MV Circuit Breaker Control with PLC and SCADA

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Abstract

Circuit breakers are one of the most significant components in high voltage (HV) and medium voltage (MV) power lines. In this work, the control of a MV circuit breaker is carried out both classically and with PLC and SCADA. The circuit breakers opening-closing (on-off) actions are performed. Also, depending on the alarms coming from buchholz relay, overcurrent relay and transformer thermometer the circuit breaker is opened. In the training equipment that was built for educational purposes, real devices are used for all components, except for buchholz relay. Via the control panel the circuit breaker can be controlled and monitored both traditionally and from the SCADA screen. PLC/SCADA control is shown to be more reliable than the classical (manual) way.

Key words: MV circuit breaker, PLC, SCADA

1. Introduction

There are various steps involved in electricity transmission, from where it is generated to where it is to be consumed. Electricity generated in the power plants, typically 5 to 15 kV, is first stepped up to high voltage levels (154-380 kV) with transformers located in the substations. It is then stepped down to medium voltage levels (15.8-36kV). Lastly, it is further stepped down to low voltage levels (0.231-0.4kV) and reaches the subscribers. In Figure 1 the steps in electricity transmission from generation to consumption are shown.
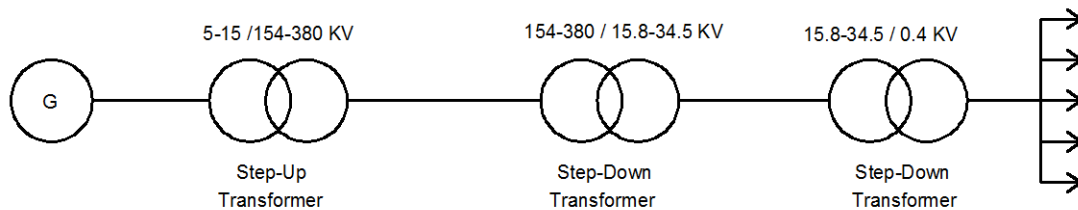

Figure 1. Steps in electricity transmission

Transmission of generated electricity in power plants to the user is carried out through transformers, poles, power transmission lines, insulators, circuit breakers, disconnectors, surge arresters and other electrical components. One of the most important items of equipment among these is the circuit breaker. Circuit breakers are items that can perform switching operation (on-off) under load in MV and HV circuits. These days, circuit breakers are used in both classic and modular (metal clad) systems [1-5].

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The reliability of remote control systems are of extreme importance in terms of occupational health and safety, which is becoming increasingly important. In Turkey, as in the rest of the world, many fatal accidents occur due to faults in disconnectors, circuit breakers, and opening and closing systems in MV and HV facilities. Due to this, disconnectors and circuit breaker control systems must be designed with extreme care to minimize the possibility of faults occuring.

In this study, the control of a MV type circuit breaker is carried out both classically and with PLC and SCADA and the safety of the two methods are compared.

2. Materials and Method

The prototype, in the form of an experimental kit, consists of one SF6 gas circuit breaker, three current transformers, one panel and a PLC placed in that panel, an overcurrent relay, transformer thermometer (thermic), rectifier, energy analyzer, warning relay, warning horn, pako switch, and buttons.

2.1. SF6 circuit breaker

Circuit breakers can perform switching operations (on-off) under load, short circuit and no load conditions in MV and HV power lines. Circuit breakers are classified according to the rated voltage they use, as medium and high voltage circuit breakers. According to the IEC (International Electrotechnical Commission) the rated voltages for MV circuit breakers are 1-6-7.2-12-17.5-24-36 kV. The standard voltages for HV breakers are 52- 72,5- 100- 123- 145- 170- 245- 300- 362- 420- 525- 765 kV. Circuit breakers are classified as reclosing and non-reclosing, according to their reclosing structure. They are also classified as indoor and outdoor circuit breakers, according to their working environment. Circuit breakers, according to their arc quenching medium, are SF6 gas, vacuum, pressurized air blower, bulk oil, minimal oil, or magnetic blower circuit breakers. Only SF6 gas type circuit breakers are going to be discussed because this type of breaker is used in this work.

