DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

AUTOMATION OF THE WATER DISTRIBUTION SYSTEMS USING SCADA

by
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March, 2008
İZMİR

AUTOMATION OF THE WATER DISTRIBUTION SYSTEMS USING SCADA

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"AUTOMATION OF THE WATER DISTRIBUTION SYSTEMS USING SCADA"** completed by **SERDAR GÜNDOĞDU** under supervision of **ASSOC. PROF. DR ÖZGE ŞAHİN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Serdar GÜNDOĞDU

AUTOMATION OF THE WATER DISTRIBUTION SYSTEMS USING SCADA

ABSTRACT

The water distribution system is the essential link between the water supply source and the consumer. This system often consists of a large number of components such as water reservoirs, booster pumping stations, and water treatment plants. The components should be controlled and monitored continuously for providing treated water to be delivered to consumer tap.

Nowadays, technologies of SCADA are widely used in control systems in industrial automation. SCADA systems provide monitoring of water production and distribution systems that are geographically distributed to the extensive areas. These systems are used not only in most industrial processes as water distribution systems, but also in some experimental facilities such as nuclear fusion. High-integrity SCADA system applications also include the electric power transmission and distribution, the natural gas distribution, the railway, and the telecommunication area.

In this study, firstly, water distribution system components are researched that used in urban water network system, and technical specs of these components are given. In the later chapters, standard and technical specs of SCADA systems and their major components, required control equipments for planning a SCADA system, sensors, RTUs are explained in detail. Lastly, planning and automation of the system is designed for a booster pump station model. This station has four motor-pumps and a large number of detectors. A microprocessor based Remote Terminal Unit (RTU) is used in order to control motor-pumps and get feedback from the booster pump station. The designed automation system includes both hardware and software configuration.

Keywords: Water distribution system, SCADA, RTU, sensors, automation.

SCADA KULLANILARAK SU DAĞITIM SİSTEMLERİ OTOMASYONU

ÖZ

Su dağıtım sistemi, su temini yapılan kaynaklar ile tüketici arasındaki temel bağlantıdır. Bu sistem çoğu zaman su depoları, pompa istasyonları ve su arıtma tesisleri gibi birçok bileşenden oluşmaktadır. Temiz suyun sağlıklı olarak tüketici musluklarına dağıtımı yapılabilmesi için dağıtım bileşenleri sürekli olarak kontrol edilmeli ve gözlem altında tutulması gerekir.

Günümüzde SCADA teknolojileri, endüstriyel otomasyonda bulunan kontrol sistemlerinde yaygın olarak kullanılmaktadır. SCADA sistemleri sayesinde geniş olarak coğrafi bölgelere yayılmış olan su üretim ve dağıtım donanımları izlenir. Bu sistemler, su dağıtım sistemi gibi pek çok endüstriyel işlevinin yanında, nükleer füzyon gibi bazı deneysel tesislerde de kullanılmaktadır. Yüksek doğruluklu SCADA sistem uygulamaları elektrik iletim ve dağıtım hatları, doğalgaz dağıtım hatları, demir yolu ve telekomünikasyon çalışma sahalarını da kapsamaktadır.

Bu çalışmada ilk olarak şehir suyu şebeke sisteminde kullanılan su dağıtım bileşenleri araştırılmış ve teknik özellikleri hakkında bilgi verilmiştir. Sonraki bölümlerde, SCADA sistemleri ve temel bileşenleri, bir SCADA sistemi planlaması için gerekli kontrol ekipmanları ve sensörleri, RTU'ların standart ve teknik özellikleri ayrıntılı bir biçimde açıklanmıştır. Son olarak, bir pompa istasyonu modelinin planlaması ve otomasyonu tasarlanmıştır. Bu istasyon dört adet motor-pompa ve birçok algılayıcı donanıma sahiptir. Model içindeki motor-pompaları kumanda etmek ve algılayıcılardan geri besleme bilgilerini almak için mikroişlemci tabanlı bir RTU kullanılmıştır. Tasarlanmış otomasyon sistemi, donanım ve yazılım yapılandırılmasından meydana gelmektedir.

Anahtar sözcükler: Su dağıtım sistemi, SCADA, RTU, sensörler, otomasyon.

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CHAPTER ONE
INTRODUCTION

Supervision, control and data acquisition bring benefits to all users from system integrator to the end-user. In recent times, Supervisory Control and Data Acquisition (SCADA) systems have become important technological structures for automatic control and information transfer. SCADA systems perform all the desired SCADA tasks, from data collecting to historical data archiving, specific application calculations etc. There are three major components in a SCADA system. These components include the master station, the remote terminal units (RTUs), and the communication media between the master station and the RTUs.

Remote sensing of operational status was first used in power industry around Chicago when power companies used telephone lines to inform the status of the power station status to the central office. In the late 1960s, the SCADA systems and process control systems became popular in pipeline industry. Systems were designed without using standards, resulting in development of a wide variety of proprietary systems. Communication with remote equipment was very radial in nature and numerous proprietary protocols were developed and are still in use today (Sandia National Labs, 2007).

The acquisition of data, the processing of those data for use by the operator, and operator control of remote devices are the fundamental building blocks upon which all modern utility control systems are based (Gaushell & Darlington, 1987). A SCADA system is complex, and the investment for the organization is a long term one. Therefore, the organization must proceed cautiously and with a logical series of steps to ensure they procure the most cost effective system that best meets their needs both now and in the future (McDonald, 1993).

The RTU architecture was chosen to be distributed in order to reduce cabling costs and cabling difficulties, caused by the several hundreds of signals that must be connected to the acquisition points (Carrapatoso & Gomes, 1997). Advances in

CPUs (Central Processing Units) and the programming capabilities of RTUs have allowed for more sophisticated monitoring and control. Applications that had previously been programmed at the central master station can now be programmed at the RTU. The configuration of sensors and actuators determines the quantity and type of inputs and outputs on a RTU; depending on the model and manufacturer, modules can be designed solely for input, output, digital, analog, or any combination (Venkatraman, 2006).

In modern manufacturing and industrial processes, mining industries, public and private utilities, leisure and security industries telemetry is often needed to connect equipment and systems separated by large distances. This can range from a few meters to thousands of kilometers (Clarke & Reynders, 2004). Telemetry is used to send commands, programs and receive monitoring information from these remote locations. SCADA refers to the combination of telemetry and data acquisition. Today's SCADA systems are a combination of legacy and modern technology (National Trans. Safety Board, 2006).

Water distribution systems use SCADA to control motors, valves, and other forms of equipment. In most cases, SCADA systems include "operator-level software applications for viewing, supervising and troubleshooting local machine and processing activities." For pipeline applications, SCADA systems consist of main PCs connected via a communication link to field sensors (pressure transmitters, chlorine transmitters, and flow meters) and pipeline components (pumps, control panels etc).

The controller monitors data and controls water distribution pump from a SCADA workstation. The SCADA interface provides feedback to the controller of actions that happen at remote sites to ensure the controller remains aware of all conditions at the pump station. Alarms are generated and displayed when field conditions exceed acceptable preset levels, when status changes occur, or when functions within the SCADA system generate an alarm. Many systems provide a maintenance/development computer platform for supervisor viewing of pipeline displays, and testing new software routines before implementing them on the SCADA computer.

In this thesis, a wide range of topics, including the basic water distribution system, general SCADA architecture, RTU and automation are covered. Experimental tests are realized on the water distribution station of the Izmir Municipality, Department of Water and Sewerage Administration (IZSU) in Turkey. The station was developed as a part of this thesis using industry standard hardware and software from ELIOP S.A. and provides several working systems to simulate real-world applications of SCADA technology. The designed water distribution system configuration is described in the thesis.

This study consists of six chapters. In Chapter two, information about water distribution system, its components and their applications are given. This thesis continues with an examination of control system, and SCADA system in particular. SCADA systems, used in water distribution systems are mentioned in Chapter three. Required control equipment for water distribution SCADA is discussed in Chapter four. These control equipments include RTU, MCC (Motor Control Center) panels, pressure transmitters, level sensors etc. Hardware and software designs of selected a pump model station are given in the fifth Chapter. In the last chapter, Chapter six, conclusion part takes place. This chapter summarizes the main findings of this study and draws out their implications.

CHAPTER TWO

DRINKING WATER DISTRIBUTION SYSTEMS

2.1 Overview of the Distribution System

The uses of water are generally classified as domestic, commercial, industrial, public, and agricultural. Domestic use includes all water used in and around residences. The amount of domestic consumption varies with the standard of living but is proportional to the resident population. Commercial use includes water used in business or commercial districts by persons who are not residents of the district. Industrial use is for manufacturing purposes, and the amount of such use bears no relation to the population of an industrial district. Public use of water is for fire fighting, street and sewer flushing, and for un-metered public buildings. Waste due to leakage and other causes, frequently a substantial portion of the total supply is sometimes classed as public use. Agricultural use is for irrigation purposes. Such use is unimportant for municipal supplies in regions of good rainfall but must be taken into account in arid regions.

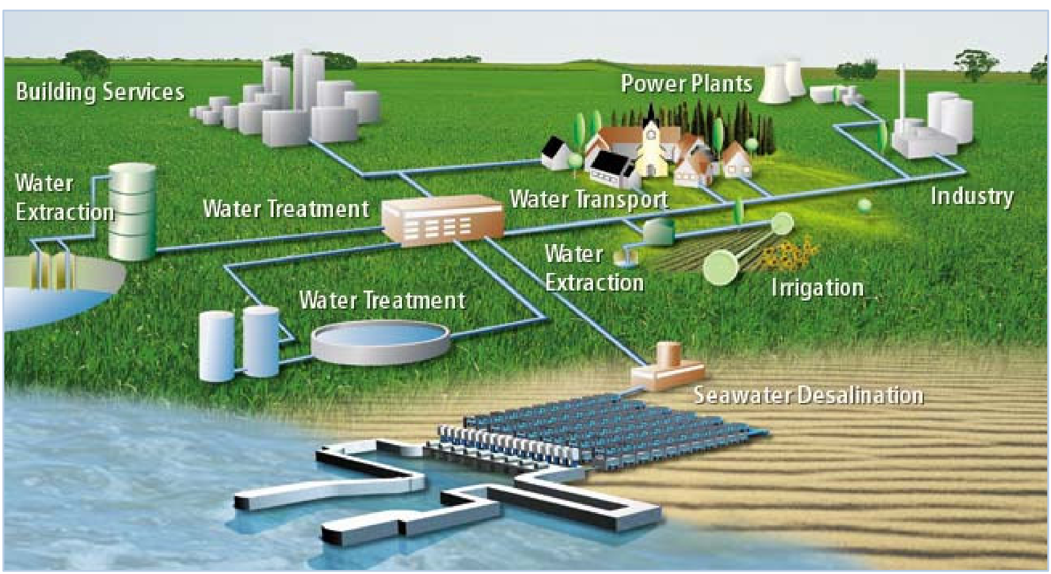


Figure 2.1 Water consumption

A distribution system should be so designed that an adequate supply of water is available to the consumers. The distribution system of a waterworks consist of the pipes, valves, hydrants, and appurtenances used for distributing the water; the elevated tanks and reservoirs used for equalizing pressures and pump discharges; and the costumer service pipes and meters. For administrative purposes, booster pump stations and treatment works located within the bounds of the distribution system are sometimes classed as distributing works.

2.2 Water Supplies and Waterworks Components

Water supplies are classified are surface and ground-water supplies (Davis, C. V., Sorensen, K. E., 1969). Surface supplies may be divided into two groups: class a, those from large rivers or lakes which must be pumped into the distribution systems, and class b, those from smaller upland streams which require storage reservoirs and aqueducts or pipe lines for delivery, usually by gravity, to the distributions systems. Ground-water supplies are obtained from wells, springs, and filter galleries. An important consideration in the selection of a new source water supply is its reliability. A new supply should be capable of furnishing an adequate quantity of water continuously with a minimum danger of interruption due to breakdown or other causes.

A waterworks system must meet at least the minimum waterworks performance standards. A Waterworks System Assessment (WSA) is an inspection and reporting process intended to aid waterworks owners to identify, analyze, and mitigate any potential adverse health risk and environmental impacts associated with waterworks infrastructure, equipment and related maintenance and operational procedures or practices. The WSA standard planning phase involves a detailed review of the available information on the water supply, treatment, storage and distribution systems. For regional systems where a supply, treatment and transmission facility may supply several separate storage and distribution facilities, a WSA is required by each permitted for their works (Office of drinking water, 2007).

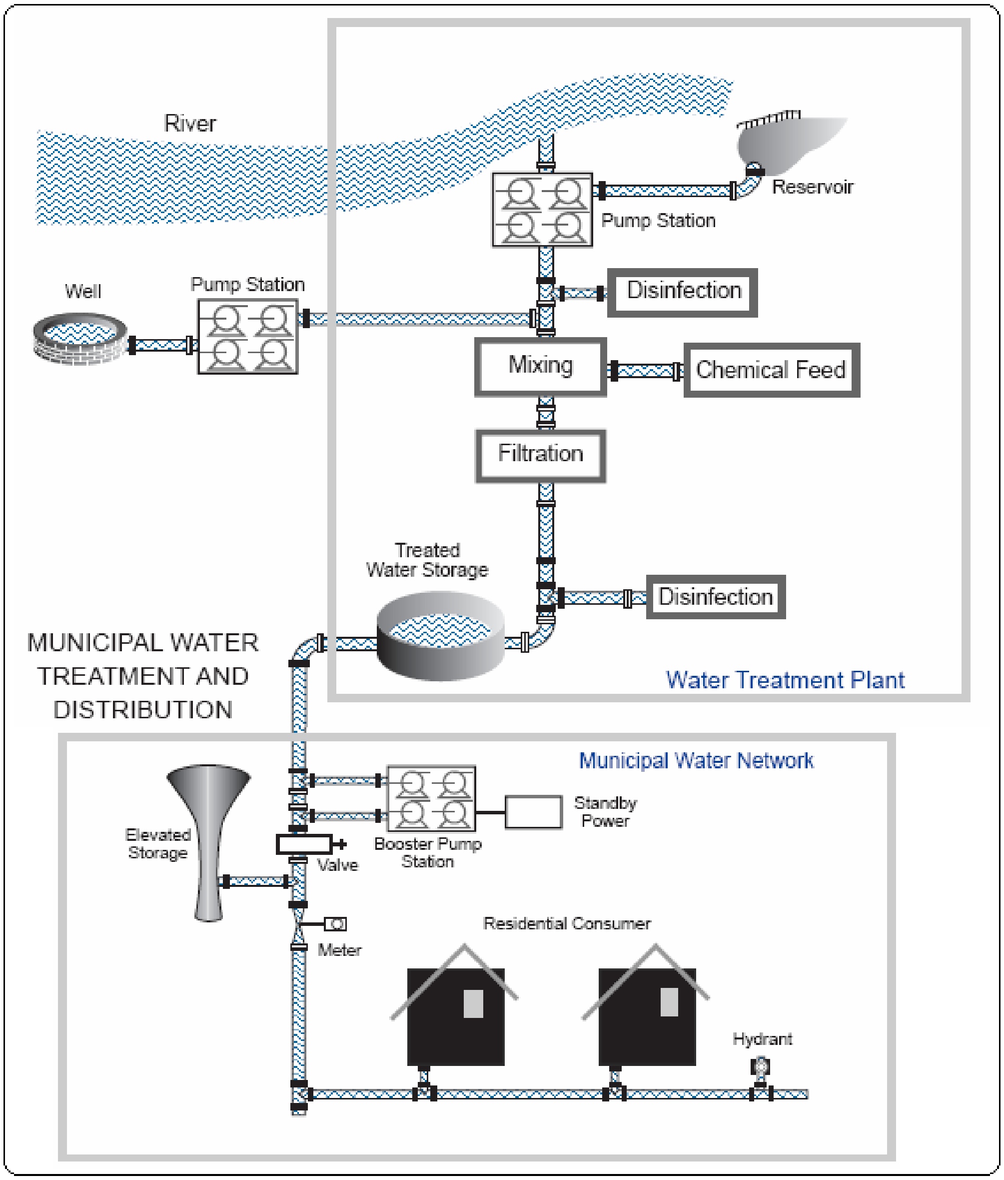


Figure 2.2 The water distribution system is the essential link between the water supply source and the consumer

2.2.1 Ground-water Supplies

Rain water which percolates into the soil beyond the reach of vegetation collects in the pores and fissures and flows, usually in the generally direction of the slope of the ground surface, toward outlet points. The water bearing strata, called aquifers, include formations of soil and sand, porous sandstone, alluvial deposits of sand and gravel, porous lava flows, glacial drift, limestone containing fissures. The upper surface of the ground water is called ground-water table. Flow through the soil is in the direction of the slope of the ground-water table. The ground-water table rises during rainy seasons and falls during droughts. Excessive draft of ground water from wells also lowers the water table. Figure 2.3 illustrates the position of the ground water and shows several different types of the collection works.

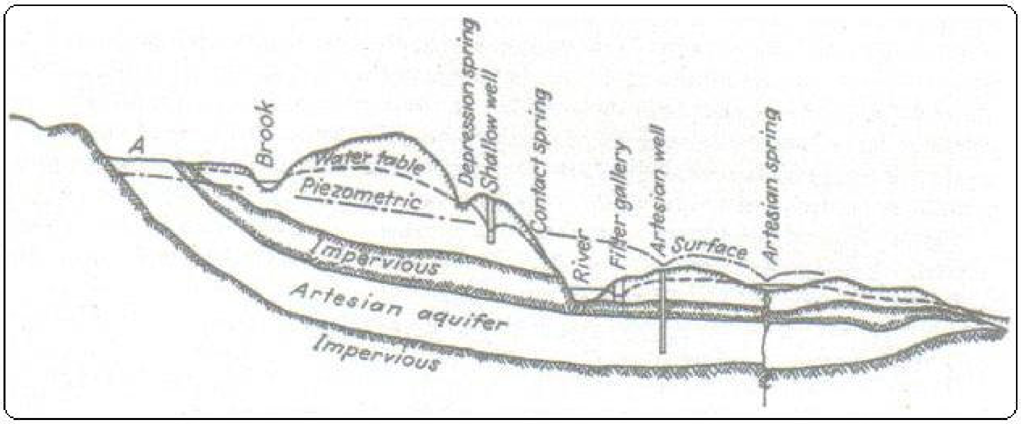


Figure 2.3 Hypothetical section showing relation of ground water to topology

Ground-waters are often superior in quality to surface waters, generally less expensive to develop for use, and usually provide a more certain supply (Steel, E. W., 1960). For these reasons, ground-water is generally preferred as a source for municipal and industrial water supplies. Against these common advantages it must be noted that ground-waters may be contaminated by toxic or hazardous materials leaking from landfills, waste treatment sites, or other sources which may not be known to either the public or regulatory agencies.

2.2.2 Surface Supplies

The quantity of water that may be drawn from a stream or lake depends upon the area of the watershed, the topography, vegetation, rainfall, climate, and amount of storage. The maximum quantity of water that may be drawn continuously after deducting losses due to evaporation from the proposed reservoir surface, leakage through and under dams, and necessary withdrawals for riparian owners downstream is called the safe yield. The estimated safe yield must exceed the estimated future demand if a proposed water supply is to be adequate. Surface supplies are more frequently taken from small upland streams than from large rivers both because of the superior quality of the water and because of the savings to be had in pumping costs.

The proper location of an impounding reservoir for a water supply is determined primarily by the existence of suitable dam sites. It is influenced by the quality of the water that may be had from the reservoir, the size of the watershed, and the distance of the reservoir from and its elevation with relation to the point of distribution. To be acceptable, a proposed reservoir site should have a tributary drainage area which, with the storage capacity it is possible to impound, will produce a satisfactory yield. Moreover, it should be possible to construct the works and supply water of acceptable quality to the city at less cost than from another available site.

2.2.3 Storage Reservoirs

Storage reservoirs are used to control floods, to conserve water, and to regulate stream flow. Reservoirs may be of two types: single purpose or multi purpose. Aside from location and structural problems, the planning for a single purpose reservoir leads to simple relationships among the available water supply, the water demand, and the volume of reservoir storage to be provided. These relationships are much more complex for a multipurpose reservoir since they involve the seasonal distribution of stream flow and the reconciliation thereto, and seasonal and other varying demands for the several purposes for which the reservoir is intended.

In dealing with reservoir storage many qualifying terms will be used. Conservation storage is impounded for later release, as required for some useful purpose, such as municipal supply, power, or irrigation. Flood-control storage is reserved solely to reduce downstream flood flows; water stored during floods is usually released as rapidly as channel capacities permit. Valley storage is the volume occupied by a stream in flood after it has overflowed its banks. In some cases, such as in an alluvial valley, this may be great. Effective storage is the volume available for the designed purpose. Storage below outlet levels is not effective. In the power reservoirs, only storage above the minimum drawdown level is effective. In flood-control reservoirs, the effective storage is the difference between actual capacity above outlet elevation and valley storage, or the storage that the flood waters would have utilized had the reservoir not been constructed.

