AUTOMATION OF 154/34.5 KV SUBSTATION USING PLC AND SCADA

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I certify that in my opinion the thesis submitted by Khaled Ahmed Hadia ALDAWILA titled "AUTOMATION OF 154/34.5 KV SUBSTATION USING PLC AND SCADA" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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This thesis is accepted by the examining committee with a unanimous vote in the Department of Computer Engineering as a master thesis. June 22, 2017

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The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabük University.

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“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Khaled Ahmed Hadia ALDAWILA

ABSTRACT

M. Sc. Thesis

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Substations have a very important role in delivering electricity from where it is produced and distributing it to where it is consumed. Modernization and renewal of control and monitoring systems of transformer substations are among the priority aims of electricity transmission distribution companies in recent years. These studies provide less trouble in substations, solve problems faster and more effectively, and therefore the negativity caused by power cuts is minimized. In this thesis, PLC-SCADA (Programmable Logic Controller-Supervisory Control and Data Acquisition) based automation of 154 / 34.5 kV Safranbolu substation of TEIAS (Turkish Electricity Transmission Inc.) was carried out. Automation of the transformer substation was done for both high voltage (154 kV) and the medium voltage (34.5 kV). The substation is prototyped and represented by circuit breakers and disconnectors, contactors and relays. The circuit breakers, disconnectors and other equipment and their functions are shown on the SCADA screen in accordance with the actual working scenario of the substation. On the SCADA screen, malfunction conditions, the positions of the circuit breakers and disconnectors, and whether bus bars are energized or not, can be monitored. Faults and alarms that occur in the system are displayed on the computer with the time of occurrence and provide the opportunity to intervene as soon as possible. In addition, disconnectors and circuit breakers can be maneuvered. The most suitable maneuvers are done automatically in accordance with the pre-worked scenarios. Power cuts are reduced as much as possible in this way. Remote control and monitoring of the system via the Internet are also provided. The prototype that has developed in this thesis has introduced a PLC-SCADA software-based approach to modernize the control-tracking system of substations. The prototype can also be used as a training tool for lectures such as Electrical Power Transmission and Distribution and Industrial Automation.

**Key Word : ** Substation, PLC, SCADA, automation.
**Science Code : ** 905.1.150

ÖZET

Yüksek Lisans Tezi

154/34.5 KV TRAFO MERKEZİNİN
PLC VE SCADA İLE OTOMASYONU

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Trafo merkezleri elektriğin üretildiği yerden tüketildiği yere kadar iletilmesi ve dağıtılması sürecinde çok önemli bir yere sahiptirler. Trafo merkezlerinin kontrol ve takip sistemlerinin modernizasyonu ve yenilenmesi elektrik iletim dağıtım şirketlerinin son yıllarda öncelikli hedefleri arasında yer almaktadır. Bu çalışmalar trafo merkezlerinde daha az arıza meydana gelmesini, problemlerin daha hızlı ve etkili çözülmesini sağlamakta ve dolayısıyla elektrik kesintilerinden kaynaklanabilecek olumsuzluklar en aza indirilmektedir. Bu tez çalışmasında TEİAŞ (Türkiye Elektrik İletim AŞ) Safranbolu 154/34,5 KV trafo merkezinin PLC-SCADA (Programmable Logic Controller- Supervisory Control and Data Acquisition) tabanlı otomasyonu gerçekleştirilmiştir. Otomasyon trafo merkezinin hem yüksek gerilim tarafı (154 KV) hem de orta gerilim tarafı (34,5 KV) için yapılmıştır. Trafo merkezinin prototipi yapılarak kesiciler ve ayırıcılar kontaktörler ve roleler ile temsil edilmiştir. Kesiciler, ayırıcılar ve diğer ekipmanlar ve bu ekipmanların fonksiyonları trafo merkezinin gerçek çalışma senaryosuna uygun olarak SCADA ekranında gösterilmiştir. SCADA ekranından ayırıcıların, kesicilerin pozisyonları, baraların enerjili olup olmadıkları, arıza durumları izlenebilmektedir. Sistemde meydana gelen arızalar ve alarmlar, oluşma zamanları ile birlikte bilgisayarda gösterilmekte ve en kısa zamanda müdahale imkanı sağlamaktadır. Ayrıca kesicilere ve ayırıcılara manevra yaptırılabilmektedir. Önceden çalışılmış senaryolar doğrultusunda en uygun manevralar otomatik olarak yaptırılmaktadır. Bu sayede enerji kesintileri mümkün olduğunca en aza indirilmektedir. Sistemin Internet vasıtasıyla uzaktan kontrolü ve izlenmesi de sağlanmıştır. Bu tez çalışmasında yapılan prototip ve PLC-SCADA tabanlı yazılım ile trafo merkezlerinin kontrol-takip sistemlerinin modernizasyonu için bir yaklaşım ortaya konmuştur. Ayrıca prototip Elektrik İletimi ve Dağıtımı ve Endüstriyel Otomasyon gibi dersler için bir eğitim materyali olarak da kullanılabilecektir.

Anahtar Kelimeler : Trafo merkezi, PLC, SCADA, otomasyon.

Bilim Kodu : 905.1.150

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

N_P : the number of primary windings

N_S : the number of secondary windings

V_P : primary voltage

V_S : secondary voltage

$\emptyset$: flux linkage

ABBREVITIONS

CM : Communication Module

DCS : Distributed Control System

FB : Function Block

FC : Function

FBD : Function Block Diagram

FD : Feeder

EEPROM : Electrically Erasable Programmable Read Only Memory

HV : High Voltage

LAD : Ladder

LV : Low Voltage

MTU : Main Terminal Unit

MV : Medium Voltage

OB : Organization Block

PLC : Programmable Logic Controller

PTL : Power Transmission Line

RAM : Random Access Memory

RTU : Remote Terminal Unit

SB : Signal Board

SCADA : Supervisory Control and Data Acquisition

SM : Signal Module

STL : Statement List

TR : Transformer

CHAPTER 1

INTRODUCTION

There is a need for high investment costs, advanced technology and trained personnel to meet increasing electricity demand. Losses arising from the use of materials which do not conform to standards or due to insufficient utilization of technology are causing great danger in terms of life and property security and the cost is paid by the consumer.

Consumers are more likely to be impacted by a breakdown in energy distribution systems than they would have been in generation and transmission systems. Since production and transmission systems are very dispersed, it is highly unlikely that all or most of them are inactive at the same time, and there is always an alternative supply to consumption locations.

Electricity is generated in power plants and then goes through various processes until it reaches subscribers. First, the voltage of the electricity is increased at the output of the power plant. Thus, the transmission is made with high voltage. At the input into cities or towns, high voltage (HV) is stepped down to medium voltage. Finally, the medium voltage (MV) distribution transformers are used to step it down to low voltage (LV).

The greatest advantages to the customer of an electrical transmission-distribution system controlled and monitored by the automation system, are that it is the most efficient and most economical way to use the available energy, and that it presents the least risks in terms of life and property safety. Apart from that, the advantages of using the automation system in substations can be listed as follows:

- With automatic maneuvers, faults and mains interruptions are reflected minimally in facilities. Thus, the shortcomings and losses in production are minimized.
- Since the energy parameters of the controlled electricity transmission-distribution system can be continuously monitored, energy consumption is under control.
- Failure of all equipment in the system can be monitored in real time from the automation system, so the failure can be intervened quickly and effectively.
- While reducing human errors, automation systems also can be controlled with a very small number of staff.
- In addition to monitoring the instantaneous values of the parameters of the system, it is also possible to reach past values. In this way, information can be accessed about the performance of the entire facility and necessary precautions can be taken in time.

Below is a summary of the literature review of the thesis topic.

An approach to harmonize standards for intelligent networking for the modeling and management of substations has been presented due to the intensive data exchange between CIM (Common Information Model) and IEC 61850. In this approach, the models that concern the connections in the standard are analyzed. Analysis-based harmonization principles are defined. A harmonized model was then created by implementing the principles and conversion algorithms defined to support the automatic conversion of CIM and IEC 61850 to the harmonized model. A simple SCADA application has been developed and the use of a model profile is shown [1].

Stochastic automata networks (SANs) formalizations have been implemented to model the reliability of power systems substations. The proposed strategy allows for the Markov chain model to reduce the size of the state space and simplify the system properties. Two case studies of the standard configuration of substations are discussed in detail. SAN models have been created with different assumptions. The modeling results show that the total independence of the automaton can be used for substations with relatively small power systems with reliable equipment [2].

The case study of a substation has been done by using fuzzy based methods. By using the recommended materials and methods, they gave a broad perspective by evaluating the reliability characteristics of repairable substation automation systems, one of the basic elements of Smart Grids. In this context, quantitative results and diagrammatic outputs are supported by a detailed analysis under different assumptions. Findings show that fuzzy outputs can be calculated and measured. They have shown how the substation automation systems will respond to variations in the reliability data [3].

They have introduced a new role-based access control (RBAC) application based on IEC 62351 using eXtensible Access Control Markup Language (XACML) for substation automation systems [4].

Application and development and modeling studies related to IEC 61850 protocol have been carried out. IEC 61850 based substation automation systems have proposed a new methodology for the testing of intelligent electronic devices (IEDs) without interruption to the end user during testing [5-9].

They have designed the monitoring and control interface of a power plant with SCADA. This model provides a real-time environment for the user of automation in a substation according to control and monitoring accuracy and reliability. The model that is presented enables comparison of the effectiveness of the proposed system with existing systems. The proposed design is based on the SCADA and PLC framework [10].

A study has been conducted on the benefits of remote control and automation of the 11 kV distribution system. Rural automation pilot schemes, operational management of the distribution system, existing remote controlled propulsion types, automation system architecture, approach to system control and benefit analysis are discussed [11].

Construction and testing of a model of 33 kV substation using SCADA has been discussed. The model works as a test platform to carry out various automation tests such as unscheduled load drop, time-based load drop, over-voltage protection and so on. The model provides control, improved accuracy, and increased substation reliability. The substation is monitored and controlled using SCADA [12].

An application for monitoring and controlling digital protection and measurement devices used in electricity distribution networks and substation via web page has been included [13].

It is aimed to control the Ulucak Çamlıbel substation from the İzmir-TEDAS general headquarters. The remote controlled relays used here are PLC controlled in the transformer control panels. For this purpose, automation software was developed on Siemens PLC [14].

Instead of protection relays, the PLC and SCADA remote control and control system were installed for protection against phase-to-earth, phase-to-phase, two-phase and three-phase faults in medium voltage networks [15].

The possible 3-phase, 3-phase ground, 2-phase, 2-phase-ground and phase-ground short-circuit currents in the 154 kV Van substation were modeled using MATLAB Simulink program with real parameters [16].

In this thesis, a 154 / 34.5 kV substation controlled by conventional (traditional) methods was prototyped and automated with PLC-SCADA. Substation automation carried out in accordance with a real work scenario has shown to increase the reliability and efficiency of the system and reduced failures compared to the traditional control method, making it possible to interrupt possible faults quickly and effectively. Considering improvements shown with the prototype, it was the decision of the authorities to implement the automation system in a real substation.

CHAPTER 2

TRANSMISSION AND DISTRIBUTION OF ELECTRICITY

Almost all electricity transmission and distribution networks in the world are AC networks. DC networks are also available in very small numbers. Since AC electricity cannot be stored, it must be transmitted immediately from where it is produced to the places where it is consumed. Transmission of generated electricity to the user is carried out through transformers, poles, power transmission lines, insulators, circuit breakers, disconnectors, surge arresters and other electrical substation components. The connection between the power plants and the consumption centers, which are usually far from each other, is provided by the interconnected system in which the transmission networks are used. In power plants, the energy of a source such as water, wind, coal is first converted to mechanical energy. Generators (alternators) are used to convert this raw energy into electricity. The voltage generated by the generators is stepped up by the power transformers and then delivered to the distribution centers near business and residential centers or industrial areas by the transmission network. The transmission network consists of poles, conductors, substations and similar units. A typical energy transmission and distribution system used to deliver electricity generated by power plants to subscribers are shown in Figure 2.1 and Figure 2.2.

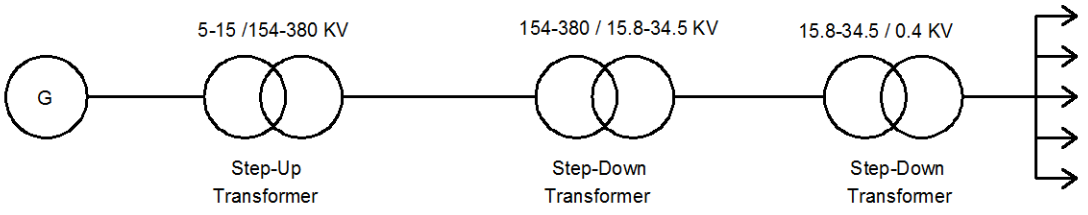


Figure 2.1. Transmission phases of electricity.

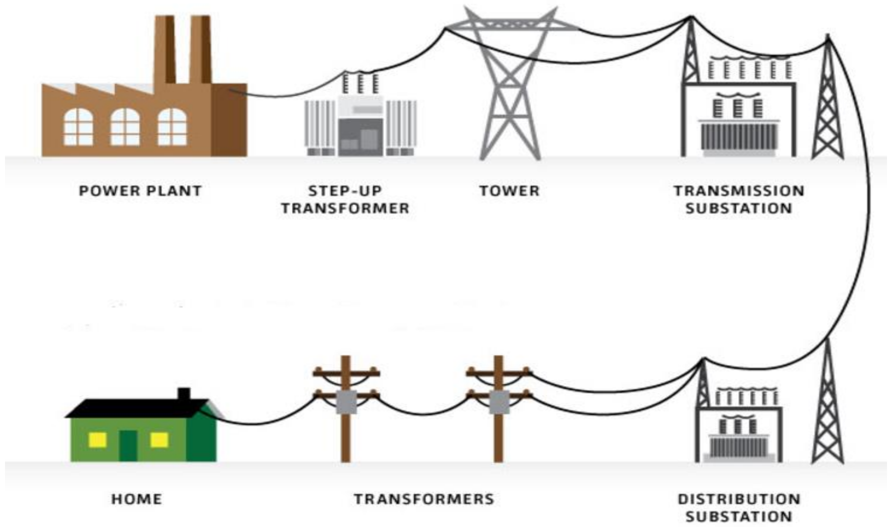


Figure 2.2. Delivery of electricity to subscribers [17].

Generated electricity in power plants is usually in the 5-15 KV range. The voltage value must be raised to HV levels in order for electricity to be transmitted over long distances (several hundred km or larger than 1000 km). Because in the HV values losses can be reduced and transmitted. These losses occur from the resistivity of the conductors.

154 KV and 380 KV HV lines are used in Turkey. The 380 kV value is also called very high voltage. Electricity transmitted over long distances by the HV energy transmission lines is reduced to MV values in transformer/electrical substations located in or near city centers. The most used MV value in Turkey is 34.5 kV; and 31.5 kV, 15.8 kV and 10.5 kV are also used. The electricity delivered from a substation in MV values is finally reduced to LV and arrives to the subscribers. The low voltage values in Turkey are 220/380V for single and three phases. The frequency is 50 Hz. Step-up and step-down of voltage values are carried out with power transformers in the transmission distribution phases.

2.1. OBLIGATIONS OF TRANSMISSION AND DISTRIBUTION NETWORKS

All facilities used to deliver electricity generated by the power plants to the consumers are called electrical networks. The network that enables the transmission of electricity to the consumption areas is called the transmission network, and the network that distributes the electricity in these areas is called distribution network. The obligations to be fulfilled in terms of network, during the delivery of electricity to the subscribers can be listed as follows [18,25-28].

- The network must provide an uninterrupted flow of electricity from generation to consumption. The cost and losses caused by energy interruption will be great especially in manufacturing, communication and communication facilities and in health institutions such as hospitals.
- The networks must be reliable, robust, simple, and understandable. For this reason, they must be well planned and utmost care must be given during their establishment. It must be reliable enough to ensure continuity of energy transmission even in a disastrous event such as an earthquake.
- Subscribers should not be affected by failures in the networks. Especially in rainy weather, when lightning strikes the lines or if there is a short circuit on the lines for some reason, the devices used by the subscriber can be affected and they can be damaged. For this reason, energy transmission lines must be protected against various failures.
- The network should be installed at an optimal cost. Because the cost of electricity, which will vary depending on the economy, is cheap, it reduces the input costs for subscribers that are manufacturers or service providers using this energy. This situation increases the purchasing power of individuals of our country and also increases the competitiveness of our industries against other countries. Nowadays, the level of development of a country is expressed by per capita electricity consumption.
- The distribution network should provide electricity with the same quality for all subscribers at the beginning, middle, or end of the line. High voltage can damage the subscriber. It is known that voltage 10% higher than the desired value can reduce the life-span of devices. Similarly, the efficiency of the electrical devices is reduced due to low voltage. Variations in the frequency change the speeds of asynchronous motors and cause unwanted events. Keeping the frequency constant is achieved by having a constant generator

revolution. To achieve this, various units are provided in the networks to keep the voltage and frequency constant [19,20].

2.2. CLASSIFICATION OF ELECTRICAL NETWORKS ACCORDING TO DISTRIBUTION SHAPES

It is possible to classify the networks that deliver the generated energy to subscribers based on how they deliver and voltage they use. Branches are created by adding electrical networks in residential and industrial areas and distribution networks are created by adding electrical networks together. In general, electrical networks can be listed according to their distribution schemes as follows. [18].

1. Branch network
2. Ring network
3. Mesh network
4. Interconnected network

2.2.1. Branch Networks

In locations such as settlement centers, industrial centers, cities, towns, villages, etc., the network is generally called a branch network, which is generally made from a single source and resembles the branches of a tree. In branch network distribution transformers are placed in the center of the electrical load in the area where the electricity is to be distributed. The electricity around this transformer reaches the final receiver, like branches in a tree, first thick bare separated into thinner arms and thin arms are separated to branches. This type of network is called a branch network because it looks like the branches of a tree.

In a branch network, the electrical lines that are close to the distribution transformer are called main lines. The electrical lines that get thinner as they move away from the transformer are called branch lines. In Figure 2.3 thick sections of lines A, B and C show the main lines, thin E, F, G and H lines represent branch lines. Branched networks are preferred because of the cheapness of the facilities, easy maintenance and operation, and easy detection of failures.

Besides these advantages, there are also features which are objectionable. There is little safety in branch networks, so a large number of subscribers may be left without power in the event of a failure. Voltages are not equal in the lines. As the distance from the distribution transformer increases, the voltage drops.

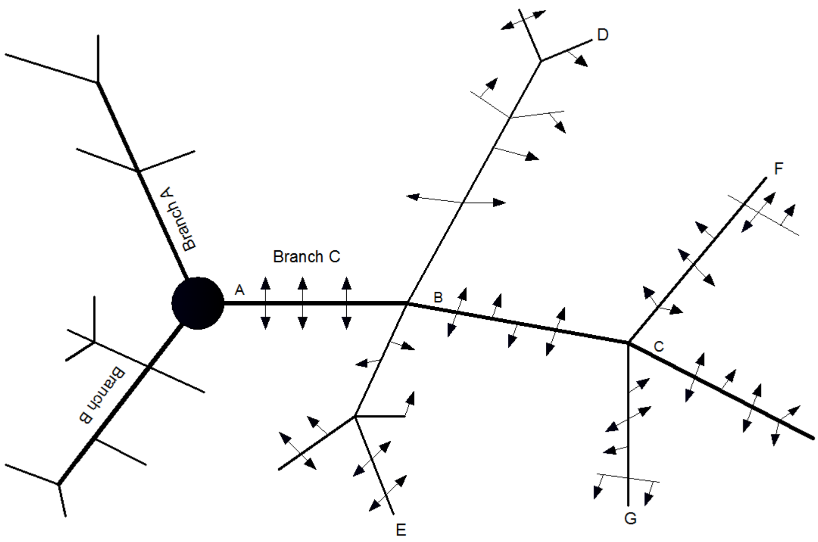


Figure 2.3. Main lines and branch lines in branch network.

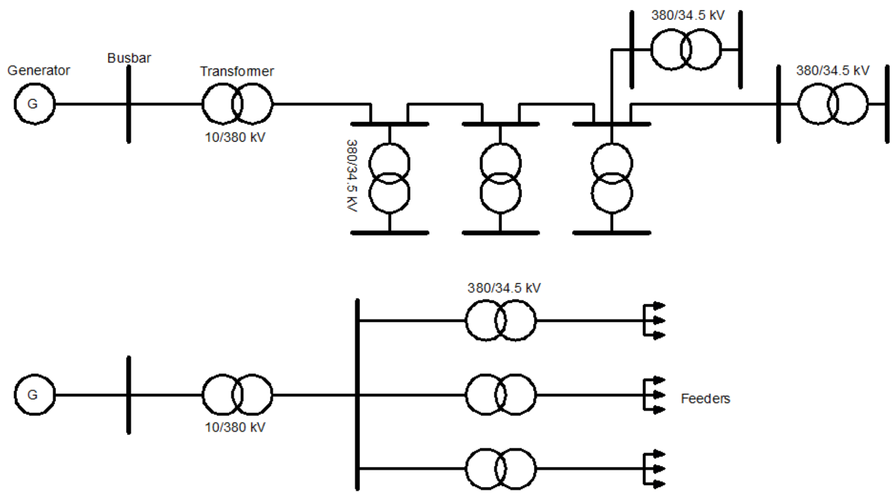


Figure 2.4. Different type of branch networks.

2.2.2. Ring Network

This is a type of network where the supply is provided with more than one transformer and all the transformers form a closed system parallel to each other.

If there is a failure in the ring due to the fact that the supply in the ring network is through more than one transformer, only the faulty part is deactivated so that very few subscribers are left without electricity. The sections of the electrical lines in the ring are the same everywhere. For this reason, the facility cost is high.

They are safer than branch networks. In the future, if the network cannot carry the current drawn by the increase of the buyers, the modification of the plant is very expensive. It is necessary to change all electrical lines in ring networks. In the case of branch networks, it will suffice to change the electrical line which has to carry more current. Figure 2.5 shows the principle diagram of the ring network.

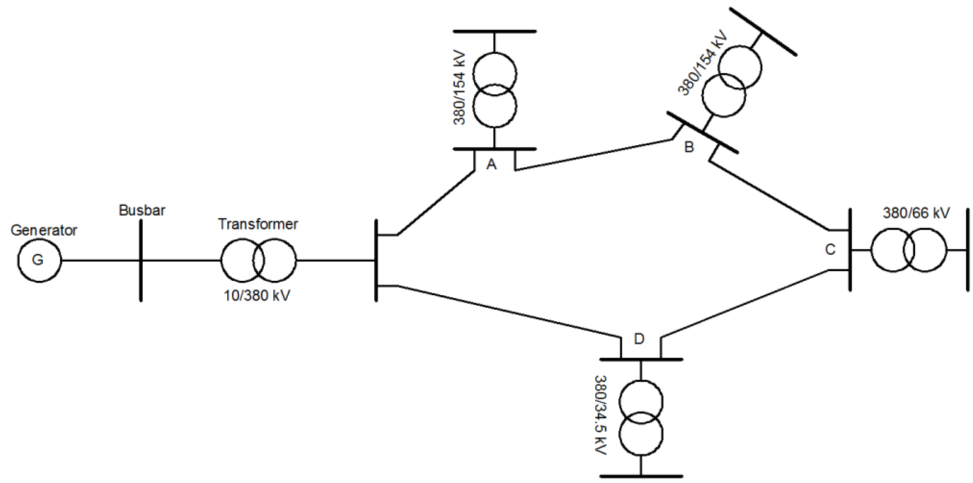


Figure 2.5. Ring network.

2.2.3. Mesh Network

A mesh network is constructed by more than one transformer and the lines that feed the buyers are woven together like a web. This type of network which is created by meshes is called a mesh network.

In mesh networks, as in the case of ring networks, the supply can be made continuously, and the failure only affects the location of the failure. If there is a failure, the failed part is deactivated with fuses or special protection elements. The energy of the other parts is not interrupted. In some mesh networks, the supply is from one place. In this case, uninterrupted energy can be supplied. However, when the transformer malfunctions, the entire network remains without power.

It has advantages such as uninterruptible power, very low voltage drop, and it can support heavy electrical loads. In addition to all of these, mesh networks are difficult to establish, operate and maintain. There are also inconvenient sides, such as the large short-circuit current effect. Figure 2.6 shows mesh networks.

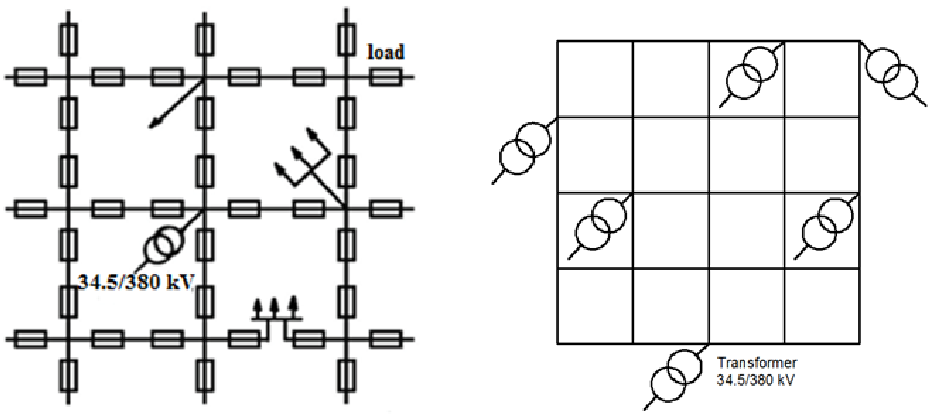


Figure 2.6. Single feed and multiple feed mesh networks.