The operating principle of the SF6 circuit breakers is based on the principle that SF_6 (sulfur hexafluoride) at constant pressure is compressed by the moving contact piston and blown on the arc to quench the arc. The quenching medium is SF6 gas at a pressure of 1.5 - 6 bar. Because of special insulation feature of SF6, the opening distance between contacts becomes very small. Pressurized gas is blown onto the arc to quench the circuit breaker's arc. Thus, the arc is cooled, the medium's conductivity between the contacts is lost, i.e. becomes an insulator, and the arc is quenched. The SF6 gas gives off sulfur and fluorine ions at the opening temperature. In the meantime, fluorine ions, which are very electro-negative, trap electrons in the environment and limit the arc current. Due to the fact that SF6 gas dissipates heat fairly quickly, the temperature drops rapidly. The arc cools down and it is quenched [6-8].

Figure 2. SF6 circuit breaker used in the project

SF6 gas circuit breakers consist of three main parts:

Polar section: This is the part where the contacts and arc quenching cell are located.

Opening-closing mechanism: In SF6 gas circuit breakers, the arc quenching cell is filled with SF6 gas. The opening-closing mechanism may be sprung or use various electromechanical systems.

Electrical hardware: The drive mechanism has a series motor that activates the transmission group to set the closing springs. In addition to that, it consists of motion end switch, opening and closing coils, auxiliary switch and the anti-pumping relay.

The Demitaş brand SF6 circuit breaker (Figure 2) used in this project can be utilized in systems up to 36 kV rated voltage and 1250 A rated current. Sulfur hexafluoride gas is used as insulation and quenching medium. The quenching medium and parts are located inside sealed pressure medium and electrically isolated tubes. The fundamental parts of the circuit breaker are enumerated and corresponding parts are shown in Figure 3.
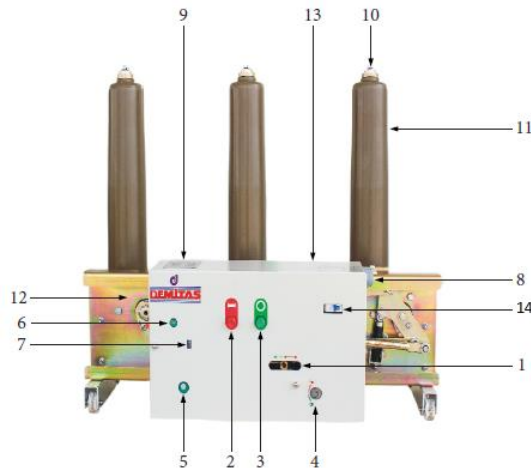

Figure 3. Enumeration of the circuit breaker parts [8]

1.Operation mechanism lever hole, 2.Closing button, 3.Opening button, 4.Mechanical lock, 5.Circuit breaker operation indicator, 6.Spring set/non-set indicator, 7.Counter, 8.LV cable connection record, 9.Specification tag, 10.MV connection point, 11.SF_6 pole, 12.Chassis 13. Operating mechanism, 14.Spring set motor fuse.

The basic parts of the circuit breaker are enumerated and corresponding parts are shown in Figure 4.
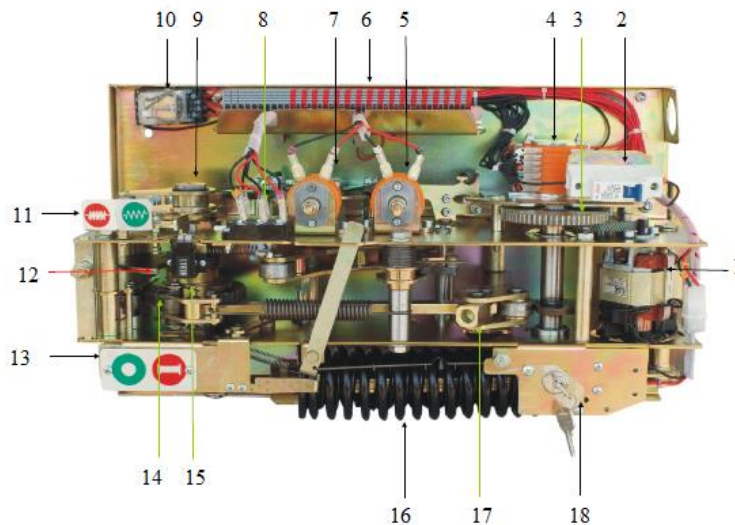

Figure 4. Enumeration of the drive mechanism of the circuit breaker [8]

1.Spring loading motor, 2.Spring loading motor fuse, 3.Reduction gear, 4.Auxiliary contacts, 5.Opening coil, 6.LV connection terminals, 7.Closing coil, 8.Micro contacts, 9.Outer lever, 10.Anti-pumping relay, 11.Spring loaded/unloaded indicator, 12.Cam, 13.Circuit breaker on/off indicator, 14.Charging lug and gear, 15.Counter, 16.Closing spring (Opening spring is in the chassis), 17.Operation lever hole, 18.Mechanical lock.