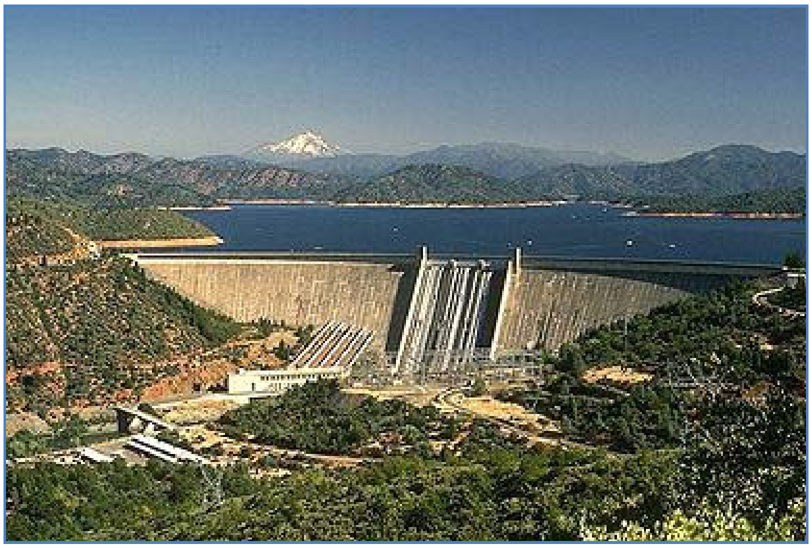


Figure 2.3 One of the first big water storage projects in the west. Shasta Dam blocks the Sacramento, McCloud, and Pit Rivers. Shasta Dam overlooks, CA (1983).

Water is stored to equalize pumping rates in the short term, to equalize supply and demand in long term, and to furnish water during emergencies such as fires and loss of pumping capacity. Elevated storage may be provided by earthen, steel, or concentrate reservoirs located on high ground or by standpipes or tanks raised above the ground surfaces.

2.2.4 Water Treatment Process

The treatment of water to improve its sanitary quality is called water purification. Purification consists of primarily of the removal or destruction of bacteria and the removal of turbidity and color. It is accomplished by sedimentation, filtration, and disinfection; with or without pretreatment of the water by chemical coagulation. A complete plant for this purpose is known as a purification or filtration plant or, more broadly, a treatment plant. In modern treatment plants, many other processes not related to sanitation are applied to the improvement of water quality to meet the exacting requirements of the consumers. These processes include corrective treatment to prevent corrosion, removal of iron and manganese, removal of odors, and softening.

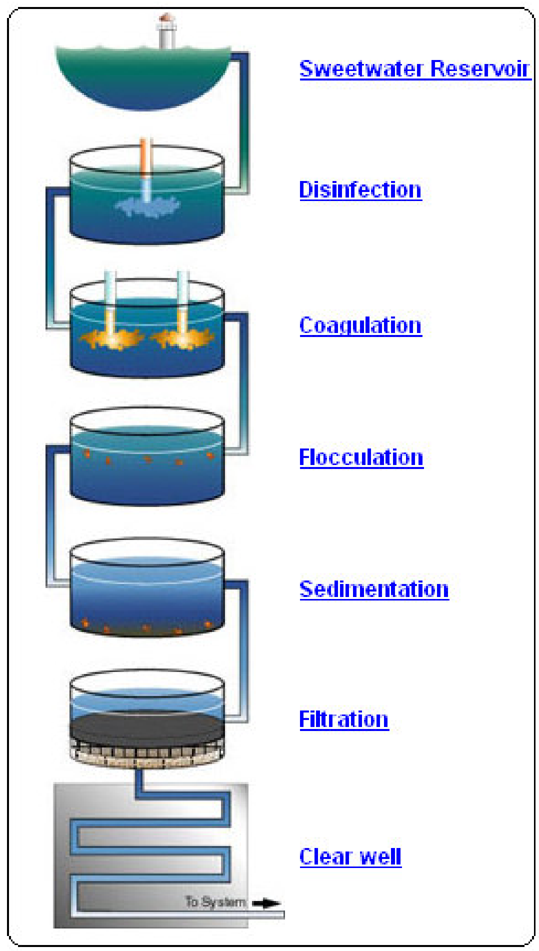


Figure 2.4 Water Treatment Process

Water treatment is very important for public health. When you fill a glass with water from your tap, you expect to drink water that is safe and pure. However, gases, minerals, bacteria, metals or chemicals suspended or dissolved in your water can affect your health and influence the quality of your water. Water is essential for life and plays a vital role in the proper functioning of the Earth's ecosystems. The pollution of water has a serious impact on all living creatures, and can negatively affect the use of water for drinking, household needs, recreation, fishing, transportation and commerce. EPA (U.S Environmental Protection Agency) enforces federal clean water and safe drinking water laws, provides support for municipal wastewater treatment plants, and takes part in pollution prevention efforts aimed at protecting watersheds and sources of drinking water. The Agency carries out both regulatory and voluntary programs to fulfill its mission to protect the nation's waters .

2.2.5 Method of Distribution

Water may be distributed by gravity, by pumps alone, or by pumps in conjunction with on-line storage. Gravity distribution is possible only when the source of supply is located substantially above the level of the city. This is the most dependable technique, provided there are multiple well-protected conduits carrying the flow to the community.

Pumping without storage is the least desirable method of distribution, since it provides no reserve flow in the event of power failure and pressures will fluctuate substantially will variations in flow. Since the flow must be constantly varied to match an unpredictable demand, sophisticated control systems are required. Peak water use and thus peak power consumption are likely to coincide with periods of already high power use, increasing power costs. Pumping with storage is the most common method of distribution. Water is pumped at a more or less uniform rate, with flow in excess of consumption being stored in elevated storage tanks distributed throughout the system. During periods of high demand, the stored water augments the pumped flow, thus helping to equalize the pumping rate and to maintain more uniform pressure in the system. It may be economical, in some cases, to pump only during off-peak hours to minimize power costs.

2.3 Equipments of Water Distribution Systems

The distribution system of a waterworks consist of the pipes, valves, hydrants, and appurtenances used for distributing the water; the elevated tanks and reservoirs used for equalizing pressures and pump discharges; and the costumer service pipes and meters. A distribution system should be so designed that an adequate supply of water is available to the consumers. It should also be constructed and operated that the changes for contamination of the water after it has entered the system are reduced to a minimum. Since most distribution systems have developed with the growth of the community served, the problem of designing a complete new system seldom arises except for small towns. The principles involved in the design of a complete system may be employed in the design of extensions and reinforcing mains with modifications to suit each individual case.

2.3.1 Aqueducts and Water Pipes

Water, whether it is drawn from surface or ground supplies, must be conveyed to the community and distributed to the users. Conveyance from the source to the point of treatment may be provided by aqueducts, pipelines, or open channels, but once the water has been treated it is distributed in pressurized closed conduits. Pumping may be necessary to bring the water to the point of treatment and is nearly always a part of distribution system. The term aqueduct usually refers to conduits constructed of masonry and built at the hydraulic gradient. Such structures are operated at atmospheric pressure and, unless available hydraulic gradient is very large, tend to be larger and more expensive than pipelines operated under pressure. The advantages of aqueducts include the possibility of construction with locally available materials, longer life than metal conduits, and lower loss of hydraulic capacity with age. Their disadvantages include the need to provide the ultimate capacity initially and the likelihood of interference with local drainage.

Pipe is used in water conveyance and distribution is always of circular cross section. The stresses which the pipe must resist are produced by the static pressure of the water, centrifugal forces caused by changes in direction of flow, external loads, changes in temperature, and sudden changes in velocity. The pressure required in the mains for normal domestic consumption depends upon the height of the buildings, the maximum instantaneous rate of flow through the house service pipes, and the friction losses in meters, house services, plumbing, and fixture outlets. The maximum instantaneous rate of flow through a house service pipe depends upon the character and number of plumbing fixtures in the building and the probability of their simultaneous use.

Pipelines are commonly constructed of reinforced concrete, asbestos cement, ductile iron, steel, or plastic and are located below the ground surface only so far as is necessary to protect them against freezing and surface loads and to avoid other subsurface structures. In selecting the type of material and pipe size to be used, one should consider carrying capacity, durability, maintenance cost, and first cost. The character of the water and its potential effect upon pipe of different materials is an important consideration as well.

2.3.2 Centrifugal Pumps

A pump is a device used to move liquids. A pump moves liquids from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system such as a water system. Centrifugal Pumps are those which convert the mechanical energy into hydraulic energy by centrifugal force on the liquid. Hydraulic energy is in the form of pressure energy. So if the mechanical energy is converted into pressure energy by centrifugal force on the liquid is called the centrifugal pumps.

A pump's performance is shown in its characteristics performance curve where its capacity is plotted against its total developed head, efficiency, required input power, and NPSHr (net positive suction head required) The pump curve also shows its speed and other information such as pump size and type, impeller size, etc**.**

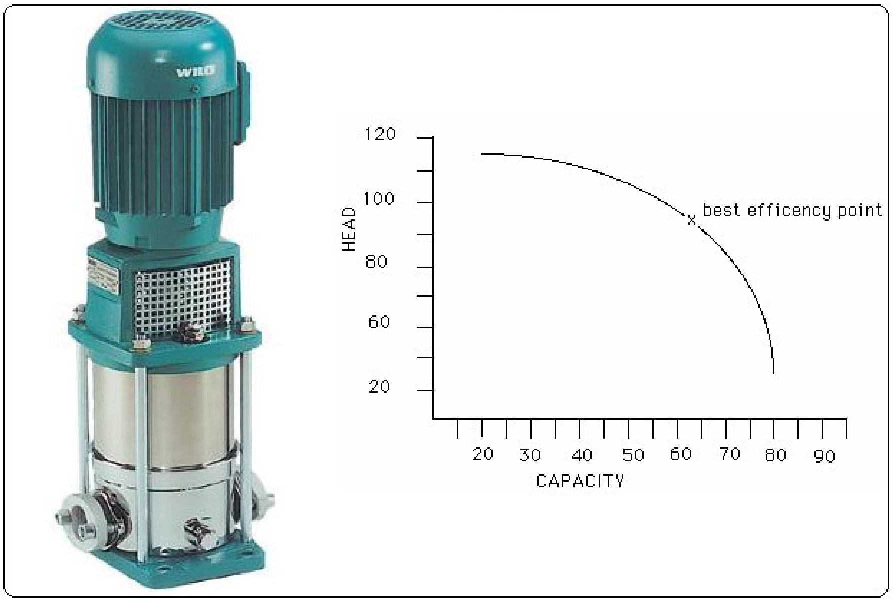


Figure 2.5 A Centrifugal Pump and its Characteristic Curve

A Centrifugal Pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. Centrifugal pumps are commonly used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radial outward into a diffuser or volute chamber, from where it exits into the downstream piping system. Centrifugal pumps work on the principle of conversion of the kinetic energy of a flowing fluid (velocity pressure) into static pressure. This action is described by Bernoulli's principle. The rotation of the pump impeller accelerates the fluid as it passes from the impeller eye (centre) and outward through the impeller vanes to the periphery. As the fluid exits the impeller, a proportion of the fluid momentum is then converted to (static) pressure. Typically the volute shape of the pump casing, or the diffuser vanes assist in the energy conversion. The energy conversion results in an increased pressure on the downstream side of the pump, causing flow.

2.3.3 Valves

A variety of valves and specialized appurtenances are used in water distribution systems. Gate valves are most commonly used for on-off service they are relatively inexpensive and offer relatively positive shutoff. Gate valves are located at regular intervals throughput distribution systems so that breaks in the system can be readily isolated. Valves which are operated frequently, such as those in treatment plants, must be designed to be resistant to wear and are often provided with hydraulic or electric operators. Most gate valves will operate properly only when installed in a vertical position. Globe and angle valves are seldom used in water distribution systems. Their primary application is in household plumbing where their low cost out-weighs their poor hydraulic characteristics. Butterfly valves are widely used in both low and high pressure applications. In large sizes, they are substantially cheaper, more compact, easier to operate, and less subject to wear than gate valves.

Check valves permit water to flow in only one direction and are commonly used to prevent reversal of flow when pumps are shut off. Check valves installed at the end of a suction line are called foot valves. These prevent draining of the suction line and loss of prime when the pump is shut down. Check valves are also installed on the discharge side of pumps to reduce hammer forces on the pump mechanism.

Pressure-regulating valves automatically reduce the pressure on the downstream side to any desired level. They function by using the upstream pressure to throttle the flow through an opening similar to that in a globe valve. The throttling valve will close or open until the downstream pressure reaches the preset values.

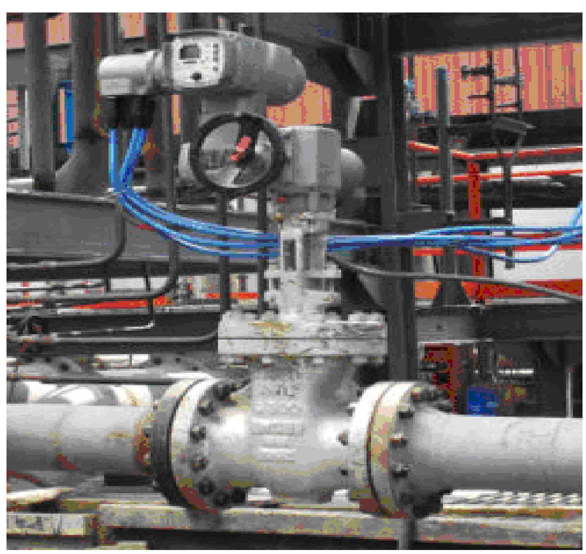


Figure 2.6 Actuator

Actuators are used for the automation of industrial valves and can be found in all kinds of technical process plants. They are used in water distribution and treatment systems. This is where they play a major part in automating process control. The valves to be automated vary both in design and dimension. The diameters of the valves range from a few inches to a few meters. Depending on their type of supply, the actuators may be classified as pneumatic, hydraulic and electric actuators Electric actuators are equipped with fully-fledged process controllers (PID controllers). Especially for remote installations, e.g. the flow control to an elevated tank, the actuator can assume the tasks of a PLC which otherwise would have to be additionally installed.

2.3.4 Distributing Reservoirs

Distributing reservoirs are used for storing water within or contiguous to the distribution area. Many surface reservoirs are built on hills. Reservoirs are said to be floating on the system when the water enters and leaves by the same pipe. They serve a variety of purposes as described below.

With regard to water quantity:

- Fire storage,
- Storage for fluctuating demand,
- Emergency storage.

With regard to pressures:

- Equalizing pressures in distribution system,
- Raising pressures at remote points,
- Equalizing heads on pumps.

Distributing reservoirs are built with and without covers. In order to prevent the contamination of the water from dust, fumes, bird droppings, algae growth, and other causes, it is highly desirable that distributing reservoirs be covered. The total amount of distribution storage required may be estimated from a reasonable combination of the three classes of storage, fire, fluctuating demand, and emergency. A major fire may readily occur on a day of large demand, but it is quite unlikely that emergency storage will be required at the same time. If the conditions are such that the required emergency storage is very large in comparison to the sum of the other two classes, the latter may be neglected safely. The location of storage may be determined by the function of the reservoirs, the available sites, or both. Storage for the control of pressures should be elevated, and the location of reservoirs for this function should be within or near the regions where pressure improvement is desired. If there are hills in the proper location, surface reservoirs may be used.

2.4 Water Consumption

It is self-evident that a large population will use more water than a small one and that water use must be, in some measure, related to population. While this is certainly true, and while water consumption estimates have been historically based on the population projections, such techniques are not always satisfactory. Water consumption is also influenced by factors such as climate, economical level, and population density, degree of industrialization, cost, pressure, and quality of the supply. A number of multivariate projection techniques have been developed which relate water use to one or more of these factors in addition to population. Since population is always a relevant factor in estimating future water use, it is necessary to predict, in some manner, what the future population will be. The selection of an appropriate technique for estimation of population is not always easy, and many engineers will test all methods which are clearly in applicable. The growth of a community with limited land area for future expansion might be modeled by the declining growth or logistic technique, while other, with large resources of land, power, and water and good transportation might be best predicted by the geometric or uniform percentage growth model. In nearly all cases, comparison is made to the recorded growth patterns of similar cities.

Municipal water demand is commonly classified according to the nature of the user. The ordinary classifications are:

- Domestic
- Commercial and industrial

- Public use
- Loss and waste

For example;

The total consumption is the sum of the individual elements listed above. In the United States in 1980, the total consumption on a per capita basis averaged 535L per day for privately owned utilities and 640L per day for publicly owned supplies. Consumption in the year 2000 has been estimated to be distributed as shown in Table 2.1.

Table 2.1 Projected consumption of water for various purposes in the year 2000

Usage field	**Liter per capita**	**Percentage of total**
Domestic	300	44
Industrial	160	24
Commercial	100	15
Public	60	9
Loss and waste	50	8
Total	670	100

2.5 Functional Requirements of the Distribution SCADA System

The operation of the facilities will be based upon the principle of balanced utilization of the existing water resources, the purification, storage and pumping capacities, according to the estimated water input and water demand. Total water input and water demand will be determined from the historical water consumption trends and the data, and considering this information assistance will be provided for the operation, planning, and programming of the existing facilities.

The water levels in the collection tanks and in main tanks will be monitored continuously and the level changes will be displayed on the computer screens, and the information obtained will be stored for historical recording purposes. The levels of water in tanks, based on the operating conditions at the relevant pump stations, will be controlled by electrically or electronically operated valves.

The output flows will be monitored continuously at certain measuring points and pump stations, the flow changes will be displayed on the computer screens, and the information obtained will be stored for historical recording purposes. Electrically and electronically valves will receive commands to control the flow rates remotely. The amount of water production and consumption will be computed from the data acquired and will be used as an aid to operate the existing production, purification and distribution stations, and to make decisions about investments which will be undertaken in these station in the future.

The input and output pressures at stations will be continuously monitored and the pressure changes will be displayed on computer screens. The data collected will be stored for historical recording purposes. The surges that may occur in the water network during power failures will be monitored by observing the pressure changes, and in such cases the pumps will be operated under proper conditions by waiting until the surges to end.

The water quality (chlorine, pH, turbidity, conductivity, dissolved oxygen etc) will be continuously monitored, and changes in the measured values of the water quality will be displayed on the computer screens. The information obtained will be stored for historical recording purposes. When those values bearing vital importance reach predetermined limits, proper warnings will have to be issued, and in dangerous conditions, assistance will be provided so that the necessary action is taken promptly.

The values about electrical measurements (3-phase current-voltage, active-reactive power, power factor) will be continuously monitored, the changes in the electrical values will be displayed on the computer screens, and the information obtained will be stored for historical recording purposes. The electrical values will provide information about the stability and cleanness of the electricity at the stations will assist to make corrections at the points where it is inappropriate, and will provide a way to observe the amount of energy consumed.

2.6 Designed Booster Pump Station Model

The energy that the system needs to deliver the water is called pressure. That energy is transferred to the water, therefore becoming water pressure, in a number of ways: by a pump, by gravity feed from a water source (such as a reservoir) at a higher elevation, or, in smaller systems, by compressed air. Pumps may be needed, therefore, to lift water from a reservoir to a water treatment plant, and after treatment another lift will be needed to force the water into the mains and elevated storage. In the system, booster pumps may be needed at certain points to keep pressure at desirable heights. The topography of a city may require pressure zoning. Most of the city may have normal pressures for all purposes but a low area, if directly connected, may have pressures that are too and house plumbing. This is remedied by supplying the low area through one or several feeder mains and installing automatic pressure-regulating valves that will maintain any desired pressure on the downstream side.

The primary consideration in the design of booster pump stations (BPSs) is that the quality of pumped water be maintained and that the operation of the BPSs does not cause water quality problems elsewhere in the water system. This includes the requirement to ensure that pressures in the distribution mains comply with the requirements of WAC 246-290-230 and 420. In general, booster pump station types may be categorized as open systems or closed systems. A closed system BPS is one which transfers water to a higher pressure zone closed to the atmosphere. A booster pump station model's selection parameters and calculations for this project are defined below. This area is industrial zone. Designed booster pump station model is shown in Figure 2.8.