2.2.4. Interconnected Network

Transmission between electricity generation plants and consumption centers, usually at long distances, is provided by interconnected networks. The work of connecting a production plant to a transmission facility and to the other facilities is called an interconnected operation, and this type of network is called interconnected network. In other words, the system established between all power plants, substations and consumers to meet uninterrupted the electricity demand of a region or country is called interconnection system. When a failure occurs in the interconnected system, only the faulty part is deactivated and the continuity of the energy exchange is ensured.

The interconnected network has the advantages of providing uninterrupted electricity, high efficiency and economy. However, it has drawbacks such as high short circuit currents and difficulty in achieving stability of the system. If there is a failure in the interconnected system, only the faulty area is deactivated. In other parts the continuity of the energy is not interrupted. When the power plant or the transformers failing in one region in the system are disabled, the other power plants and transformers continue supplying these regions.

Every country has an interconnected network. All of the plants in the country can be connected to the interconnected system. In other words, the type of power plant, hydroelectric, thermal, nuclear, etc., is not important. In addition to that, the difference in generation capacity between power plants does not constitute an obstacle. Interconnected networks can also be connected to systems of some neighboring countries. Figure 2.7 shows an interconnected network.

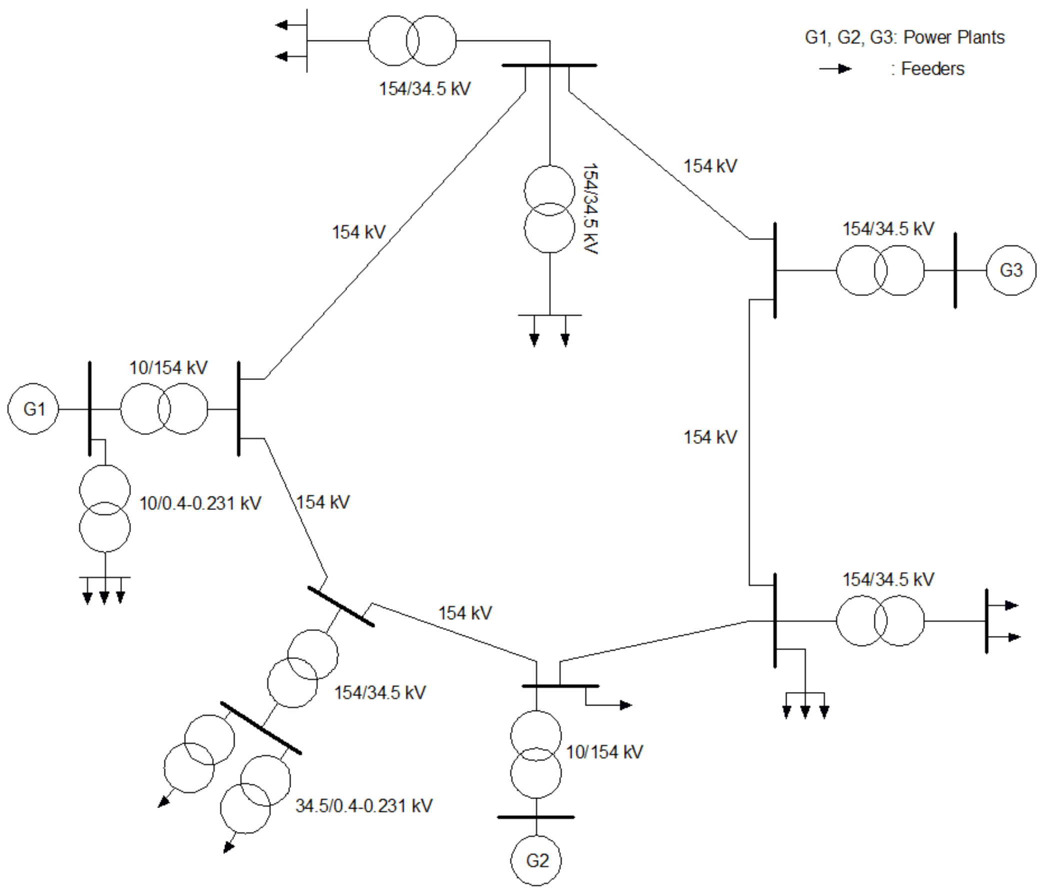


Figure 2.7. Interconnected network.

2.3. CLASSIFICATION OF ELECTRICAL NETWORKS ACCORDING TO VOLTAGES

Transmission and distribution networks can be classified in terms of the voltages they use as well as distribution patterns. These can be listed as:

- Low voltage networks (LV networks, 0-1 kV)
- Medium voltage networks (MV networks, 1-35 kV)
- High voltage networks (HV networks, 35-154 kV),
- Very high voltage networks (VHV networks, > 154 kV)

2.3.1. Low Voltage Networks

Low-voltage networks are networks with voltages between 1 volt and 1000 volts (1 kV). These networks consist of electricity lines from distribution transformers to consumers (subscribers). Low voltages are installed close to subscribers as they are easy to insulate and protect. Low voltage transmissions are used in distribution networks rather than transmission because the voltage and power loss are high for low voltage transmission. Low voltage in Turkey is used as 220 V and 380 V at subscribers.

2.3.2. Medium Voltage Networks

Medium voltage networks are networks between 1000 volts (1 kV) and 35 000 volts (35 kV). These networks are used in the connection of high and very high voltage networks to low voltage networks. Direct supply of high voltages is unsuitable for insulation and safety reasons. For this reason, the high voltages are reduced to the appropriate values and connected to the medium voltage networks. Medium voltage networks are used to transport electrical energy to small cities and industrial areas. The medium voltages are connected to the distribution transformers at the entrance of cities. It is distributed to subscribers from here. In medium voltage networks in Turkey 10.5, 15.8, 31.5, 33 and 34.5 kV are used. In PTLs (Power Transmission Lines) used in medium voltage networks, line voltage is determined according to the length of the electrical line. According to this, the following generalization can be made. It is suitable to use the following voltages according to the length of the line: 3 to 10 kV up to 3 km, 10 to 12 kV up to 20 to 30 km, 20 to 35 kV up to 70 km and high voltages for distances more than 70 km.

2.3.3. High Voltage Networks

High-voltage networks are networks that use voltages between 35 kV and 154 kV. It is the network that starts from the power plants where electricity energy is generated and is used between the big cities and the beginning of the regions. High voltage distribution is not possible. High voltage is most suitable for transmission. While at long distances low voltages have high power loss, high voltages are often used in transmission networks because power loss at high voltages is very low. The high voltage values used in Turkey are 66 and 154 kV. High-voltage networks are usually used at distances between 70 to 250 km.

2.3.4. Very High Voltage Networks

Very high voltage networks are networks using voltages above 154 kV. 380 kV is used as very high voltage in Turkey. In some countries voltages of up to 500 and 750 kV are used. Very high voltage networks are installed for inter-city and inter-station connections.

2.4. ELECTRICAL SUBSTATIONS

Electrical power plants are constructed far away from the consumption centers, and electricity generated in the plants reaches the consumption centers with the help of transformer substations. These centers generally include disconnectors, circuit breakers, bus bars, step-up/step-down transformers, relays, fuses, output feeders and other auxiliary elements. In general, transformer substations can be defined as places that receive energy from one or more transmission networks and distribute it to the transmission networks with MV/LV voltage.

The area where the outdoor type substation equipments are installed is called an electrical substation. Disconnectors, circuit breakers, bus bars, transformers and auxiliary devices are located together. It is a facility with units for collecting or distributing electricity. Transformer substations from 36 kV to 800 kV are installed as open electrical substations. At lower voltages, they are installed in the building. In closed type substations, various arrangements are made depending on the magnitude of the voltage, operation and maintenance, and power.

Outdoor substations are made in various types.

- Series transverse installation
- Series longitudinal installation
- Diagonal installation

Equipment found in electrical substations can generally be classified into three main groups. Transformers, switching equipments, protection equipment. This equipment is controlled from the command room.

The key point in the installation of electrical substation is to provide energy efficiency and energy continuity at low cost. In addition, a high level of field safety is important and it must be open to future innovations. The following factors should be taken into account when establishing an electrical substation.

- System security
- Investment capital
- Operational simplicity
- Maintenance simplicity
- Location selection
- Environmental conditions

CHAPTER 3

DEVICES AVAILABLE IN TRANSFORMER SUBSTATIONS

3.1. DISCONNECTORS

In medium and high voltage systems, a disconnector is a device that is capable of performing open-close (on-off) operations while the circuit is unloaded and forming a clearly visible gap in the open position. A disconnector is shown in Figure 3.1.

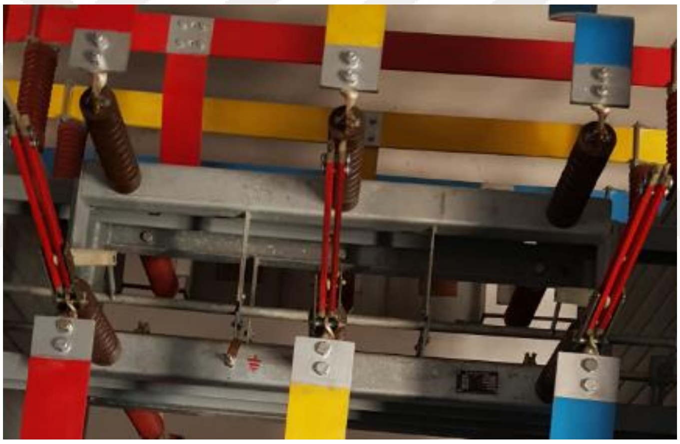


Figure 3.1. Disconnector.

It separates the facility sections to ensure that maintenance and control work is carried out safely. It is also used to prepare and connect the systems with more than one main bus bar to the opening and closing maneuvers. When the current is flowing through the disconnectors, that is, when the circuit is loaded, the switching operation is not performed. If it is done, the person who performs the switching action of the disconnector can be damaged. For this reason, when performing the opening and closing operations of a disconnector, first of all it is not closed or opened. The following sequence is implemented during switching on and off operation [19].

- The circuit breaker is opened first.
- The disconnectors at the input and output of the circuit breakers are then opened.
- When turning off, as the reverse operation, the disconnectors are closed first.
- The circuit is then energized by closing the circuit breaker.
- If there is no circuit breaker, the loads are deactivated and then the disconnector is opened.

3.1.1. Types of Disconnectors According to Their Tasks

Disconnectors can be classified according to their tasks as follows.

- Line disconnector
- Bus bar disconnector
- Earth disconnector
- Bypass disconnector
- Transfer disconnector
- Bus bar partitioner disconnectors

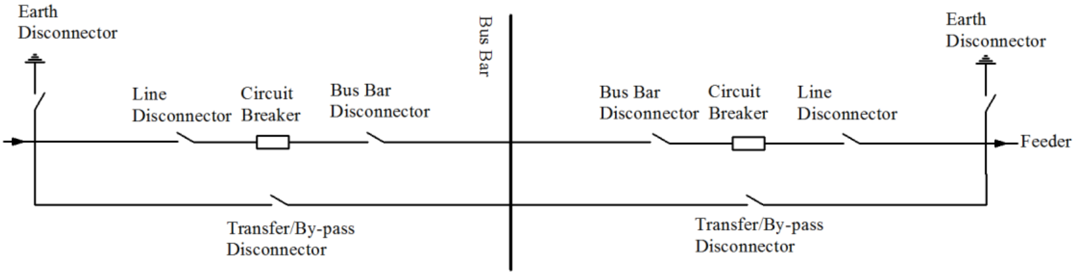


Figure 3.2. Type of disconnectors.

3.1.1.1. Line Disconnector

It is used at the input or output of power transmission lines. The line disconnector is used in conjunction with a circuit breaker in the energizing bus bars with a bus bar disconnector. It is a disconnector which can be opened and closed when the circuit breaker connected to the front is open.

3.1.1.2. Bus Bar Disconnector

It is connected between the circuit breaker and the bus bar at the input and output of the power transmission lines. It is a disconnector that can be opened and closed when the circuit breaker used in conjunction is open.

3.1.1.3. Earth Disconnector

It is a disconnector that drains the residual energy in the deactivated circuit or line to the ground. It can be closed after the circuit breaker and disconnector used in conjunction are opened. When the line is energized, it cannot be closed. There are different types of locking mechanisms that work to prevent the device from being turned off when there is power. These locking mechanisms prevent the closure of the earth disconnector when the disconnector and circuit breaker are closed.

3.1.1.4. Bypass Disconnector

In a single bus bar system, when the energy is transferred from the circuit, that is, when the circuit breaker used along with it is closed, it can be opened and closed, and it is connected to the circuit breaker in parallel. It can be used to energize the bus bar when the circuit breaker fails or is in maintenance. It is a load disconnector that can be used as a circuit breaker when the circuit breaker is broken or in maintenance.

3.1.1.5. Transfer Disconnector

In a double bus bar system, it combines the main bus bar and the transfer bus bar. It is a disconnector that opens and closes when its circuit breaker is closed. When the feeder’s circuit breaker and disconnector are broken or in maintenance, energy continuity is provided through the transfer bus bar.

3.1.1.6. Bus Bar Partitioner Disconnectors

They are disconnectors used for joining or separating bus bars that are at the same voltages.

3.1.2. Disconnector Types According to Structure

- Blade disconnectors
- Rotary isolated disconnector
- Load disconnector

3.1.3. Disconnectors According to Their Control Types

Disconnectors according to the control types; manually controlled, mechanically controlled, controlled by electric motor and pressurized air.

3.1.4. Disconnector Label Values

The information that should normally be included on a disconnector's label is;

Type: Depending on manufacturer's standards, they include certain numbers and letters. It also determines the type and structure of the disconnector.
Nominal voltage (Un): The maximum voltage at which the disconnector can operate continuously.
Nominal current (In): The current value that we can continuously pass through the contacts of the disconnector.
Short circuit current (Is): The values of the maximum short-circuit current given for certain time intervals of the disconnector.
Dynamic force current: It is the value of the dynamic force that can be acted on the disconnector.

3.2. CIRCUIT BREAKERS

Circuit breakers are devices that cut off the load and short circuit current in medium and high voltage networks. These devices can open or close the circuit in no load, loaded or especially short circuit conditions and also enable opening or closing operations with the help of automatic control. The circuit breakers have both arc extinguishing properties and very fast movement property. Before cutting off the energy, the circuit breakers must be opened, then the disconnector must be opened [20].

3.2.1. Circuit Breakers According to Their Voltage Usage

Depending on the voltage used, the circuit breakers can be classified as Medium Voltage circuit breakers and High Voltage circuit breakers Standard rated voltages of MV circuit breakers (kV) according to IEC are 1- 6- 7.2- 12- 17.5- 24-36 kV. Standard rated voltages of HV circuit breakers according to IEC are 100- 123- 145- 170- 245- 300- 362- 420- 525- 765 kV.

There are also varieties of circuit breakers according to the closing process and working environment.

According to the reclosing process, the circuit breakers are:

- Recloser
- Non-recloser

Circuit breakers according to working environment are:

- Indoor (internal)
- Outdoor (external)

3.2.2. Circuit Breakers According to the Medium Where the Arc is Quenched

The circuit breakers are manufactured in different types according to the medium where the arc is quenched They are SF6 gas, vacuum, compressed air blower, bulk oil, minimum oil, magnetic blower circuit breakers.

3.2.2.1. SF6 Gas Circuit Breakers

Because of its small dimensions, it is usually used in closed spaces. The operating principle of the disconnectors is based on the principle that SF6 (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. SF6 gas being non-toxic, pumping small amount of gas to quench cells, and minimal effect of arc, this type of circuit breakers does not require maintenance frequently. Due to these advantages, they are widely used in medium, high and very high voltage systems. In Figure 3.3, a MV SF6 circuit breaker is seen.

Figure 3.3. SF6 gas circuit breaker.

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, becomes an insulator, and the arc is quenched. The SF6 gas gives off sulfur and fluorine ions and electrons at the opening temperature. In the meantime, fluorine ions, which are very electro-negative, trap electrons in the environment and limit the arc current. The temperature drops rapidly due to the very fast dissipation of SF6 gas. The arc cools down and it is quenched. The rated voltage of this type of circuit breaker is higher than that of compressed air circuit breakers. These circuit breakers are divided into gas insulated and air insulated according to the insulation classes. Gas insulated circuit breakers are used from 36 kV to 500 kV and air insulated circuit breakers from 72.5 kV to 420 kV. SF6 gas circuit breakers consist of three main parts:

Polar section: It 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 spring or 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 the motion end switch, the opening and closing coils consist of the auxiliary switch and the anti-pumping relay.

3.2.2.2. Vacuum Circuit Breakers

In this type of circuit breaker, the breaking cell consists of a high vacuum cylinder shaped ceramic container with two contacts, one of which is movable and the other is fixed. When the contacts are disconnected, the current flowing through the arc flows up to the zero point. At the zero point of the current, the arc is quenched and the mine vapor is concentrated on the contacts. Since there is a high vacuum area outside the arc region, the mine vapor quickly escapes to that area and the medium quickly becomes insulated. Thus the arc is quenched. There is no arc quenching material in the vacuum circuit breaker. These circuit breakers are not used in very high voltage ranges. They are used particularly in medium voltage ranges (7.5kV-12kV).

They are a mechanically robust type of circuit breaker. Their electrical life is very long. It can make 100 opening operation in short circuit condition and 20000 opening condition at the rated current. The drive mechanism can be installed either manually or with the help of a motor. It is widely used in medium voltage in recent years as it is a circuit breaker that has high performance and requires little maintenance.

3.2.2.3. Compressed Air Blower Circuit Breakers

The working principle of these types of circuit breakers is based on the principle that the arc that flows between the contacts is cooled down with compressed air. The aggressively cooled arc is quenched with the help of compressed air providing deionization after a half period when the current is zero.

3.2.2.4. Bulk Oil Circuit Breakers

Bulk oil circuit breakers contain too much oil, so there is a danger of fire. For that reason, they are no longer used today. When the quenching process of the bulk oil circuit breakers is examined, we can see the moving contact is separated from the main contact a little and an arc is created. The oil turns into gas with the high temperature of the arc. A gas balloon surrounds the arc. The gas balloon, which is at a specific pressure, pushes the oil, so the oil level rises.

3.2.2.5. Minimal Oil Circuit Breakers

Breaking cells of such circuit breakers are equipped with fixed arc quenching chambers consisting of fiber elements. The principle of arc quenching is as follows: the arc is created by exposing the contact element in the oil evaporates in its vicinity and makes a considerable amount of oil gas. In this way, the gas and vapor particles make a sphere around the arc. In the sphere, temperature gradients are created. The innermost arc core is the hottest region (at 10,000 ° C). Its outside forms the gas envelope. Then, from innermost to outermost, the steam zone, the steam-shell zone, and lastly the oil layer. During the evaporation of the oil, the gas vapor mixture drifts to the oil layer dragging the arc along with it. The dragging is done with the aid of plates in the cell. The steam and gas mixture is swirled around the arc, reducing the diameter of the arc. Both the vortex effect and lengthening of the path allow quenching to be easily achieved.

3.2.2.6. Magnetic Blower Circuit Breakers

In such circuit breakers, using the iron carcass during the opening, the natural magnetic field of the current is intensified and the arc is pushed in one direction. This area is thrown out between the arc plates by the blowing effect. Here the arc is cooled down by convection and turbulence. Since the arc is in a conductive structure, the direction can be changed by the magnetic field. Thus the magnetic force extends the length of the arc, reduces the heat and quenches it. The magnetic blowing coils are switched on or off depending on the line current. The arc between the contacts is transferred to the coil system to be quenched.

3.3. POWER TRANSFORMERS

The energy generated in power plants must be transmitted to the places where it is to be consumed. The transfer process is achieved by first increasing the voltage and then decreasing the voltage at the area of consumption. Transformers are machines that change the voltage and current values within a certain ratio (step-up or down) by electromagnetic induction without changing the frequency.

Figure 3.4. Power transformer.

Transformers are electrical devices that have no moving parts. Currently, transformers with a capacity of 250 MVA and a voltage up to 750 kV are manufactured. Two winding type transformers are widely available, but also three winding types are also available. Transformers are usually manufactured for single and three phase systems. The transformers consist of two coils isolated from each other and the ground, and an iron core carrying the windings on it. One of the greatest features of transformers is that their efficiency is higher than other electric machines. Up to 99.5% efficiency can be achieved in a large transformer [24].

Transformers are made of thin sheets and wrapped around insulated conductors with a closed magnetic circuit called an iron body and two coils placed on the iron body. Apart from the auto transformers, these two coils are completely electrically isolated from one another.

Typically, transformers have two windings: Primary winding, Secondary winding. Voltage is applied to the primary winding of the transformer. This winding is wrapped very tightly with thin-section conductor in a step-down transformer. In a step-up transformer, it is wound with not tightly with thick cross-section conductor. In the secondary winding the converted voltage is created. The secondary winding is the winding to which the receiver is connected. In a step-down transformer, the winding is wrapped loosely with thick conductors. In a step-up transformer, the winding is wrapped tightly with thin section conductors. Figure 3.4 shows the general working principle and symbol of the transformers. Where, V_P is the primary voltage, V_S is the secondary voltage, N_P is the number of primary windings, N_S is the number of secondary windings, Φ is the flux linkage.

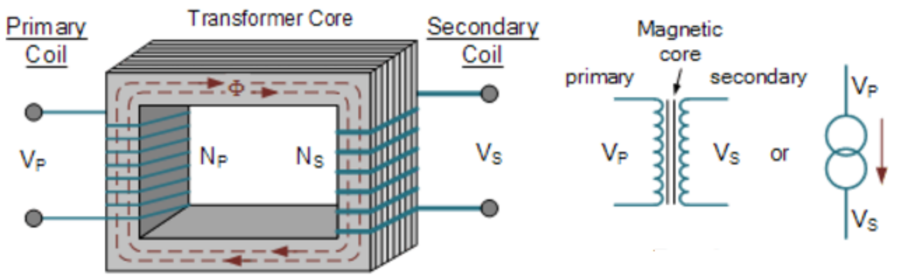


Figure 3.5. General principle diagram and symbols of transformers [29].

If an alternative voltage is applied to the transformer, an alternating current flows from the primary windings. This current creates a time-varying magnetic field whose magnitude and direction changes with time. This magnetic field circuitry is completed by flowing through the secondary winding. The variable magnetic field force lines induces EMF (Electromotor Force) by crossing the cross section of the conductors in the secondary winding. In this way, the alternative voltage that is applied to the primary winding is induced to the secondary side without an electrical connection at the same frequency.

There are three types of cooling systems in order to allow the heat generated in the transformers to flow out and to cool them:

- Air cooling
- Oil cooling
- Water cooling

Cooling mode selection factors are:

- Location and operating conditions for the transformer
- Amount of heat to be removed from the transformer
- Construction and transportation difficulties of transformer
- Operating expenses and price

Transformer windings are connected in 3 types: star, delta and zigzag. 3 phase transformers can be connected in the following ways: star-star, delta-delta, delta-star, star-delta, star-zigzag and delta-zigzag. Secondary windings usually also include setting coil to compensate for voltage drops.

3.3.1. Bushings

The transformer winding leads need to be taken out of the tank so that they can be connected to the bus bar. Since the tank is grounded, it is necessary that the winding leads do not come into contact with the tank, and there is a proper insulation suitable for the voltage levels. This insulation is provided by porcelain cylindrical elements called "bushing". Since the voltage level in the medium voltage is low, only porcelain bushings are used which are manufactured without taking any precaution. However, at voltages higher than 154 kV the bushings’ length will increase excessively, and thus it will be uneconomical to install the expansion tank (reservoir tank) in high places. A separate reservoir tank with a smaller volume for bushings is installed and the oil in the bushing is kept separate from the oil in the transformer tank [23,24].

Figure 3.6. Bushings.

3.3.2. Spark Gap

The spark gaps form the structure of the metal bars facing each other, mounted on the line and earth sides of the insulators and bushings. The gap between the metal bars is called the jump distance, the insulation in the gap is provided by air. The gaps in spark gaps are checked. If they are distorted, the gaps are adjusted so that the tips are facing each other.

Figure 3.7. Spark gap.

3.3.3. Boiler and Radiator

As in all machines, transformers also suffer losses in winding and iron core, and losses appear as heat. The heat must be transferred to the air in a suitable way. Air or oil is used as a cooling medium. According to the cooling scheme, the transformers are divided into two, namely, dry transformers and oil transformers. The dry transformer boiler construction depends on the size of the transformer and the cooling scheme, transformer breather and expansion tank. As it is known that transformer oil expands as it gets hotter shrinks as it gets cooler. Oil increases in volume. The transformer boiler should not be affected by this volume change. This can be achieved with the transformer breather.

3.3.4. Expansion Tube

The sudden expansion and pressure created by the extreme temperature during winding failures in the transformer can not be avoided by the expansion tank via the Bucholz connection. In such cases, in order to prevent damage to other weak spots in the transformer, a transition path is needed to ensure that the expanding oil is safely taken out to the atmosphere. For this purpose, a safety tube is installed. A diaphragm (thin aluminum plate) that bursts easily with high pressure was placed at the tip of the safety tube. Thanks to this, the oil in the boiler does not come into contact with the atmosphere.

3.3.5. Voltage Changer

Both the losses in the power transmission lines and the loading in the secondary circuit cause the secondary circuit voltage to drop. In the energy business, it is desirable that the voltage of the energy given to the customer does not change. To compensate for this voltage drop an adjustment coil is added to the transformer windings.