2.2. Control panel

Views of the panel designed to control the circuit breaker are shown in Figure 5. The panel is made out of 1.5 mm thick DKP sheeting.

Figure 5. Views of the panel designed

2.3. PLC

The system uses Siemens CPU 1214 DC/DC/ DC PLC. There are 14 digital inputs, 10 digital outputs and 2 analog inputs on the PLC. The CPU memory is designed to be 100 kB, but an additional 4 GB memory card can be added. PLC is powered by 24VDC.

Figure 6. S7-1200 1214 C DC/DC /RLY PLC.

2.4. Overcurrent and earth relay

Two phase one earth overcurrent relay steps down the current coming from the current transformers with its current transformer to a level that the microprocessor can sense. In this way, the relay senses the current flowing in the line and when the current is above the threshold value, the circuit breaker is deactivated with the help of the decision-making units' contact output. The contact output is connected to the tripping coil of the circuit breaker. In this system, 10A/5A current transformer outputs are connected to relays terminals. The choice of 10A/5A current transformer is mainly due to the lack of a large and powerful receiver in the school environment and the current drawn is typically less than 10A. In Figure 7, a two phase-one earth overcurrent relay's connection schematic is shown.
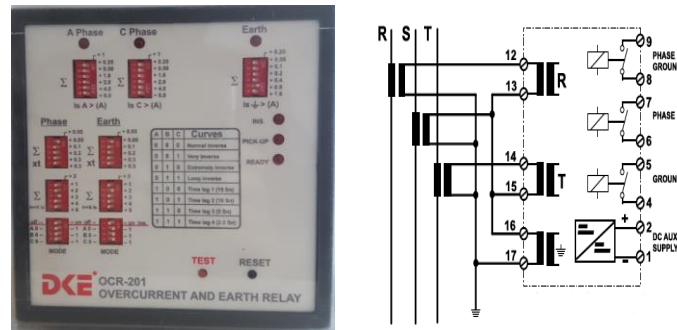
Figure 7. Overcurrent and earth relay

2.5. *Buchholz relay*

The protection mechanism of a Buchholz relay relies on excessive heat resulting from an internal fault in power transformers, which expands the gas. The Buchholz relay is installed between the expansion tank and the transformer tank. There are two independent contacts for opening and alarming in the relay. Under normal operating conditions, the transformer tank and buchholz equipment are completely filled with oil. The upper and lower contacts in the Buchholz relay are open. The electrical connections are made in such a way that when the upper contact is closed, the alarm is activated and when the lower contact is closed, the opening is made. In a Buchholz relay there are two moving buoys. The upper one works on minor faults and the bottom one works on major faults. In case of fault condition gas bubbles moving upward make buoys move. The mercury in the buoys allows the opening and alarm systems to be activated by closing the circuit. Thus, damage caused by the fault is prevented. Due to its large volume, instead of a buchholz relay, two buttons are used as upper and lower contacts [9].

Figure 8. Buchholz relay [10]

2.6. Transformer thermometer

In transformers, the winding temperature should be determined and limited to a specific value. The protection component used for this purpose is called a transformer thermometer. The transformer's oil temperature is measured representatively and the alarm and opening (off) action are performed using contact systems. The most loaded winding is selected for temperature measurement and a probe is place in the hot spot of the transformer. Since no transformer is used in the project, i.e. oil temperature measurement cannot be made, to make the relay give an alarm, the thermometer's needle is moved by hand to the first set temperature. To make the relay open, the thermometer's needle is moved to the second set temperature. In other words, the transformer thermometer is made to give an alarm and warning manually. In Figure 9 the transformer thermometer used in this project can be seen.