<u>At this project area</u>:

Living personnel pollution: 23200 (%45 first zone and %55 second zone)

Daily working hours: 8-12 h/day

Daily water consumption: 130 liters/day/person

<u>First zone</u>

Pollution: 23200 *0.45 =10440 person

Maximum drinking-water demand: Qmax=10440*130/86400*1.5=23.56 l/s

Required total head (H): 56 m

Required pumps: 2 Centrifugal (1 main + 1 auxiliary)

Pumps: Layne Bowler-VTP10RMA7/40-1450 rpm (2 units) (for 58 mSS, 28 l/s)

Pump input power: Q (l/s)*H (m)/n=28*58/0.70=22.55 kW

Motors selection: Asynchronous, 30 kW, 1450 rpm, 60.9 A (with star/delta starter)

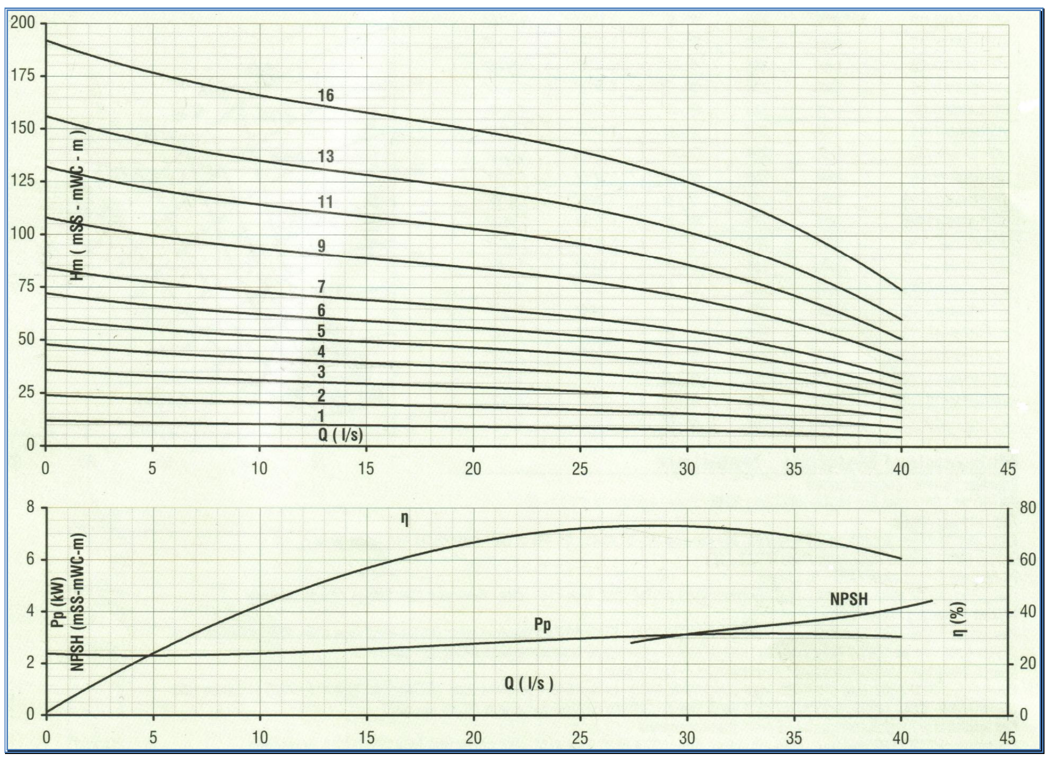


Figure 2.7 Layne Bowler Mark's Pump H-Q Curve

<u>Second zone</u>

Pollution: 23200 *0.55 =12760 person

Maximum drinking-water demand: Qmax=12760*130/86400*1.5=28.80 l/s

Required total head (H): 65 m

Required pumps: 2 Centrifugal (1 main + 1 auxiliary)

Pumps: Layne Bowler-VTP10RMA9/50-1450 rpm (2 units) (for 66 mSS, 32 l/s)

Pump input power: Q (l/s)*H (m)/n=28.8*65/0.70=26.74 kW

Motors selection: Asynchronous, 37 kW, 1450 rpm, 73.5 A (with star/delta starter)

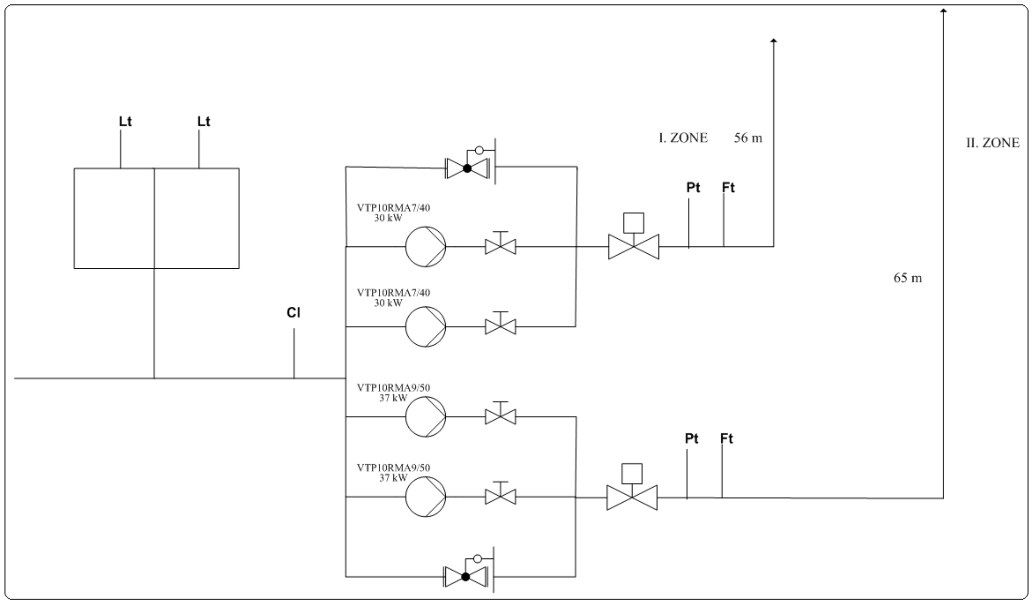


Figure 2.8 Designed booster pump station

CHAPTER THREE
SCADA SYSTEMS

3.1 Basic SCADA System Concepts

The acquisition of data, the processing of those data for use by the operator, and operator control of remote devices are the fundamental building blocks upon which all modern utility control systems are based. The systems to accomplish these functions are known as Supervisory Control and Data Acquisition (SCADA) systems SCADA systems are widely used in industry for Supervisory Control and Data Acquisition of industrial processes. SCADA systems are complex, and the investment for the organization is a long term one. Therefore, the organization must be proceed cautiously and with a logical series of steps to ensure they procure the most cost effective system that best meets their needs both now and in the future.

Supervisory control and data acquisition systems consist generally of a master station (master) and a number of geographically dispersed remote terminal units (RTUs). RTUs are interconnected to the master via a variety of communication channels, including radio links, leased lines, and fiber-optics (Gaushell, D.J., Block, R.B., 1993). A typical SCADA system communication architecture is shown in Figure 3.1. The master station consists of computer hardware, SCADA software and possibly application software. The communication methods from the master station to RTUs are usually not available from the SCADA manufacturer. Typical methods are telephone, radio, fiber optics and cable. The SCADA manufacturer's equipment can accommodate different communication methods, so it is up to you to determine the desired communication methods to use. Remote terminal units are available in different sizes to cost effectively meet the point count capability. Collected data of RTUs include analog inputs, status inputs, accumulator inputs and control outputs. With the microprocessor intelligence present in RTUs, they can perform local calculations such as simultaneous closed loop control algorithms (McDonald, J.D., 1993).

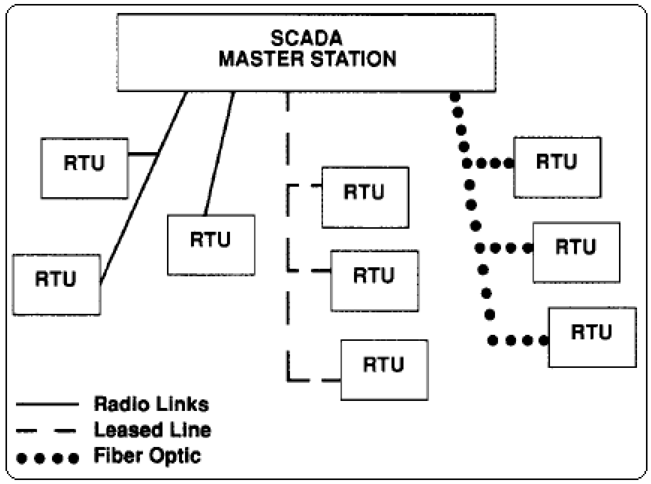


Figure 3.1 SCADA communication systems

A typical control system consists of one or more remote terminals connected to a variety of sensors and actuators, and relaying information to one or more master stations. A RTU is used to monitor and control sensors and actuators, and to transmit data and control signals to a central master monitoring station. Sensors and actuators are specialized hardware and software components that elicit information about the current status of or provide a means for influencing the process. The Master Station periodically obtains data from the RTU and provides an interface for control of remote devices.

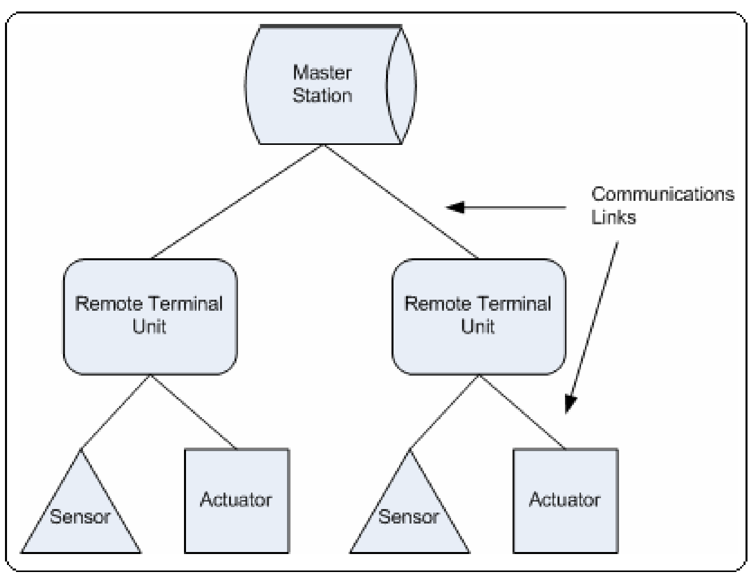


Figure 3.2 Three levels of a typical SCADA system

Supervisory Control and Data Acquisition (SCADA) is the term commonly applied to control systems involved in the distribution of a commodity. Figure 3.2, reproduced illustrates a generic three tiered-approach to SCADA control system design incorporating the three main components.

3.2 Control of Water Distribution Pipelines Using SCADA

In the pipeline industry, SCADA systems are used to collect data from pipeline sensors in real time and display these data to humans who monitor the data from remote sites and remotely operate pipeline control equipment (National Transportation Safety Board, 2006). For pipeline applications, SCADA systems consist of a main control computer connected via a communications link to field sensors (flow meters, pressure, transmitters, and temperature transmitters) and pipeline components (valves, pumps, control unit). The communications link can be made using leased telephone lines, satellite, microwave, radio circuits or a variety of other methods.

The controller monitors data and controls the pipeline from a SCADA workstation. The interface between pipeline controller and the SCADA system consists of displays on computer monitors and input devices, such as keyboards and mice. Figure 3.3 shows a current interface for pipeline controllers using multiple computer screens arranged around the controller. The controller uses this interface to assess conditions on the pipeline and to operate the pipeline. The SCADA interface provides feedback to the controller of actions that happen at remote sites to ensure the controller remains aware of all conditions along the pipeline. Alarms are generated and displayed when field conditions are outside acceptable preset levels, when status changes occur, or when functions within the SCADA system generate an alarm.

Field data for a limited time frame are stored in an operationally active database. For most systems, selected portions of the historical data are archived to another medium, typically an optical disc or tape drive. Many systems also provide a development computer platform for supervisor viewing of pipeline displays, training, and testing new software routines before implementing them in the SCADA computer.

Figure 3.3 The SCADA center of the İZSU Water Distribution System, İZMİR

Advances in technology have reduced the cost of SCADA systems, facilitating widespread SCADA implementation for pipeline control. Further, technological advances have increased the functionality of SCADA system. SCADA developers are also adding more analytic tools to assist controllers in detecting possible leaks, monitoring specific products in the pipeline, and monitoring trends on the pipeline across time.

3.3 SCADA System Architecture

SCADA system is defined as the computer system that performs the supervisory and control function and responds to the outside asynchronous event instantly. The principle function of the system is that it must identify and respond to the discrete events as soon as possible and process or stores all the acquired real time information. As the development of computer technology, SCADA system has been widely used in the area of transportation, water system and chemistry industry etc (Chen Qizhi, Qian Qingquan, 2000). The general architecture of SCADA consists of the subsystems with different degrees of complexity, as described below.

- Interface with the Operating system,
- Databases Subsystem ,
- Man-Machine Interface Subsystem,
- Communications Subsystem,
- Distribution Subsystem,
- Control Subsystem.

3.3.1 System Configuration

SCADA systems have previously been constructed as centralized systems using proprietary control computer and operating systems. But a centralized system imposes a burden on industrial company in the sense that it is sometimes difficult and uneconomical to expand or upgrade the system (Toshida, N., Uesugi, M., Nakata, Y., Nomoto, M. & Uchida, T., 1998). When a utility wants to improve and add some functions, it sometimes has to upgrade the existing computer's memory capacity or replace it with high grade computer. On the other hand, a recently emerging trend in the development of computer and communication technology has been making it possible to establish open distributed computer systems. The requirements for such a new SCADA system supported by latest technology are:

- Expandability and flexibility,
- Conformity to international standards,
- High reliability,
- High functionality and high performance,
- High-level human interface.

The system configuration is shown in Figure 3.4. This configuration is consisting of servers and engineering workstations which are mutually connected through local area networks using Ethernet. The servers are front end processors, real-time data servers, DMS servers, and data servers. The engineering workstations provide the human interface.

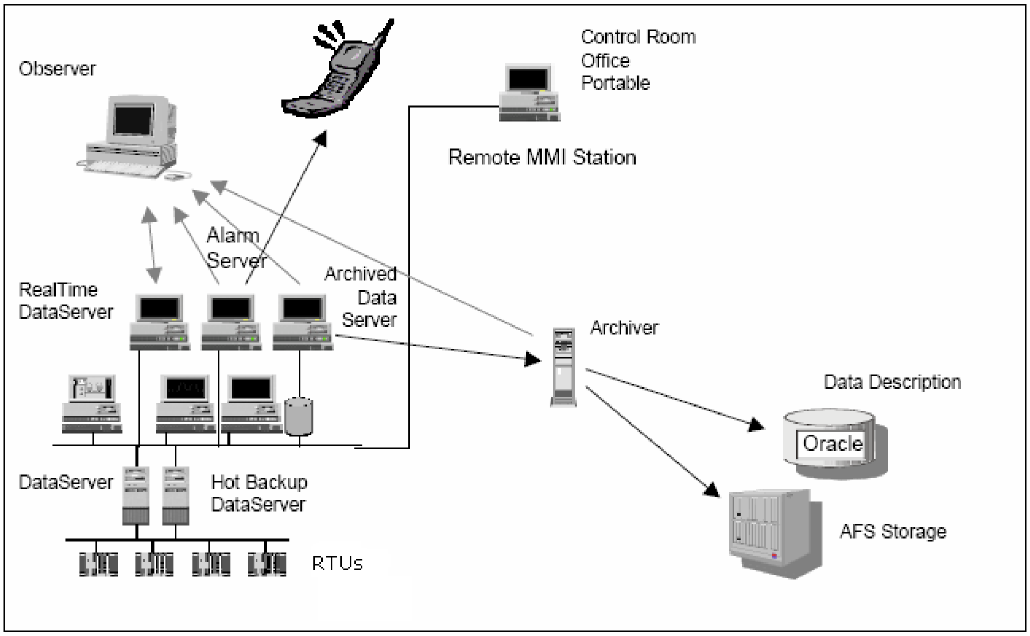


Figure 3.4 SCADA system hardware configurations

The development task of SCADA system aims on the development of application software. As the key part of real-time SCADA system, the software platform plays an important role for supervisory software developing. The software platform chosen for SCADA system not only must have the character of fast real-time response and high reliability, but also must own the all necessary attributes of open system, such as the flexible expansion, easy mutual operation and strong ability of network communication. Generic software architecture is shown in Figure 3.5. The SCADA software will be based on a client-server architecture, whereby the failure of a computer connected to the LAN will not affect the operation of other computers on the network.

The operating system that drives the computer hardware on which the SCADA software runs will be of an architecture that provides a multi-tasking operating environment and the SCADA software will also be multi-tasking. Therefore, multiple tasks such as receiving the measurement results from the RTU's, displaying these results on the computer screen, storing on a computer disk, sensing the alarm conditions that may occur based on the measurement results, and displaying them to the users, generating reports from the collected data, and printing them out, transferring issued commands to the RTUs that the SCADA software is supposed to execute, can be handled simultaneously without one task waiting for another.

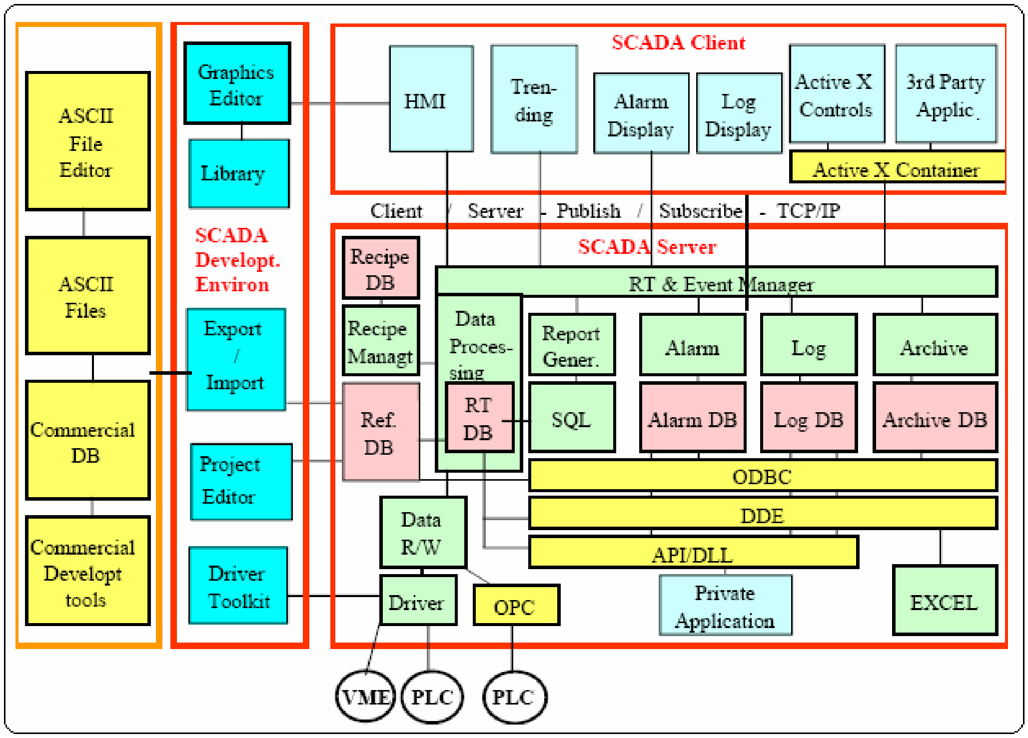


Figure 3.5 Basic software configurations

The SCADA software will be easily configurable by a system engineer who will be responsible for the technical aspects of the SCADA system. The system configuration definitions can be either defined directly by using a keyboard or another interactive tool or mechanisms that allow importing of the configuration definitions from a text file created with a text editor. Making additions to the configuration definitions, modifying existing configuration definitions, or deleting the configuration definitions of the SCADA system will be provided for directly without the need for modifying, re-compiling, or linking the source codes.

Adding an RTU to the system, or deleting an RTU from the SCADA system, changing the configuration information related to an existing RTU definitions, modifying the definitions in the database containing information about the measurement and control points, creating the screens which provide operators to monitor and control the SCADA system, and all similar configuration will be able to be done on line while the SCADA system is operating.

As an excellent open operation system, UNIX system has been used widely as the developing platform for application system development. Although UNIX has many characteristics that are suitable for SCADA system, it really is a time-sharing operation system and has many obstacles for SCADA system development. The characteristics of UNIX, which are suitable for real-time supervisory and control system, can be described as the following:

- UNIX system is the symbol of open system,
- Perfect and fast inter process communication mechanism,
- Multi process schedule supporting,
- Strong and perfect ability of network communication,
- A lot of tools for program debug and maintenance,
- Real-time response ability is enhanced than before,
- UNIX has made great progress in many areas, such as SMP, micro kernel, multi thread support, graphical administration and operation interface, tolerance process, security and stability etc.

3.3.2 Functionality

Operator interface, human machine interface (HMI), and man machine interface (MMI) are all terms used to describe equipment that allows an operator or system user to manipulate or control a process. The products support multiple screens, which can contain combinations of synoptic diagrams and text. They also support the concept of generic graphical object with links to process variables (Daneels, A., Salter, W., 1999).

Synoptic are windows that enable the user to show the information in a graphical form, variable and configurable by using dynamic objects with many possible ways of representing them (bitmap sequence, color changes, scaling according to values, changes to text, etc.). These objects are customized for each application. Example of synoptic screen for a SCADA system is shown in Figure 3.6. The behavior of the dynamic elements on the screen can be associated with a large amount of information contained in the RTDB:

- Value of an analog signal,
- Status of a digital signal,
- Tag and characteristics of a signal (active, inactive, deactivated alarms, etc) ,
- Pending alarm Acknowledge,
- Communications status with RTUs and peripherals from the central Workstation.

