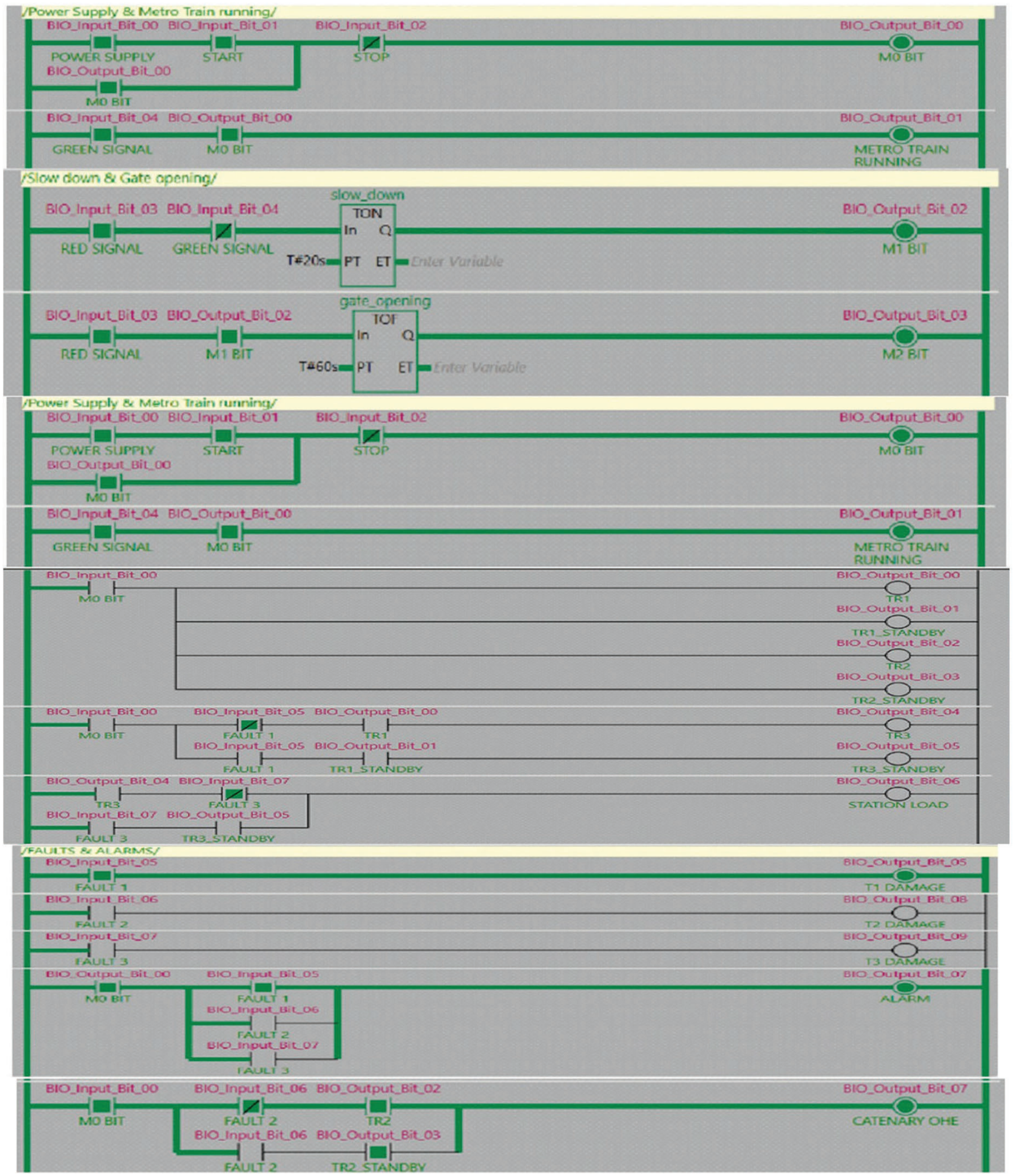
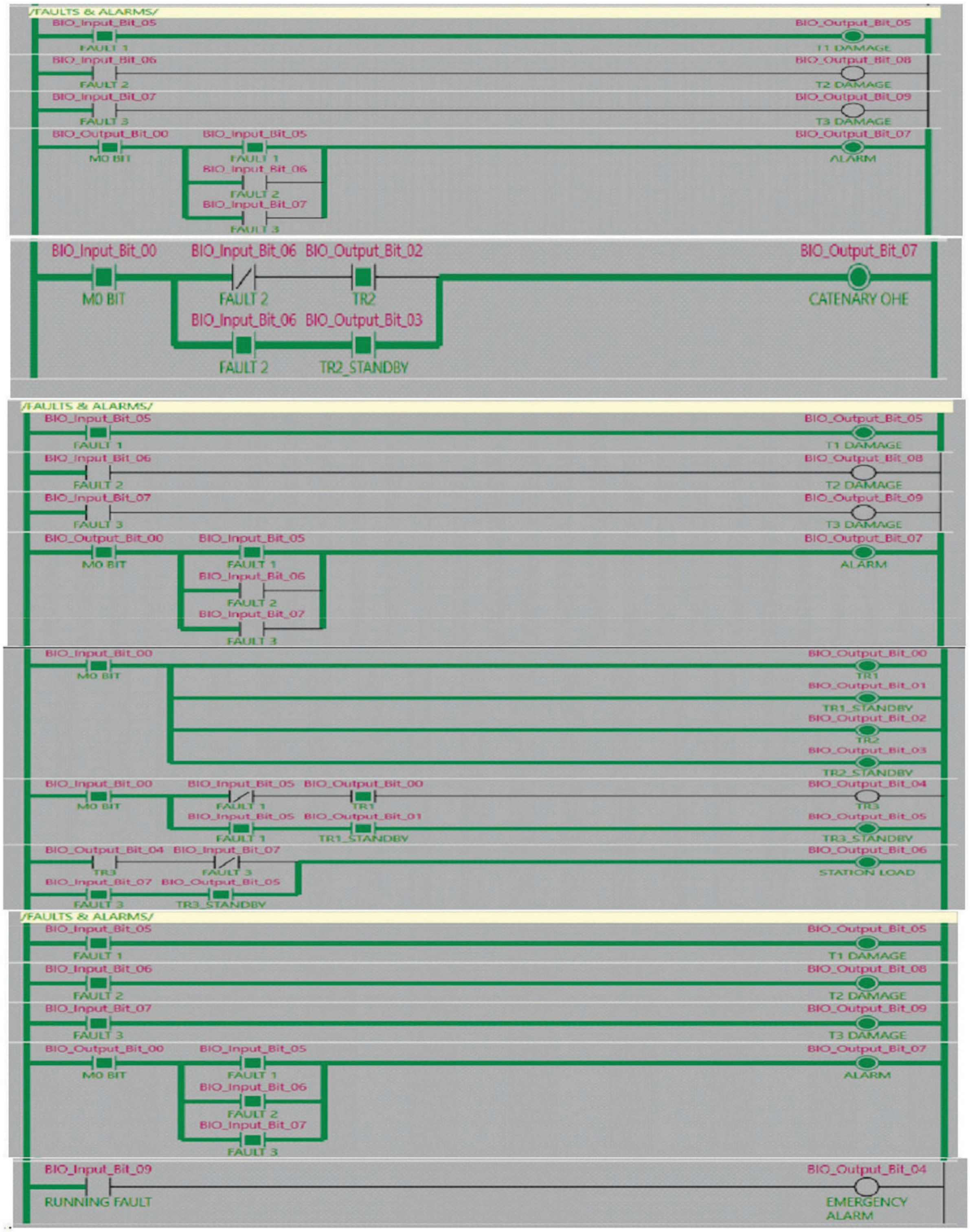
Appendix:

PLC Ladder Logic for the proposed system




/FAULTS & ALARMS/
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FAULT 1
BIO_Output_Bit_05
T1 DAMAGE
BIO_Input_Bit_06
FAULT 2
BIO_Output_Bit_08
T2 DAMAGE
BIO_Input_Bit_07
FAULT 3
BIO_Output_Bit_09
T3 DAMAGE
BIO_Output_Bit_00
M0 BIT
BIO_Output_Bit_07
ALARM
BIO_Input_Bit_00
BIO_Input_Bit_06
BIO_Output_Bit_02
TR2
BIO_Input_Bit_06
BIO_Output_Bit_03
TR2_STANDBY
CATENARY OHE
BIO_Output_Bit_00
TR1
BIO_Output_Bit_01
TR1_STANDBY
BIO_Output_Bit_04
TR3
BIO_Output_Bit_05
TR3_STANDBY
BIO_Output_Bit_06
STATION LOAD
BIO_Input_Bit_09
RUNNING FAULT
EMERGENCY ALARM