Figure 9. Transformer thermometer

2.7. Current transformer

Current transformers are special kinds of transformers that steps down the current flowing in the circuit to which it is connected with a certain ratio and supplies the devices connected to the secondary terminals with that current and isolates them from the high voltage. Current transformers transfer the current flowing in the *primer* circuit to secondary *circuit* and the devices connected to that circuit with magnetic coupling. The current drawn by the power transformers are transferred to the protection relay with the help of current transformers. If the current drawn is above the set current, the relay outputs the contact and opens the circuit breaker. Due to financial and physical constraints, instead of a MV current transformer a 10/5A LV current transformer is used. Instead of a MV load a 3 phase LV (380 V) load is connected to the circuit breakers terminals.

Figure 10. 10/5A current transformer

2.8. Rectifier

Rectifiers and batteries are indispensable in critical applications, such as electrical substations and transformer substations. The DC current at the output of the rectifier is typically used to charge the batteries. The constant voltage charging method is used and the starting current is limited to 1.5 A. The battery life and performance is increased with this method. 220 V AC input voltage is stepped down to 30V AC, then to prevent heating of regulator circuitry and losses this AC voltage is converted to DC voltage with the help of a phase controlled rectifier and filter. Two independent 12V batteries, having minimum capacity of 6.5 Ah, are used. These two batteries are connected in series to obtain 24 V DC voltage. The circuit breaker's opening-closing coils and PLC works with DC 24V supply. The rectifier connection schematic is shown in Figure 11.
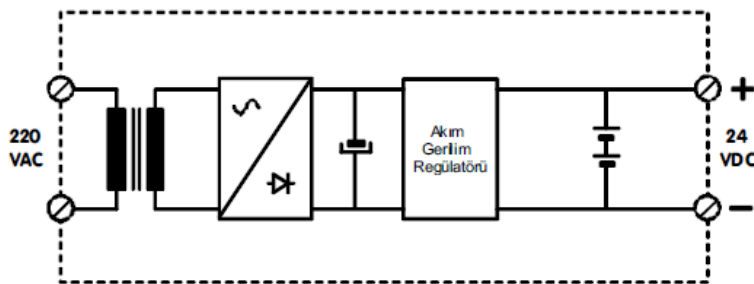

Figure 11. Rectifier connection schematic

2.9. Power analyzer

The measurement equipment that measures the components of the energy consumption in a system is called power analyzer. Up to 10 measurements that are made in different conditions and times can be simultaneously displayed and necessary comparisons and various tasks can be

performed. Additionally, in multiple phase systems power analyzer can measure the voltage and current of each phase separately. Power analyzers are devices that are used for measurement and monitoring of power line electricity parameters. Power analyzers can be applied to single, two or three phase systems. Power analyzers measure the energy consumption in a system. Measurements are displayed on the screen of the device. Previous measurements are also displayed on the screen for comparison. The power line analyzer that is used in this project is shown in Figure 12.

Figure 12. Energy analyzer

2.10. Warning relay

A combination of indicator and relay are used in medium voltage modular cells and medium voltage panels. There are six warnings (overcurrent tripping, earth tripping, buchholz warning, buchholz tripping, thermic warning and thermic tripping) on the relay's indicator panel. The corresponding warning LED lights up when one of the fault inputs receives a warning. The horn relay and opening relay are energized simultaneously. Additionally, the corresponding warning relay is energized. This relay can be used for signalization. If a fault condition is continuously received at the input the corresponding LED flashes. Even if the fault signal is removed the LED continues to flash (until reset). To remove the warning (if the fault is not continuous) it is sufficient to press the *delete lamp* button. After this, by pressing the (horn shut off) button the horn deactivated. The test (LED check) button is used to check the LEDs. There is a single hex switch on the back of the device. With the help of this switch, which warning are to energize the relay are selected.

Figure 13. Warning relay

2.11. Other devices

The warning horn is used for audible announcements in case of a fault coming from the warning relay. When the pako switch is in the 0 position the system is shut down; in position 1 the system is manually controlled, and in position 2 the system is controlled with PLC. The green LED panel button is used to activate the circuit breaker from the panel. The red LED panel button is used to deactivate the circuit breaker from the panel.

3. Application

The control of a medium voltage circuit breaker is implemented with the classical remote control and PLC/SCADA.

3.1. Classical control

In this step, internal connections are first made in the control panel. To supply relays and breakers, the opening-closing coils used in the control panel with 24V DC, a rectifier connection is made. After connection rectifier's 24V DC output to the fuse, it is then connected to the terminal for distribution. When the pako switch is in position 0, the entire system is off. If it is in position 1 relays and breaker's opening-closing coils are energized.