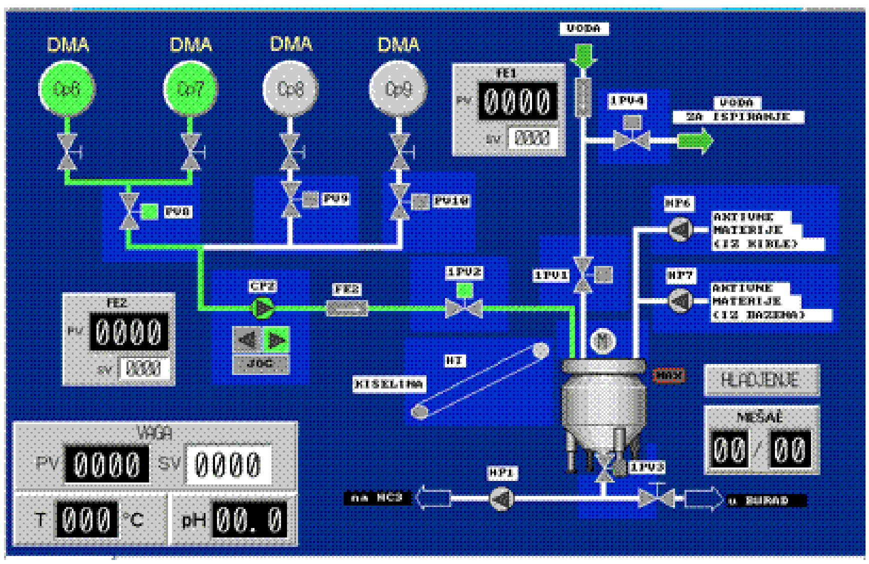


Figure 3.6 Example of synoptic screen

The products all provide trending facilities and one can summarize the common capabilities as follows and a received graphic from the water distribution system is shown in Figure 3.7.

- The parameters to be trended in a specific chart can be predefined or defined on-line,
- Real-time and historical trending are possible, although generally not in the same chart,
- Historical trending is possible for any archived parameter,
- Parameter values at the cursor position can be displayed.

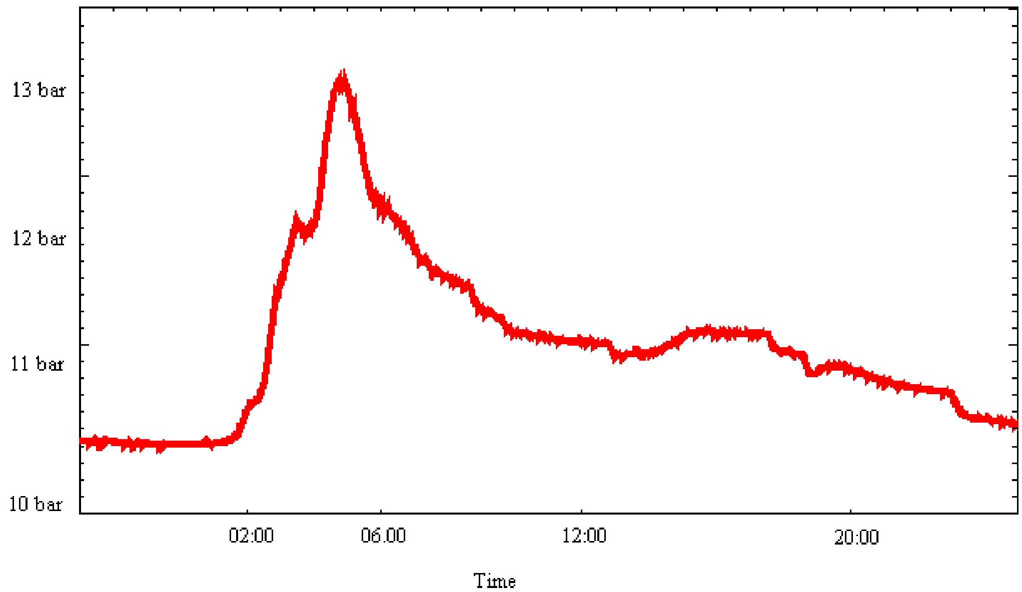


Figure 3.7 Pressure-time trend curves

Alarm handling is based on limit and status checking and performed in the data servers. More complicated expressions (using arithmetic or logical expressions) can be developed by creating derived parameters on which status or limit checking is then performed. In addition to, reports can be produced using Oracle type queries to the archive, RTDB or logs.

3.3.3 Database Management System

All the information who's updating is not subjected to stringent time restrictions as configuration, historic events, etc. is stored and processed with a database management system. Therefore, access can be gained to this information from many tools on the market, such as other databases, editors, etc. SHERPA software by ELIOP firm can be selected for this project which uses two main methods for storing and managing the information, which are consistent with the way that the information is structured and handled. Configuration database method contains all the information about the telecontrol, communications, central workstation and information that specifies how SHERPA behaves in each application; it is supported on the database system. Real-time database stores all the information that is arriving from the field through the remote stations and other equipment.

Historic database stores information concerning digital signals, analog signals and meters for a variety of periods that are pre-established. Alarm database contains data concerning events, detected by software, which have been configured as alarms and are presented like that to the operators.

3.4 SCADA System Communication

SCADA systems consist generally of a master station and a number of geographically dispersed RTUs. These remote terminal units are interconnected to the master via a variety of communication channels, including radio links, fiber-optics etc. Due to the limited availability and high cost of communication channels, the design of master and RTUs is profoundly affected. Communication channels limit the speed at which data acquisition and control can be performed, thus affecting the master user interface and applications software design. In addition, noise occurring randomly on the communication channel requires additional master and RTU hardware and software design to guarantee that information is transferred correctly from master to RTU, and from RTU to master. Configurations of communication systems are dictated by:

- Number of RTUs,
- Number of points at RTUs and required update,
- Location of RTUs,
- Communication facilities available,
- Communication equipment and techniques available.

Two basic types of modems are utilized for transmitting information via a communication channel: asynchronous and synchronous. The asynchronous type utilizes separate timing sources such as crystals at each end of a data link to make the receiver demodulate the data at approximately the same rate at which it was modulated by the transmitter. Due to this approximation, the data message must be frequently resynchronized by dividing the message into short blocks or characters, each with their own synchronization bits. This is an advantage for short messages where a quick synchronization is desired. Thus, the efficiency is relatively high because of the synchronization overhead. Cost is very low, due to simplicity. The synchronous modem, on the other hand, transmits a synchronizing clock signal along with the data stream, so that the receiver is precisely synchronized with the transmitter;. This technique allows very long messages and high data rates to be transmitted without any problem with falling out of synchronization. However, it does require a longer period of time to establish synchronization, a disadvantage for short messages because the ratio of overhead to data is high. Synchronous modems are generally available from 2400 bps to 1 Mbps and are higher in cost than the asynchronous type.

The transmission of information between the master and RTUs using TDM techniques requires the use of serial digital messages. All messages are divided into three basic parts:

- Message establishment, which provides the signals to synchronize the receiver and transmitter and the unique RTU address,
- Information, which provides the data in a coded form to allow the receiver to decode the information and properly utilize it,
- Message termination, which provides the message security checks and a means of denoting the end of the message. Message security checks consist of logical operations on the data which result in a predefined number of check bits transmitted with the message. At the receiver, the same operations are performed on the data and compared with the received check bits. The message is accepted if they are identical; otherwise, a retransmission of the original message is requested.

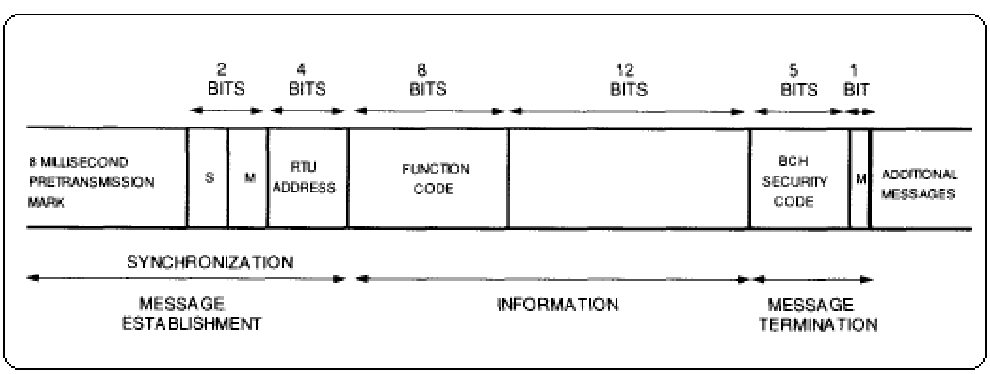


Figure 3.8 Format of a typical asynchronous message

A typical example of commonly used asynchronous message format is shown in Figure 3.8. The efficiency of the example format is 12/32 or 37.5 percent, which is typical for the asynchronous format.

3.5 Standards and Protocols

In SCADA systems, the three major categories of protocols involve the specifications for design and manufacture of sensors and actuators, specifications for RTUs, and the specifications for communications between components of a control system. The specifications for design and manufacture of sensors and actuators are concerned with the engineering requirements for specific industrial components such as valves and measurement equipment, and also dictate safety tolerances, measurement thresholds, and environmental considerations. They are typically issued by the ISO (International Standards Organization) or the IEC (International Electrotechnical Commission. The rationale for protocol standards includes the need to avoid customization when interfacing different systems, different RTUs, system upgrades, etc. A continual problem in the industry has been the proliferation of master to RTU message formats requiring several different communication interfaces for a typical system and making additions to the system much more difficult and expensive. Additional system software plus custom hardware/firmware are required to provide the required interface.

With regard to master-to-master station communication, as well as master-to-sub master levels of the same system, a standard message protocol would promote interchange of information between the various entities. This would provide for a more effective system and allow for many new application functions to be performed by the SCADA systems. Within a utility's SCADA system, exchange of data between sub masters, masters, and applications processors is required to provide for proper control of various system elements and to allow applications functions using data from different hierarchical levels to be used. For example, line flow data from SCADA sub masters could be passed to the master station for monitoring, and used by applications processors in a state estimator program. The results would be passed back to the sub masters. Presently, these internal data exchanges utilize the protocols of the manufacturers of the various system levels. Therefore, if a hierarchical level is replaced, often with the equipment of a different supplier, then custom interfaces are required.

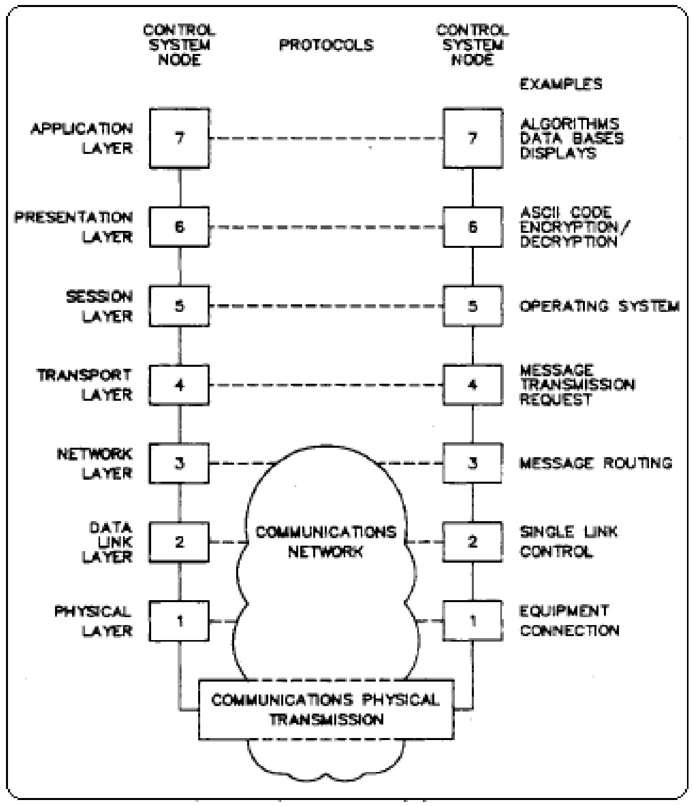


Figure 3.9 OSI seven layer reference model

The OSI (Open Systems Interconnection) reference model is shown in Figure 3.9. This model describes the functions involved in communications between systems, and the terms used to define those functions. The OSI model breaks the overall process into a seven-layer structure; each layer defines a set of message protocol functions which may be performed using hardware, software, or firmware. The bottom three layers; physical, data link, and network, defines the components of the communication network, while the top three layers; session, presentation, and application, represent the functions of the end system. The middle layer, transport, links the bottom and top layers. The interfaces between layers are specified to allow different suppliers of the individual layers. In other words, the overall communication process is divided into seven predefined layers to stimulate common development of individual components. Thus not only can we communicate between different systems, we can interface between different components within a system.

3.5.1 RTU Design-Programming Standards

The prevalent standard for water distribution system RTU design and programming is the IEC 61131 series, developed by the two IEC working groups, the Industrial Process Measurement and Control group and the IT Applications in industry group. It is a series of seven publications that serve to standardize the programming languages, instruction sets, and concepts used in industrial control devices as RTUs. Detail of IEC standard 61131 is given in the Table 3.1.

Table 3.1 Detail of IEC Standard 61131 Description

Standard	**Description**
IEC 61131-1	General Information
IEC 61131-2	Specifies requirements and related tests for PLCs and associated peripherals. Establishes definitions and identifies principal characteristics. Specifies the minimum requirements for functional, electrical, mechanical, environmental and construction characteristics, service conditions, safety, Electromagnetic Compatibility (EMC), user programming and testing.
IEC 61131-3	Specifies syntax and semantics of programming languages for programmable controllers
IEC 61131-4	Technical Report. Provides guidelines addressing the application PLCs and their integration into automated systems.
IEC 61131-5	Specifies communications aspects of a PLC. Specifies behavior of the PLC as it provides services on behalf of other devices and the services the PLC application program can request from other devices. Specified independent of the particular communication subsystem.
IEC 61131-6	Reserved for future use
IEC 61131-7	Specifies a means to integrate fuzzy control applications in the PLC languages as defined in Part 3.
IEC 61131-8	Technical report addressing the programming of PLCs using the PLC languages defined in Part 3

3.5.2 Open SCADA Communication Protocols

The key benefit of an open standard is that it provides for interoperability between equipment from different manufacturers. This means for example that a user can purchase system equipment such as a master station from one manufacturer, and be able to add RTU equipment sourced from another manufacturer. The RTU in turn may have a number of control relays connected to it which are intelligent electronic devices and also use the protocol. All of this equipment may be sourced from different manufacturers, either in an initial installation, or progressively as the system is developed over time. Arising from recognition of the need for open SCADA communication protocol standards, work was carried out by standards organizations on a number of fronts over a period of some years. These led by the end of the 1990s to two open SCADA communications protocols, known as DNP3 and IEC 60870. Two open protocol standards have emerged from the EPA model and the specification of frame formats in IEC 60870 (Clarke G., Reynders D., 2004).

DNP3: Distributed Network Protocol Version 3.3 is a telecommunications standard that defines communications between master stations, remote telemetry units (RTUs). DNP3 was designed specifically for SCADA applications. These involve acquisition of information and sending of control commands between physically separate computer devices. It is designed to transmit relatively small packets of data in a reliable manner with the messages involved arriving in a deterministic sequence. DNP3 is an open protocol that is gaining widespread acceptance and usage across a number of industries and countries. It is optimized for SCADA communications, and provides secure and efficient communications for the types of messages transferred by these systems. DNP3 defines four layers, physical, data link, pseudo-transport, and application. It is less restrictive than IEC 60870 and thus allows for expandability beyond the water industry.

IEC 60870: The standard provides a detailed functional description for telecontrol equipment and systems for controlling geographically widespread processes, in other words for SCADA systems. The standard is intended for application in the electrical industries, and has data objects that are specifically intended for such applications; however it is not limited to such applications as it has data objects that are applicable to general SCADA applications in any industry. Details of IEC 60870 standards are described in the Table 3.2.

Table 3.2 IEC Standard 60870

Standard	**Description**
IEC 60870-5-1	Transmission Frame Formats (1990)
IEC 60870-5-2	Link Transmission Services (1992)
IEC 60870-5-3	General Structure of Application Data (1992)
IEC 60870-5-4	Definition and coding of Information Elements (1993)
IEC 60870-5-1	Basic Application Functions
IEC 60870-5-101	Transmission Protocols, companion standards especially for basic telecontrol tasks (1995)
IEC 60870-5-102	Companion standard for the transmission of integrated totals in electric power systems (1996)
IEC 60870-5-103	Transmission protocols, Companion standard for the informative interface of protection equipment (1997)
IEC 60870-5-104	Transmission Protocols, Network access for IEC 60870-5-101 using standard transport profiles (2000)

Of particular importance is section 3.5 of this chapter which redefines the 7-layer OSI Reference Model to fit a SCADA environment. IEC 60870-5 and four companion standards define physical, link and application layers, as well as a "user process" above the application layer for non-networked (point-to-point) applications. It also defines a five layer model for networked applications, adding a network and transport layer. These standards are IEC 60870-5-101 and -104 respectively.

Modbus: Modbus is a relatively slow protocol that does not define interfaces, thus allowing users to choose between EIA-232, EIA-422, and EIA-485 or 20mA current loop. While slow, it is widely accepted. The Modbus protocol is still one of the most popular protocols used in the world today and is used extensively in industrial automation and SCADA systems. The Modbus is accessed on the master/slave principle, the protocol providing for one master and up to 247 slaves. Only the master initiates a transaction.

Profibus: Profibus is a German standard that defines three types; Field Message Specification (FMS) for use in general data acquisition systems, Decentralized Peripherals (DP) for use when fast communication is required, and Process Automation (PA) for use when highly reliable and safe communication is required. It defines three layers: physical, data link and application.

CHAPTER FOUR
SCADA EQUIPMENTS

4.1 Overview of Control Systems

The use of automation in manufacturing and industrial processes presupposes a mechanism for the operator to control and monitor physical functions in real time. As Complexity of these processes increases; the ability for remote control and monitoring from a central location provides increased labor and cost efficiency and offers opportunities to increase the economies of scale. Further, aggregation of feedback data provides supervisors and management personnel the ability to monitor trends, forecast requirements, and optimize procedures. A control system is the generic term for the hardware, software, and procedures used to control and monitor these processes, and to manage the accumulated data for later study. A typical control system consists of one or more remote terminal units (RTU) connected to a variety of sensors and actuators, and relaying information to a master station. Figure 4.1 illustrates control system design.

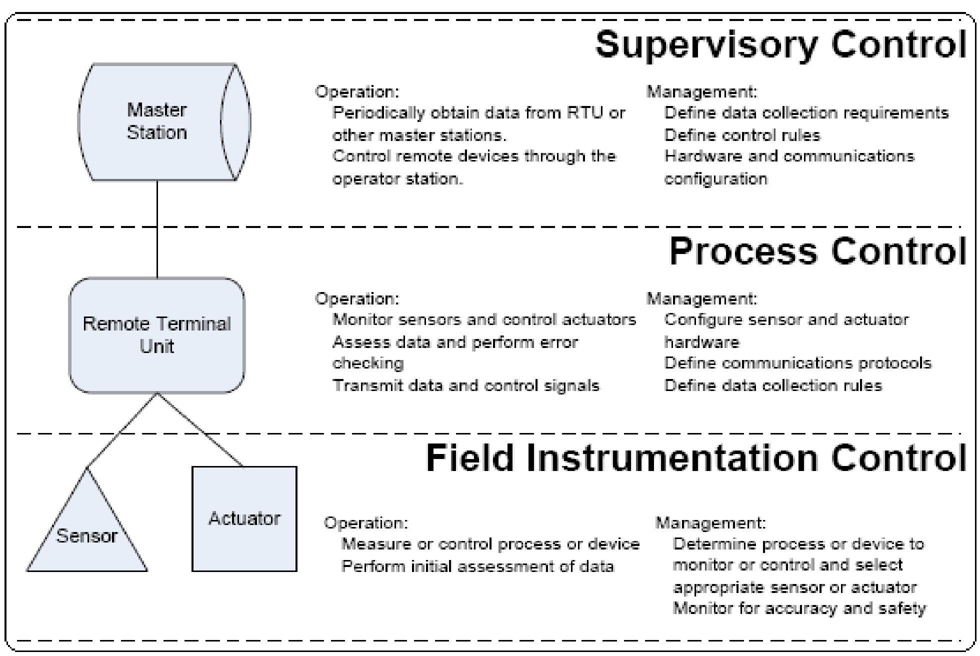


Figure 4.1 Schematic of the available methods of supervisory control, of process control, and field instrumentation control

The design and function of the RTUs, sensors, actuators, and master station, as well as the means of communication between components, are implementation details that will vary depending on the manufacturing or industrial process being controlled. A distributed control system may have multiple master stations or layers of master stations.