3.3.6. Oil Level Indicator

Oil is a very important element as it provides both insulation and cooling to the transformer. As it is known, the volume of oil varies depending on the load state of the transformer and the ambient temperature. There must be a certain amount of oil in a transformer boiler. The change of oil with temperature should be constantly monitored. The amount of oil is usually controlled based on the amount of oil at 20 ° C.

3.4. SURGE ARRESTER

The surge arrester is a device that prevents and reduces damage by lightning strike, harmful very high voltage shocks caused by circuit breaker maneuvers and traveling waves that occur. To put it simply, it is a device that grounds the excessive voltage in transmission lines. Surge arresters, depending on their construction, can be classified as variable resistance, metal oxide, piped, discharge tube. Since the first two are used in practice, only variable resistance and metal oxide surge arresters will be discussed.

3.4.1. Variable Resistance Surge Arrester

It grounds the overvoltage with the help of its voltage dependent resistance property. In this case, the arc current is reduced to a value that can be easily cut by means of variable resistors and cut by means of electrodes connected in series with these resistors. Generally, a noticeable voltage drop on the mains due to the arc current does not come into play. The surge arrester mainly consists of two sections. These are voltage dependent resistors and jump spaces. Generally a hollow porcelain cylinder with a multi-compartment arc chamber in the cylinder and a sequence of series-connected voltage dependent resistor (VDR) disks can be found. It is basically a resistor in series with a spark gap. They are installed between phase and ground. In case of excessive voltage, the resistance value of the surge arrester goes down, and the insulation between the serial jumps is also broken down and an arc is created. As the value of the surge voltage decreases at the start, the variable resistor value rises and limits the flow of current. After a few microseconds, eventually the arc quenches. The surge arresters act like a safety valve for the network [23,25].

3.4.2. Metal Oxide Surge Arrester

In a metal oxide surge arrester, zinc oxide (ZnO) blocks are used as active elements for semiconductor material instead of a variable resistor. There is no series spark in this type of surge arrester. Therefore they are simpler and safer than variable resistor surge arresters. Metal oxide resistors, which are the main element of metal oxide surge arresters, contain mainly bismuth oxide (BiO), manganese oxide (MnO) and antimony oxide (SbO), zinc oxide (ZnO).

3.5. PROTECTION RELAYS

3.5.1. Buchholz Relay

Relays that works with the effects of the expansion of oil and the gas coming out resulting from internal faults in power transformers are called Buchholz relays.

Figure 3.8. Buchholz relay.

The Buchholz relay is installed between the expansion tank and the transformer boiler. There are two independent contacts for opening and alarming in the relay. These are 5 A, 250 V AC or 0.2 A, 250 V DC. Under normal operating conditions, the transformer tank and buchholz element are completely filled with oil. The upper and lower contacts in the Buchholz relay are open. The electrical connections are made so that when the upper contact is closed, the alarm is activated and when the lower contact is closed, the opening is made [22].

According to the voltage and power of the transformer. There are three forms of application for Buchholz relays:

- Transformer buchholz relay
- Step buchholz relay
- Bushing buchholz relay

If the gas collected at the top of the relay is examined after the operation of the Buchholz relay, it is possible to obtain information about the formation of the fault. For this purpose, the upper part of the buchholz relay is enclosed in a glass container, or in this part, the observation window is placed. From the glass container or observation window, it is possible to have a certain knowledge about the malfunction by observing the amount of gas and its color.

- The amount of gas collected gives information about the importance of the fault.
- The color of the collected gas makes it possible to infer the following faults.
- White gas indicates the paper insulation has burned down.
- Black or gray colored gas indicates insulation oil has burned down.
- The yellow gas indicates that the tree parts are damaged.
- Colorless gas indicates air.

In addition, the combustibility of the collected gas must be determined in order to be able to interpret the cause of the operation of the buchholz relay. The gas discharge valve at the top of the relay is opened and the flame emitted from the faucet is checked to see if it is flammable by approaching with the flame of the match. The fact that the gas is flammable means that an internal fault has occurred in the transformer. In this case, the power transformer should not service before the necessary tests and maintenance are carried out. If the gas is not flammable, the gas from the faucet is air and can be taken from the transformer after the discharge with the permission of the authorized individuals. In the test conducted under operating conditions, it has been observed that when the arc is applied to a transformer tank filled with oil, the relay trips within 50-100 milliseconds.

In the Buchholz relay there are two moving buoys. The upper one works on minor faults and the bottom one works on major faults. Gas bubbles moving up during the fault move the buoys. The mercury in the buoys allows the opening and alarm systems to work by closing the circuit. Thus, damage caused by the fault is prevented.

3.5.2. Overcurrent Relay

3.5.2.1. Secondary Overcurrent Relay

Relays connected to the secondary circuit of the current transformers are called secondary relay. Relays are used to protect transformers and alternators against over currents. This type of relay protection is used especially in high voltage circuit, but it has also used in low and medium voltage circuits.

Electromechanical secondary overcurrent relays are relays that operate according to the principles of electromagnetics, induction disc and electrodynamics. According to the principles of electromagnetics, the excessive current passing through the external circuit activates the relay coil. When the relay coil is energized, it draws its core and controls the circuit breaker and the circuit breaker opens the circuit [21].

In electronic intelligent electronic devices (IEDs), the relay measures the current of the system that it protects by transferring the current information from the main current transformer to the electronic circuits through the auxiliary current transformers in it, and it disables the system if the measured current value is above the rated current.

Figure 3.9. Overcurrent relay.

3.5.2.2. Differential Overcurrent Protection Relay

There are many types of faults, such as phase-to-ground fault, short circuit faults between alternator phases, and incorrect connection of the system. With the occurrence of these faults, the systems are damaged and the protection of these systems is provided by differential relays. In other words, it provides security against possible mistakes in places we cannot reach for control purposes. Differential relays are used as protective elements in high current and slow switching applications in alternators and transformers [22].

Differential relays are based on the principle that the primary and secondary currents of power transformers are equal with 180-degree phase difference between them. The region between the primary and secondary current transformers of the transformer is called the "differential protection zone." When there is a fault in the protected area, the difference between the incoming and outgoing currents is calculated (under normal conditions, the voltages of the incoming and outgoing currents are equal and the difference current is zero). Auxiliary current transformers are used to balance the amplitudes and phases of these currents.

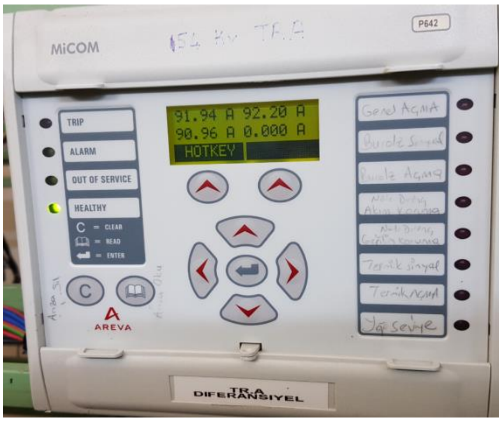


Figure 3.10. Differential relay.

3.5.3. Phase-Earth Leakage and Protection Relay

Relays used to protect the power transformer and the alternator in phase-to-ground (leakage to the body) fault in the circuit fed by the secondary winding of the alternator and transformers and the grounded secondary winding are called phase-earth leakage protection relays. In the case of phase-ground short circuit, to be protected, transformer and alternator star connection points must be grounded directly or through a resistor whose ohmic value is very high [21].

In a directly grounded circuit, the phase-earth leakage protection relay is fed from the secondary of the current transformer placed at the neutral point. In a phase-to-ground fault in any of the feeder, a short circuit current flows from the neutral point of the secondary winding of the power transformer. This current completes the circuit from the primary winding of the current transformer. In this case, a certain amount of fault current is reflected to the secondary winding of the current transformer. However, since the relay is set to a certain time delay, when the feeder-ground protection does not function, the relay will operate at the end of the set time. In this case;

- Sounds a warning (horn rings).
- Fault-to-earth fault signal on the panel is on.
- Transformer output circuit breaker opens the circuit.

If the ohmic value is grounded through a resistor with a very high resistance, if one of the windings leaks to the ground, a current flows in the circuit that is closed on the ground. This current is used to operate the earth-leakage protection relay by keeping it at a non-dangerous level. In this case;

- Sounds a warning (horn rings).
- Fault-to-earth fault signal on the panel is on.
- Input circuit breaker is opened.
- General opening relay operates.
- Closing circuit is locked.

Figure 3.11. Phase-earth protection relay.

3.5.4. Heat Protection Relay

Thermal protection is used to ensure that the transformer's oil and coil temperatures do not exceed a certain limit. The causes of heating in the transformer are:

- Overcurrent
- Short circuit current
- Internal fault
- Short circuit between turns
- Short circuit between windings

- Winding-ground short circuit faults
- External fault
- Short circuit between phases
- Phase-ground short circuit
- Overload
- Overvoltage
- Internal overvoltage Phase-earth short circuit, line breaks etc.
- External overvoltage: Lightning and ambient temperature

There are two types of thermal protection relays: thermal (temperature control) protection relay and tank temperature protection relay [22].

3.5.4.1. Thermal (Temperature Control) Protection Relay

In transformers and alternators, the winding temperature should be determined and limited to a certain value. The protection device used for this purpose is called temperature relay.

A small heater, fed from the secondary winding of a current transformer with a suitable ratio, placed at one of the windings in the temperature control relay, is placed in a small pocket inside the body.

The transformer’s oil temperature is measured and a contact system is used for alarm and opening when oil temperature is high. For the winding temperature, the most loaded coil of the transformer is selected and the probe (PTC sensor) is placed in the hot spot of the transformer. The load-proportional current from the current transformer connected to phase R of the loaded transformer winding or the primary winding heats the prob. The R resistor, which varies very sensitively with temperature, changes the current in the display circuit and the needle points to a certain value. In the substation, thermal (temperature control) relays measuring the oil and winding temperature of power transformers are used. Alternators are also used.

Figure 3.12. Transformer's oil and winding temperature protection relays.

3.5.4.2. Tank Temperature Protection Relay

The tank temperature protection relay is the thermal protection used to ensure that the transformer and the alternator are protected so that the tank temperature does not exceed a certain limit.

The structure consists of a probe, a probe housing, a pocket and a control unit. In the control unit, there are two contacts placed on the DC voltage terminals. Hydrogen gas is used as the refrigerant gas in the probe cavity.

Two contacts are placed on two needles with voltage. One of these contacts is at the alarm contact and the other can touch the disconnecting contact. If the temperature of the refrigerant reaches 70°C, the auxiliary alarm relay operates. The alarm sounds, the thermal alarm light on the panel lights up. If the temperature reaches a temperature of 85°C, the trip assist relay is activated and the alternator is deactivated to lock the closing circuits. With thermal protection, if there is a warming in the tank on certain temperature values, the alarm sounds first, then the circuit turns on.

Figure 3.13. Tank temperature protection relay.

3.5.5. Distance (Impedance) Relay

In the case of short-circuit faults that occur in the power transmission lines that form the interconnected network, distance relays are those which detect the faulty part and deactivate.

It is essentially a resistance relay and the name comes from the fact that the resistances of the lines and the networks depend on the length. Although the old models are electro-mechanical type, microprocessor-based types which are capable of electronic and more accurate protection are preferred today. The relay consists of three main units that undertake different tasks:

- Initiation unit
- Direction unit
- Measurement unit

The distance relay is a secondary type of relay that provides selective protection. Proper protection depends on the initiation, direction and measurement units linked up and performing their tasks. The most important feature of these relays is that the failure time is proportional to the distance from the failure point to the supply point. Overcurrent relays are also used in conjunction with distance relays.

In general, the distance protection relays are based on a comparison of the current and voltage values at a point in the line regardless of the structure. In the event of a short circuit, the line voltage value decreases, the current value increases. Accordingly, the short-circuit impedance is smaller than in normal operating conditions. The measured impedance value of the relay depends on the distance between the fault point and the relay. The impedance value is proportional to the length of the line.

If the measured impedance of the distance protection relay is less than the value set by the relay, it activates the initialization chain. In the interval between the operation of the initialization chain and its functioning, the decisions as to whether or not to break, the direction of the fault current and after how long it will give the break are made after measurements. The initiation unit, direction unit and measuring unit must be linked in order to provide full selective protection of the distance protection relay.

The short circuit fault current that flows through the power transmission lines forming an interconnected network is quite large because the network is fed from several sources. For this reason, it is necessary to determine the location of the short circuit on the line and take it out of service immediately. The distance relay is a protection element that detects and deactivates the faulty part in the event of a short circuit fault and maintains the continuity of the energy without interrupting the power of the non-faulty parts of the line.

Figure 3.14. Distance relay.

3.5.6. Pressure Relief Valve

The pressure relief valve, placed on top of transformer main tank, is an electrical device that sends an opening signal by the operation of pressure controlled torr type pressure relief devices which can pressure 500 grams of cm^2 of a 1 mm thick metal sheet. It works with the high pressure coming out of the main transformer tank in case of faults. When this device does not exist, a metal tube called camel neck, which is covered with a thin film membrane, is aligned on the level of the transformer expansion vessel with the tank which prevents the contact with the air of the insulating oil of the transformer tank which discharges the oil in the presence of oil. If the pressure relief valve is in operation; the transformer expansion vessel valve is closed or the transformer expansion vessel has failed; the transformer is not expanding. This phenomenon is especially observed in the hot seasons when the insulating oil in the transformer tank expands.

3.5.7. Tank Protection Relay

This is one of the transformer's self-protection devices. It is a useful protection system because it is simple and economical. In the case of a winding-ground fault in star-connected and neutral-point grounded primary or secondary windings, they are used to limit the damage and deactivate the faulty transformer. In case of tank protection, in winding-ground short-circuit failure, the current flowing to the earth from the transformer tank is used. To perform tank protection, the transformer tank is connected to the ground with a conductor and insulation is applied between the wheels and rails. A current transformer between the tank and the ground is placed and an operational current relay is immediately fed from the second terminal. This type of current transformer is called a tank protection current transformer and the relay is called the tank protection relay.

A transformer that is deactivated with the operation of tank protection current transformer should not be operated without necessary the controls and tests. The situation is reported to the responsible individuals and action is taken according to the given instruction. Faults, tripping the tank protection relay due to operating principle can be summarized as follows.

- The winding-ground short circuit fault formed in the primary or secondary winding of the power transformer
- In case of cracking of input and output bushings,
- In case of discharge occurring in the bushings or spark gaps on the bushings,
- If the surge arresters placed on the transformer discharge from the tank,
- Cooling fans or circulation pumps that complete the circuit over the tank winding ground or in case of a short circuit failure.

3.5.8. Protection Relay Through Neutral Resistor

These type of relays protect the transformer windings by reducing the short-circuit current in the phase-to-ground fault that may occur in the part of the power transformers supported by the star-connected and neutral-point grounded secondary windings. The relay performs a protection function in the following fault conditions.

- The burst of neutral resistor,
- The fact that the ohmic value of the neutral resistor is not suitable for the system,
- Inadequate insulation of the neutral resistor,
- Inadequate grounding of the neutral resistor. The discharge time of the fault current is long.
- If protection relay does not function properly, the thermal and dynamic effect which occurs over the breakdown period breaks resistance. When this happens, the transformer is insulated. When the voltage transformer, which is the rearguard relay and in parallel with the resistor, works the resistor is disconnected.

If the transformer is to be switched on after this signal is received, the neutral resistor is deactivated by closing the ground disconnector, and the neutral secondary bushing is directly grounded.

3.5.9. Frequency Protection Relay

The frequency protection section protects the system from frequency fluctuations. If the frequency out of the desired frequency band, the system is deactivated at the end of the set delay time.

3.5.9.1. High Frequency Protection

If the frequency remains above the upper limit for longer than set time delay, the relay is activated. In order for relay to activate the system again, the frequency's upper limit value should be lowered until hysteresis.

3.5.9.2. Low Frequency Protection

If the frequency remains below the lower limit for longer than a set time delay, the relay is activated. In order for the relay to activate the system again, the frequency should be larger than the lower limit by a hysteresis value. Generally upper and lower limits are set between 35 and 70Hz. For an accurate setting the high frequency is set at least 2Hz higher than the low frequency.

Figure 3.15. Frequency protection relay.

CHAPTER 4

SAFRANBOLU SUBSTATION

154 / 34.5 kV TEIAS (Turkish Electricity Transmission Inc.) Safranbolu substation was established in 1984 in the Safranbolu district of Karabük province in Turkey. At the substation there are two 50 MVA power transformers, which are the most important part of the system. There are three 154 kV feeder, namely the Araç, Karabük and Çaycuma. From these feeders up to the bus bar, 3 ground disconnectors, 3 line disconnectors, 3 circuit breakers, 3 bus bar disconnectors, and 3 transfer disconnectors are used.

There are 4 bus-bar; 154 kV main busbar, 154 kV transfer bus bar, 34.5 kV main bus bar, and 34.5 kV transfer bus bar. At the entrance of the transformers there are 2 bus bar disconnectors, 2 circuit breakers, 2 line disconnectors and 2 transfer disconnectors to protect the transformers. There are 2 disconnector and 1 circuit breaker for transfer between main bus bar and transfer bus bar in the 154 kV bus bar section. After the transformers, the voltage level is reduced to 34.5kV. At the exit of the transformers there are 2 line disconnectors, 2 circuit breakers, 2 bus bar disconnectors and 2 transfer disconnectors. After that 34.5 kV bus bars are located.

Subsequent to 34.5 kV bus bars, there are 15 feeder outputs and 1 transfer block. Three of the feeder outputs are empty for emergency use. There are 2 disconnector and 1 circuit breaker for transfer between main bus bar and transfer bus bar in the 34.5 kV bus bar section. There are 15 bus bar disconnectors, 15 circuit breakers, 15 line disconnectors, 15 transfer disconnectors, and 15 ground disconnectors.

The substation consists of a total of 88 disconnectors (line, bus bar, transfer and ground disconnectors), 24 circuit breakers, 2 power transformer and auxiliary elements.

Figure 4.1. Safranbolu substation.

In Figure 4.1 Safranbolu electrical substation is shown. It is 154kV distribution site. Maneuvering elements such as disconnectors, circuit breakers used in the system and protective equipment, such as isolators, are located within the area surrounded by wires. There is a separate control room that allows the whole system to be checked by the staff. Maneuver sites, fault information, instantaneous value measurement of the system, etc. are observed and intervened in this control room. Control room is demonstrated in Figure 4.2.

Figure 4.2. Safranbolu substation control room.

The substation control room has the elements and the battery chamber used to control the system. In the battery chamber 110V DC supply is used to power the relays and

24V is used for lighting. All control and guidance of the system is carried out by the auxiliary elements in this building.

In the Safranbolu Substation single line schematic the numbers written on the side of the disconnectors and circuit breakers represent specific things. The numbers that end with '0' are the earth disconnectors, the numbers whose last digits are '1 or 3' are the line and busbar disconnectors the numbers ending with 9 are the transfer disconnectors, and numbers ending with 6 are the circuit breakers. Safranbolu substation single line schematic is shown in Figure 4.3.

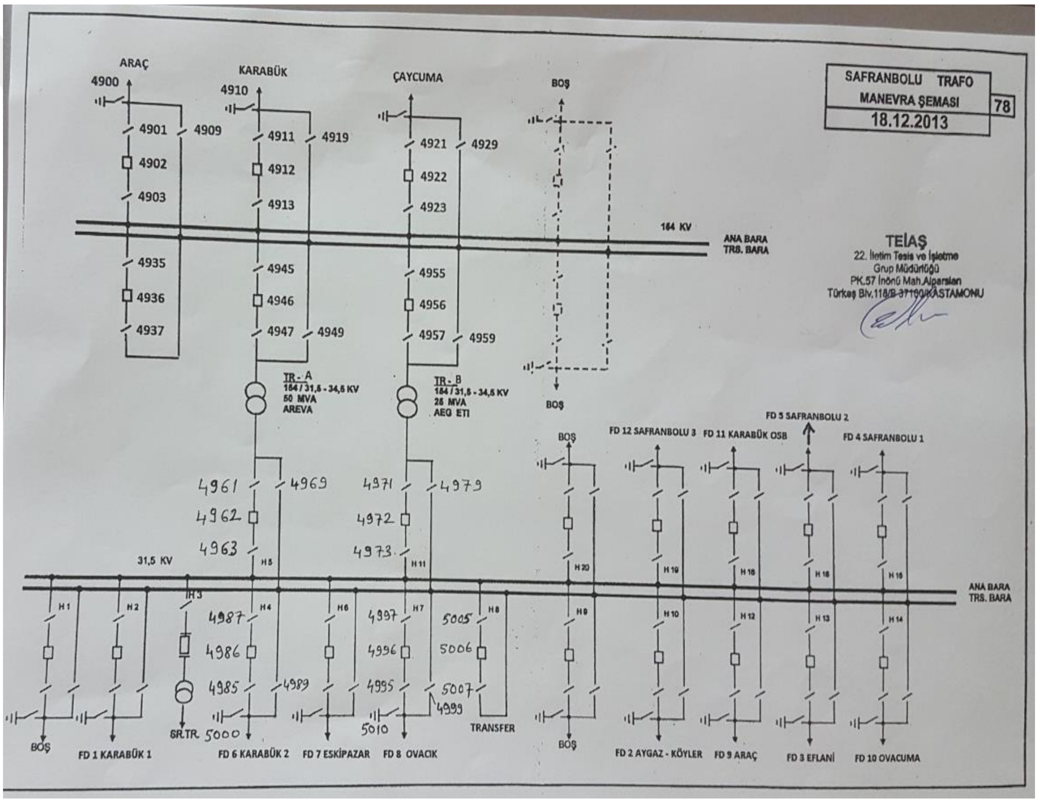


Figure 4.3. Safranbolu substation maneuvre (single line) schematic.

CHAPTER 5

PLC AND SCADA

5.1. PLC

PLC (Programmable Logic Controller) is a mass-manufactured, generic, universal control element. In the solution of all control problems logic operations, memory functions, timers and counters are needed. These are already available by the manufacturers in PLCs. With simple programming, all these facilities can be combined in the solution of the problem.

In a process, the operation and signal elements (motor, sensor, etc.) do not change regardless of the method used in designing of the control system (Relay, contactor, digital circuits, PLC etc.). However, since the control circuit is provided with software in the solution made with PLC;

- Circuit design is simple and reliable.
- They take up less space on the control panel and they are less faulty.
- They can adapt to a new application more quickly.
- They are not easily affected by harsh environmental conditions.
- They require fewer cable connections.
- The status of inputs and outputs can be monitored.

The development of industrial control has determined the true status of PLCs. As the analog systems, which can be called analog computers, became insufficient, digital systems were developed and began to be used. The acceleration of digital systems over time and the fact that many functions can be done with a very small volume make them even more active. However, the main improvement is the emergence of programmable digital systems and the active use of microprocessor control [30,32].

Typically a PLC consists of a Input module, Power supply, Central processing unit, Memory, Communication module and Output module.

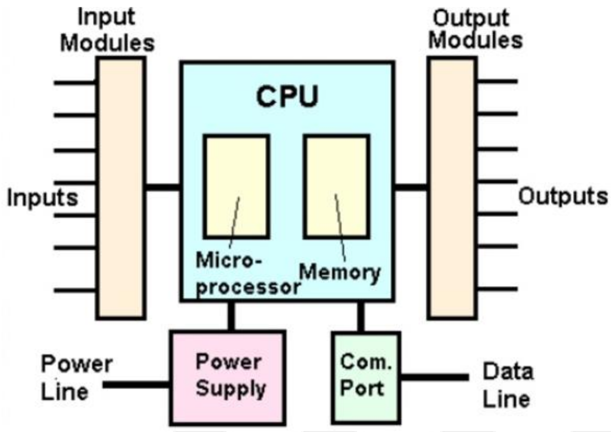


Figure 5.1. PLC components [31].

5.1.1. Input

The input unit of the PLC is the unit that converts electrical values (input signals) from the controlled system, such as pressure, level, temperature sensors and buttons and limit switches, into logical values (0-1) in the CPU. The input signal can be digital or analog. The supply voltage is usually 24VDC. The analog inputs are 0-10V or 0-20mA.

5.1.2. Power Supply

It is used to meet the power requirement of modules connected to PLC and PLC itself. The power supply may be internal or external, depending on the brand / model.

5.1.3. Memory

The data memory is the memory of the PLC. In this memory RAM (Random Access Memory), EEPROM (Electrically Erasable Programmable Read Only Memory) integrated circuit are used to store program data and information. RAM is a type of memory whose content can be easily changed or erased. The information inside the RAM is protected as long as the power is supplied. When no power is supplied to the

RAM, its content is deleted. For this reason, rechargeable batteries are used to support the RAM in PLCs. As long as the PLC is powered, it will charge the battery. When the power is turned off, the battery keeps the RAM memory powered and keeps the information in it until the battery is discharged. EEPROM is a memory that is only readable after programming and can store information without requiring a battery

5.1.4. CPU (Central Processing Unit)

It reads the input values. It executes the program according to the information loaded into the memory and passes the result values to the output. S7 1200 CPUs are manufactured compactly. In other words, a certain number of digital inputs/outputs, analog input, fast counter modules are located in the same body as the CPU. When needed, signal modules (SM) can be installed on the right side of the CPU, communication modules (CM) on the left side and signal boards (SB) functioning as a signal module can be installed on the CPU body. The CPU operating voltage is 5V and it is insulated from the input by the optocouplers.

5.1.5. Communication Module

Communication modules such as Profibus, Profinet, RS232, RS485 and GPRS are modules that communicate with other PLCs or devices.