After connecting the S1 terminals of the current transformers connected to the circuit breaker's output to the overcurrent relay, the S2 terminals of the current transformers were bridged and the earth terminal of the overcurrent relay was connected to the earth fault terminal. The current transformer's P2 output terminal was connected to the analyzer's voltage terminal.

The relevant connections between the phase and earth protection outputs of the overcurrent relay and the warning relay were made.

Due to its large size and weight, instead of a buchholz relay an on-off button is used. The green button is used for the signal coming from the buchholz relay, the red button is used for the second

incoming signal and closing the circuit breaker. Additionally, the connection with the warning relay is also made.

The transformer thermometer is manually made to give an alarm and perform the opening. For the first set temperature the relay gives a warning, for the second set temperature the circuit breaker performs the opening.

The green bulb is connected to indicate the state of the breaker's spring. To see if the spring is loaded or not the bulb is connected to the control panel from the circuit breaker's 5th and 6th terminals. When the spring is in the unloaded position the bulb lights up. After the connections are completed, switching maneuvers are performed with the opening-closing buttons. The circuit breaker is opened automatically when a predetermined alarm is received from the system.

3.2. Control of the Circuit Breaker with PLC and SCADA

Keeping the working scenario of the circuit breaker in mind, first it was decided what to control and how they are controlled with PLC and SCADA. PLC software was developed in Simatic Step 7 TIA Portal V13 using ladder programming language. SIMATIC HMI Application/WinCC RT Advanced was used as the operator panel. No real (physical) operator panel was used.