4.2 Sensors and Actuators

The philosophy behind control systems can be summed up by the phrase "If you can measure it, you can control it". Sensors perform measurement, and actuators perform control. Sensors measure level, pressure, flow, current, voltage, temperature, a binary status, or react to some other external stimulus. The acquired data can be either analog or digital. The results of the measurements are transmitted via a communications link to the RTU in either a raw form or manipulated by a processor found within the sensor itself before transmission to the RTU. The communications link itself may be analog or digital. Actuators are the mechanical devices for moving or controlling a mechanism such as valves. These equipments accept a signal and convert it to a physical action. Actuators can be applied to butterfly valves for water distribution networks.

4.2.1 The Required Instrumentations for Water SCADA

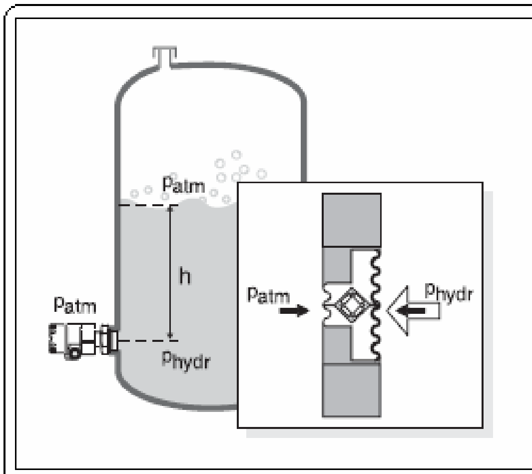
Instrumentations are installed at remote field locations consist of measuring devices for items such as pressure, temperature, flow, current, voltage etc., as well as sensors that indicate the status of equipment and/or facility related items (valves, pumps, security alerts, etc.). In addition, a typical SCADA application would also normally include certain controllable devices capable of starting/stopping pumps, opening/closing valves, flow rate controller. The instrumentations which are suitable for real-time supervisory and control system can be described as the following;

- ✓ Level information (Tank, Observation),
- ✓ Flow information (Momentary, total),
- ✓ Pressure information,
- ✓ Quality of water (Chlorine, pH, Turbidity, Conductivity, O2),

- ✓ Motor temperature information,
- ✓ Valve position (%),
- ✓ Electrical values (Current, Voltage, Active power),
- ✓ Energy information (Active, Reactive),
- ✓ Position information (Open/Close, On/Off).

All of the used sensors/transmitters are powered from 24 Vdc power supplies. Transmitters are used to convert the signal produced by the sensor to an electrical signal recognizable to the processing instrumentation. The inputs of the sensors are connected to the measurement points, and outputs of transmitters are connected properly to the analog inputs of the RTUs. The outputs all the transmitters are given 4-20 mA-dc.

The level transmitters to be used as an intermediate device in level measurements (hydrostatic level measurements) to be performed at the stations will function as the converter between the RTUs and the measurement points. They will be installed at the places determined at the stations, and outputs of the transmitters will be connected to the analog inputs of the RTUs. The mathematical formula for level measurement is given in the Figure 4.2.



$$p_{hydrostatic} = \rho \times g \times h$$

ρ = density
g= gravitational constant
h = distance between the surface of the liquid and the center of the process diaphragm

Figure 4.2 The principle of level measurement

The pressure transmitters to be used in gauge-pressure measurements to be performed at the stations will serve as the converter between the RTUs and the measurement points. They will be installed at the points determined at the stations, and outputs of the transmitters will be connected to the analog inputs of the RTUs. A typical pressure transmitter is shown in Figure 4.3.

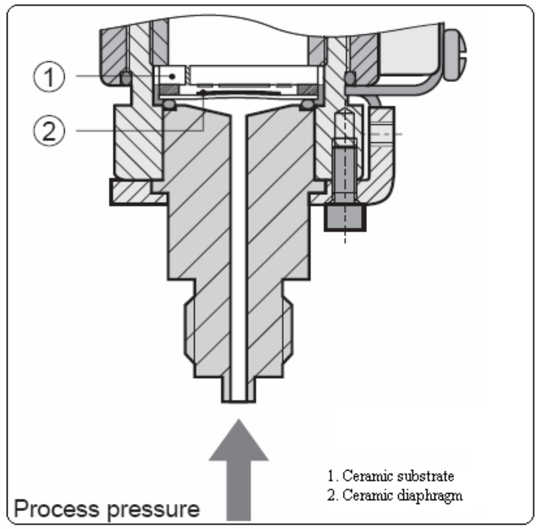


Figure 4.3 A typical pressure transmitter

The ceramic sensor is a dry sensor with the process pressure acting directly on the rugged ceramic diaphragm. A pressure proportional change in the capacitance is measured by the electrodes on the ceramic substrate and diaphragm. The measuring range is determined by the thickness of the ceramic diaphragm.

The chlorine measuring system is used to measure the chlorine. This system will basically contain a chlorine sensor, a sensor assembly and a chlorine transmitter to function as the converter between the RTUs and the measurement point. The membrane covered sensor consists of a cathode electrode and an anode electrode. These electrodes are immersed in an electrolyte. Electrodes and electrolyte are separated from the medium to be measured by a membrane. This membrane prevents the loss of electrolyte. A fixed polarization voltage is applied the anode and the cathode.

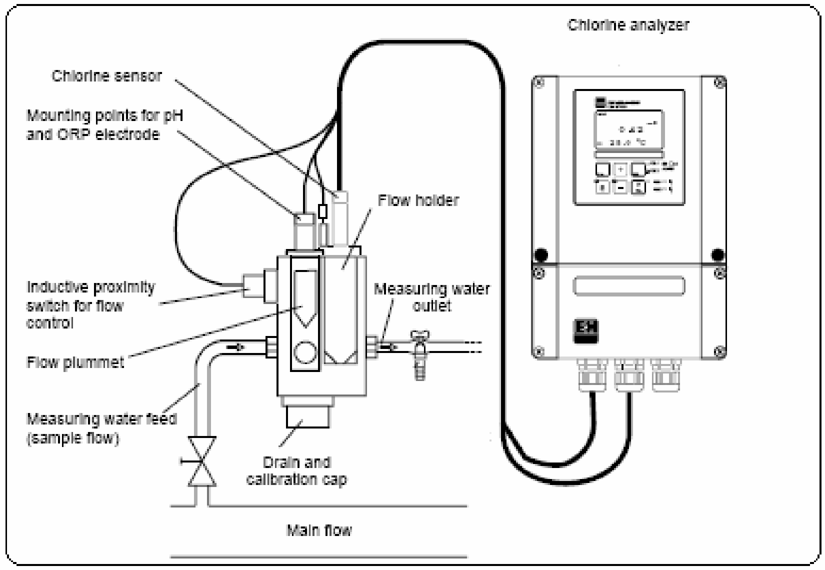


Figure 4.4 Chlorine measuring systems consist of a chlorine sensor, a chlorine assembly, and a chlorine transmitter

4.2.2 Electromagnetic Flow meters

The electromagnetic flow meters to be used in flow measurements at the station will function as the converter between the RTUs and the flow measurement points. They will be installed on the pipes indicated at the stations, and the connections of the sensors will be made at transmitter. The outputs of the transmitters will be connected to the analog inputs of the RTUs. The electro magnetic flow transmitters will indicate the instantaneous as 4-20 mA-dc analog output, total flow as pulse output, and sensor breakdown or power failure as a dry contact.

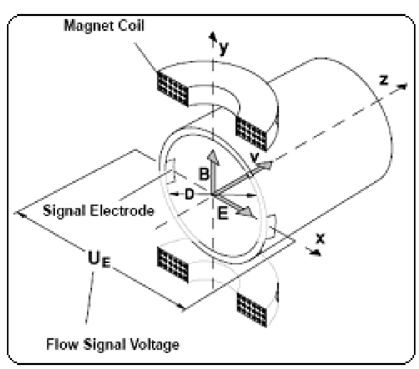


Figure 4.5 Flow meter's measuring cell

The electrode probes sense the electromagnetic force induced and this signal is conditioned so it can be used by external displays and recording instruments such as microcontrollers. Depending upon the specific applications, the output may be calibrated. Because of the weak magnetic field the magnitude of the induced electromagnetic force is extremely small. The small electromagnetic force may lead to problems with electrical noise and significant errors in the measurement. If it is desired to install an electromagnetic flow meter, precautions must be checked to ensure that the meter is installed properly and it is operational. For example; it must be avoided locations near equipment producing electrical radiation such as transformers, radio transmitters, motors, ignition systems, cathodic protection system, and other equipment that causes electromagnetic or electrostatic interference. Electromagnetic or electrostatic interference affects the operation of an electromagnetic flow meter. Failure in grounding the detector properly will result in unsteady readings and inaccurate measurements.

4.2.2.1 E.M.I Effects of Cathodic Protection on Flow meter

The DC source of cathodic protection system drives positive current from impressed current electrode through the corrosion media and onto the metal structure. The protective electrical currents cause electromagnetic or electrostatic interference. Transducer performance can be affected since electromagnetic interference (EMI) can distort the magnetic field of the electromagnetic flow meter. If specific precautions; such as installing an electromagnetic flow meter in pipelines with cathodic protection are not taken, measurements will be wrong.

Figure 4.6 shows the electrically insulated test set-up. Short circuit is occurred between two reciprocal flanges. When a short circuit occurs between two flanges, cathodic protection current flows through EMF sensor. This event is an undesired problem and causes measurement error.

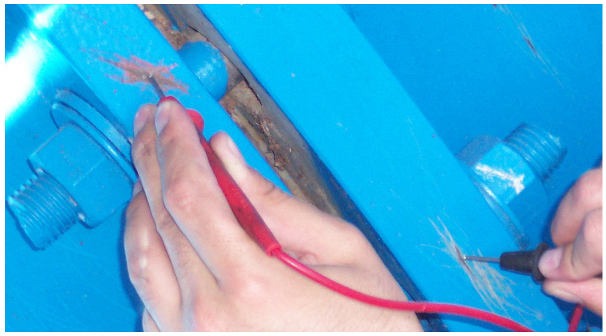


Figure 4.6 Short circuit tests between two reciprocal flanges

Approximate measurement results for pipes with cathodic protection are reported in Table 4.1. According to the experimental operation it can be noticed that; if DC voltage and current values increase, the flow meter values decrease. Measurement results in Table 4.1 are shown graphically in Figure 4.7. The graphic represents the effect of the cathodic protection current on the flow rate of the electromagnetic flow meter (Gündoğdu S., Şahin Ö.; January 26, 2007).

Table 4.1 Reported measurement results

Measurement Results		
DC Source(T/R)		**EMF's value**
Voltage (V)	Current (A)	Flow (lt/sn)
0	0	425
2	2.1	420
4	4.2	415
6	6.35	390
8	8.4	380
9	9.5	350
10	10.5	230
12	13	210
14	15.5	205
16	19	195

The diameter of the steel pipe investigated in this study is 1000 millimeters and its length is about 7 kilometers. These types of pipes are generally used by the Izmir Municipality, Department of Water and Drainage Administration (IZSU) in Turkey. Cathodic protection method used for this pipeline is impressed current anode system. Current requirement from transformer/rectifier (T/R) unit varies between 5 and 7 Amperes depending on the season. It can be seen from the graphic that the measured flow rate decreases as the current increases. Decrease in flow rate becomes more important when current value exceeds 9 Amperes.

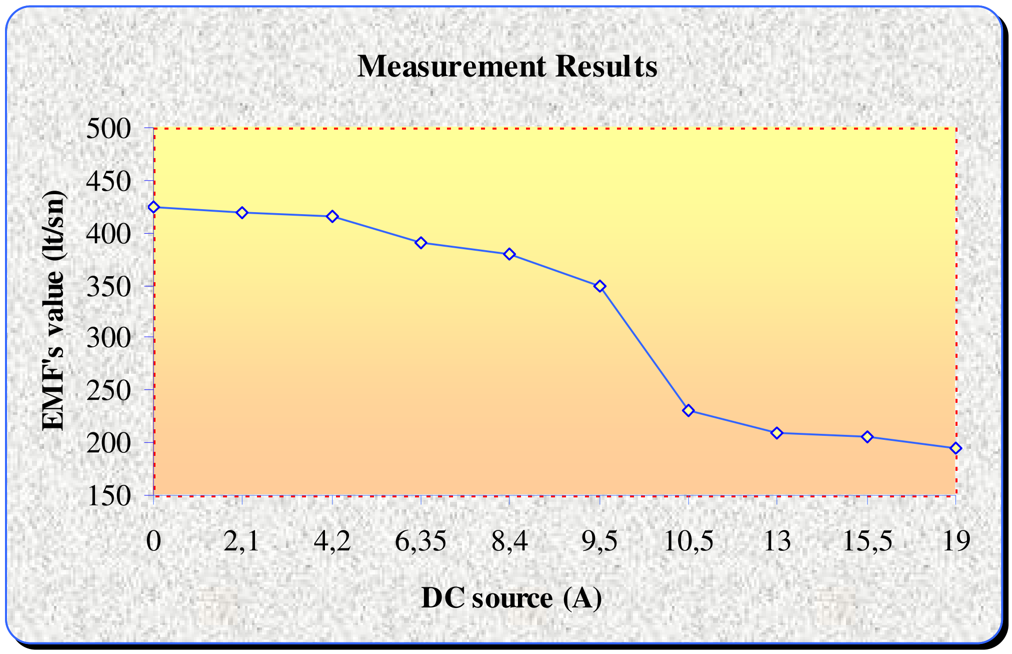


Figure 4.7 Graphic representation of the EMF's value-dc current characteristic

When installing an electromagnetic flow meter in pipelines with cathodic protection, some specific conditions must be taken into account. The sensor and the medium must have roughly the same electrical potential to ensure that the measurement is accurate and no electrical erosion takes place at the electrodes. Normally the reference electrode in the sensor or the metal pipe ensures that the potentials are equalized. The transmitter must be supplied through an isolation transformer for compact mounting. The EMF should be installed with grounding plates, located between flanges, up- and downstream of the flow meter which are insulated from the pipeline in order to provide a shunt path for the Cathodic Corrosion Protection (CCP) potential for pipelines with interior insulating liners. The grounding plates up and downstream of the EMF are at the ground potential.

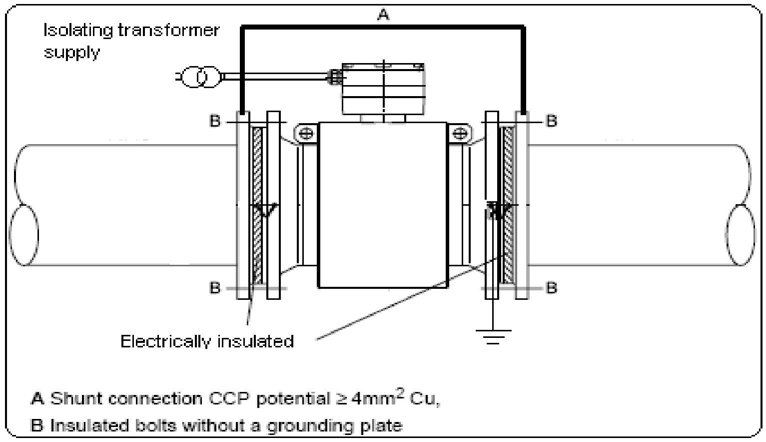


Figure 4.8 Applicable some precautions for reducing error.

Grounding plates should be installed up and downstream of the flow meter primary. They must be insulated from the flanges and connected to ground together with the flow meter primary. The flange bolts should be insulated and installed properly. The CCP potential must be shunted around the insulated flow meter primary.

Measurements are realized on the water distribution pipelines of the Izmir Municipality, Department of Water and Drainage Administration (IZSU) in Turkey. Cathodic protection method used for this pipeline is impressed current anode system. It is noticed from the measurement results that the measured flow rate decreases as the current increases. Decrease in flow rate becomes more important when current value exceeds 9 Amperes. Current requirement of the pipeline on which the measurements are made does not exceed 7 Amperes. So, maximum flow meter error is less than 10%. At galvanic anode systems where low current is used, flow meter operation is usually not affected by electromagnetic interference in a great deal. But for high current requirements, impressed current anode systems are used and experimental results obtained in this study shows that the flow rates decrease when the current is greater than 9 Amperes. It is concluded that the CCP method used by the IZSU is appropriate and flow meter error is less than 10%. Some precautions, proposed can be applied for reducing flow meter error for applications with higher current requirements.

4.3 Remote Terminal Units

A Remote Terminal Unit (RTU) is a standalone unit used to monitor and control sensors and actuators at a remote location, and to transmit data and control signals to a central master monitoring station. RTUs are generally remotely programmable, although many can also be programmed directly from a panel on the RTU. Figure 4.9 shows schematic diagram of a typical RTU. A RTU consists of a power supply, a central processing unit (CPU), memory, and a series of inputs and outputs. The CPU controls communications with the sensors and actuators through the inputs and outputs, and with the master station through a serial port, an Ethernet port, or some other interface. A programming interface can also be connected to any of these interfaces. The central bus serves as the conduit for communications between the components of the RTU.

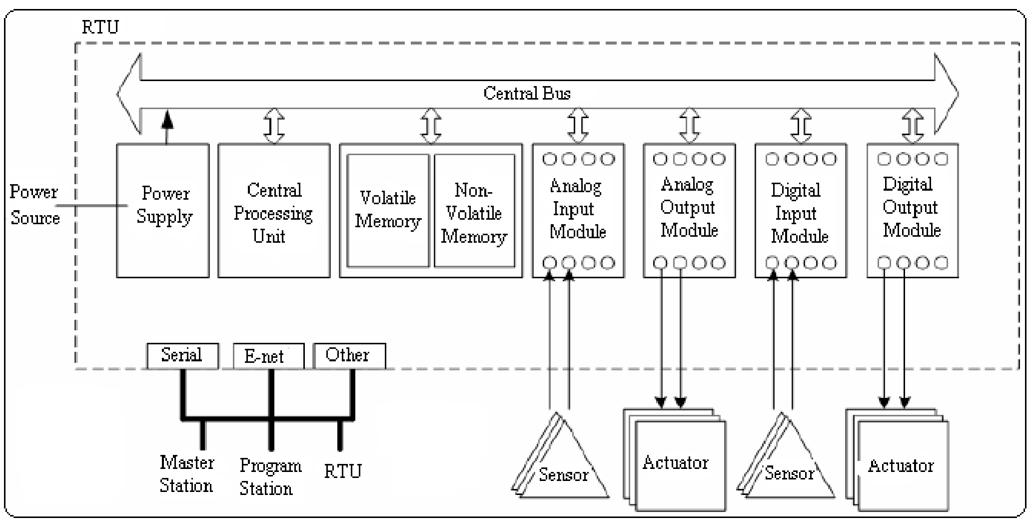


Figure 4.9 Schematic diagram of a typical RTU

4.3.1 RTU Hardware Modules

Advances in CPUs and the programming capabilities of RTUs have allowed for more sophisticated monitoring and control. Applications that had previously been programmed at the central master station can now be programmed at the RTU. The configuration of sensors and actuators determines the quantity and type of inputs and outputs on a RTU; depending on the model and manufacturer, modules can be designed solely for input, output, digital, analog, or any combination (Venkatraman A. , 2006).

An analog input module has a number of interfaces, usually binding posts or screw posts, which are wired directly to a number of sensors. A multiplexer in the module samples each of the analog interfaces in turn and passes the reading to an analog/digital converter to convert the analog signals to digital representations for transmission to the CPU over the central bus. Typical analog input modules have 8, 16, or 32 inputs. Digital input modules typically are used to indicate status and alarm signals. A number of binding or screw posts receive a signal from the sensor to indicate either an open or closed circuit, and can usually be configured to read a variety of voltages or currents. Digital output modules are used for switching AC and DC loads such as relays, motor starters, or indicator lamps.

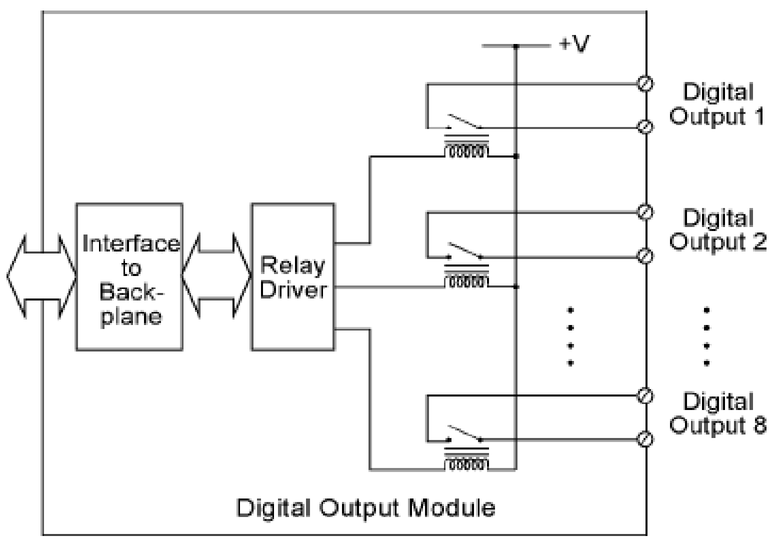


Figure 4.10 Digital output module

Modern RTUs offer a wide variety of communications means, either built in directly or through a module. Each of communication methods could be used to communicate with the master station, other PLCs or RTUs, the programming station, or operator consoles. The following list represents a variety of transmission methods supported:

- ✓ RS-232/RS-442/RS-485,

- ✓ Dialup telephone lines,
- ✓ Dedicated telephone lines,
- ✓ Microwave,
- ✓ Satellite,
- ✓ X.25,
- ✓ Ethernet,
- ✓ 802.11a/b/g,
- ✓ Radio (VHF, UHF, etc).