5.1.6. Output

Input signal results which are processed by the program are sent to the output memory. In this output memory, relevant outputs are Set-Reset and the logic states of switchable elements such as contactors, signal lamps, solenoid valves, etc. are determined.

The output unit can be a relay, transistor or triac output. Relays are used to drive elements that requires different voltage values than the PLC and they are also used where the output signal is not frequent. (DC/AC 2A). Transistors are used at the DC outputs when high frequency switching is required (DC 0.5A). Triac are used for applications requiring high frequency switching at the AC outputs (AC 1A).

5.1.7. Programming Software

Software is set of commands that notify the hardware (electronic components comprising the PLC) about how to react under certain situations and ensure communication between the programming device and hardware. Each piece of equipment has its own unique software. S7 1200 PLCs are programmed with TIA PORTAL programming software. Today, the same software can be used to program S7-300, S7-400 and S7-1500 type CPUs, Operator Panels, SCADA and drivers as well.

There are two types of programming: linear and structural. In linear programming, commands are entered based on their sequence in the program memory. After processing the command in the final line, the program proceeds with the first line. It means that there is a continuous loop. The time required for all instructions in a program to be processed once is called cycle time. This time depends on the number and types of commands. It should be as short as possible. Linear programming is generally used for simple and non-extensive programs where the whole program is written on a single program block.

While processing, the structural program is divided into small logical blocks (sub-programs such as FB, FC) according to the functions. An organization program (MAIN_OB1) is created to call all of these sub-programs in an order. Constant data to be used in the program is stored in the data blocks.

TIA PORTAL programming software offers wide range of programming options. The programming languages include LAD (ladder), FBD (Function Block Diagram), STL (Statement List), and SCL (Structured Control Language).

5.2. SCADA

SCADA ("Supervisory Control and Data Acquisition") is used to continuously collect field data from various devices such as Programmable Controllers (PLC), Loop Controllers, Distributed Control Systems (DCS), I / O Systems and Intelligent Sensors (on the control unit) used in process, industrial and building automation in real-time. SCADA is then used to assess this information according to defined criteria to produce early warning messages when necessary. It also enables monitoring of various factors affecting production from a central point in a graphical or curve (trend) format and enables remote control of the field control points.

SCADA systems from a central control point enable safe, reliable and economical operation of oil and gas fields, piping systems, water networks, valves in transmission and distribution facilities of thermal and hydraulic power generation systems, disconnectors, circuit breakers, electrical machines, remote switching of electrohydraulic and electropneumatic valves, adjusting the setting points, viewing alarms, collecting data such as humidity, frequency, weight, number and status of the elements.

Using dynamic graphical drawing tools, the process required to be observed can be animated very close to reality and alarms can be dramatic. SCADA software includes features that allow operators to draw attention and ease of use, such as motion, sizing, blinking, and unloading, along with graphics using core software in their own structures. It is possible to prepare alarms in different colors, sizes and shapes that will make it easier for operators to see and to display emergency measures to be taken in case of alarm.

Modern SCADA systems, as well as classic controllers, use software components called graphical triggers for manual control during use.

SCADA system can be defined as the monitoring and control of production facilities spread over a wide area via a computer. Basically SCADA is software and is installed with the computer that will control the system. It can work on a single

computer or it can work on a computer network in large installations, allowing for multiple control and monitoring. Some of the most widely accepted and widely used SCADA softwares are; WinCE, Citect, WinTR, Teos, ICONICS, iFIX, InduSoft, Intouch, Entivity Studio, Entivity Live, Entivity VLC, Trace Mode, Wizcon.
Although different features are required for different systems, all SCADA systems usually have the following features [34-37].

- Multiple User
- Graphical interface
- Simulation of operations
- Real-time and historical monitoring
- Alarm system
- Data collection and record
- Data analysis
- Report preparation

5.2.1. Layers of SCADA Systems

An integrated SCADA system consists of the following layers:

- Operation control layer: The layer where the physical controls are made. The mechanical and electromechanical devices are connected to the remote terminal units (RTU) to fulfill the operation functions.
- Process control layer: It provides synchronization between facilities and machines with monitoring and data collection functions. This layer includes the central control room and SCADA software.
- Business management layer: It ensures cooperation between departments by making operation decisions in accordance with the strategies taken in the upper layer. Directorate of Business undertakes the task.
- Resource management layer: The layer in which the resources required for the production of the business are planned and the production and service strategies are determined.

A SCADA system can be summarized as,

- The elements that are to be controlled (input and output elements, machines and workstations),
- Controllers (Microcontrollers, PLC or Distributed Computer Systems DCS),
- SCADA software (installed on a central computer),
- Network elements (for multiple systems)
- SCADA software is located on the third layer of a four-layer automation pyramid (five layers in some perspectives).

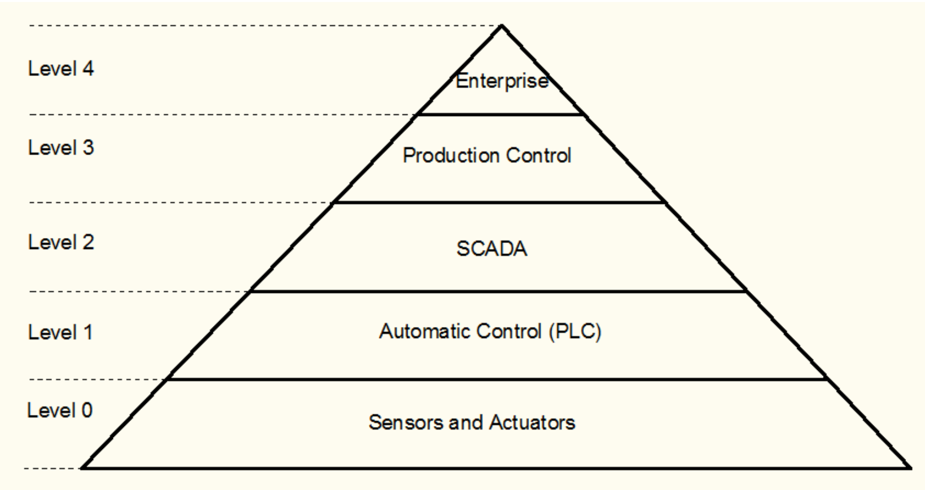


Figure 5.2. Automation pyramid.

When the above pyramid is examined, at the bottom of the pyramid, elements such as the machine, conveyor, etc. on production line can be seen. These elements are the working elements, that is, the controlled elements. They are usually the motor, heater, and similar apparatus. In addition to these there are also sensors used for feedback [33].

The second layer contains microprocessor based control elements. Control elements are used to control the elements and make the system behave in a certain way. Computers and PLCs are the most used systems in the industry. Specifically modules such as motor speed and position controllers, temperature controllers and drivers are used either alone or in conjunction with the computer and PLC.

The first two tiers of the pyramid are inevitably involved in all manufacturing businesses. The third tier is where SCADA systems are located. All subsystems are monitored and controlled by the third tier.

The fourth and fifth tiers are the system that covers and monitors the entire chain from order to production, from production to sales. In such a system, any activity can be interrupted or manipulated. The sectors that usually involve in large-scale and costly production (such as automotive firms) benefit greatly from this type of system.

In a typical SCADA hardware; communication lines between the (Server-Master) and Client Computer (Client-Slave) and RTU and field equipment are found.
Master Server - Main Terminal (MTU): MTU (Main Terminal Unit) is the main station or computers that act as the main controller in SCADA Systems. MTU system Computer based network structure consists of server and client computers, printer and other elements.
Remote Terminal Units (RTU): It is a SCADA unit that collects system variables in a network, stores them if necessary, and sends the information to the control center via a specific communication path.
Communication Path: It is the network structure that is formed to exchange information between the MTU located in the main center and the RTU devices located in the remote areas.
Field Equipment: Field equipments is defined as PLC, DCS and Smart electronic cards.

5.2.2. SCADA System Functions

SCADA system functions can be:

- Monitoring functions
- Control functions
- Collecting functions
- Data storage and record keeping

In order to develop application software using SCADA systems, it is necessary to define the communication protocols and define the database structure. Communication protocols in SCADA, being the information backbone in the business, provide communication between the units that need to communicate with each other in order to fulfill the mission.

Input and output information of the process is defined in a database so that the SCADA system takes over the observation and control functions. Each piece of information in the database corresponding to process variables is defined as label, gate or point. The alarms related to the levels for which these process variables must be found and the process blocks to be used when these variables are to be processed are performed during the definition of the database.

CHAPTER 6

SUBSTATION PROTOTYPE AND AUTOMATION

154 / 34.5 kV Safranbolu substation and SCADA screen were designed as an application prototype. The prototype was built on 600x1800mm hardboard platform.

6.1. PROTOTYPE

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. Due to the high number of outputs in our system, a total of 3 external digital output modules are used; 1 SM 1223 and 2 SM 1222.

Figure 6.1. S7-1200 1214 C DC / DC / DC PLC.

In addition, power supply is used to feed the PLC in the system. The input voltage of the power source is 100-240V AC, the output voltage is 24V DC input current value is 3.5A, and the output current value is 10A.

Figure 6.2. Power supply.

Relays and contactors are used to represent the disconnectors and circuit breakers in the system. The circuit breakers are represented by contactors with a coil voltage of 24V DC and the disconnectors are represented by relays with a coil voltage of 24V DC.

Figure 6.3. Contactor.

There are 3 normally open main contacts and one normally closed (NC) auxiliary contact in the contactors. There is an LED light on the relay indicating that it is energized.

Figure 6.4. Relay

The transformers located in the system are represented by the signal lamps used in the panel. These lamps operate with 24V DC voltage.

Figure 6.5. Signal lamp.

The contactors used in the prototype are shown in Figure 6.3, relays are shown in Figure 6.4, and signal lamps are shown in Figure 6.5. Figure 6.7 shows the general view of the prototype.

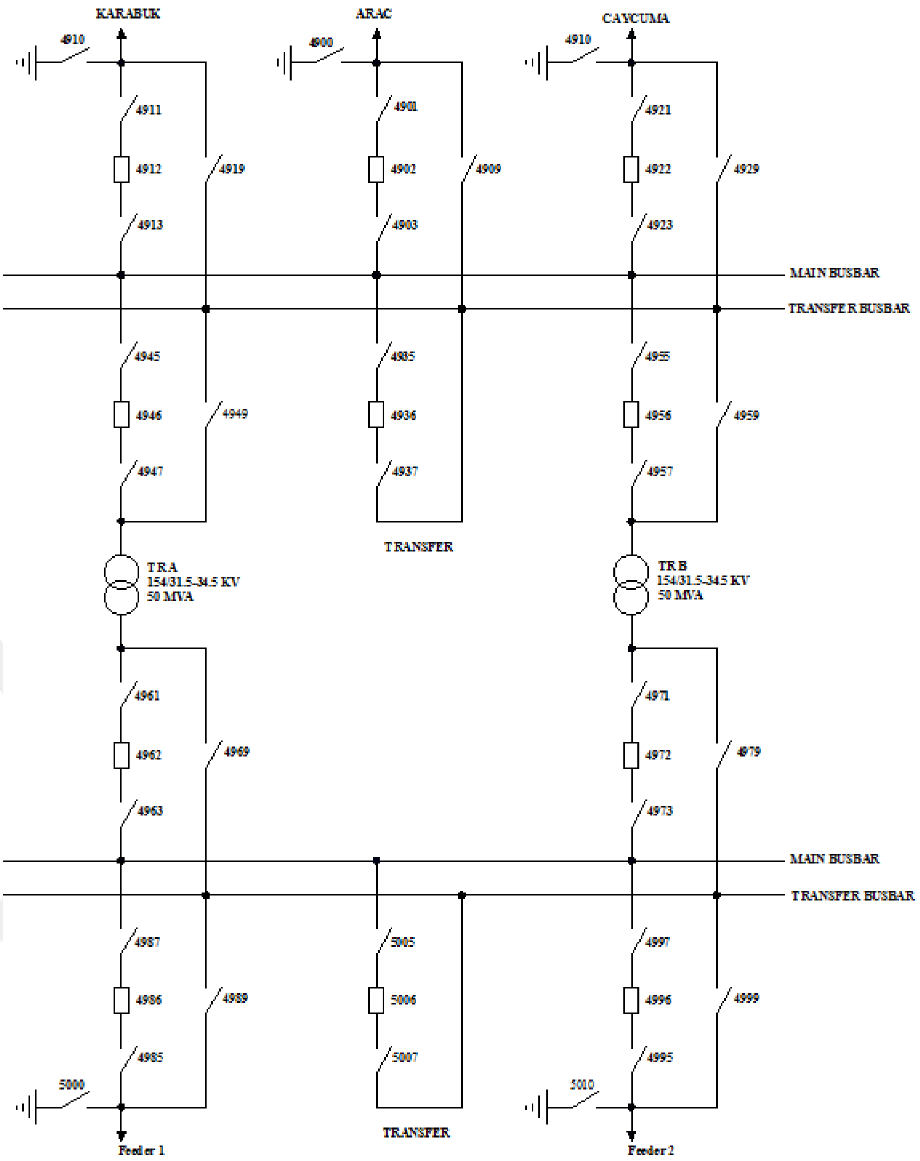


Figure 6.6. Prototype maneuvre (single line) scheme.

The prototype was built in accordance with the diagram in Figure 6.6. This scheme has been drawn completely according to maneuvering scheme of the Safranbolu substation. The only difference is that 34.5 kV feeder outputs are 2 instead of 12.

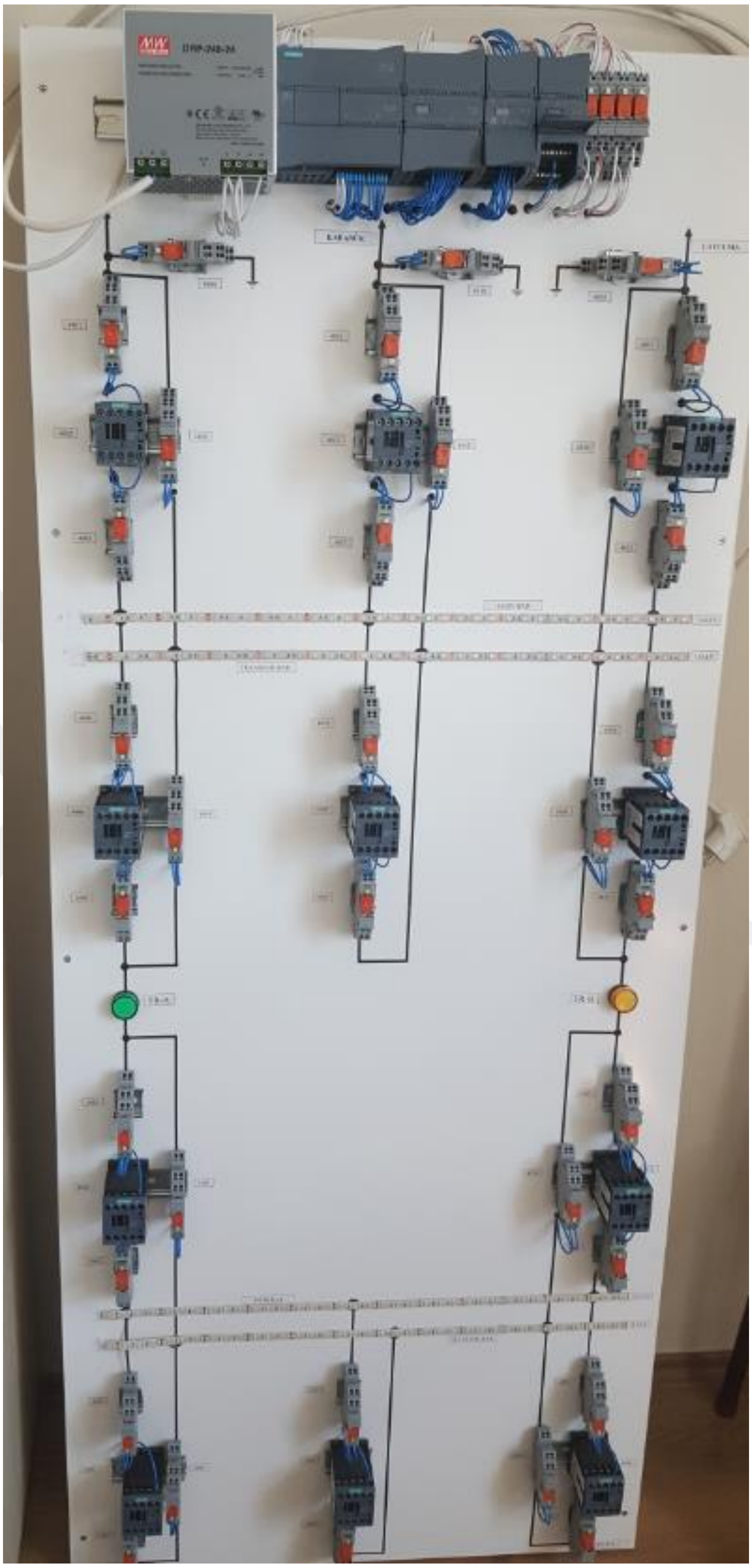


Figure 6.7. Prototype of the substation.

Figure 6.8 shows the prototype after the maneuvers of power on from the SCADA screen.

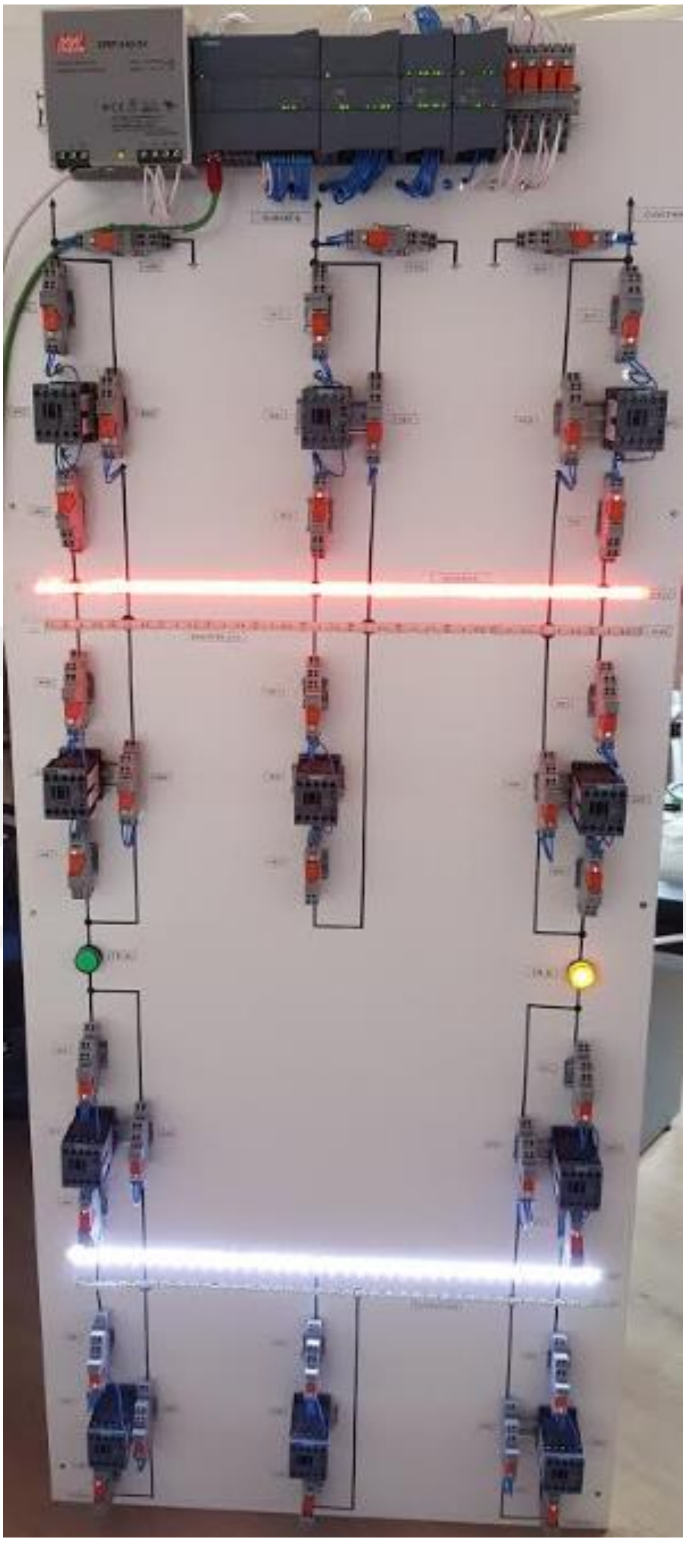


Figure 6.8. Prototype of the substation after energized.

On the prototype 154 kV and 34.5 kV bus bars are shown in different colors. All disconnectors and circuit breakers and two transformers from 154 kV feeder inputs to 34.5 kV feeder outputs are shown physically on the prototype. In total, 11 contactors and 33 relays were used. Only two of these 12 feeders are shown because all of them cause an increase in size and cost making it impractical, even though there are a total of 12 feeders at the output of 34.5 kV. However, this does not constitute an obstacle for the prototype and SCADA in understanding the operation of the system.

6.2. PLC SOFTWARE AND SCADA SCREENS

PLC software was developed in Simatic Step 7 TIA Portal V14 using ladder programming language. SIMATIC HMI Application/WinCC RT Advanced was used as the operator panel. No real (physical) operator panel was used. In TIA Portal project, Devices & Networks and Portal View are shown in Figure 6.9 and Figure 6.10.

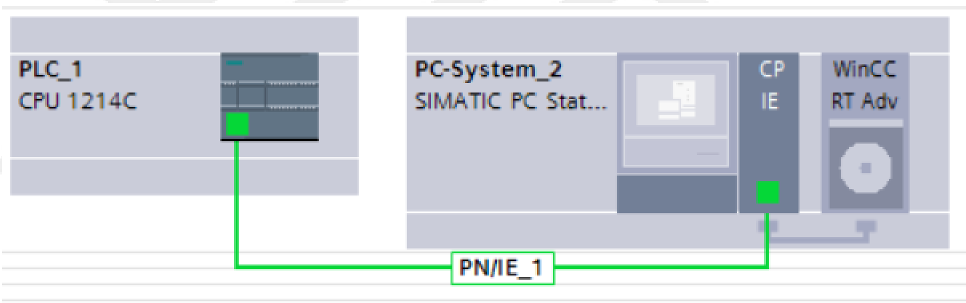


Figure 6.9. Devices & networks.

The software has 1 main block, 11 functions, and 1 data block. Functions were used for 34.5 kV and 154 kV bus bar and transformers energization and transfer maneuvers while data block was created for webserver.

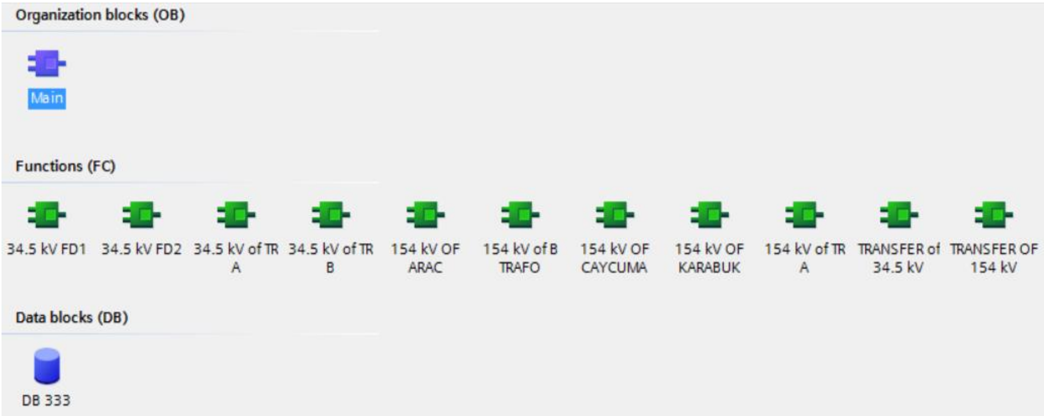


Figure 6.10. Portal view of the project.

Three SCADA screens, the manoeuvre screen, the value monitoring screen, the alarms screen were created. The manoeuvre screen is designed to fit the Safranbolu substation single line scheme. Two separate buttons are used for the circuit breakers on the SCADA screen since the coil for the circuit breakers used in the system is controlled by two separate buttons. Opening and closing control is provided with a single button for the disconnectors.

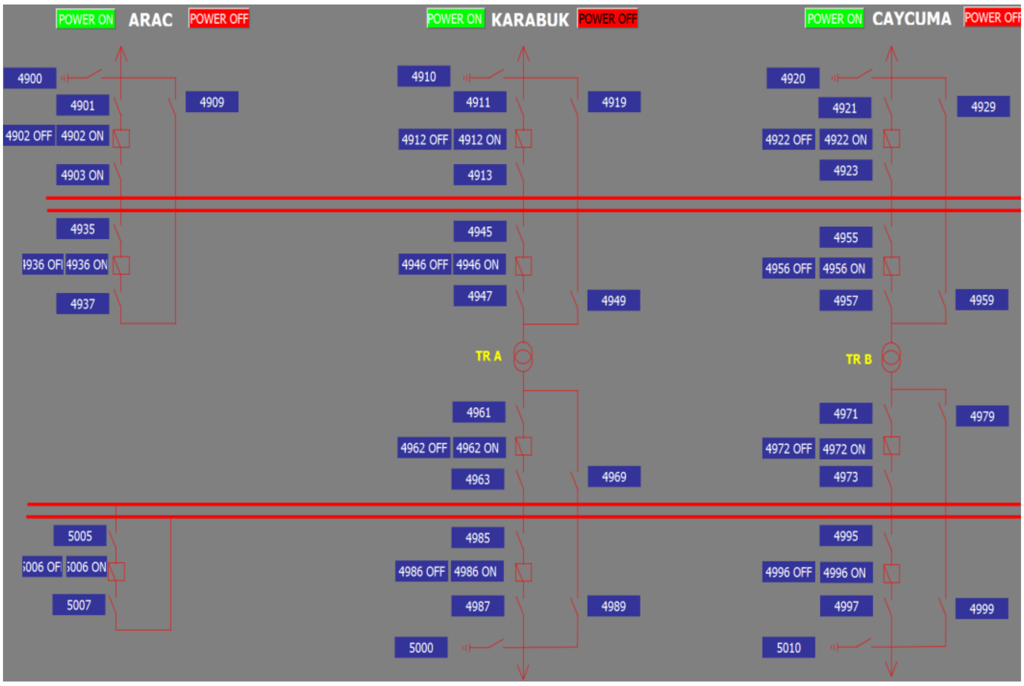


Figure 6.11. SCADA maneuver screen.