In the software when overcurrent tripping, the buchholz tripping and the thermic tripping signals are received, and the circuit breaker is opened. When the buchholz warning and thermic warning are present, the circuit breaker does not open. They are only displayed on the screen. If one of the alarms that open the circuit breaker is continuous, the circuit breaker is not going to be closed. Opening- closing maneuvers are performed with the on-off buttons. Figure 14 shows the SCADA screen when the circuit breaker is in the off position and there is no alarm or warning.
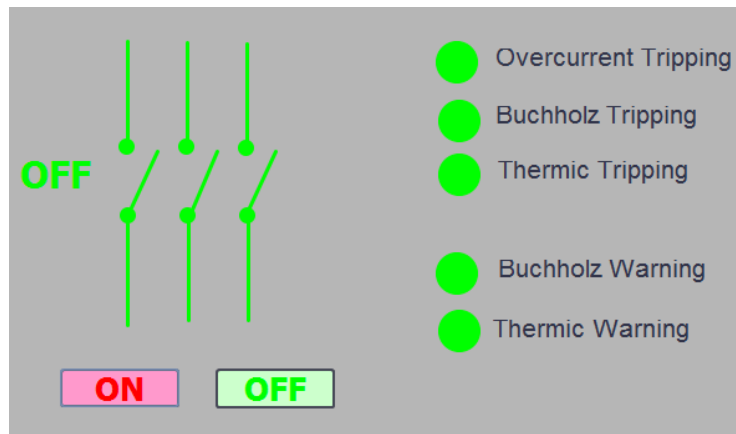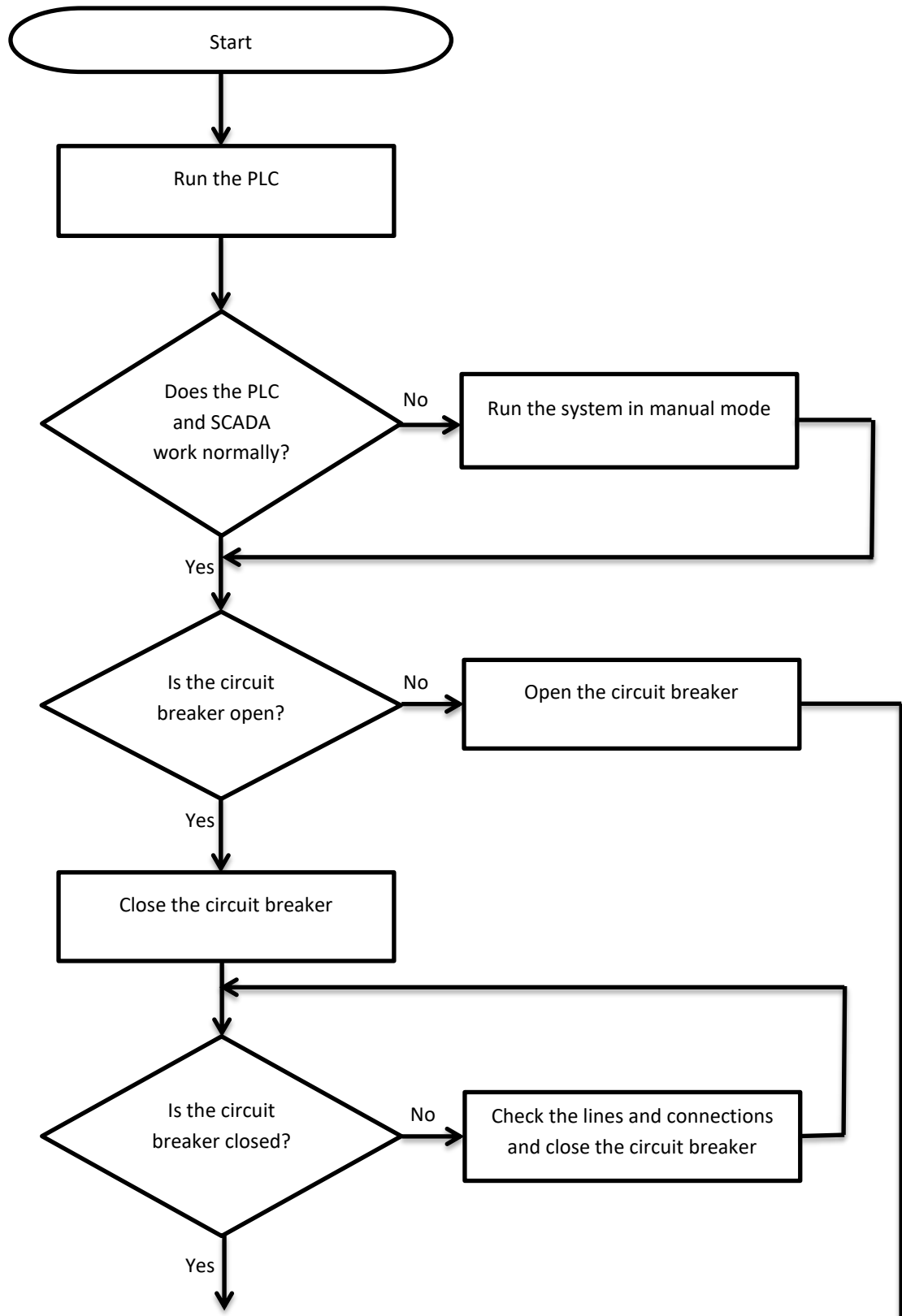
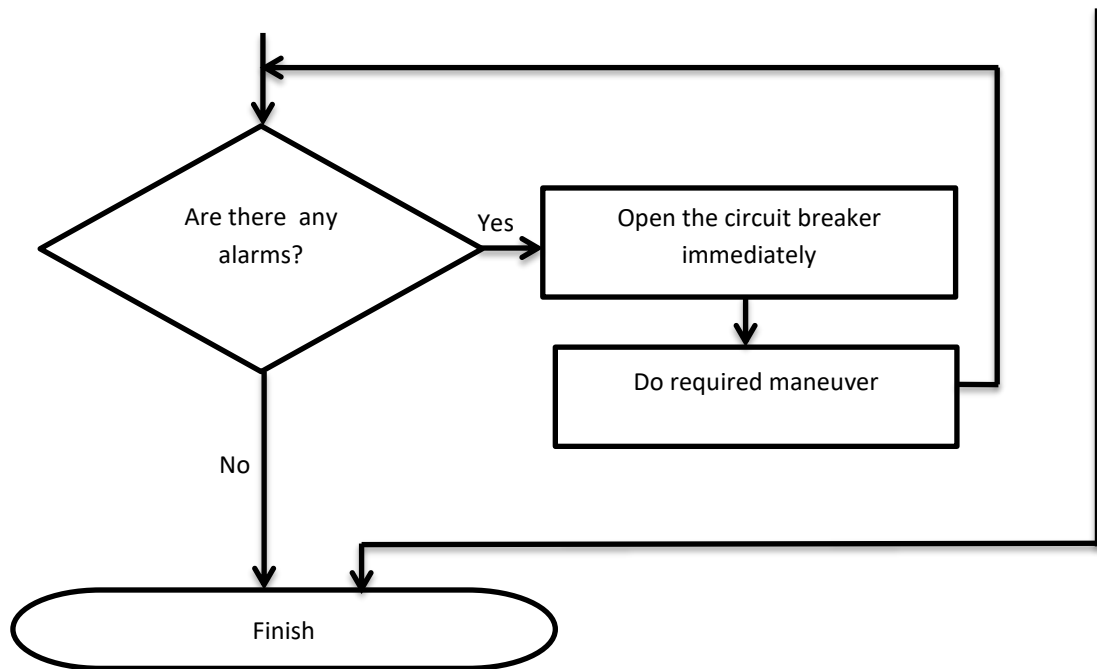**Figure 14.** SCADA screen (off position)