4.3.2 RTU Software

The RTU software is based upon a real-time (not miss events occurring and respond to these events in certain time), multitasking (process multiple tasks at the same time) operating system. RTU's are programmed with a general purpose programming language. The programming language is capable of providing a multitasking structure. The language will allow accessing all the inputs and output of the RTU, and will enable the alarm conditions, time and date, etc. information be used within the program. All the RTU outputs will be able to be commanded via the application program. The programming language will provide high level features such as comparisons and calculations at the Boolean and numeric values in the program, looping, calling procedures, etc. Certain values required to be measured will be achievable by making computations in the application program as pump operating time. RTU's software will perform the following functions:

- Creation of the RTU configuration, application specific database definitions and the application program, and downloading to the RTU,
- Local and remote monitoring and testing of the RTU application program to ensure correct operation of the program,
- Testing the RTU hardware locally and remotely and again monitoring the applied test results locally and remotely,
- Monitoring the message flow traffic in the data communication network that will handle communication of the RTUs among themselves and with the center,

- Monitoring, locally or remotely through the designated communication channel, the error log generated for hardware or software errors that occur in the RTU,
- Monitoring and Control Functions including PLC functions under the IEC 61131-1 standard.

The start-up programmer includes the initial auto-diagnosis, a set of routines designed to execute the validation for the entire equipment hardware before it begins its regular operation. In addition, once the equipment has initiated its normal operation, a permanent auto-diagnosis system executes periodical checks. The permanent auto-diagnosis routines verify the RAM memory status, the EPROM memory status, the EPROM FLASH memory status, and the stability in the accuracy of the analog signals acquisition circuit. The results generated by the auto-diagnosis procedures can be accessed by the different functions of the control application. When the permanent auto-diagnosis programmer detects any fault condition, it verifies if the data in the memory are consistent, in which case it performs a warm start-up, according to what has been selected by means of the options available in the configuration files.

4.3.3 Programmable Logic Controller

A programmable logic controller (PLC) is a computer based solid state device that controls industrial equipment and processes. It was initially designed to perform the logic functions executed by relays, switches and mechanical timer and counters. Analog control is now a standard part of the PLC operation as well. The local automatic control functions included in the RTU PLC features into this equipment. The basic purpose of this function is to execute the combinational and sequential automatic controls defined by means of a program that the equipment's user can execute via an easy-to-learn language and adapted to this type of automatic control functions. A project is composed of configurations. A configuration is a hardware platform composed of one or more resources. A resource represents a target kernel. A resource is divided into several programming units called POUs (Program

Organization Unit). The POUs of a resource are linked together in a tree-like architecture.

4.4 Star/Delta Switching of Three Phase Motors

Star/Delta starters are probably the most common reduced voltage starters in the 50Hz world. They are used in an attempt to reduce the start current applied to the motor during start as a means of reducing the disturbances and interference on the electrical supply. The Star/Delta starter is one of the lowest cost electromechanical reduced voltage starters that can be applied and this is why it has been so popular. The Star/Delta starter complied with the regulations, but did not achieve the desired results. Power and control circuits of a star/delta starter are shown in Figure 4.11.

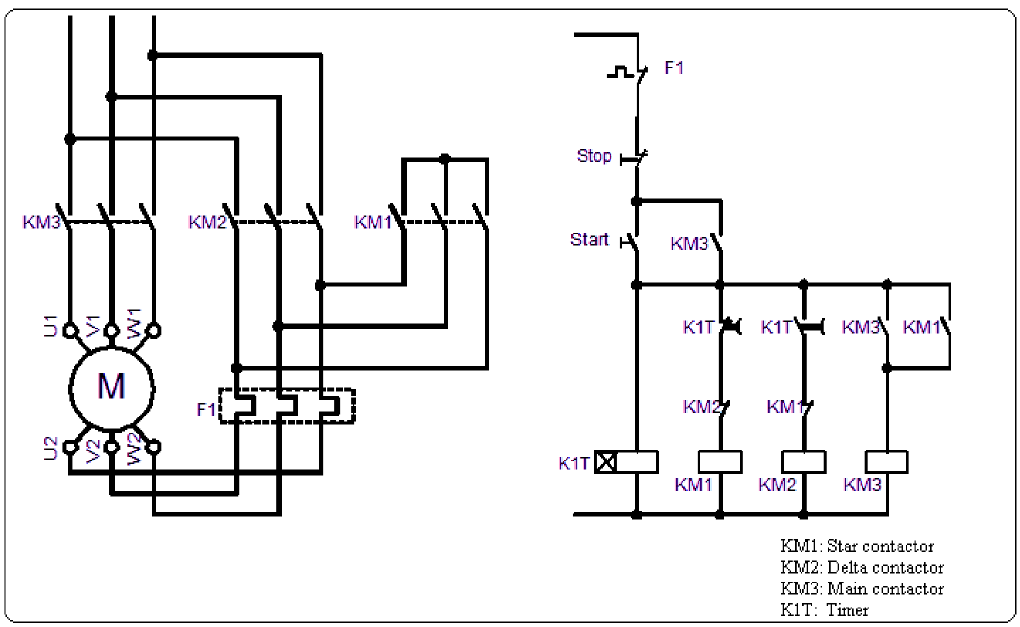


Figure 4.11 Power and control circuits of a star/delta starter

This type of operation is called open transition switching because there is an open state between the star state and the delta state. The Star/Delta starter is manufactured from three contactors, a timer and a thermal overload. The contactors are smaller than the single contactor used in a Direct On Line (DOL) starter as they are controlling winding currents only. The currents through the winding are 1/root 3 (58%) of the current in the line. There are two contactors that are close during run, often referred to as the main and the delta contactors. The third contactor is the star contactor and that only carries star current while the motor is connected in star.

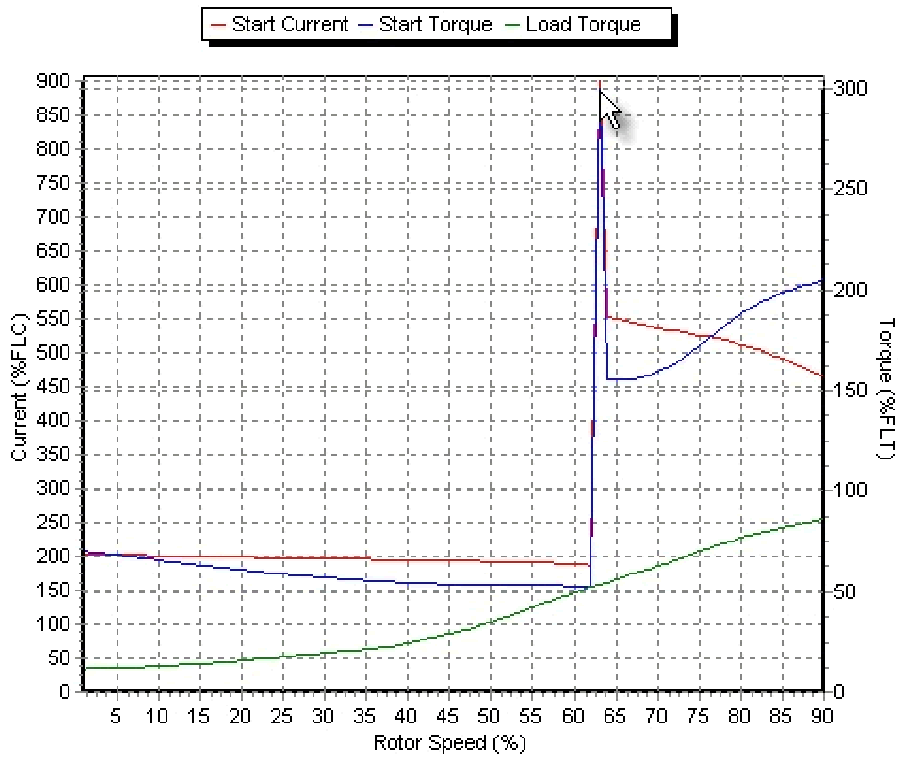


Figure 4.12 Graphic representation of the current-rotor speed-torque characteristic

CHAPTER FIVE
PLANNING AND AUTOMATION OF THE SYSTEM

5.1 Planning SCADA of the Water Distribution System

The main purpose of this thesis project is to establish a computer-based centralized management at a location determined by the administration of water distribution system to monitor and control of potable water production, purification, distribution stations which are located within a geographically wide area, within the borders of a city, where the administration is responsible for operation and maintenance. For this purpose, a SCADA system will be established to continuously monitor the status of the stations and to control required stations from the center, and to provide continuous statistical information related to the measurements taken from the stations. This thesis project covers the necessary equipment, hardware, software, electrical installation about connections for the integration of the SCADA system at the potable water production and distribution facilities. The proposed components to realize the SCADA systems are as follows:

- A supervisory control and command computer and connected peripherals to be installed at a location identified and allocated by the administration,
- Microcomputer based intelligent RTUs to be used at the stations,
- A communication network which will provide communication between the center and RTUs, and among the RTUs themselves,
- Instrumentation hardware to be installed at the stations.

5.1.1 Requirement Stations for Distribution Processing

Water distribution systems are needed to convey the water drawn from the source, through treatment and storage facilities, to the points where it is delivered to the users. The operation and maintenance of the water distribution system includes upkeep of the pipes, storage tanks and pumps that convey water from the water treatment location to the customers.

The water distribution system in this project consists of 4 dam sites, 4 major water treatment plants, 38 booster pump stations, 54 storage tanks and 20 valves. Every node is placed 1 RTU for this SCADA project. This thesis project covers 120 RTU panels. The measurements and commands to be realized each RTU station type (dam treatment station RTU, booster pump station, tank station and valve station) are as follows:

Dam Site Station: RTU panels have been installed for the dam treatment stations. They execute the following measurements and controls:

- pH measurement at water inlet and the city outlet line,
- Turbidity measurement at water inlet and the city outlet line,
- Chlorine measurement at the city outlet line,
- Dissolved oxygen measurement at the city outlet line,
- Flow measurement at the city outlet line (instant and total flow).

The following measurements and controls are same for all the stations.

- RTU mains power fail status,
- RTU enclosure switch status,
- Station main entrance door status,
- Alarm lamp control,
- RTU/Local selector position, etc.

Tank Station: RTU panels have been installed for the tank stations. They execute the following measurements and controls:

- Level measurement at the reservoir.

The following measurements and controls are same for all the stations.

- RTU mains power fail status,
- RTU enclosure switch status,
- Station main entrance door status,
- Alarm lamp control,
- RTU/Local selector position, etc.

Valve Station: RTU panels have been installed for the valve stations. They execute the following measurements and controls:

- Open/close valve command,
- Valve "fully open/close" switch status,
- Actuator alarm contact status,
- Valve position feedback signal measurement,
- Pressure measurement.

The following measurements and controls are same for all the stations.

- RTU mains power fail status,
- RTU enclosure switch status,
- Station main entrance door status,
- Alarm lamp control,
- RTU/Local selector position, etc.

Booster Pump Station: RTU panels have been installed for the pump stations. They execute the following measurements and controls:

- R/S/T phase voltage-current measurements for each pump,
- Instantaneous active-reactive power measurement for each pump,
- Total active-reactive power calculation for each pump,
- Power factor calculation for each pump,
- Motor body temperature measurement for each pump,
- Motor thermal shutdown status for each pump,
- Pump start/stop control for each pump,
- Pump start/stop button status for each pump,
- Pump running/stopped information for each pump,
- Inlet/outlet pressure measurements,
- Flow measurement at the city outlet line (instant and total flow) ,
- Flow sensor alarm status.

The following measurements and controls are same for all the stations.

- RTU mains power fail status,
- RTU enclosure switch status,
- Station main entrance door status,

- Alarm lamp control,
- RTU/Local selector position,
- Pump control panel switch status, etc.

5.1.2 Chosen SCADA System Architecture

A monitoring and control system makes it possible to exchange data in the form of discrete and analog values form I/O devices and control devices as RTU. The system also allows information to be easily shared between computer systems and applications through an open systems design and architecture. The system also makes it possible to support modular applications such as alarming, logical functions, analysis and can communicate with external systems over a network. The system should be designed to pass data and information between a variety of computer platforms and operating systems. It should support industry standards, be modular in design, and provide program interfaces to allow easy customization.

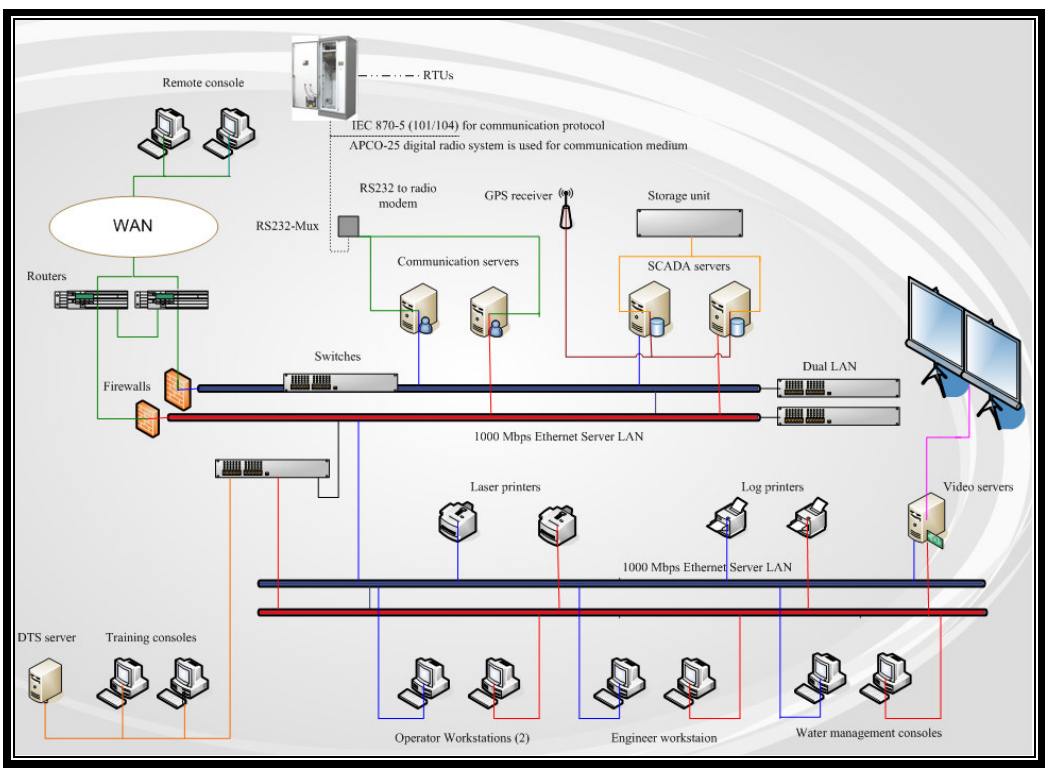


Figure 5.1 Proposed the SCADA system architecture

The systems are based on an open system concept and fully redundant architecture for mission critical applications. Proposed the SCADA system architecture for this thesis project is shown in Figure 5.1. All computers of SCADA servers, communication servers, printers and workstations have a dual Ethernet network connection using the same IP address on both. Each connection ends with two joined switches. SCADA communication functions run in two communication servers. It is a complete solution based on a processor design providing IP access to the serial interfaces to UHF radio-modems. LAN proposed is a redundant Ethernet TCP/IP network able to run 1000 Mbps managed by the switches. Software used to control the central host computer hardware. The software can be based on UNIX or other popular operating systems.

Servers for these functionalities are redundant to avoid single point failure. Each server has the complete software and hardware to guarantee a complete functionality. SCADA servers working in hot-stand-by are the core of the system, they connect with communication server to retrieve data from RTU and provide information for the DTS server, engineer and operator workstations, water management consoles, and the other consoles.

Configuration database, historical database and real time database are used by the SCADA system. Historical and configuration databases are kept at the storage unit and real time database is kept at the SCADA server. The database connection is offered with a unique IP address with different users.

5.1.3 Planning SCADA System Communication

SCADA systems encompass the transfer of data between a SCADA central host computer and a number of Remote Terminal Units (RTUs) and the central host. The communication network refers to the equipment needed to transfer data to and from different sites. The medium used can either be cable, telephone or radio (Gündoğdu S., Şahin Ö.; November 23, 2007).

SCADA systems are generally implemented diversified forms. Every RTU (Total numbers of RTUs are 120) and center host at this project is far each other. Cable is not practical for this project because of covering large geographical areas. Remote sites are usually not accessible by telephone lines. GSM-data call, GPRS, radio and satellite methods can be used to remote sites.

Many SCADA applications are using radio communication where the GSM data service is an ideal replacement, eliminating problems with available radio frequencies. SCADA is the obvious user of GSM data communication. For all that, the cost of using GSM data can be high; there are no guidelines for the pricing, check with the GSM provider. Most GSM providers will negotiate a discounted price. Also, the highest possible communication speed of the GSM data is 9.6 Kbits. GPRS mobile data service on a global system for mobile communications (GSM) system offers new opportunities to deploy extremely efficient and cost effective communications architectures. The GPRS system is always online and thus instantly available for communications. Transfer rates of GPRS are theoretically up to 171.2 kbps. However, transfer rates of between 30-50 kbps are common because they are depend on several factors such as distance to the base transfer station (BTS) and numbers of users in the same area. GSM data calls are billed per minute of connection time regardless of whether data is actually sent. On the other hand, when using the GPRS system, billing is based on the number of communication packets and is independent of connection time. GSM cellular phone networks can be affected by weather conditions or electrical interference, and in the worst case, communications can be lost. In the same way, a GPRS link over a GSM network connecting a SCADA system to RTUs can be cut at any time. However, the RTUs (with GPRS system) can automatically reestablish the communications link if this occurs. The use of satellites has been investigated for a number of years. Satellites use both the C-band and the Ku-band. VSATs are most commonly used to transmit narrowband data for SCADA applications. VSAT data rates typically range from narrowband up to 4 Mbit/s. Satellite systems have a higher initial capital cost. The use of radio offers an economical solution. Radio modems are used to connect the remote sites to the host. Radio systems also generally have a higher initial capital cost. You'd need a radio survey in most cases and maybe a license. The hardware needed includes radio transceivers, towers, radio frequency (RF) cable, and antennas. Maximum data rates of 9.6 kbps are typical for SCADA radio systems. The following table shows comparison of a variety of communication methods for water distribution system SCADA (If “+” numbers increase, the advantages increase).

Table 5.1 Comparison of a variety of communication methods for water distribution SCADA system

Parameters	Radio	GPRS	Satellite	GSM
Data transfer rate	++	+++	++++	++
Initial capital cost	+	+++	+	+++
Outgoings per year	++++	+++	+	++
Outer vendor dependent	++++	++	++	++
Choice of SCADA communication methods	++++	+++	++	+

The data rate of 9.6 Kbps is sufficient for this project. According to the shown Table 5.1, the use of radio is best solution for water distribution SCADA system. This solution’s main disadvantage is establishment cost of radio sites. Important advantages of radio system are little outgoings per year and independency from outer vendor. Between digital radio systems, APCO-25 refers to a suite of standards for digital radio communications for use in Turkey. Therefore, selection of this project’s SCADA communication is digital radio system and this system’s standard name is APCO 25. In addition to IEC 870-5 (101/104) SCADA protocol is proficient. Table 5.2 shows the calculation of communication traffic for at this project (120 RTUs and 8 radio sites are used).

Table 5.2 Communication traffic calculation

Parameters for digital radio system	Values
Total amount of RTUs	120
Total number of sites	8
Total number of RTUs per site	15
Blocking probability	2 %
Number of transceivers required per site	2*8 (site)
Total traffic that can be handled	1.6824

5.2 Automation of the Booster Pump Station Model

In this section, the measurements and the commands are introduced in the model station which has two zone's four motors, two level meters, two pressure meters, two flow meters, one chlorine meter and four temperature meters as shown Figure 2.8. The abbreviations regarding to the type of measurements and commands for this project are as follows:

- AI : Measurement that requires an analog input (4-20 mA) in the RTU
- DI : Measurement that requires a digital input (dry contact input) in the RTU
- DO : Command that requires a digital output (dry contact output) in the RTU
- RSW: Measurement to be determined with computation by the RTU software

There are two zones-four pump booster station (every zone has two pumps) with reservoir in the region. The RTU installed in the model booster station will execute the measurements and controls listed in the table below.