154 kV and 34.5 kV faults and transformer faults are defined separately. The power transmission in the system is animated with a green light in the bus bars and lines where the energy is transmitted. Transmission lines are animated in red when there is no energy in the system, the power is not transmitted, or when the user deactivates the circuit breaker by turning off the line where the circuit breaker is connected.

Figure 6.11 shows the not powered maneuver screen (under initial conditions) while Figure 6.12 shows the powered maneuver screen.

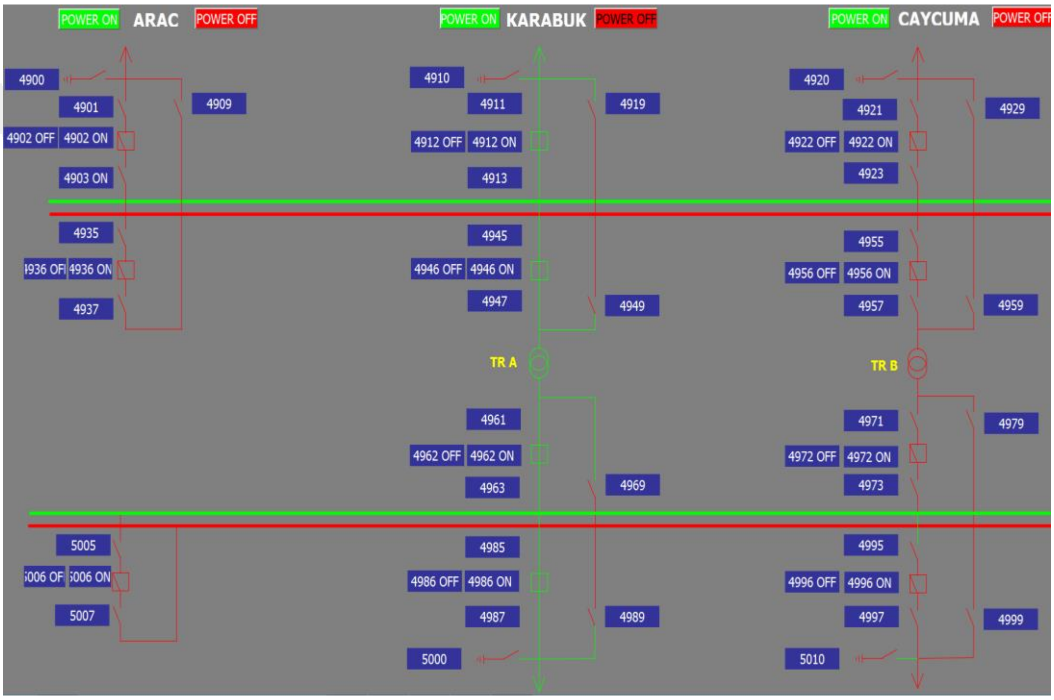


Figure 6.12. Powered maneuver screen.

After power on, Karabuk feeder is shown in Figure 6.13.

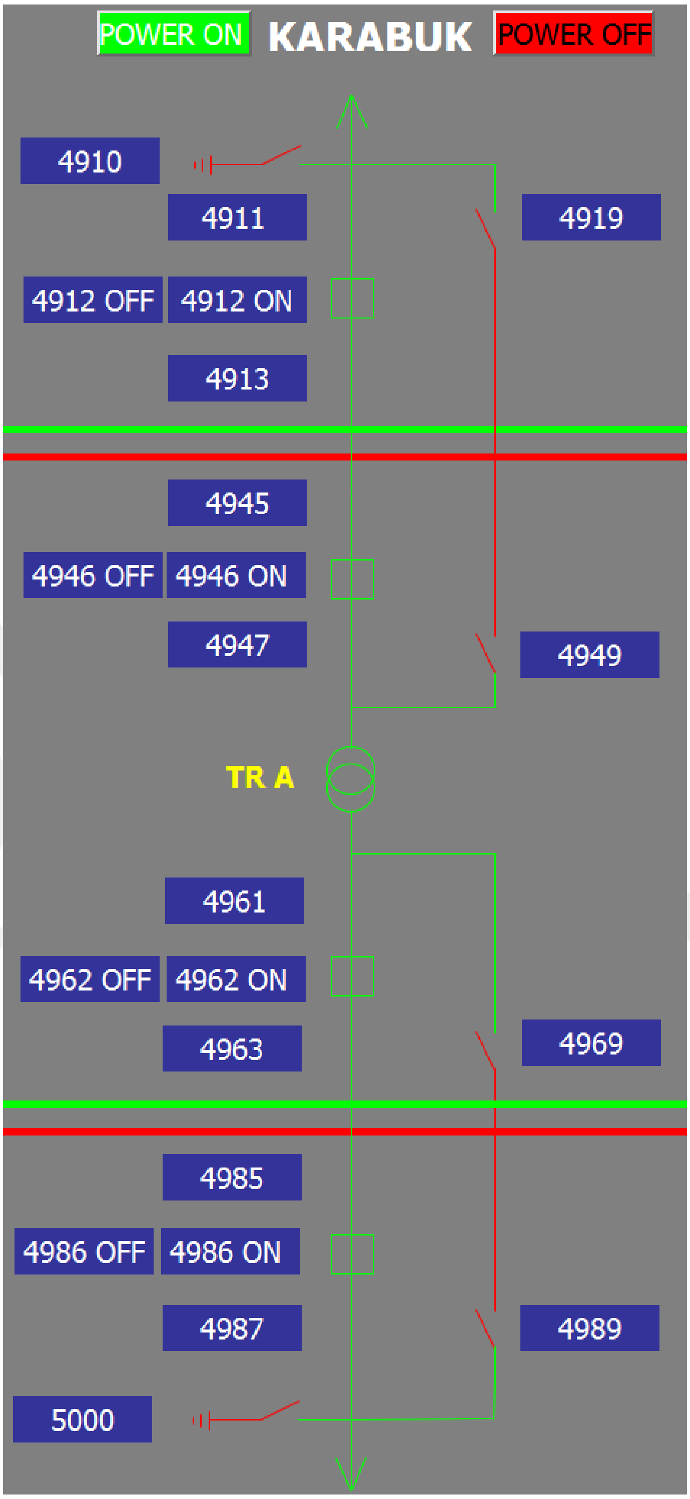


Figure 6.13. Karabuk feeder.

The software is written completely according to the maneuvering scheme of the Safranbolu substation. The algorithm of the system is as follows:

- It is of extreme importance that when powering on, circuit breakers must not be closed when disconnectors are not closed nor, when powering off, disconnectors must not be opened when circuit breakers are not open.

- Before powering on the system, the state of the ground disconnector should be checked whether it is opened or closed. If it is closed, the energy given to the system will flow directly to the ground, causing a phase-ground short circuit. When it is certain that the ground disconnector is open, first one of the supply lines should be chosen (Araç, Karabük, Çaycuma) and its disconnector should be closed. When it is certain that the disconnectors are closed (turned on), the circuit breaker is closed and the 154 kV main bus bar is energized.

- If the main bus bar is energized, the transformer primary windings are energized when the disconnectors and circuit breaker in front of the transformer are closed. This way 154 kV of energy is transferred to the transformer in a safe and controlled manner. Up to the transformer, the energy comes from one of the three feeder lines. If the unit fails to operate due to malfunctions in the incoming energy line, disconnector or circuit breaker, or due to damage caused by overcurrent, transfer operation is required.

- When transferring, first the disconnectors in the transfer block are closed with the circuit breaker in the fault to be transferred and the transfer operation is completed by closing the circuit breaker in the transfer block. However, the transfer can be done in only one line. That is, no other transfer disconnector can be closed while any transfer disconnector is closed.

- The voltage level is reduced to 34.5kV in the secondary side of the power transformer is transferred to the disconnector and circuit breaker at the output of the transformer. When the disconnectors at the output of the power transformer are closed and the circuit breakers are also closed, the energy is now transferred to the 34.5 kV bus bar. By closing the final disconnector before the feeder section and closing the circuit breaker, energy flow to the feeders is ensured safely.

The algorithm of the system is shown in Figure 6.14

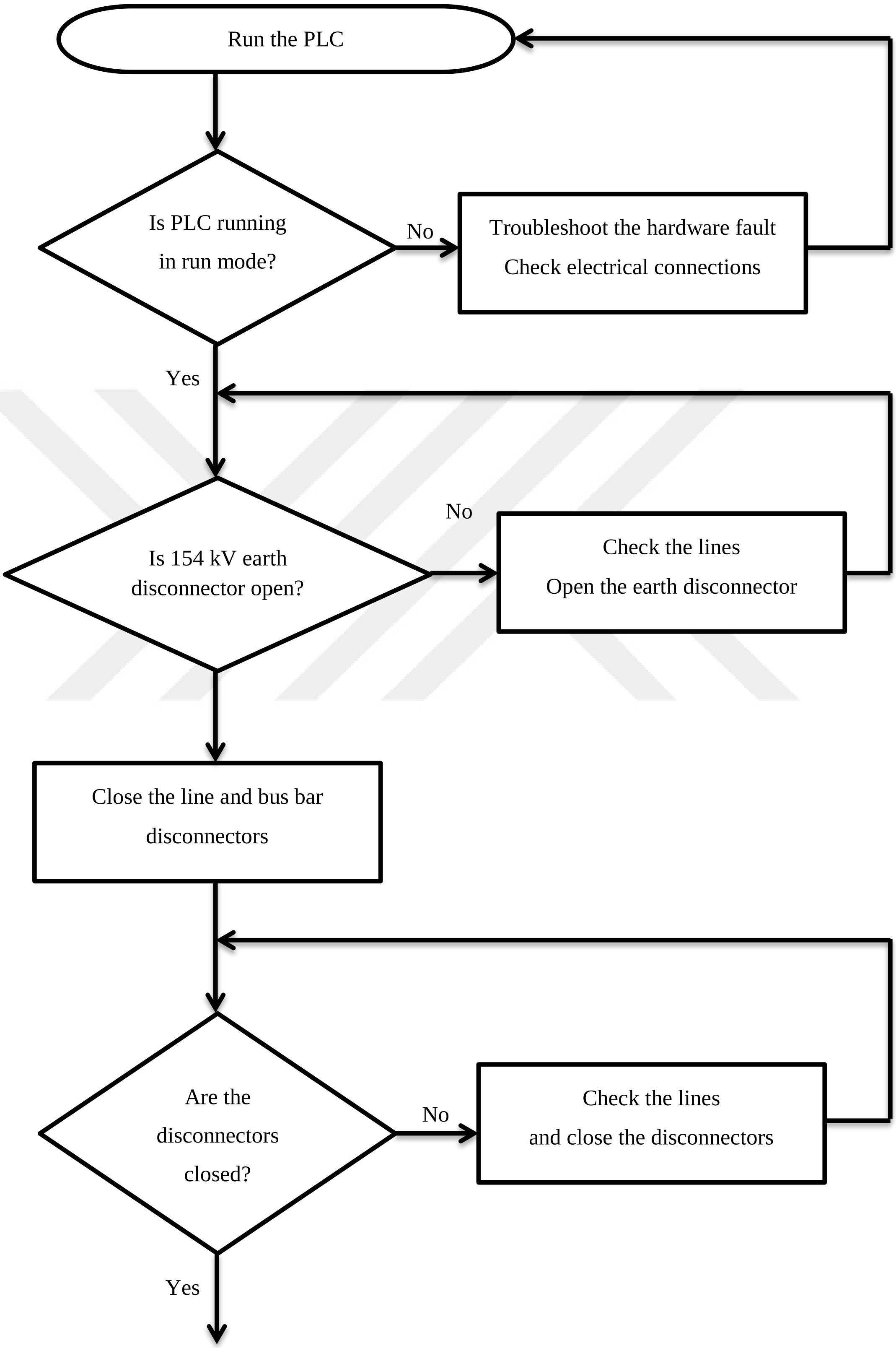


Figure 6.14. Flow chart for powering of the substation.

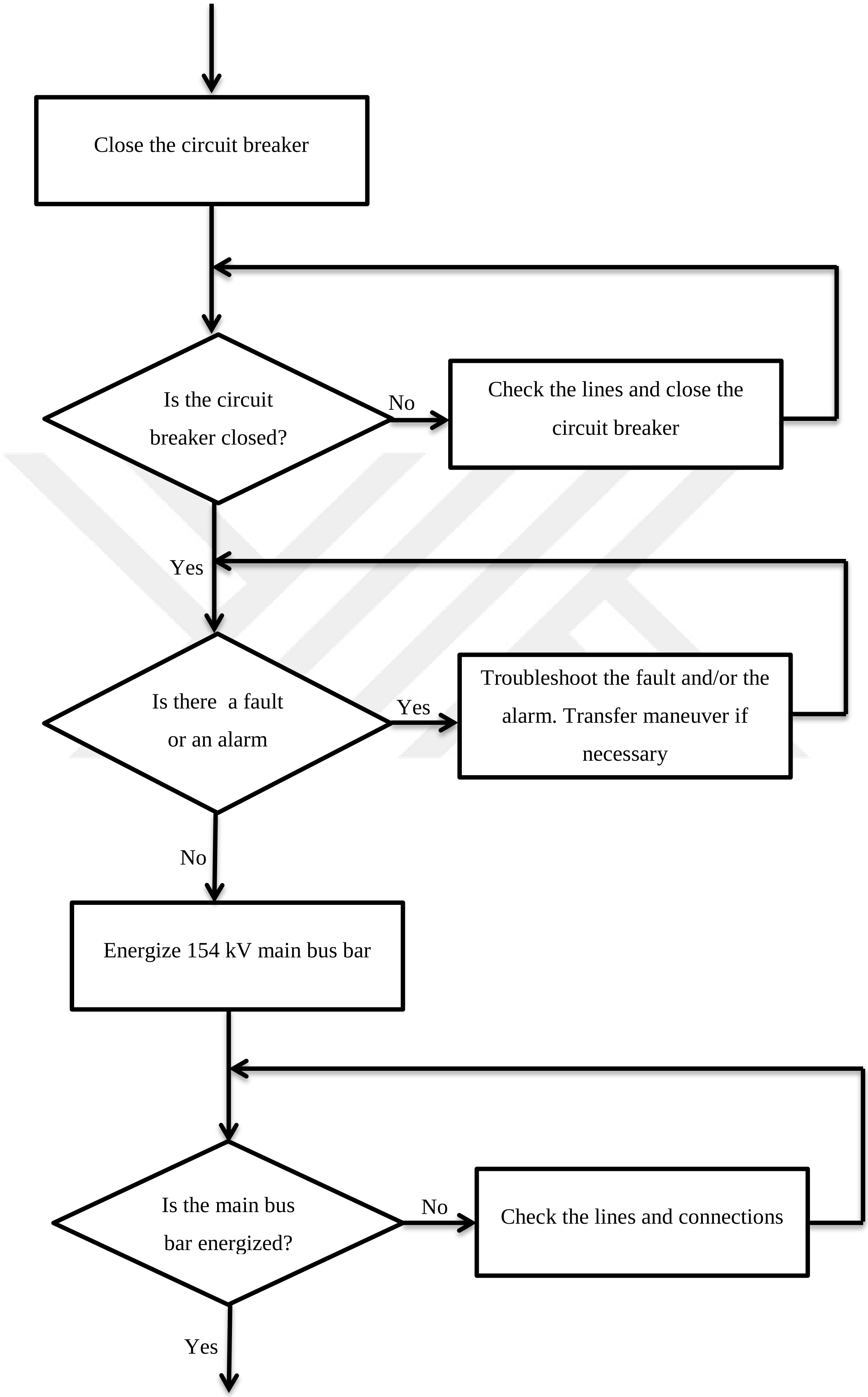
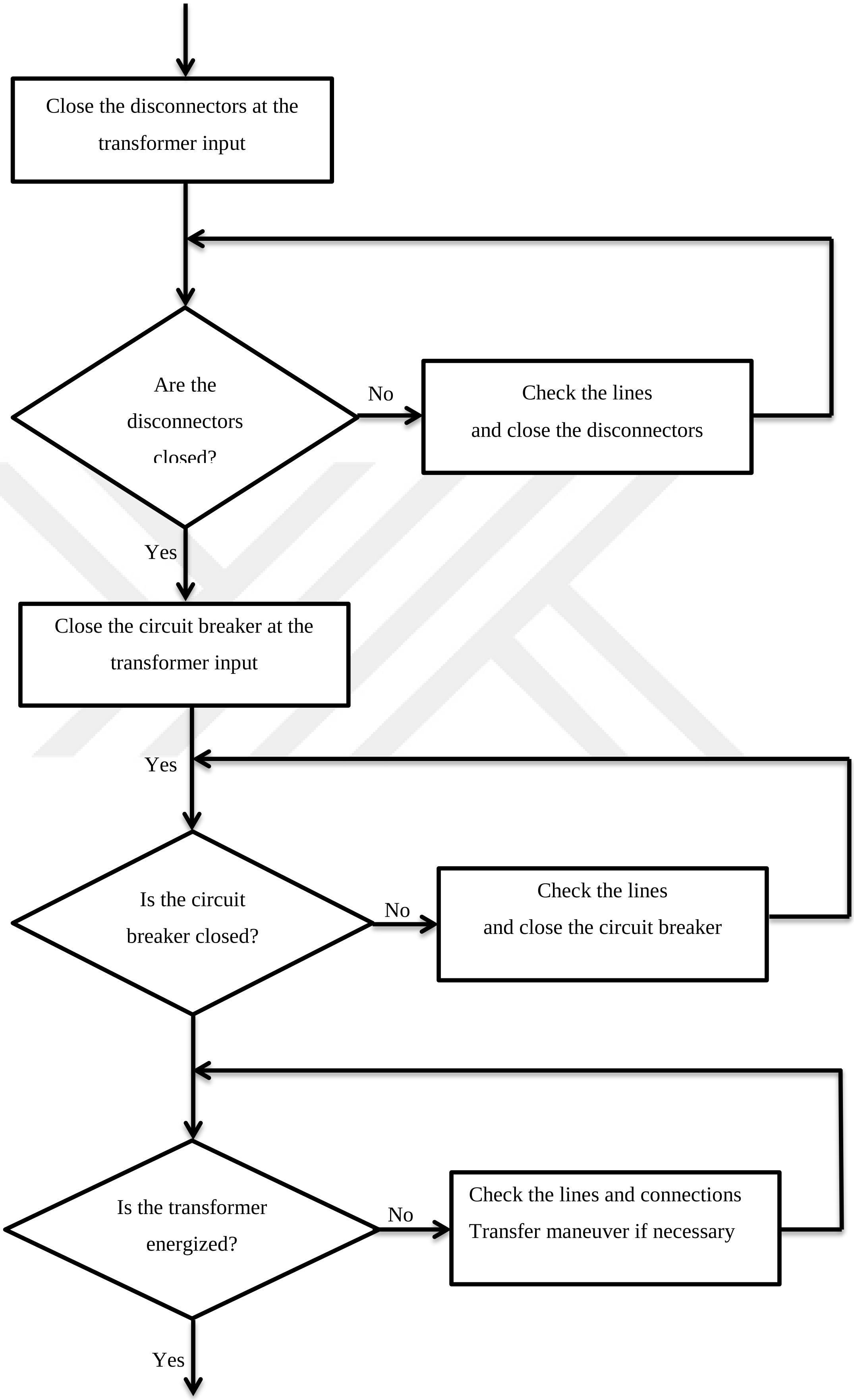


Figure 6.14. (continuing).



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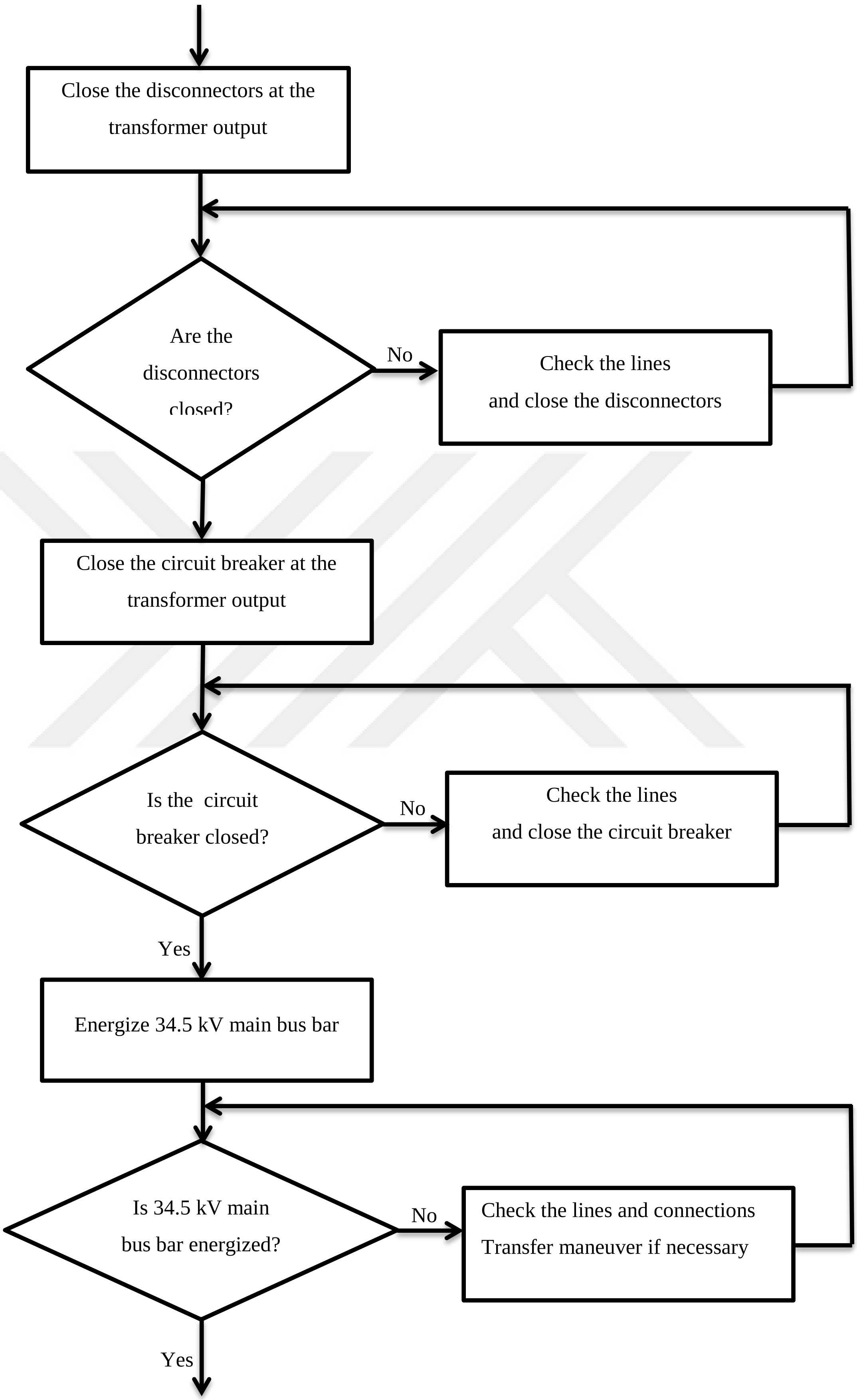