Figure 15. Flow card

The flow diagram of the system is given in Figure 15.

On the SCADA screen, the open (off) position of the circuit breaker is animated with green while the closed (on) position is animated with red.
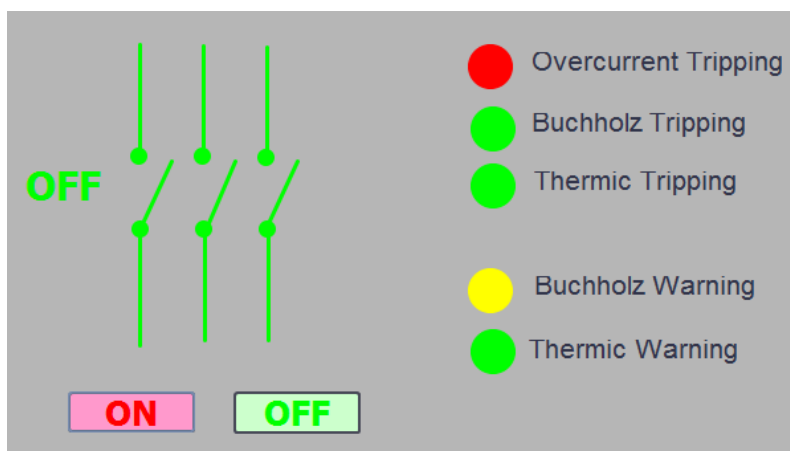

Figure 16. SCADA screen (with tripping and warning)

The alarm indicators are green when there are no alarms or warnings. When an alarm occurs (tripping alarms) it turns into red, while a warning occurs it turns into yellow color. In figure 16, SCADA screen is shown when overcurrent tripping and buchholz warning occur.
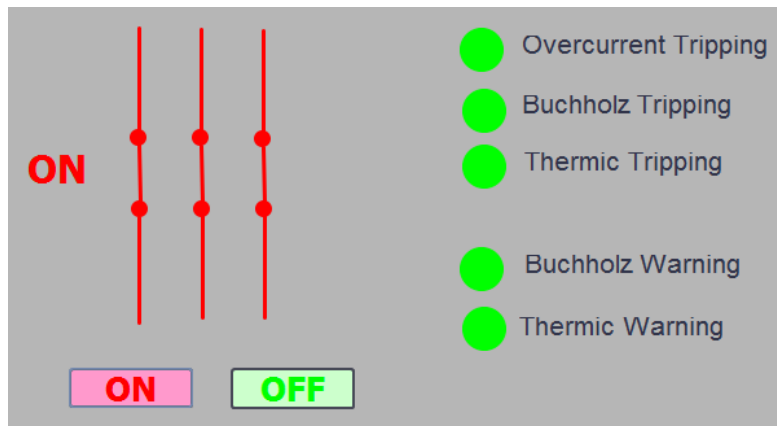

Figure 17. SCADA screen (on position)

SCADA screen is shown when the circuit breaker is in the on (closed) position in Figure 17.