Table 5.3 Desired Basic Inputs/Outputs

Desired Basic I/Os for Booster Pump Station Model		
Description	**Type**	**Total**
R-S-T phase voltage measurements (3*4 pumps)	AI	12
R-S-T phase current measurements (3*4 pumps)	AI	12
Instantaneous active power measurement (4 pumps)	AI	4
Total active power calculation (4 pumps)	RSW	4
Instantaneous reactive power measurement (4 pumps)	RSW	4
Total reactive power calculation (4 pumps)	RSW	4
Power factor calculation (4 pumps)	RSW	4
Motor body temperature measurement (4 pumps)	AI	4
Motor thermal shutdown status (4 pumps)	DI	4
Pump start operations (4 pumps)		4
Pump start control	DO	4
Local pump start button status	DI	4
Local pump running lamp control	DO	4

Pump stop operations (4 pumps)		4
Pump stop control	DO	4
Local pump stop button status	DI	4
Local pump stooped lamp control	DO	4
Level measurement at each cell of the model reservoir	AI	2
Pressure measurement at the main outlets (two zones)	AI	2
Flow measurement at the main outlets		2
Instant flow measurement	AI	2
Total flow measurement	DI	2
Flow alarm status	DI	4
General measurements and controls at the station		
RTU mains power fail status	DI	1
RTU enclosure switch status	DI	1
Station main entrance door status	DI	1
Alarm lamp control	DO	1
Pump control panel switch status	DI	1
RTU/Local selector position	DI	1

5.2.1 Hardware Configuration

A RTU's automation system is designed that can control field equipment such as MCC panels and receive information about them at the water distribution station. Thence, the system is separated into two parts as control to the field and data acquisition from the field. They are programmed by using RTU. The RTU belongs to a microprocessor module (MPB-463 module). Microprocessor's code was written in configuration software and Elibase language. General electrical connections between RTU, MCC panels and sensors are shown in Figure 5.2. Microsoft Office Visio 2003 drawing programmer is used for creating the figure. The detail of the MCC panels' components (Star/delta starter panels), sensors and ELITEL-4000 RTU hardware configurations to be used for this project is included in Appendix C.

The missions of the system is control to MCC panels for running or stopping pumps and collect more information about detected signal. If the water distribution system is needed running pump, the RTU will send to MCC panel run command. After this command, MCC panel will run the pump. Likewise, also executes stopping operations. These operations are doing by the control department. At the data acquisition section, RTU collects fixed required information for water distribution system. The system uses flow sensor, level sensor, pressure sensor, chlorine sensor, pt100 temperature sensor, thermic magnetic switch, contactor, fuse, current transformer etc… Additionally, the system is also detected the binary inputs as motor running/stopped/thermic information, RTU/Local position.

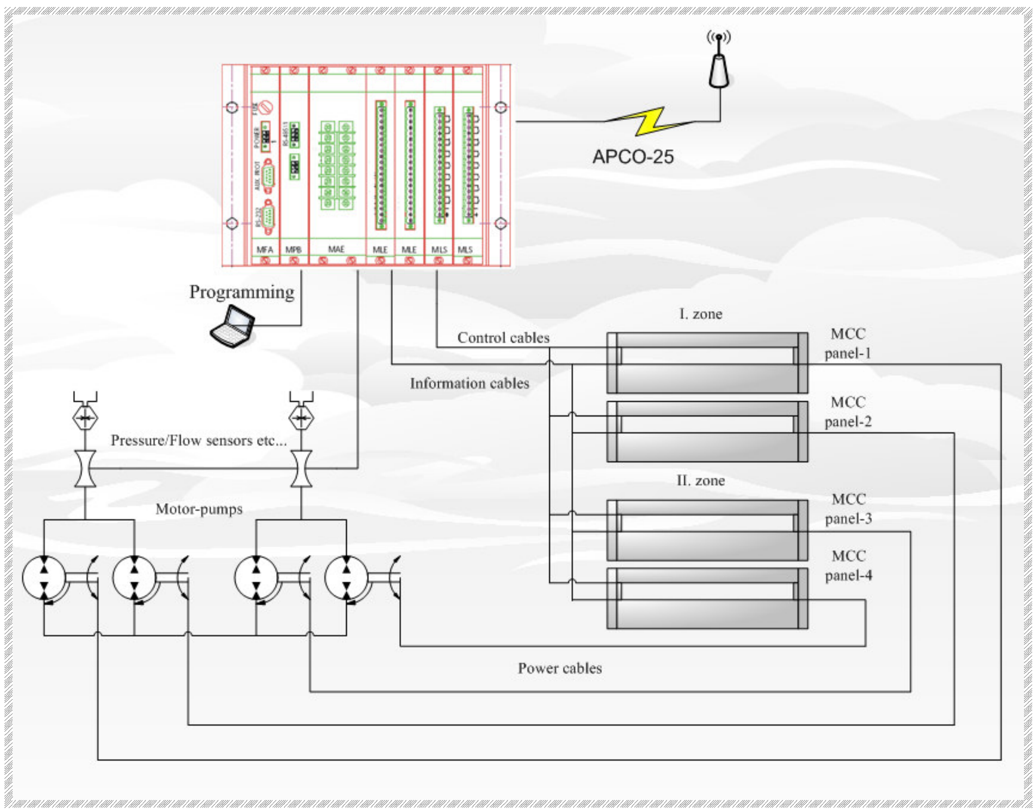


Figure 5.2 General electrical connections between control equipments

As part of this thesis, the configuration and installation of the station components was initiated. In the scope of this project, ELITEL-4000 RTU (from ELIOP), star-delta motor controllers and the sensors are used which are selected according to the information and control demands at the installed pumping station.

5.2.1.1 Selected RTU Type and Its Modules

The ELITEL-4000 RTU is a modular hardware and software platform by a 32 bit main processor and based on open architecture and adjusted to standards. It is the solution contributed by ELIOP (manufacturer of selected RTU) to the supervision and control systems demands. The ELITEL-4000 is a RTU equipment to be controlled from head-board RTUs or directly from control centers, via RS232, RS485, radio etc. It is designed for modularity, expandability, and provides flexibility in meeting feedback, control and communications requirements. The ELITEL-4000 is equipment that has been designed to build distributed control systems. For this purpose, it combines its field signals handling capacity (inputs and outputs) with powerful monitoring and control functions and outstanding communications capabilities; it offers local and distributed PLC functions. Used RTU modules are those.

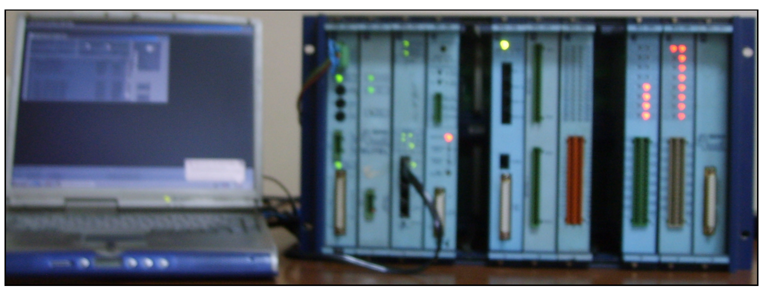


Figure 5.3 RTU modules are configured by ts-4 service terminal using PC

Microprocessor module (MPB-463): MBP-463 was used as microprocessor module. Microprocessor's code was written in configuration software and Elibase language. The processor module's CPU belongs to the industrial family of Intel® 80486 32-bit processors. The processor module is responsible for controlling all the system modules, the communications ports, the optional local interface with the user, and the connection to the ts-4 service terminal. The ELITEL-4000 processor module houses the main CPU, including a real time clock and a battery to maintain the data memory and the real time clock in the absence of the main power supply. It also contains the memory files for the start-up, programmed, data, configuration, and register.

Power Supply-Chassis (MFA-461/ USM-461): The main power supply of the RTU is 48 volts in direct current. For the power, the auxiliary supply which is obtained 48 Vdc form the alternative voltage can be equipment. An existing converter on the module USM-461 is used for the power supply of the frame. Other converters which have been located in the module MFA-461 and their output voltages supply the power to own main chassis.

Interface module : The processor module incorporates the basic resources required by the majority of applications, with up to RS 232 communication port. There is also an option to add specific modules for radio. These communication modules are designed with advanced controllers that prevent the overload of the equipment main processor, which allows the ELITEL 4000 to operate as a powerful communications node, in any control system. The RTU equipment includes the IEC 60.870-5-101 communications protocol, specially designed to communicate with remote control equipment. It can also support the most common communications protocols such as the IEC 60.870-5-104, 101 over TCP/IP.

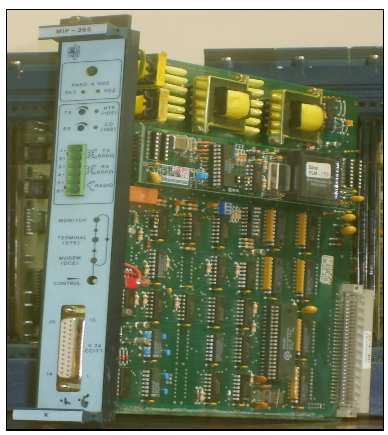


Figure 5.4 MIP-365 Interface module

Analog input modules (MAE-467/MAE-468): The ELITEL-4000 equipment possesses several types of specialized modules for analog signal measurement, which contain sixteen numbers of insulated channels, one or more analog to digital signal converters, and a digital signal processor (DSP). The various analog measurement modules are classified in two main groups, the direct AC voltage and current reading modules (MAE-468) and the standard (MAE-467) sensors measurement acquisition modules. MAE-467 and MAE-468 modules have 16 ports each one.

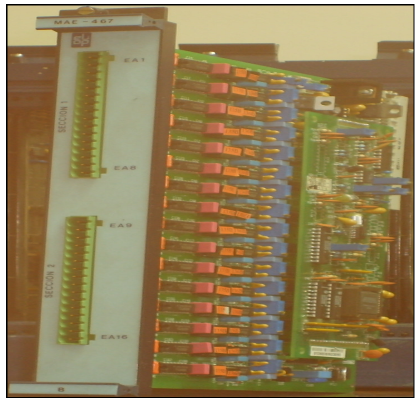


Figure 5.5 Standard analog input module

The direct measurement modules (MAE-468) allow the measurement of three-phase line currents and intensities, at 50 Hz. The measurement functions consider the transformers relations and the conversion factor needed to express the measurement in engineering units; the user can program both factors. The internal calculations provide RMS values for the three phase currents, the neutral or ground current, and the three phase voltages. Active and reactive powers are calculated for the three phases and their total values with sign, the apparent power and frequency of the voltage waves. Based on the instantaneous measurements of the active and reactive power, the active and reactive energy of the three phases and total are calculated by integration, discriminating the four quadrants. Standard reading module (MAE-467) is also possible to measure the output from different types of conventional analog sensors from the ELITEL-4000 equipment by means of analog measurement transmitters, since there are specific modules for the acquisition of the analog measurements on standard ranges. The configuration of these signals allows to define relatives parameters of smoothed and noise of the signals, events generation and alarms in function of the established limits, hysteresis, communication sending according to the threshold of change, value out of range, setting a variable to a concrete value in manual mode, etc. 1, 2 (for direct reading) and 31 (for standard reading) analog input module numbers are used while creating the configuration software.

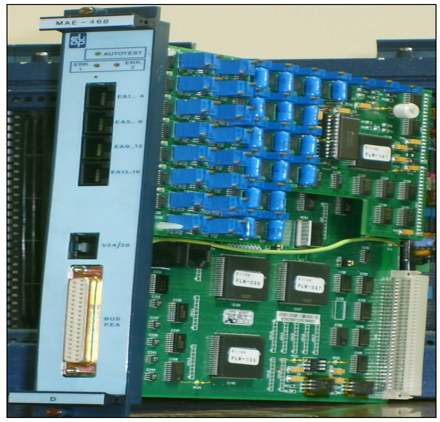


Figure 5.6 Direct reading AI module

Digital input/output modules (MLE-369/MLS-369): The ELITEL-4000 digital input module (for one MLE-369) has 32 digital input ports. It has the capacity to process a high number of digital type inputs, with a refresh cycle suitable for the protection and control functions. The ELITEL-4000 has the capability to command 16 digital output ports (1 MLS-369) equipped in specific output modules. The general purpose digital output module includes a medium power relay for each output. 32, 33 digital input module numbers and 48, 49 digital output module numbers are used while creating the configuration software.

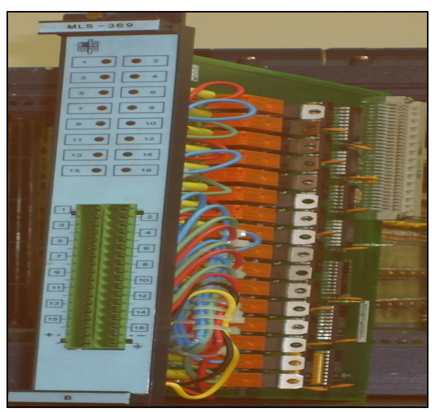


Figure 5.7 Digital output module

The RTU installed in the model booster station has the modules (modules' types, numbers, quantities, functionality) listed in the table below.

Table 5.4 Desired Basic Inputs/Outputs

Module type	**Number**	**Quantity**	**Function**
USM-461		1	Power supply of the frame (Main chassis)
MFA-461		1	Auxiliary power supply of modules
MPB-463		1	Responsible for controlling all the system modules.
Int. Module		1	Interface module is used for radio
MAE-468	1-2	1	Measure the direct AC voltage and current reading
MAE-467	31	1	Measure the output from analog sensors (pressure, level, flow, chlorine sensors)
MLE-369	32-33	1	Measure the digital inputs
MLS-369	48-49	2	Either opens or closes the circuit (Pump start/stop control)

5.2.1.2 Control of Motors Using MCC Panels

Motor control centers are cabinet systems for powering and controlling motors in the pumping station. The motor controller might include a manual or automatic means for starting and stopping the motor, and protecting against overloads and faults. It is connected to a power source and control circuitry in the form of analog or digital input signals. Star-delta type pump control panels are used in this project. Star/Delta motor controllers are used in an attempt to reduce the start current applied to the motor during start as a means of reducing the disturbances and interference on the electrical supply. This project’s control panels use a UL type 3R enclosure, which contains:

1. NH fuses, thermic magnetic switches
2. 1-pole and 2-pole circuit breakers
3. Current transformers, relays and switches
4. Power, control and signal cables

5. Three magnetic contactors for Star-Delta motor starting (S-D-M)
6. Pushbuttons (local start and stop), warning lamps
7. Compensation capacitors and its contactor
8. Asynchronous motors
9. Control terminals for the RTU connections

These components have been used in this system and their electrical connections are shown in Appendix C. EPLAN 5.50.3 drawing programmer is used for creating the technical electrical connection drawings. Used MCC panel's components are those.

NH fuses: They are available in seven sizes with a current range of 3 to 1600 Amps. NH fuses have knife blades at both ends, which mount into three pole fuse bases. Fuse bases can be panel or DIN rail mounted. This equipment is mounted to the "Main Electrical Entrance" circuit for protection oriented (see page 1 of App.C).

Figure 5.8 NH type fuses

Thermic-magnetic switches (Q): There must be a thermic magnetic switch in each one motor's control panel. Switch's thermic adjustment level must be within the each one motor's nominal current and consumption of total current. The thermic unit of the switch protects the alternator against overloads and the magnetic unit of the switch protects the alternator against short-circuits. These equipments are put to the “Main Electrical Entrance” and “Motor Control” circuits for protection oriented (see page 1, 2, 3, 4, 5 of Appendix C).

Figure 5.9: Thermic magnetic switch

Circuit breakers (1-2-3 pole): A circuit breaker is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are used in the “Main Electrical Entrance”, “RTU Panel Supply” and “Voltage/Current Line Reading” circuits.

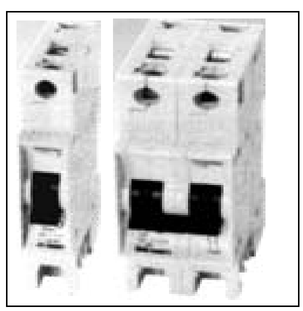


Figure 5.10 Circuit breakers

Current transformers (CT): A current transformer is a type of instrument transformer designed to provide a current in its secondary winding proportional to the alternating current flowing in its primary. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured. Secondary current values generally are applied 5 amperes. For example, a 4000:5 CT would provide an output current of 2.5 amperes when the primary was passing 2000 amperes. While 250:5 CT is used in the “Main Electrical Entrance” circuit (see page 1 of Appendix C); and 100:5 CTs are located in the “Motor Control” circuit (see page 2, 3, 4, 5 of Appendix C) for this project. Output of CTs and voltage terminals are entered to direct analog input modules of RTU using the PAE-264 card (see page 19, 20, 21, 22 of Appendix C).

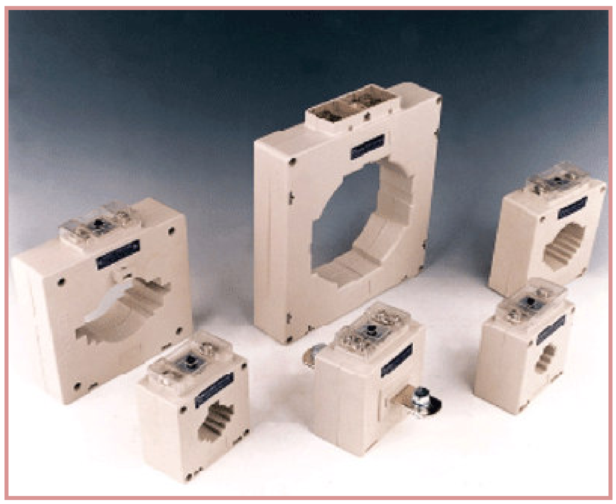


Figure 5.11 Current transformers

Contactors for Star-Delta motor starting (S-D-M contactors): Motor contactors are relays with large current capacity for connecting and disconnecting motors from power supplies. Most motor contactors are multi-pole devices in order to control all of the current-carrying conductors. When the maximum load value is crossed, the overload protection device opens the motor starter control circuit and turns off the motor. Contactors typically have multiple contacts, and those contacts are usually normally-open, so that power to the load is shut off when the coil is de-energized. The top three contacts switch the respective phases of the incoming 3-phase AC power. The lowest contact is an "auxiliary" contact which has a current rating much lower than that of the large motor power contacts. The auxiliary contact is used in a relay logic circuit, One contactor may have several auxiliary contacts, either normally-open or normally-closed, if required. Star (S), Main (M) and Delta (D) contactors are used for starting the motors. These contactors' coil terminals and their auxiliary contacts are located in "Motor Control" circuit (see page 2, 3, 4, 5 of Appendix C). At the same time, their top switches are used in the "MCC Power" circuit (see page 6, 7, 8, 9 of Appendix C). Power transfer of motors is achieved through contactor's top contacts. When the coils of delta contactor are energized, R (pump running information relay) and C (compensation contactor) components are passed active position.

Figure 5.12 Contactor

Relays: Relays are electrical switches that open and close under the control of another electrical circuit. Its contacts are changed position (open or close) when the coil terminal is energized. RLs (RTU/Local), R (Run information) and T (thermic alarm) relays are used in the MCC panels. RL, T and R relays are energized by RTU/Local switch, thermic switches and delta contactor's auxiliary contacts.

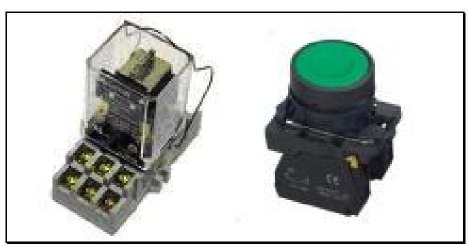


Figure 5.13 Relay and push button

Pushbuttons (local start and stop), warning lamps: The pushbutton is a component that connects and separates two points in the circuits and when pressed it such as local start/stop pushbutton. A warning lamp is a lamp designed for use on authorized emergency such as phase breakdown at this project.