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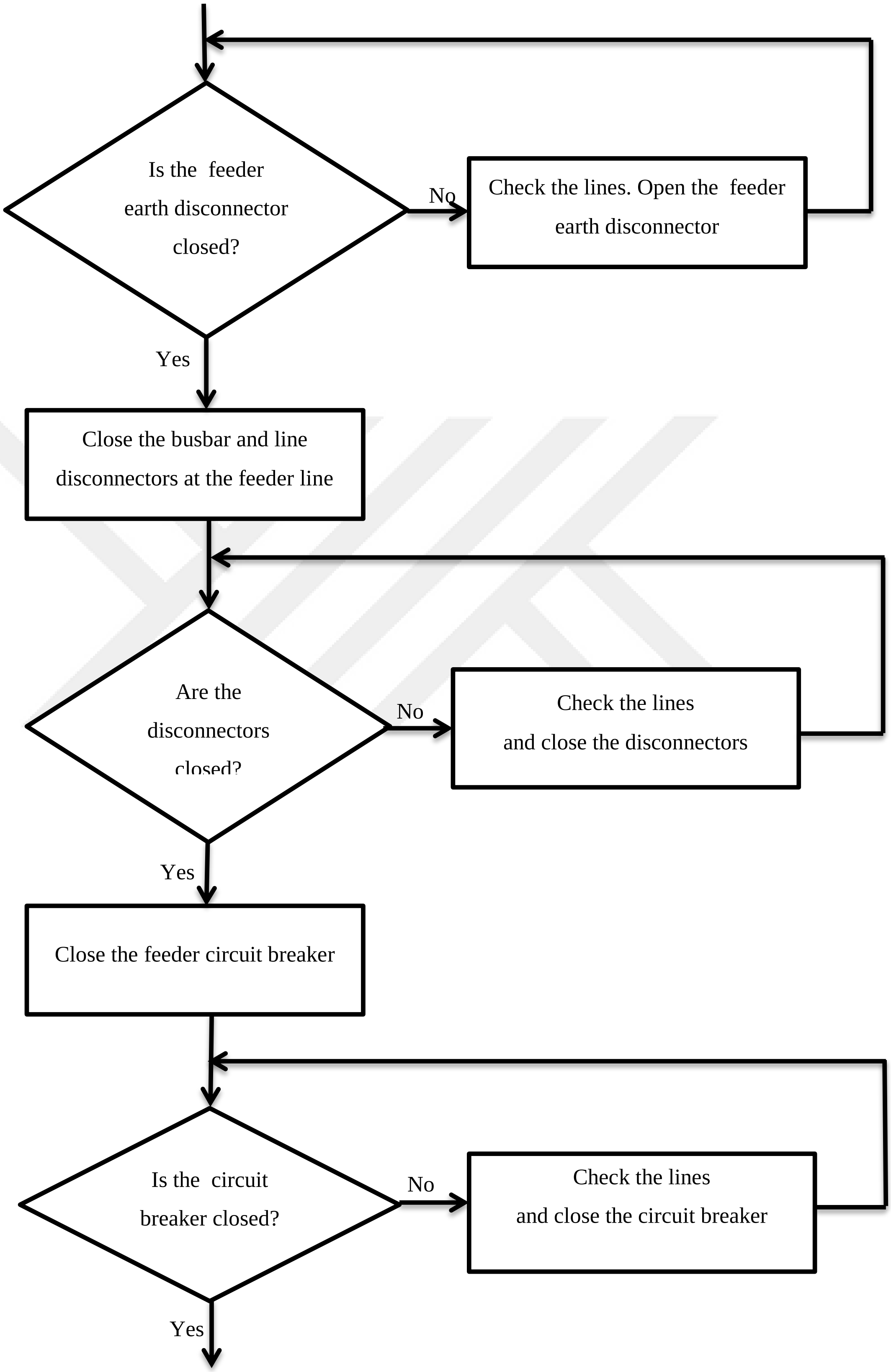

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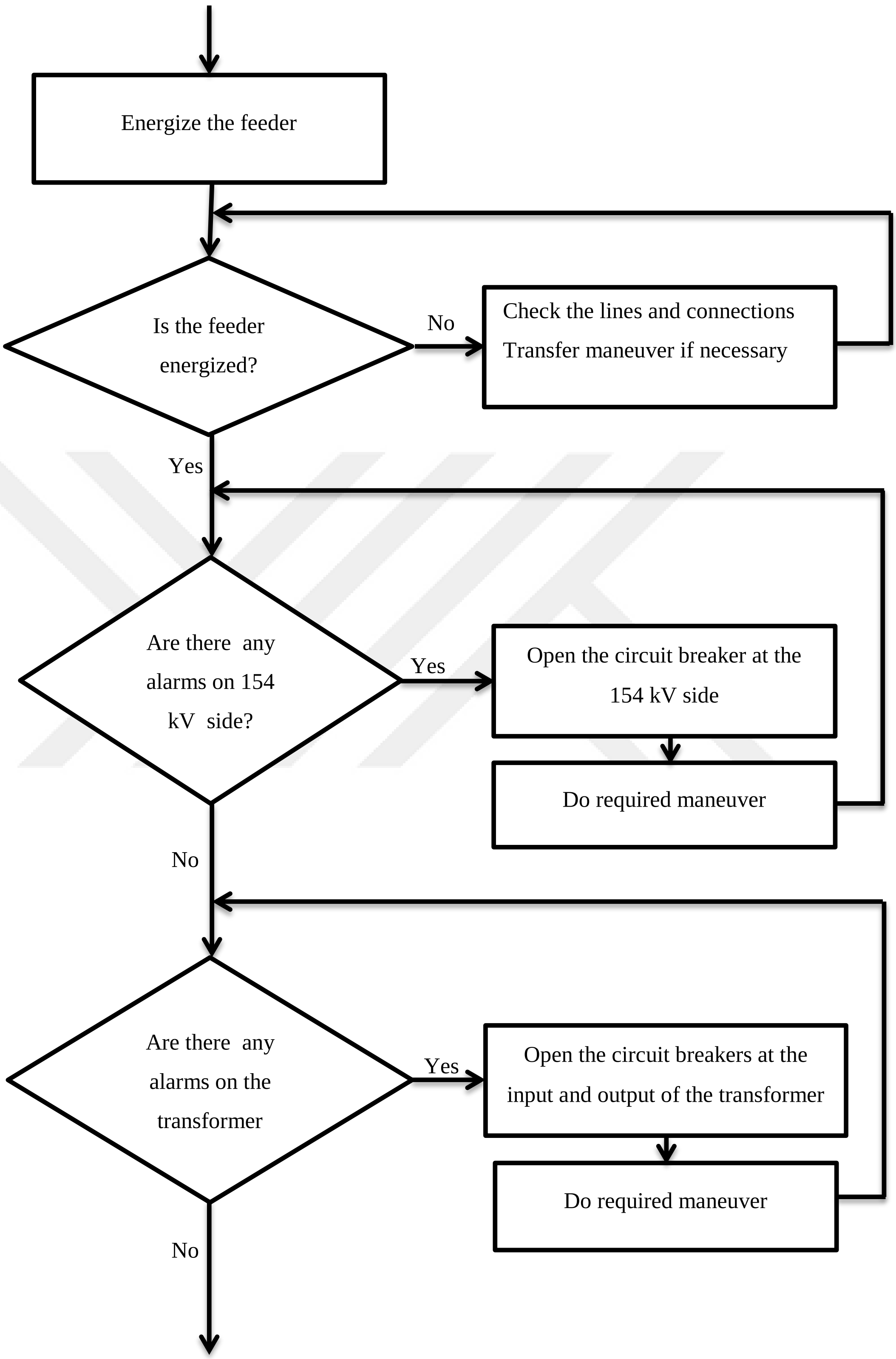

Figure 6.14. (continuing).

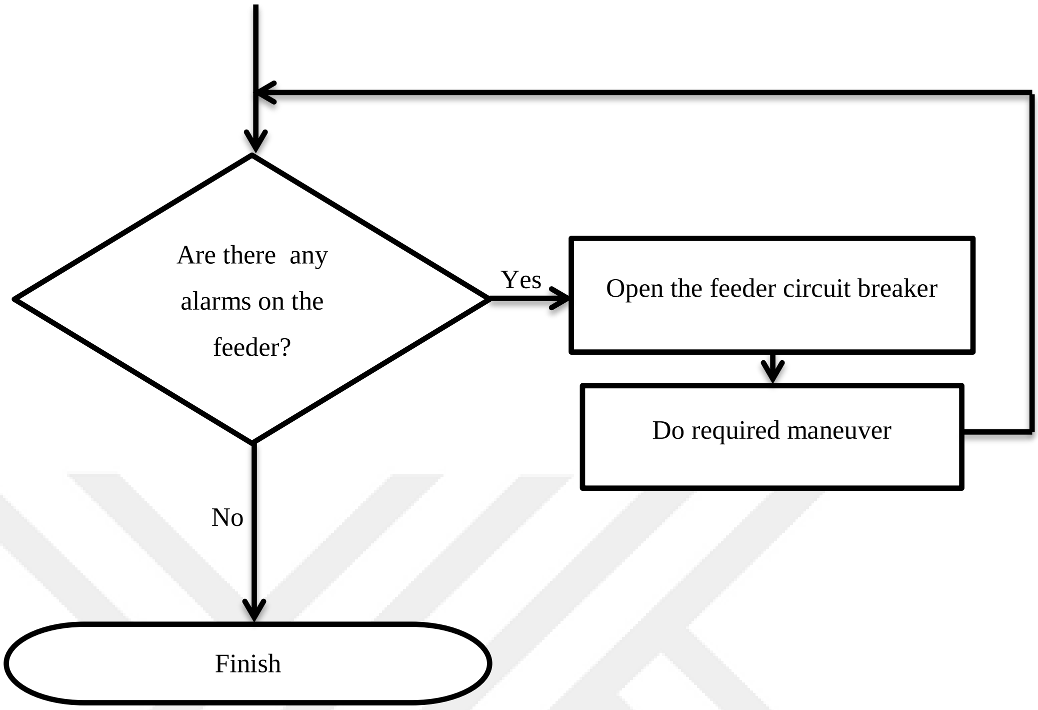

Figure 6.14. (continuing).

If there is a fault in one of the triple blocks of as disconnector-circuit breaker-disconnector, transfer maneuver is done. The flow card for the transfer maneuver is given in Figure 6.15.

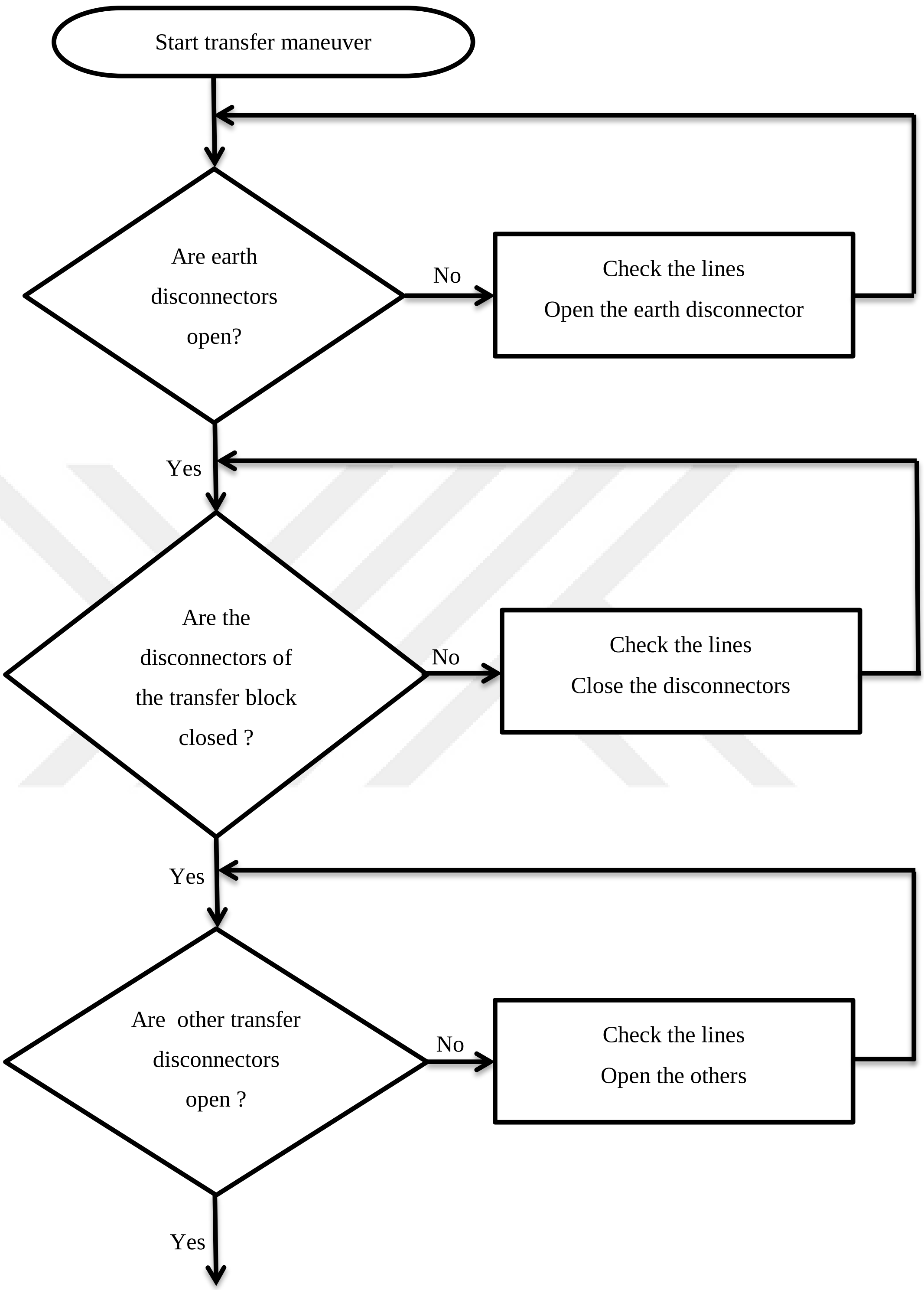

Figure 6.15. Flow chart for transfer maneuver.

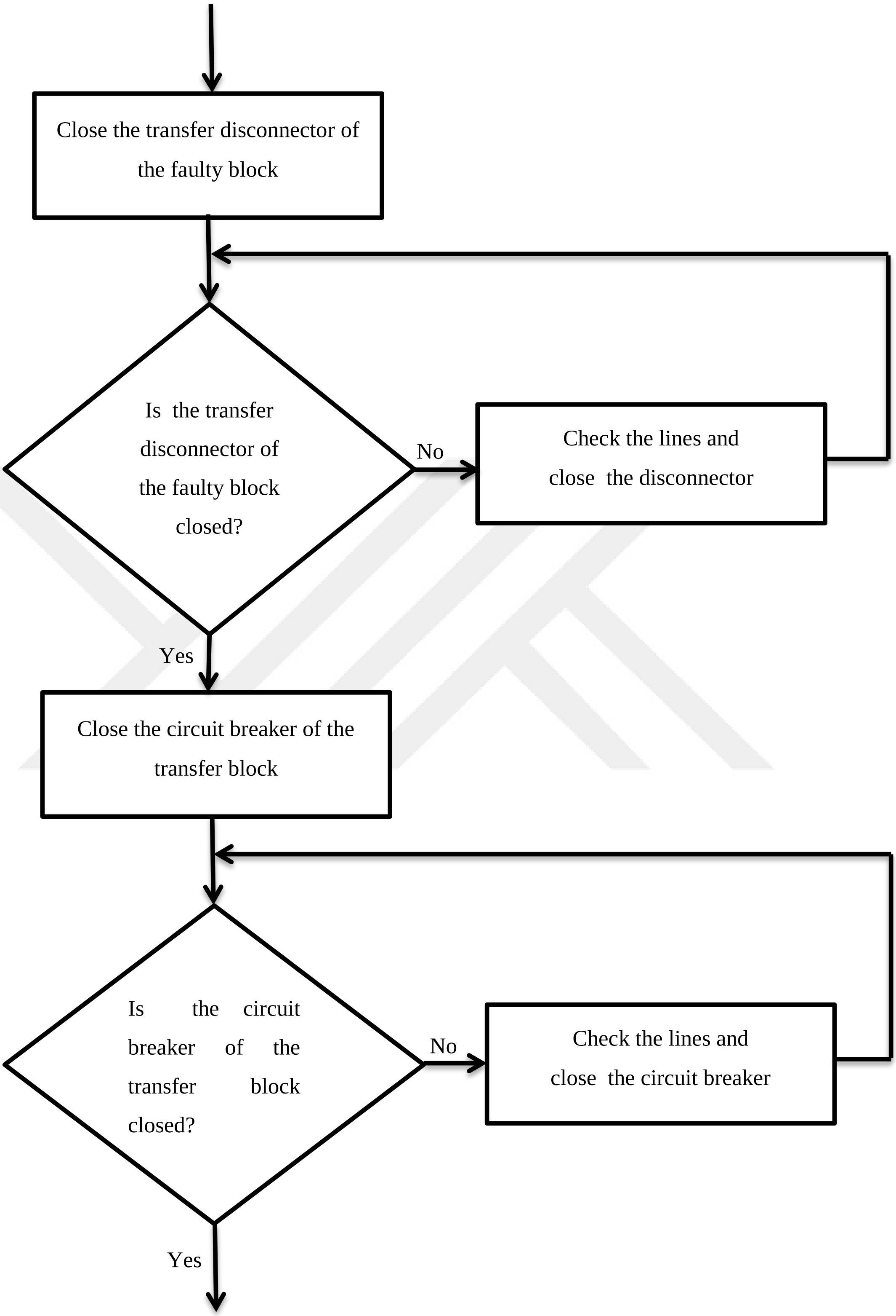

Figure 6.15. (continuing).

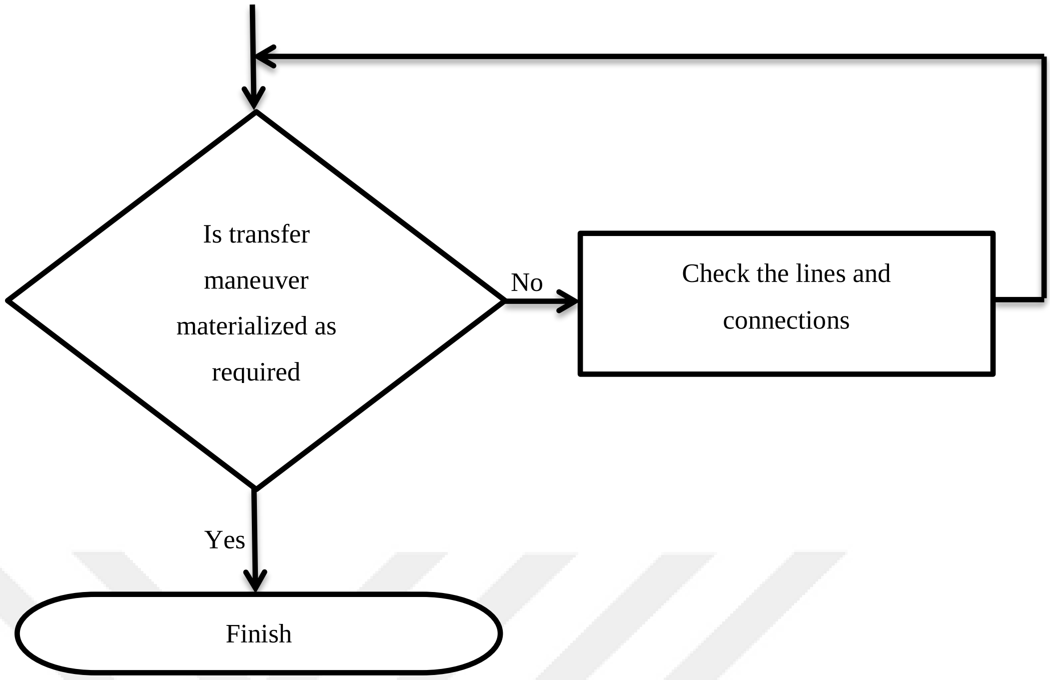

Figure 6.15. (continuing).

The following alarms are displayed on the SCADA alarms screen:

Distance protection, overcurrent and under frequency failures for circuit breakers on the 154 kV side. Overcurrent and ground faults for 34.5 kV feeder circuit breakers. Buchholz alarm, buchholz tripping, overcurrent, thermal (temperature) alarm, thermal tripping, differential faults for transformers.

Circuit breakers on the 154 kV side will trip if any of the distance protection and overcurrent fault signals occur. The 34.5 kV feeder circuit breaker will trip when any of the overcurrent and ground fault signals occur. If any bucholz tripping, overcurrent, thermal tripping (85^{o}C), or differential fault signals occur at the transformer, the circuit breaker at the entrance and exit of the transformers will trip. These faults will be displayed on the alarm screen and the fault information will be displayed on the screen.

In case of the failure of the SCADA system, the system can be controlled manually using the pacco switch. In order to be able to monitor the system remotely, a web server feature was activated in the PLC, allowing people who are responsible for the operation to maneuver.

These alarms tripped the circuit breakers except buchholz alarm and thermal alarm. On the alarms screen, the alarms acknowledged by the operator are removed from the screen.

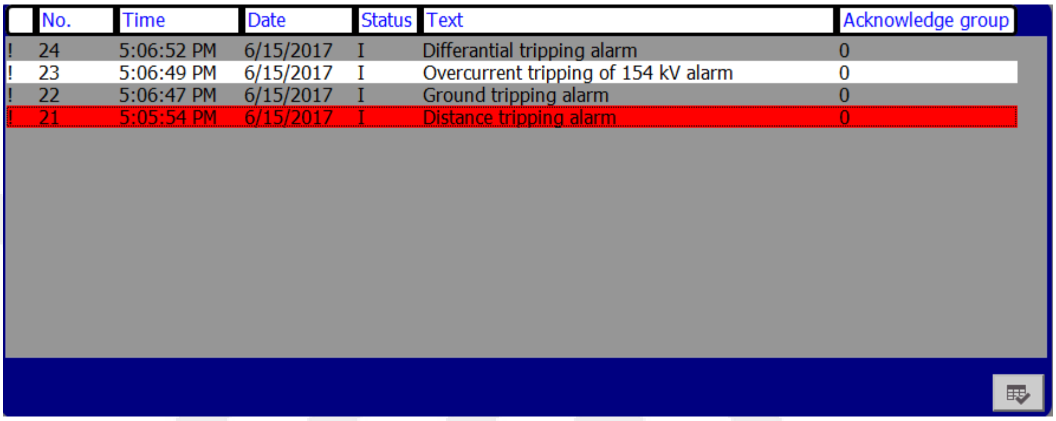

Figure 6.16. Alarm screen.

On the value monitoring screen, the current and the powers of transformer A and transformer B is shown. It can be also alarmed by entering values via this screen.

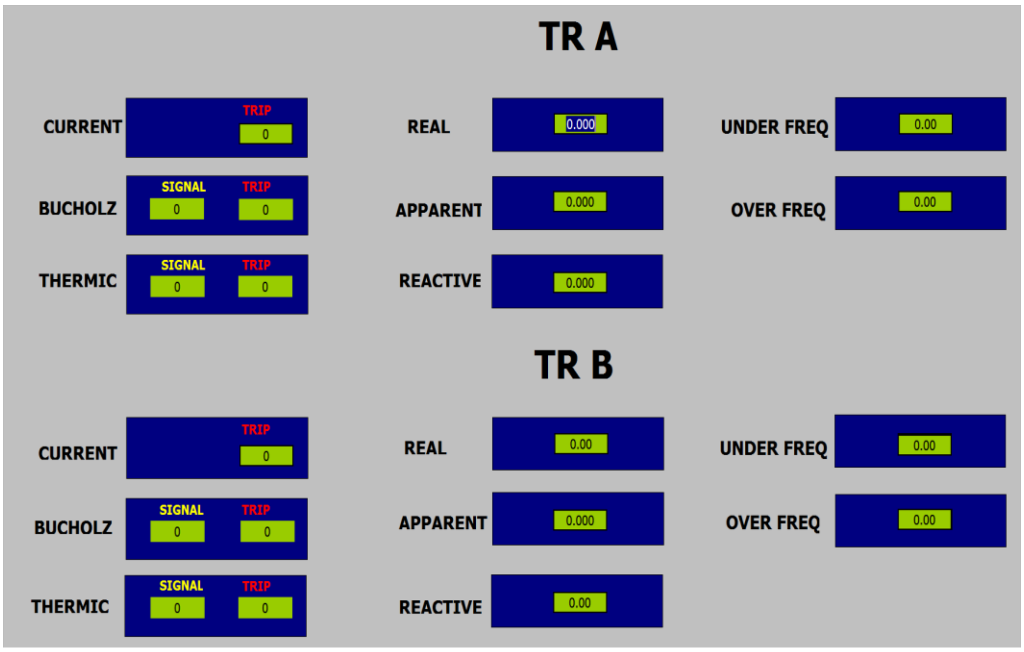

Figure 6.17. Value monitoring screen.

Current, voltage, active, reactive and apparent power values can be displayed on the screen separately for the transformer A and transformer B in the value monitoring screen in SCADA. These values are derived from the values entered from the SCADA screen and not from an actual current and voltage transformer or from a genuine smart electronic devices. This is because of physical and financial constraints. However, it does not constitute an obstacle to the monitoring and understanding of the system.

The value monitoring screens before and after the data is entered are shown in Figure 6.17 and 6.18 respectively.

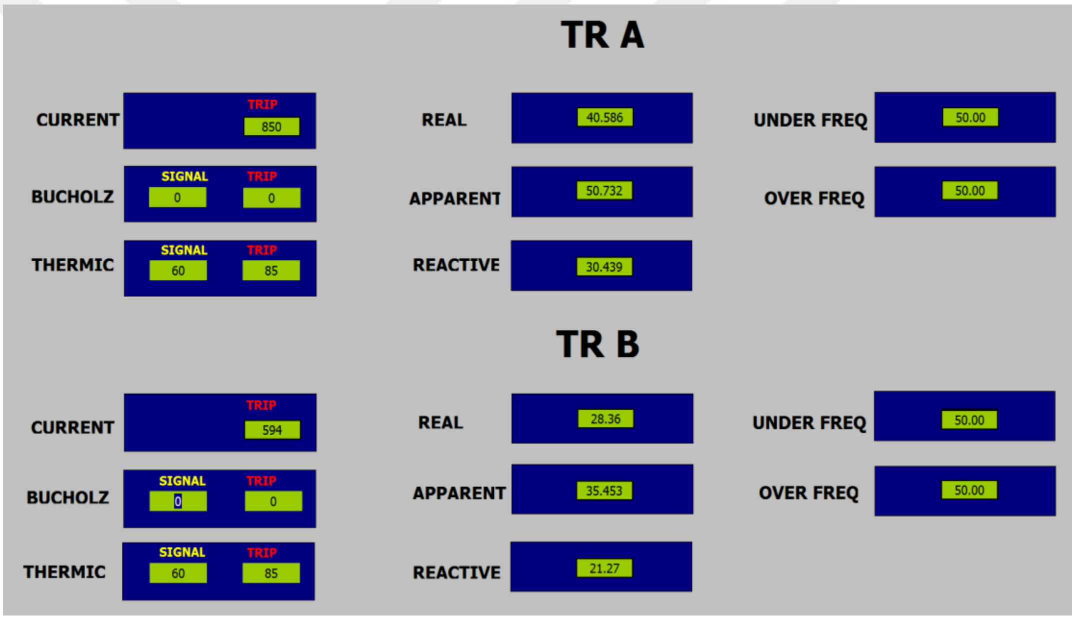

Figure 6.18. Value monitoring screen after data entered.