As a result of the connection made between PLC S7-1200 and the warning relay, by sensing the warning signals occurring during the operation of the system, the circuit breaker maneuver can be controlled. In the event of any fault in the SCADA system, the system can be switched to manual (classical) control. Part of the ladder diagram is illustrated in Figure 18.
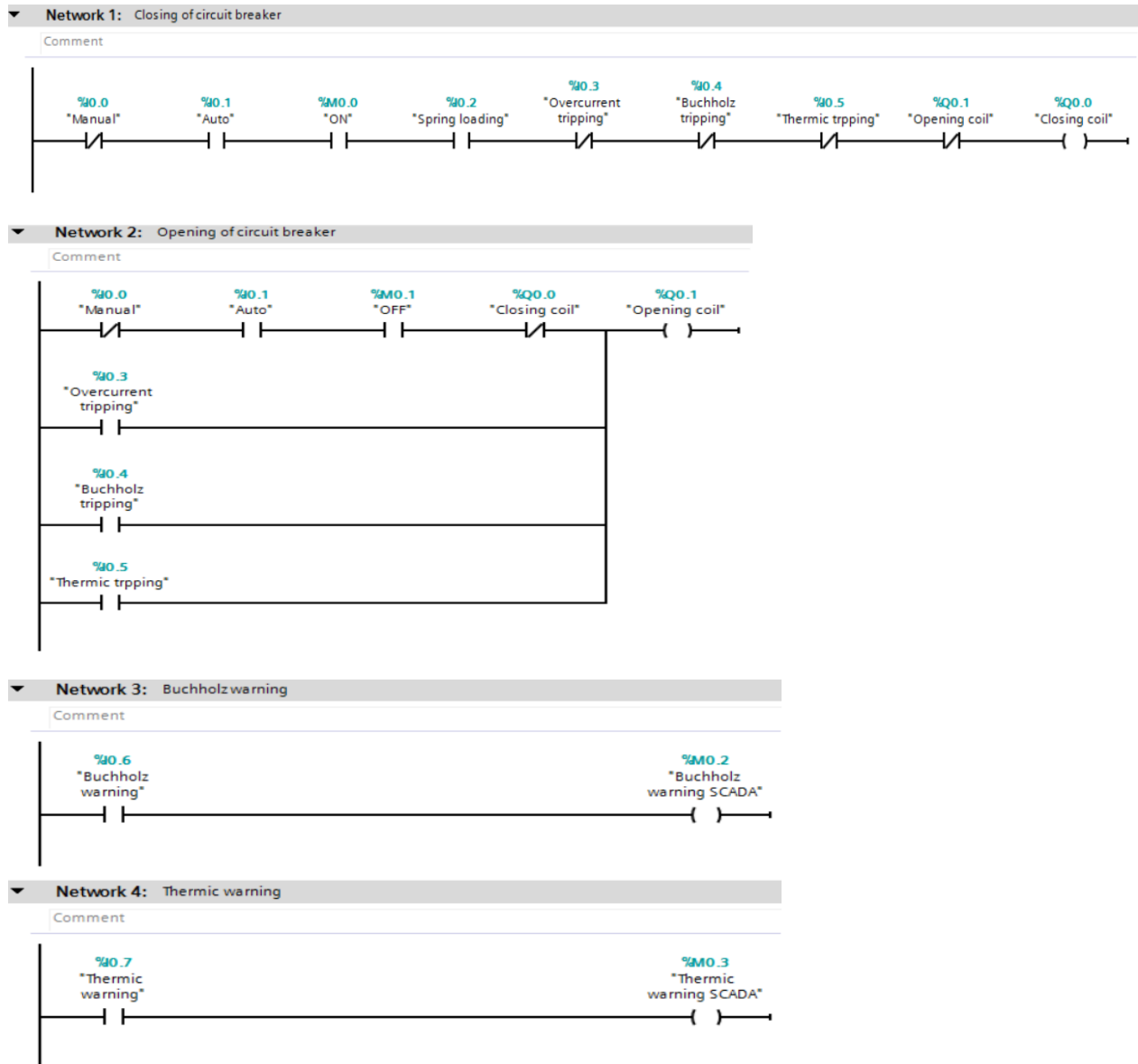
Figure 18. Part of the ladder diagram

Conclusions

It is much more likely that human error occurs in systems controlled by conventional methods, in comparison to systems controlled by automation. In systems controlled by automation and intelligent devices, the human factor is minimized in number and function.

In this study, the control of a SF6 gas MV type circuit breaker is carried out both classically and with PLC and SCADA. It can be used as educational material for lectures, such as Automation Systems, High Voltage Technique and Power Transmission Systems. Due to the fact that more security measures can be implemented in software, PLC and SCADA control has shown to be more reliable than classical control.

Further research can be carried out to increase the security precautions and develop a user-friendly interface for SCADA.

Acknowledgments

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