6.3. REMOTE CONTROL OF THE SYSTEM OVER THE INTERNET

An Internet page was created using the PLC webserver function. On this web page, circuit breakers and disconnectors can be opened and closed (on-off) and alarms from the system can be seen.

Thanks to this system, after the remote IP number is entered, a web server programmed with the HTML5, JavaScript and Css programming language will be presented to the user. The webserver on the system reveals the possibility of seeing the remote control and data stream in the related setting files. In the program it is possible to access the home page after user name and password is entered via Internet. By default, username and password are defined as teias. JavaScript and Ajax Functions have also been used for coding in order to make the site functional, and to form a basis for further scientific work.

Internet homepage and maneuver-alarm selection menu page are shown in Figures 6.19 and 6.20

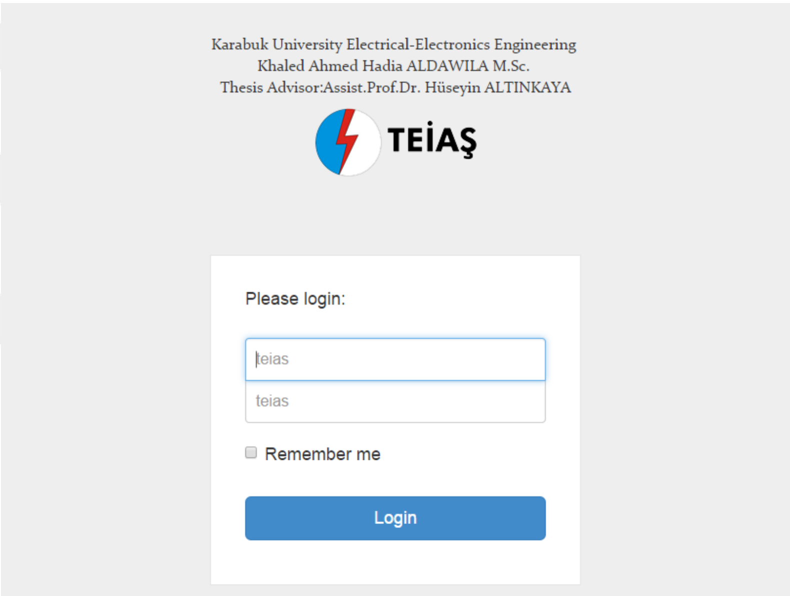

Figure 6.19. Internet home page.

After a successful login with the homepage, the maneuver and related status control screens can be accessed to monitor the flow of the system.

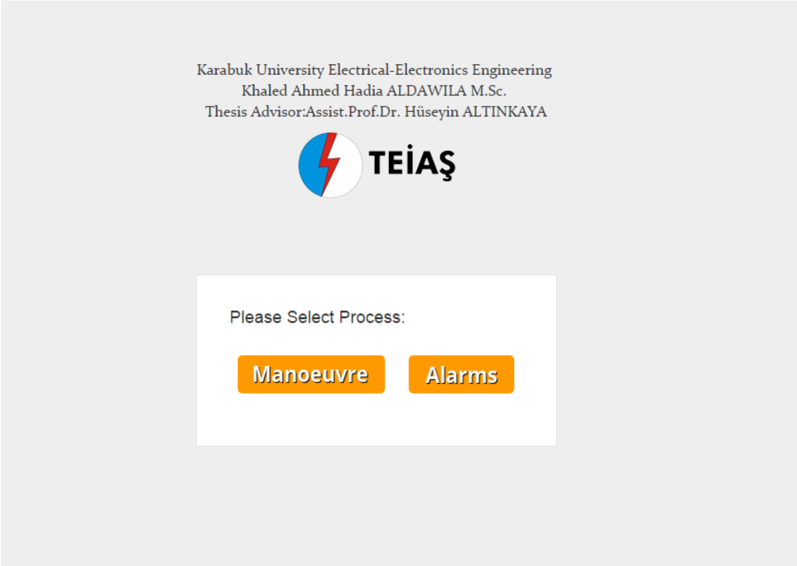

Figure 6.20. Manoeuvre-alarms selection.

After double-clicking the maneuver button, the maneuver screen appears. Just like on SCADA screen, opening and closing operations of the disconnectors and circuit breakers can be done via this page. Powering the 154 kV Karabuk feeder via Manouver page is shown in Figure 6.21.

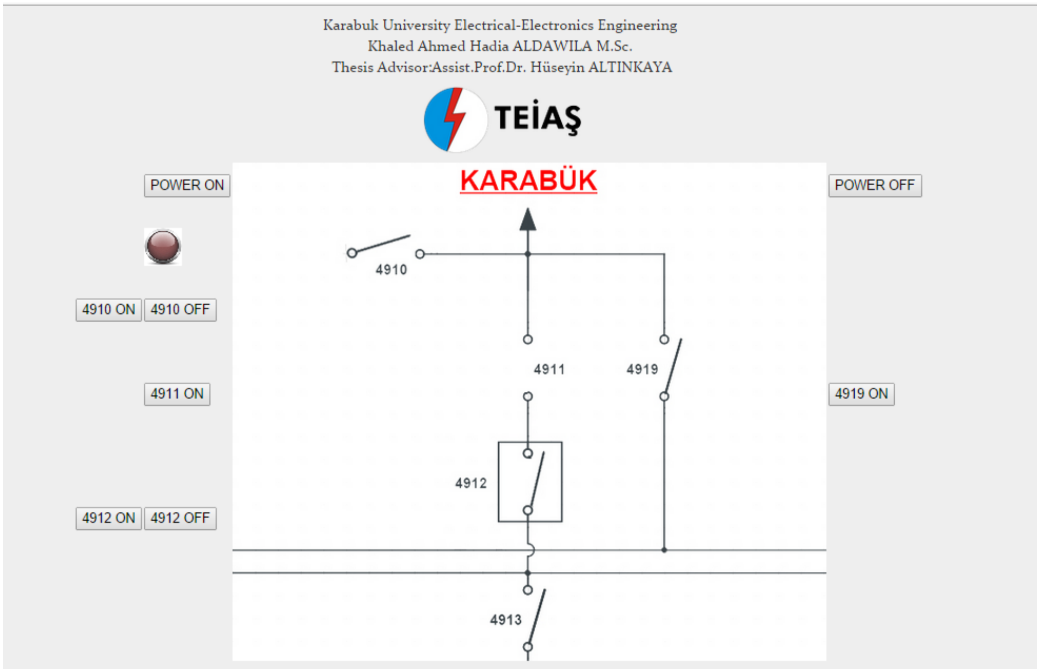

Figure 6.21. Manoeuvre page.

On the alarm page, over current, thermal and buchholz alarms from the transformer are displayed. Green indicates no alarm, red indicates alarm. Alarm page is shown in Figure 6.22.

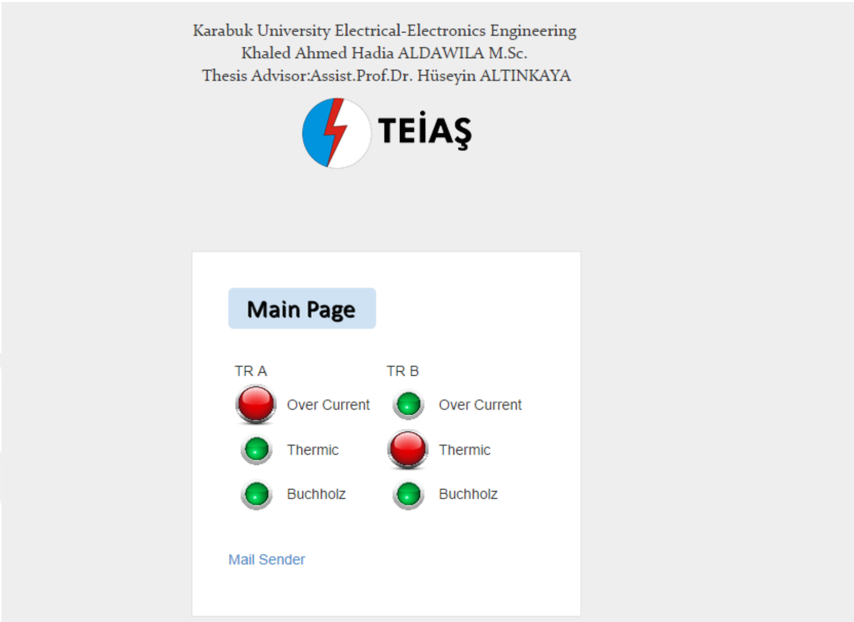

Figure 6.22. Alarms page.

The internet page can be easily accessed from operating systems like Android and IOS. The new system can also be controlled and monitored from mobile phones. In addition, when an alarm is received, notification is automatically sent to the authorized person by e-mail.

CHAPTER 7

CONCLUSION

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.

All systems used from generation to consumption of electricity have grown in parallel with technological developments and have a complex structure. These complex systems have become almost impossible to monitor and control manually. It has been difficult to identify and eliminate failures in such systems, and the failure to resolve these failures in a timely manner has led to problems that cannot be compensated. With today's advanced automation systems, even very complex systems can be monitored and controlled from a single computer. Thanks to the advanced SCADA systems, detailed measurement results can be obtained about monitored systems and these measurements can be recorded and analyzed in detail.

In this thesis, a 154/34.5 kV substation controlled by classical methods is controlled by a prototype, PLC and SCADA. All maneuvers in the substation have been tested on the prototype. Similarly, according to the actual scenario, the circuit breakers are opened according to possible alarms from the system. General status of the substation and alarms can be monitored from the SCADA screens, and opening and closing operations can be done with circuit breakers and disconnectors.

The remote control and monitoring of the system via the Internet allows authorized persons to monitor the substation at any place and to interrupt if necessary. In addition, when a predefined alarm is triggered, it automatically notifies the authorized person by e-mail.

This work was done on a prototype, completely in accordance with real working scenarios.

Due to physical and financial constraints, all details of the system's operation were not taken into consideration. However, all the important maneuvers and situations are provided for the system. For this reason, the proposal and decision of the applicability of prototype and PLC-SCADA software in real systems have been authorized by TEIAS.

The project is open to development and innovation. In the project, besides monitoring and control of a substation with WebServer, it could be possible to monitor and control all substations belonging to TEIAS individually from a computer in the headquarters and/or from the SCADA system. For this reason, the most suitable SCADA program can be chosen. The main aspect of the project that can be improved is the ability to perform maneuvering remotely with full control. It is imperative to have a modernized substation with remote controllable units. This is again a decision that TEIAS officials can make. It is also possible to conduct a study to reduce the cost of the hardware and software used in the project.

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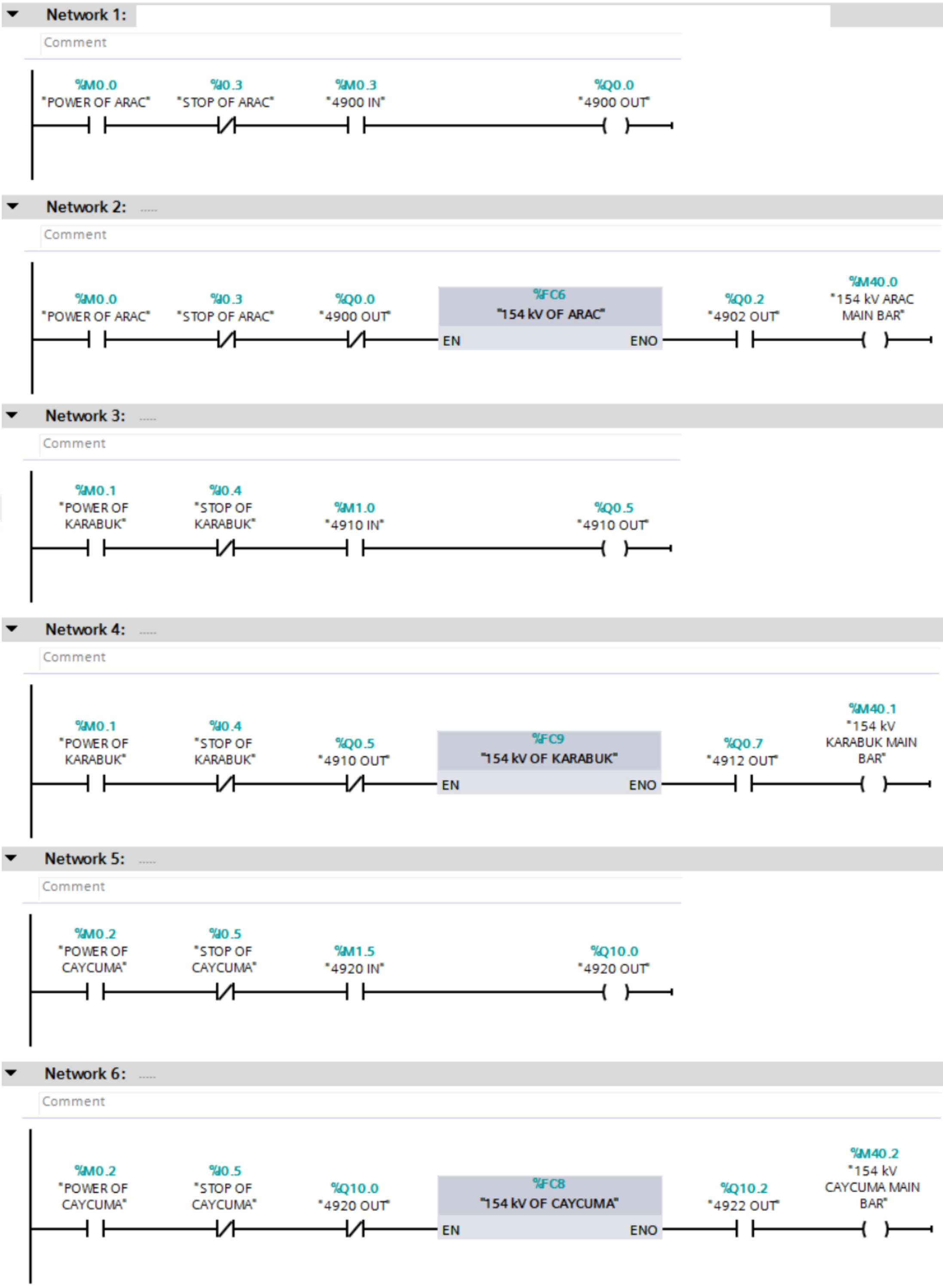
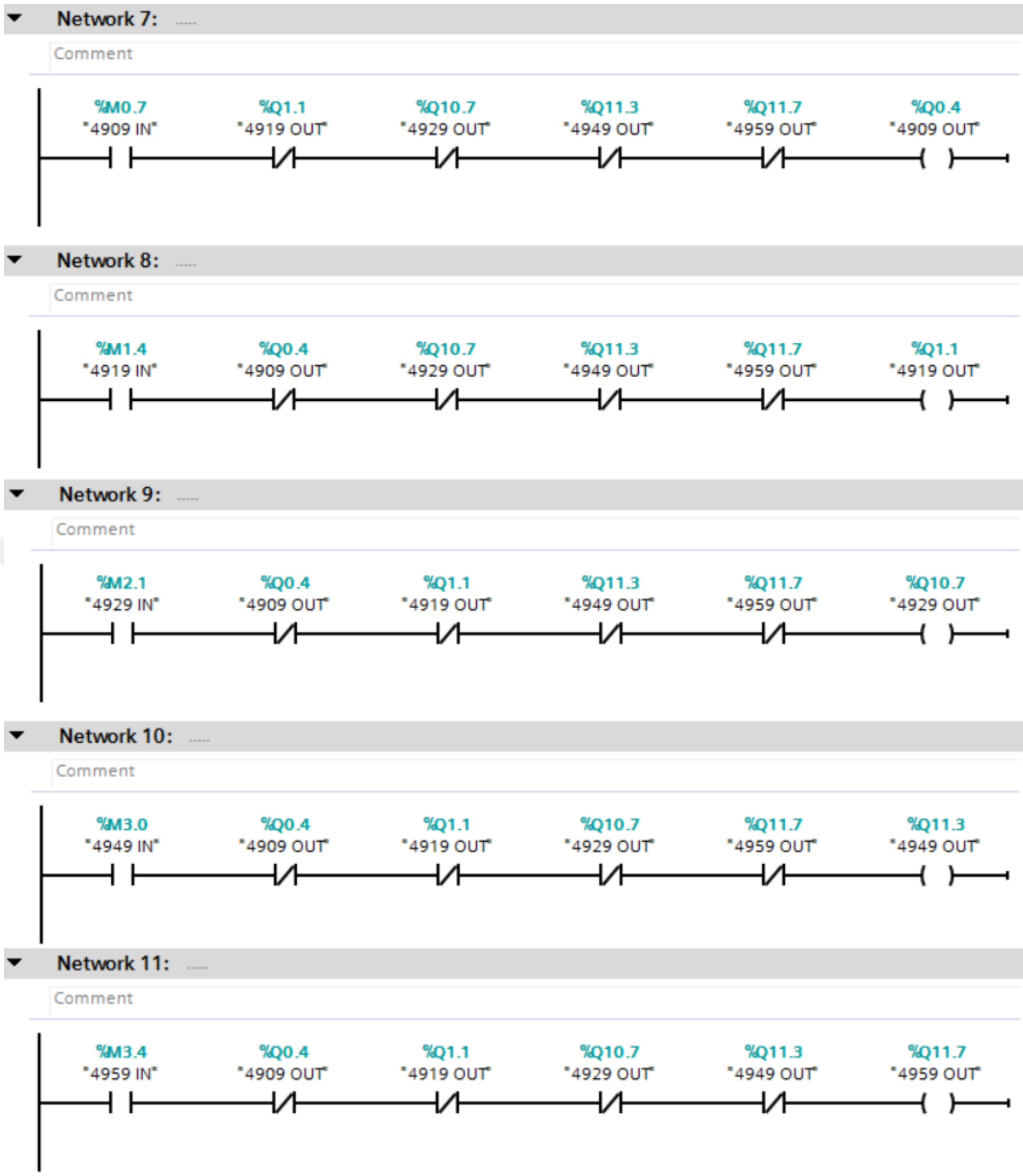
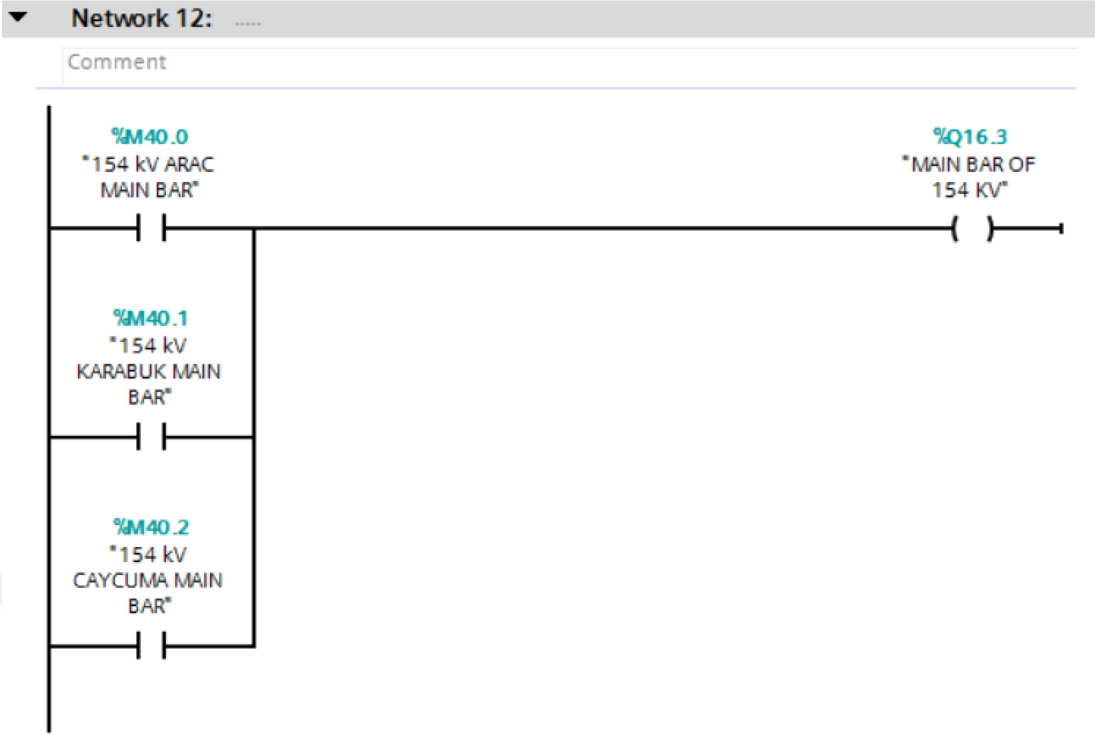
APPENDIX A.

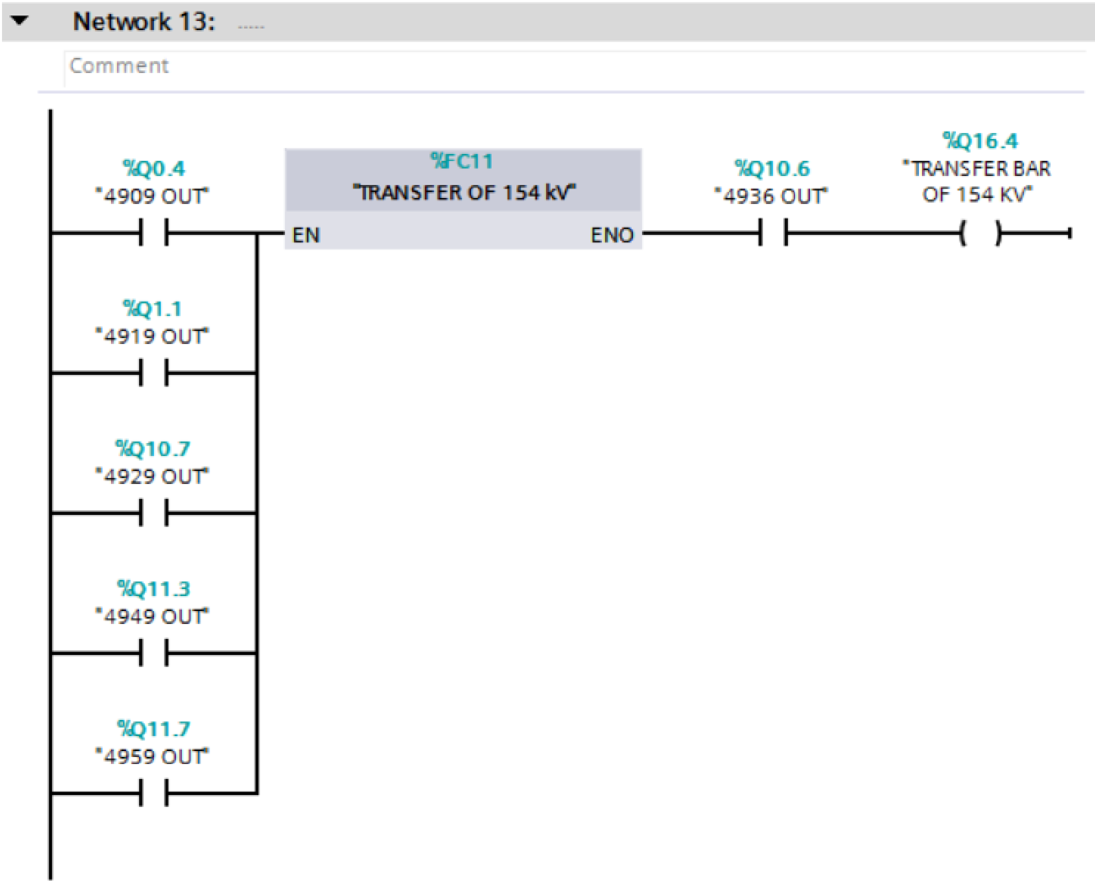
PLC LADDER DIAGRAM (PART OF MAIN OB1)


Network 1:
Comment
%M0.0
"POWER OF ARAC"
%I0.3
"STOP OF ARAC"
%M0.3
"4900 IN"
%Q0.0
"4900 OUT"
Network 2:
Comment
%M0.0
"POWER OF ARAC"
%I0.3
"STOP OF ARAC"
%Q0.0
"4900 OUT"
%FC6
"154 kV OF ARAC"
EN
ENO
%Q0.2
"4902 OUT"
%M40.0
"154 kV ARAC MAIN BAR"
Network 3:
Comment
%M0.1
"POWER OF KARABUK"
%I0.4
"STOP OF KARABUK"
%M1.0
"4910 IN"
%Q0.5
"4910 OUT"
Network 4:
Comment
%M0.1
"POWER OF KARABUK"
%I0.4
"STOP OF KARABUK"
%Q0.5
"4910 OUT"
%FC9
"154 kV OF KARABUK"
EN
ENO
%Q0.7
"4912 OUT"
%M40.1
"154 kV KARABUK MAIN BAR"
Network 5:
Comment
%M0.2
"POWER OF CAYCUMA"
%I0.5
"STOP OF CAYCUMA"
%M1.5
"4920 IN"
%Q10.0
"4920 OUT"
Network 6:
Comment
%M0.2
"POWER OF CAYCUMA"
%I0.5
"STOP OF CAYCUMA"
%Q10.0
"4920 OUT"
%FC8
"154 kV OF CAYCUMA"
EN
ENO
%Q10.2
"4922 OUT"
%M40.2
"154 kV CAYCUMA MAIN BAR"



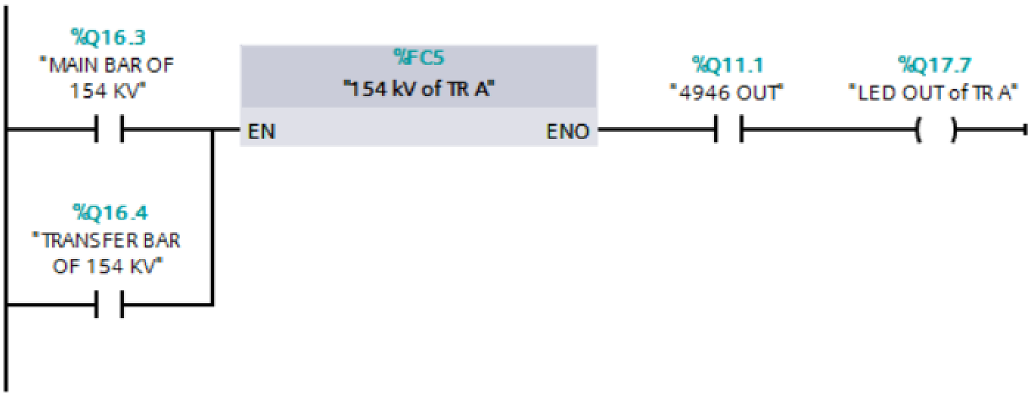
Network 7: ......
Comment
%M0.7 "4909 IN"
%Q1.1 "4919 OUT"
%Q10.7 "4929 OUT"
%Q11.3 "4949 OUT"
%Q11.7 "4959 OUT"
%Q0.4 "4909 OUT"
Network 8: ......
Comment
%M1.4 "4919 IN"
%Q0.4 "4909 OUT"
%Q10.7 "4929 OUT"
%Q11.3 "4949 OUT"
%Q11.7 "4959 OUT"
%Q1.1 "4919 OUT"
Network 9: ......
Comment
%M2.1 "4929 IN"
%Q0.4 "4909 OUT"
%Q1.1 "4919 OUT"
%Q11.3 "4949 OUT"
%Q11.7 "4959 OUT"
%Q10.7 "4929 OUT"
Network 10: ......
Comment
%M3.0 "4949 IN"
%Q0.4 "4909 OUT"
%Q1.1 "4919 OUT"
%Q10.7 "4929 OUT"
%Q11.7 "4959 OUT"
%Q11.3 "4949 OUT"
Network 11: ......
Comment
%M3.4 "4959 IN"
%Q0.4 "4909 OUT"
%Q1.1 "4919 OUT"
%Q10.7 "4929 OUT"
%Q11.3 "4949 OUT"
%Q11.7 "4959 OUT"


Network 12: ......
Comment
%M40.0
"154 kV ARAC MAIN BAR"
%M40.1
"154 kV KARABUK MAIN BAR"
%M40.2
"154 kV CAYCUMA MAIN BAR"
%Q16.3
"MAIN BAR OF 154 KV"


Network 13: ......
Comment
%Q0.4
"4909 OUT"
%Q1.1
"4919 OUT"
%Q10.7
"4929 OUT"
%Q11.3
"4949 OUT"
%Q11.7
"4959 OUT"
%FC11
"TRANSFER OF 154 kV"
EN
ENO
%Q10.6
"4936 OUT"
%Q16.4
"TRANSFER BAR OF 154 KV"

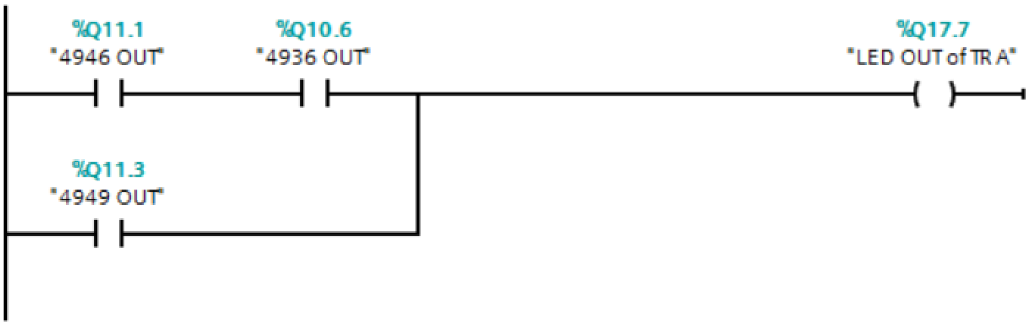
Network 14: ......

Comment



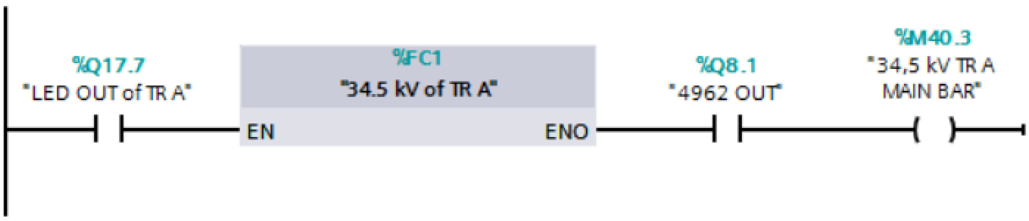
Network 15: SUPPLY OF ON THE TRANSFER BAR OF A TRAFO.

Comment



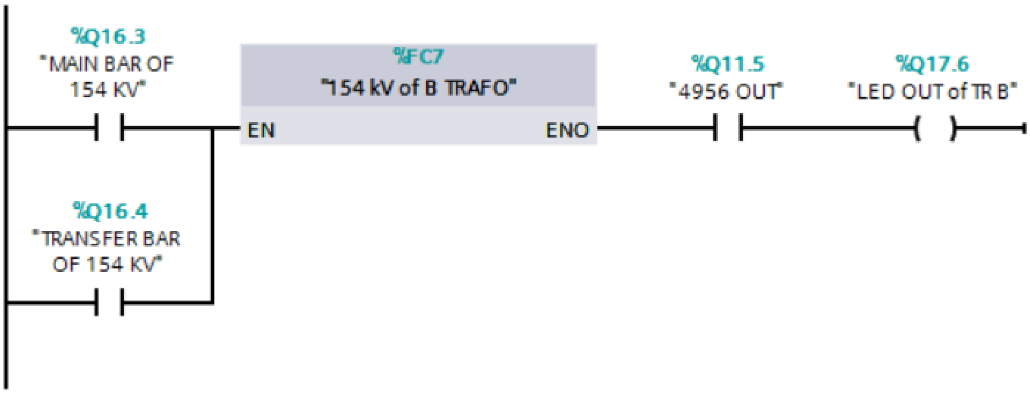
Network 16: ......

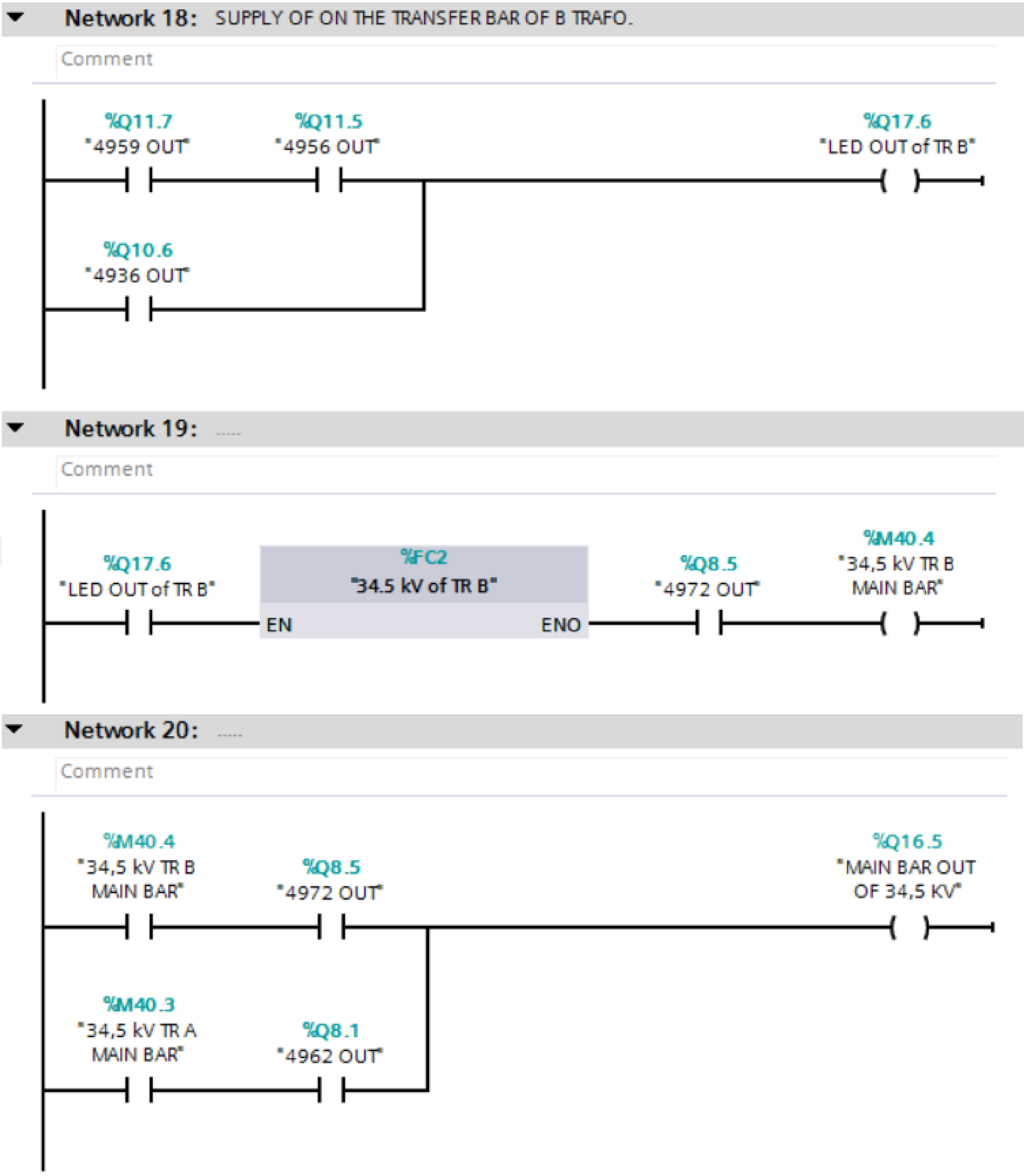
Comment

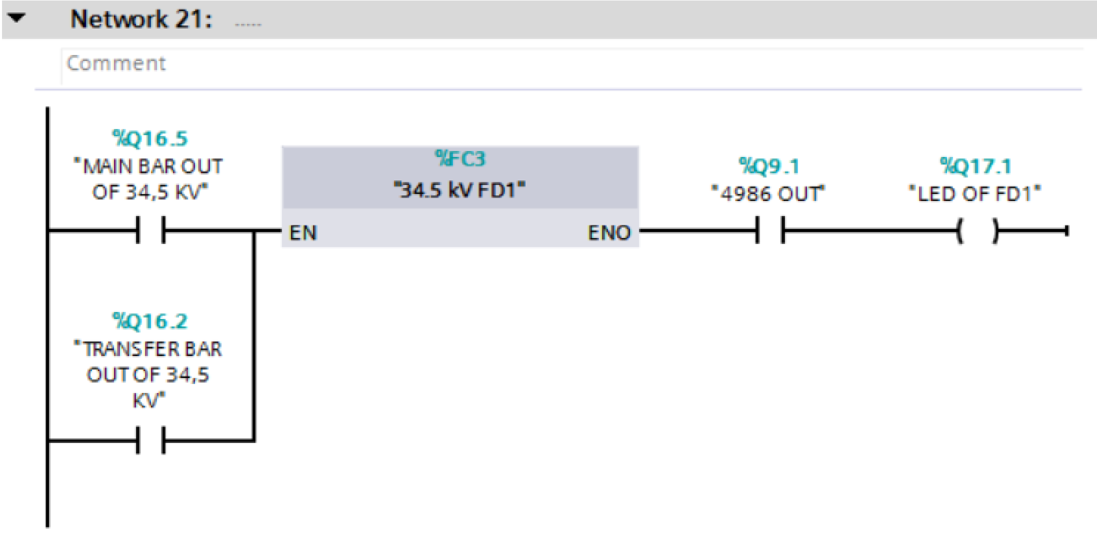


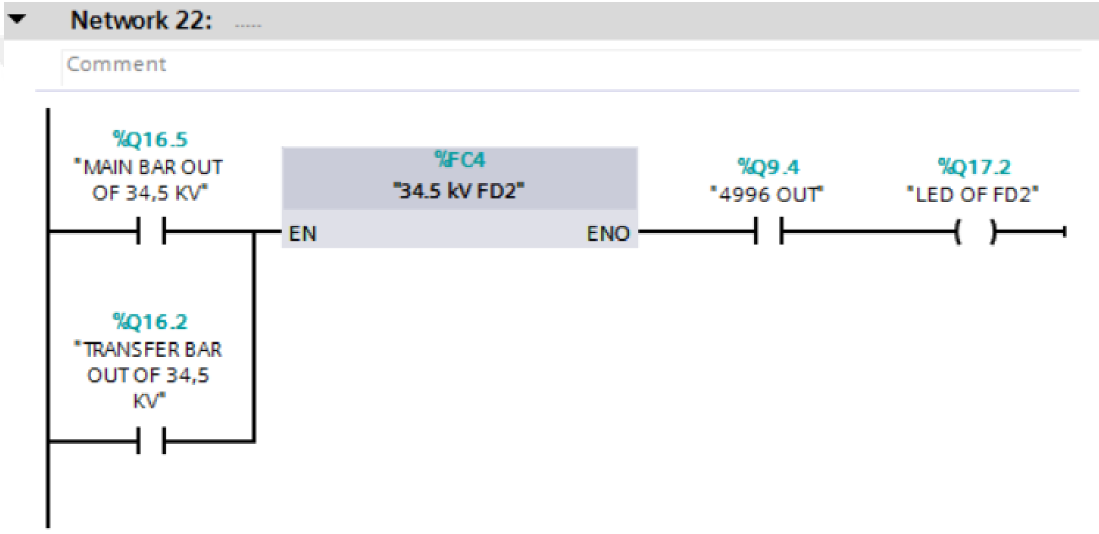
Network 17: INSIDE OF B TRAFO.

Comment




Network 18: SUPPLY OF ON THE TRANSFER BAR OF B TRAFO.
Comment
%Q11.7
"4959 OUT"
%Q11.5
"4956 OUT"
%Q17.6
"LED OUT of TR B"
%Q10.6
"4936 OUT"
Network 19: ......
Comment
%Q17.6
"LED OUT of TR B"
%FC2
"34.5 kV of TR B"
EN
ENO
%Q8.5
"4972 OUT"
%M40.4
"34,5 kV TR B
MAIN BAR"
Network 20: ......
Comment
%M40.4
"34,5 kV TR B
MAIN BAR"
%Q8.5
"4972 OUT"
%Q16.5
"MAIN BAR OUT
OF 34,5 KV"
%M40.3
"34,5 kV TR A
MAIN BAR"
%Q8.1
"4962 OUT"


Network 21: .....
Comment
%Q16.5
"MAIN BAR OUT OF 34,5 KV"
%FC3
"34.5 kV FD1"
EN
ENO
%Q9.1
"4986 OUT"
%Q17.1
"LED OF FD1"
%Q16.2
"TRANSFER BAR OUT OF 34,5 KV"


Network 22: .....
Comment
%Q16.5
"MAIN BAR OUT OF 34,5 KV"
%FC4
"34.5 kV FD2"
EN
ENO
%Q9.4
"4996 OUT"
%Q17.2
"LED OF FD2"
%Q16.2
"TRANSFER BAR OUT OF 34,5 KV"

APPENDIX B.

HTML CODES

MAIN PAGE:

```
<!DOCTYPE html>
<html >
<head>
  <meta charset="UTF-8">
  <title>Teias Safranbolu Substation Maneuver Schema</title>


  <link rel='stylesheet prefetch'
href='http://netdna.bootstrapcdn.com/bootstrap/3.0.2/css/bootstrap.min.css'>

      <link rel="stylesheet" href="css/style.css">


</head>

<body>
<div  align="center" class="wrapper">
  <p>Karabuk University Electrical-Electronics Engineering
    <br>
    Khaled Ahmed Hadia ALDAWILA M.Sc. <br>
    Thesis
    Advisor:Assist.Prof.Dr. Hüseyin ALTINKAYA </p>
  <p><img src="images/logo.png" width="166" height="70" /></p>
</div>
<div class="wrapper">
    <form class="form-signin" method="post" action="index1.html">
      <h2 class="form-signin-heading">Please login:</h2>
      <input  type="text"  class="form-control"  name="username"  placeholder="teias"
required autofocus />
```

```
    <input type="password" class="form-control" name="password"
placeholder="teias" required/>
    <label class="checkbox">
      <input type="checkbox" value="remember-me" id="rememberMe"
name="rememberMe"> Remember me
    </label>
    <button class="btn btn-lg btn-primary btn-block" type="submit">Login</button>
   </form>
  </div>


</body>
</html>
```

MENU PAGE:

```
<html >
<head>
  <meta charset="UTF-8">
  <title>Teias Safranbolu Substation Maneuver Schema</title>

  <link rel='stylesheet prefetch' href='http://netdna.bootstrapcdn.com/bootstrap/3.0.2/css/bootstrap.min.css'>

      <link rel="stylesheet" href="css/style.css">

</head>

<body>
<div  align="center" class="wrapper">
  <p>Karabuk University Electrical-Electronics Engineering <br>
    Khaled Ahmed Hadia ALDAWILA M.Sc. <br>
    Thesis
    Advisor:Assist.Prof.Dr. Hüseyin ALTINKAYA </p>
  <p><img src="images/logo.png" width="166" height="70" /></p>
</div>
<div class="wrapper">
    <form class="form-signin" method="post" action="index1.html">
      <h2 class="form-signin-heading">Please Select Process:</h2>
      <p><a href="manoeuvre.html"><img src="images/button_manoeuvre.png" width="155" height="40" /></a>      <a href="alarms.html"><img src="images/button_alarms.png" width="111" height="40" /></a></p>
    </form>
  </div
</body>
</html>
```

MANOEUVRE PAGE:

```
<!DOCTYPE html>
<html >
<head>
  <meta charset="UTF-8">
  <title>Teias Safranbolu Substation Maneuver Schema</title>
        <meta http-equiv="refresh" content="3" >    <!-- meta tag refreshes page every second -->

  <link rel='stylesheet prefetch' href='http://netdna.bootstrapcdn.com/bootstrap/3.0.2/css/bootstrap.min.css'>

      <link rel="stylesheet" href="css/style.css">



</head>

<body>
<div  align="center" class="wrapper">
  <p>Karabuk University Electrical-Electronics Engineering
    <br>
    Khaled Ahmed Hadia ALDAWILA M.Sc. <br>
    Thesis
    Advisor:Assist.Prof.Dr. Hüseyin ALTINKAYA </p>
  <p><img src="images/logo.png" width="166" height="70" /></p>
  <table width="200" border="0">
    <tr>
      <td> </td>
      <td><input type="button" name="button7" id="button7" value="POWER ON"></td>
```

```
    <td rowspan="11"><img src="images/mano1.jpg" width="627" height="525" /></td>
    <td><input type="button" name="button8" id="button8" value="POWER OFF"></td>
    <td> </td>
  </tr>
  <tr>
    <td> </td>
    <td><img src="images/light-red-flash.gif" width="40" height="40" /></td>
    <td> </td>
    <td> </td>
  </tr>
  <tr>
    <td><input type="button" name="button3" id="button3" value="4910 ON"></td>
    <td><input type="button" name="button2" id="button2" value="4910 OFF"></td>
    <td> </td>
    <td> </td>
  </tr>
  <tr>
    <td> </td>
    <td> </td>
    <td> </td>
    <td> </td>
  </tr>
  <tr>
    <td> </td>
    <td><input type="button" name="button" id="button" value="4911 ON"></td>
    <td><input type="button" name="button6" id="button6" value="4919 ON"></td>
    <td> </td>
  </tr>
```

```
<tr>
  <td> </td>
  <td> </td>
  <td> </td>
  <td> </td>
</tr>
<tr>
  <td> </td>
  <td> </td>
  <td> </td>
  <td> </td>
</tr>
<tr>
  <td><input type="button" name="button5" id="button5" value="4912 ON"></td>
  <td><input type="button" name="button4" id="button4" value="4912 OFF"></td>
  <td> </td>
  <td> </td>
</tr>
<tr>
  <td> </td>
  <td> </td>
  <td> </td>
  <td> </td>
</tr>
<tr>
  <td> </td>
  <td> </td>
  <td> </td>
  <td> </td>
</tr>
<tr>
```

```
      <td> </td>
      <td> </td>
      <td> </td>
      <td> </td>
    </tr>
  </table>
  <p> </p>
</div>



</body>
</html>
```

ALARM PAGE:

```
<!DOCTYPE html>
<html >
<head>
  <meta charset="UTF-8">
  <title>Teias Safranbolu Substation Maneuver Schema</title>

  <link rel='stylesheet prefetch'
href='http://netdna.bootstrapcdn.com/bootstrap/3.0.2/css/bootstrap.min.css'>

      <link rel="stylesheet" href="css/style.css">

</head>

<body>
<div  align="center" class="wrapper">
  <p>Karabuk University Electrical-Electronics Engineering <br>
    Khaled Ahmed Hadia ALDAWILA M.Sc. <br>
    Thesis
    Advisor:Assist.Prof.Dr. Hüseyin ALTINKAYA </p>
  <p><img src="images/logo.png" width="166" height="70" /></p>
</div>
<div class="wrapper">
    <form class="form-signin" method="post" action="index1.html">
  <h2 class="form-signin-heading"><a href="index1.html"><img
src="images/button_main-page.png" width="144" height="40" /></a></h2>
      <table align="center" width="298" border="0">
        <tr>
          <td colspan="2">TR A</td>
          <td colspan="2">TR B</td>
        </tr>
        <tr>
```

```
          <td><img src="images/light-red-flash.gif" width="42" height="42" /></td>
          <td>Over Current </td>
          <td><img src="images/Green-Light-Button-90684.gif" width="42" height="41" /></td>
          <td>Over Current</td>
        </tr>
        <tr>
          <td><img src="images/Green-Light-Button-90684.gif" width="42" height="41" /></td>
          <td>Thermic</td>
          <td><img src="images/light-red-flash.gif" width="42" height="42" /></td>
          <td>Thermic</td>
        </tr>
        <tr>
          <td><img src="images/Green-Light-Button-90684.gif" width="42" height="41" /></td>
          <td>Buchholz</td>
          <td><img src="images/Green-Light-Button-90684.gif" width="42" height="41" /></td>
          <td>Buchholz</td>
        </tr>
      </table>
      <p> </p>
            <form id="form1" name="form1" method="post">
              <a href="mailsender1.html">Mail Sender
          </a>
    </form>
    </form>

  </div>

</body>
</html>
```

MAIL SENDER PAGE:

```
<!DOCTYPE html>
<html >
<head>
  <meta charset="UTF-8">
  <title>Teias Safranbolu Substation Maneuver Schema</title>


  <link rel='stylesheet prefetch'
href='http://netdna.bootstrapcdn.com/bootstrap/3.0.2/css/bootstrap.min.css'>

      <link rel="stylesheet" href="css/style.css">


</head>

<body>
<div  align="center" class="wrapper">
  <p>Karabuk University Electrical-Electronics Engineering <br>
    Khaled Ahmed Hadia ALDAWILA M.Sc. <br>
    Thesis
    Advisor:Assist.Prof.Dr. Hüseyin ALTINKAYA </p>
  <p><img src="images/logo.png" width="166" height="70" /></p>
</div>
<div class="wrapper">
    <form class="form-signin" method="post" action="index1.html">
  <h2 class="form-signin-heading"><a href="index1.html"><img
src="images/button_main-page.png" width="144" height="40" /></a></h2>
     <form action="https://formspree.io/teiassafran@gmail.com" method="post">
  <p class="input-block">
        <label for="contact_author">
          <strong>Data 1:</strong></label>
```

```
    <input name="contact_author" type="text" required id="contact_author" value="Output 0: :=">
  </p>
  <p class="input-block">
    <label for="contact_author2"><strong>Data 2:</strong></label>
    <input name="_replyto" type="email" required id="_replyto" value="Output 1: :=">
  </p>
 <p class="input-block">
  <input type="hidden" name="_next" value="thanks.html">
  <input type="submit" formaction="thanks.html" value="SEND">
</p>
</form> <p> </p>
    <p> </p>

  </form>

 </div>


</body>
</html>
```

RESUME

Khaled Ahmed Hadia ALDAWILA was born in Libya in 1986 and he graduated first, elementary and high school education in this country. After that, he finished undergraduate program in The High Institute of Comprehensive Professions Department of Electrical Engineering in 2010. In 2015, he started graduate study in Karabuk University Department of Electrical & Electronics Engineering. He has been still continuing his education in this section.

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