The project's panel controls power to the four pump-motors through the NH fuses, thermic magnetic switches (Qs), three magnetic contactors (S, M and D contactors), and the relays (R, TI and T relays) at this project. Every pump-motor has the same control circuit which controls the logical of direction and the same power circuit which provides the energy to motor. The control circuit has been used thermic magnetic switch for protection the system. Motors are started or stopped by local, and remote, and RTU is received more information as motor's running or stopped information, thermic alarm information and reading consumption current values via the control circuit. This circuit is detected the pump run/stop control output from RTU or local start/stop operation. The magnetic contactors are controlled by both the transition timer (TI relay) and the selector switch (Local-RTU). The selector switch determines:

1. Local: Operation from the hand (local start-stop pushbuttons).
2. RTU: Operation from the RTU.
    - Hand: Operation from the pushbuttons on RTU.
    - Auto: Operation by the software of RTU

The RTU will not perform pump control while this selector is on local position. Therefore, the subject selector will be put to local position to obtain positive safety for maintenance work, and other purposes. When the selector is set to the RTU position, all of the commands to related to the station will be executed by the RTU, but the local command buttons on the panel which are directly connected to the field equipment will not be keep out of the circuit. The position of RTU/local selector will be monitored from the SCADA center and RTU. There are pump start and pump stop buttons, a lamp for every pump on the RTU panel. These buttons are connected directly to the digital inputs (DI) of the RTU (see page 13, 14, 16 of Appendix C). These buttons, when the selector is on local position, is not performed any functions. When the selector is on RTU position, and in case pump start is pressed, the RTU that senses that the button is pressed will begin the pump start operation in the way it was programmed. When the RTU determines that the pump is started completely without any abnormality, it will be illuminated the lamp integrated to the pump start button with a digital output (DO). Similarly, in the case the pump stop button is pressed, the same logic will be repeated in reverse order. The pump will be stopped by the RTU and the lamp integrated to the pump stop button will be illuminated again with a digital output (DO).

This Star Delta type motor starter operates under a two step starting sequence. Each time the motor is started, the motor is initially star connected, with contactors “S” and “M”. Once the transition timer times out, the motor will be reconnected for full delta operation with contactors “M” and “D”. In operation, the Main Contactor (M) and the Star Contactor (S) are closed initially, and then after a period of time, the star contactor is opened, and then the delta contactor (D) is closed. The control of the contactors is by the timer (TI) built into the starter. The Star and Delta are electrically interlocked and preferably mechanically interlocked as well. In effect, there are four states:

- ✓ Off State: All Contactors are open,
- ✓ Star State: The Main and the Star contactors are closed and the delta contactor is open,
- ✓ Open State: The Main contactor is closed and the Delta and Star contactors are open. There is voltage on one end of the motor windings, but the other end is open so no current can flow,
- ✓ Delta State: The Main and the Delta contactors are closed. The Star contactor is open. The motor is connected to full line voltage and full power and torque are available.

Three phase motors are always connected as either star or delta. Always all 3 phases are used. If only 2 phases are used an unbalanced motor is created and can cause damage to the motor windings. The RTU is wired into the motor control circuits and signaling circuits within the utility's control panel through electrical conduit.

5.2.1.3 Used Sensors

Electromagnetic flow meters, pressure, level, chlorine and PT100 temperature sensors are required to control the water distribution system. These eleven sensors can be controlled continuously. The outputs of all the sensor and transducers are selected 4-20 mA (dc). Transformation into engineering units (lt/sc, bar, ampere and volt, etc) are performed by the RTU, and all the measurements are delivered to the user as engineering units. The inputs of the sensors and transducers to be used are connected to the measurement points, and the outputs of these equipments are connected properly to the analog inputs (AI-31. module) of the RTU. All the sensors and transmitters are powered 24 Vdc power supplies. It is very important parameter that the transmitters and sensors, playing a role in decision making of all the system, accurately take the measurements. Every error introduced by the sensors may result in the incorrect operation of the decision making mechanism, therefore the proposed sensors and its transmitters must be accurate and reliable devices. All of the used sensors for this project are selected from Endress+Hauser firm and electrical connection transmitters of these sensors are shown electrical connections in Appendix D.

Electromagnetic flow meters: With the Promag 33 model flow meter most liquids can be measured provided they have a minimum conductivity of 5 μS/cm drinking water. The electromagnetic flow sensors and transmitters to be used in flow measurements at the station will function as the converter between the RTU and the flow measurement two points. The Promag transmitter converts the measured values coming from the sensor into standardized output signals. The following outputs are available from these sensors:

- The instantaneous flow as 4-20 mA current output,
- Total flow as pulse output,
- Sensor breakdown or power failure as a dry contact.

Figure 5.14 Electromagnetic flowmeter

Analog signals have come from two points (I-II zone) to 31 AI module and 1-2 channel numbers [(31, 1), (31, 2)] analog inputs of RTU. Flow analog signals are converted to digital data by analog digital converter in the RTU. The transmitter transforms the current signal into the measuring unit concentration in l/sc. Determined lower warning limit (10 l/sc), lower alarm limit (10 l/sc), upper warning limit (80-90 l/sc) and upper alarm limit (100 l/sc) values are compared measured value. Flow of measurement point is decided as warning, alarm or normal by RTU. If it is any lower or upper limit, “lower” or “upper” messages interested in flow value of measurement point is transmitted to destination SCADA center.

Pressure sensors: Pressure sensors to be used in measurements to be performed at the station. The Cerabar S transmitter accurately measures the pressure of liquids and is used in all areas of process engineering. The modular design of the Cerabar S enables it to be used in all industrial environments. The 4…20 mA current output is available for this transmitter. Cerabar S PMC 731 sensors are used the capacitive pressure measurement with dry ceramic sensor up to 40 bars.

Pressure analog signals have come from two points (I-II zone) to 31 AI module and 3-4 channel numbers [(31, 3), (31, 4)] analog inputs of RTU. Determined lower warning limit (4.5 bar), lower alarm limit (4 bar), upper warning limit (7 bar) and upper alarm limit (7.5 bar) values are compared measured value for I zone. The transmitter transforms the current signal into the measuring unit concentration in bar.

Similarly, determined lower warning limit (5.5 bar), lower alarm limit (5 bar), upper warning limit (8 bar) and upper alarm limit (8.5 bar) values are compared measured value for II zone. Level of measurement point is decided as warning, alarm or normal by RTU. If it is any lower or upper limit, "lower" or "upper" messages interested in pressure value of measurement point is transmitted to destination SCADA center.

Figure 5.15 Pressure sensor

Level sensors: Level sensors are detected the level of water in the tank. These sensors are used in order to protect the pump from running dry. The Deltapilot S product range is designed for continuous level measurement of liquids in water distribution system. The 4…20 mA current output is available for this transmitter. The measuring point consists of a Deltapilot S sensor with the FEB electronic insert and a separate transmitter.

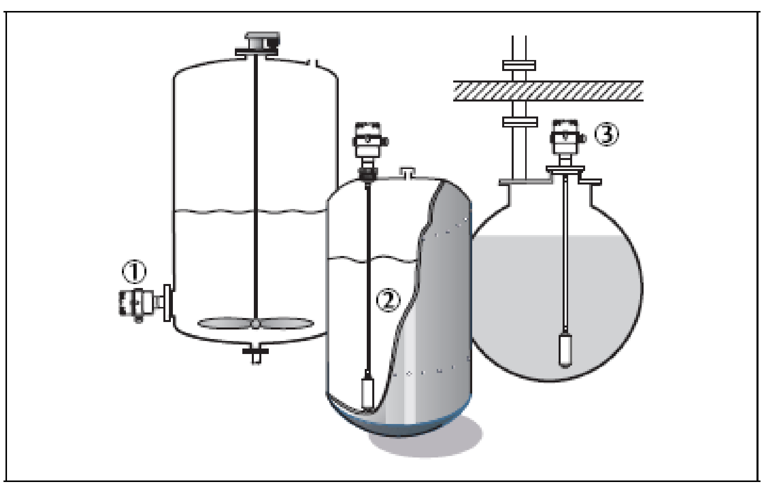


Figure 5.16 Level sensors

Level analog signals have come from two points in the tank (2 levels) to 31 AI module and 5-6 channel numbers [(31, 5), (31, 6)] analog inputs of RTU. The transmitter transforms the current signal into the measuring unit concentration in m. Determined lower warning limit (0.8 m), lower alarm limit (0.5 m), upper warning limit (3.8) and upper alarm limit (4 m) values are compared measured value. Pressure of measurement point is decided as warning, alarm or normal by RTU. If it is any lower or upper limit, “lower” or “upper” messages interested in level value of measurement point is transmitted to destination SCADA center.

Chlorine sensors: The CCS-140 sensor is applied for measurement of free active chlorine in the water distribution pipe. The membrane-capped CCS140 sensor consists of a cathode serving as the working electrode and an anode acting as the counter electrode. These electrodes are immersed in an electrolyte. Electrodes and electrolyte are separated from the medium by a membrane. The membrane prevents the loss of electrolyte and the penetration of contaminants. A complete measuring system comprises at least:

- ✓ Chlorine sensor,
- ✓ Liquisys M CCM 253 transmitter,
- ✓ Special measuring cable,
- ✓ Flow assembly.

Chlorine analog signal has come from measurement point to 31 AI module and 11 channel numbers (31, 11) analog input of RTU. The transmitter transforms the current signal into the measuring unit concentration in mg/l. Determined lower warning limit (0.8 mg/l), lower alarm limit (0.5 mg/l), upper warning limit (1.5 mg/l) and upper alarm limit (2 mg/l) values are compared measured value. Chlorine of measurement point is decided as warning, alarm or normal by RTU. If it is any lower or upper limit, “lower” or “upper” messages interested in chlorine value of measurement point is transmitted to destination SCADA center.

Pt100 is the chemical symbol for platinum, 100 is the resistance in ohm of the Pt100 at 0 °C. The resistance changes with temperature are: 0.385 Ohm/°C for

European and 0.392 Ohm/°C for American elements. So, by measuring the resistance we can calculate the temperature. Pt100 sensors are connected with two wires to the measuring device at this project. PT100 sensors are used to protect the motor from running hot. Temperature analog signals have come from measurement point to 31 AI module and 7-8-9-10 channel numbers [(31, 7), (31, 8), (31, 9), (31, 10)] analog inputs of RTU. The transmitter transforms the current signal into the measuring unit concentration in °C. Determined lower warning limit (0 °C), lower alarm limit (0 °C), upper warning limit (80 °C) and upper alarm limit (85 °C) values are compared measured value. Temperature of measurement point is decided as warning, alarm or normal by RTU. If it is any lower or upper limit, “lower” or “upper” messages interested in temperature value of motor body is transmitted to destination SCADA center.

5.2.2 Application Software

The RTU software is based upon a real time, multitasking operating system. RTU Microprocessor’s code was written in configuration software and Elibase language. Essentially, the application software consists of the configuration and the automatism software. Automatism conditions were written in configuration software; automatism outputs were directed from the written code in Elibase language.

5.2.2.1 Configuration Software

The configuration software allows describe all the inputs and outputs of the RTU, and enables the warning and alarm conditions, time etc. All the RTU outputs can be commanded via the software. This language provides high level features such as comparisons and calculations on the Boolean and numeric values in the program. Certain values required to be measured will be achievable by making computations in the application program as total flow.

Used configuration software for operation of the RTU and SCADA database is considered in this department. Physical and logical inputs and outputs of RTU and these signals spec are defined via this configuration operation. Configuration software has been written at “Wordpad MFC” for MBP-463 integrated of ELIOP firm as microprocessor module has been used. Configuration programmer was required to compile the written codes as “thes.dat file” to hexadecimal codes. So the written “thes.dat” is converted to the “thes.pr1”. RTU can be read this “.pr1” codes. The connection of this software operating on personnel computer to the RTU is established directly via RS-232 port of the personnel computer. Programmed microprocessor configuration software is attached in Appendix A and detail of the one is explained in the following lines. There are five major parts in the configuration file. These are those:

- Digital inputs (DI),
- Analog inputs (AI),
- Counter inputs (CI),
- Digital outputs (DO),
- Algorithms.

Digital Inputs: Digital input signal means for receiving digital inputs (DI) from hardware configuration in the Appendix C. These are connected between the detector and the MLE-369 module of RTU as hardware. The module has 32 ports. Digital inputs module (32 DI) consist of PPI, AYI and PYI tables.

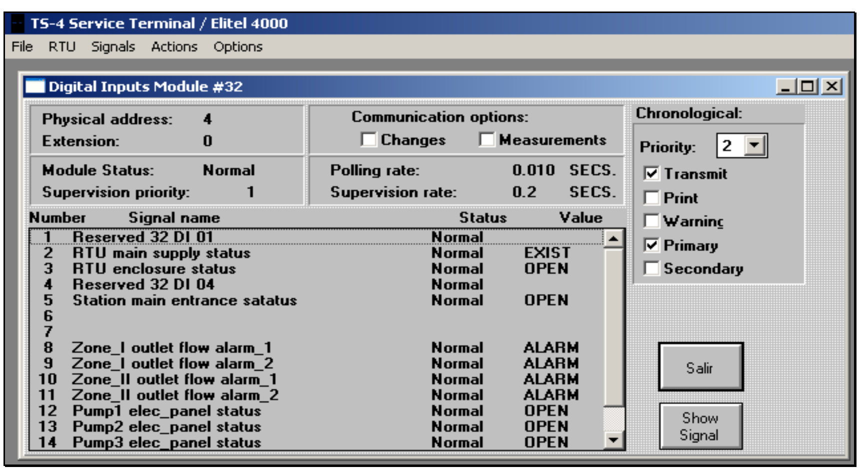


Figure 5.17 A screenshot of the ts-4 service terminal, showing the digital inputs

PPI table is module parameter table and its column descriptions are explained in the below table.

Table 5.5 PPI table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PPI
5-7	Position of the first DI card module	5
9-11	Quantity of DI card modules	1
13	Repetitive alarm filter	Y
15-19	Supervision period for the filter	5 sc.
21-25	Upper threshold to enable the filter	20
27-31	Lower threshold to disable the filter	2

1 DI card module has been used for this project and position of this module is five in the rack of RTU. Repetitive alarm filter is performed. Filter is implemented at this condition. If any input is changed twenty times in five seconds, RTU will resist it. But if this change is two, RTU will not resist the signal. AYI table is the first channel parameters table and its column descriptions are explained in the below table.

Table 5.6 AYI table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYI
4-7	Digital input key	1…32 / 66...85
9-11	Station number	65
13-15	Module number	32-33-109-110
17-18	Channel number	1…16
20	Input kind	S (single)-D (double)-F (impulsive)
22	Priority	0…2
24-53	Channel name	Change every channel number.
55	Response of RTU or SCADA events	R (RTU)-S (SCADA)-B (Both-S+R)
57-67	Name attached to the active channel status	Change every channel number.
68-78	Name attached to the inactive channel status	Change every channel number.

32DI, 33DI (physical digital inputs) and 109DI, 110DI (logical digital inputs) module numbers have been used for this project. Two examples have been given about this table at below (used lines are taken from Appendix A).

Example 1:

```
AYI0002 065 032 02 S 2 RTU main supply status           NOT        EXIST
```

This station's number is 65 between the SCADA RTUs. It has used 32.Module - 2.Channel number (32, 2) of digital input card. Main supply relay contact's output is sent to MLE-369's port2 pin. If there is electrical in RTU, port2 pin of MLE-369 is '0' (inactive channel>>Exist). So it is normal. If there is not electrical in RTU, port2 pin is '1' (active channel>>Not). "RTU main supply>> Not Exist" message is informed and data is held by MLE-369. When port2 pin is '1', if electrical comes to RTU, "RTU main supply>> Exist" message is informed.

Example 2:

```
AYI0066 065 109 01 S 0 P1 Min_Max Current_condition     YES        NO
```

The station has used 109.Module - 1.Channel number (109, 1) of logical digital input. Minimum or maximum current condition contact's output is sent to automation code. If there isn't current condition in RTU, 1.channel of 109.module is '0' (inactive channel>>No). So it is normal. If there is current condition in RTU, channel1 pin is '1' (active channel>>Yes). "Min_Max Current_condition>> Yes" message is informed and data is held by microprocessor. When channel1 pin is '1', if condition leaves, "Min_Max Current_condition>> No" message is informed.

PYI table is the second channel parameters table and its column descriptions are explained in the below table.

Table 5.7 AYI table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PYI
4-7	Digital input key	1…32 / 66...85
13	Algorithm space	R (RTU)
15-132	Algorithm space for determined channels	Change every channel number

Start and stop conditions are explained in the PYI table. These algorithms are defined for RTU (R) configuration. One example has been given about this table at below.

Example 3:

```
PYI0080     R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,10) OR
```

P3 stop other_conditions (see AYI0080 in the Appendix A) are formed according to the before-mentioned line. This algorithm is written for RTU configuration. This line is simply explained in the following schematic.

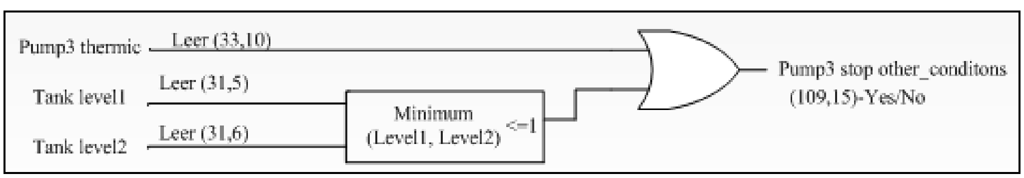


Figure 5.18 Schematic showing the pump3 stop other conditions using logical gates

Analog Inputs: Analog input signal means for receiving analog inputs from hardware configuration in the appendix C. These are connected between the transmitter of sensors and the MAE-467/MAE-468 modules of RTU as hardware. The modules have different 16 ports. Analog inputs department of the configuration files consist of PPM, AYM, BYM and PYM tables.

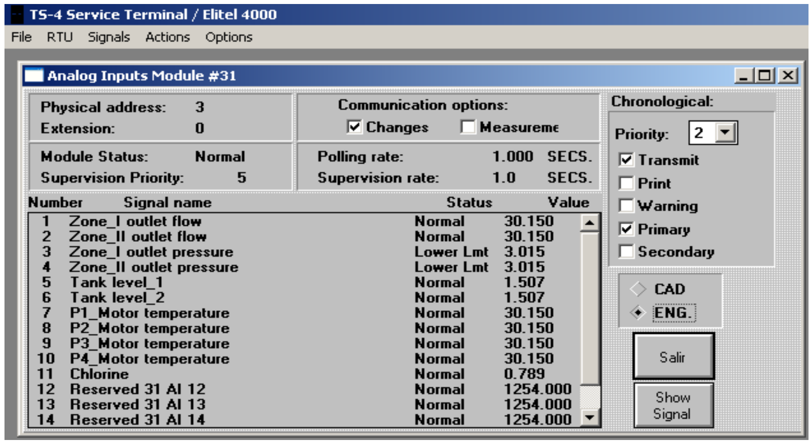


Figure 5.19 A screenshot of the ts-4 service terminal, showing the analog inputs

PPM table is module parameters table and its column descriptions are explained in the below table.

Table 5.8 PPM table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PPM
5-7	Position of the first 4-20mA AI Module card	4
9-11	Quantity of 4-20mA AI Module cards	1
13-15	Position of the first DR AI Module card	3
17-19	Quantity of Direct AI Module cards	1
21-22	Time for confirmation of a fast variation	10 sc
24-25	Noise Factor to start fast AI variation Mode	25 per cent
27-29	Filtering Factor in units per cent	5 per cent

2 numbers AI card modules (1-standart reading and 1-direct reading AI module) have been used for this project and positions of these modules are three and four in the rack of RTU. Filter will be performed on the analog input signals because of the fast AI variations can be dangerous for the systems. Therefore; time for confirmation of a fast variation, noise factor and filter factor parameters are added the table. AYM table is the first channel parameters table and its column descriptions are explained in the below table.

Table 5.9 AYM table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYM
4-7	Analog input key	1…60 /90...100
9-11	Station number	65
13-15	Module number	31-105-1-2
17-18	Channel number	1…16
20-21	Input kind	Un, RM, P4, R4, F4
23-24	Input type	mA, DR
26	Priority	0…2
28-57	Channel name	Change every channel number.
60-63	Historical data storage type	1A04 for 15 minute-2A04 for 1 hour
65-67	SCADA profile of channel	FLW, PRS, LEV, TMP, CLR

1-2 and 31 AI module numbers have been used for this project. Two examples have been given about this table at below.

Example 4:

```
AYM0017 065 001 01 RM DR 2 P1 R_Phase voltage              2A04 VLT
```

This station's number is 65 between the SCADA RTUs. It has used 1.Module - 1.Channel number (1, 1) of direct reading (DR) analog input card. "P1 R_Phase voltage" value is read to MAE-468's port1 pin. This signal's alarm priority is selected two. It has feature of one hour historical data storage (2A04).

Example 5:

```
AYM0005 065 031 05 Un mA 2 Tank level_1                    1A04 LEV
```

This station's number is 65 between the SCADA RTUs. It has used 31.Module - 5.Channel number (31, 5) of standard reading analog input card. The analog input module can be read 4-20 mA input type. "Tank level_1" value is read to MAE-467's port5 pin. This signal's alarm priority is selected two. It has feature of fifteen minutes historical data storage (1A04). BYM table is the second channel parameters table and its column descriptions are explained in the below table.

Table 5.10 BYM table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYM
4-7	Analog input key	1…60 /90...100
12-17	Minimum Value of Analog input	Change every channel number.
18-23	Maximum Value of Analog input	Change every channel number.
25-33	Engineering Units (E.U.)	Change every channel number.
35-40	Lower Warning Limit in E.U.	Change every channel number.
41-46	Upper Warning Limit in E.U.	Change every channel number.
51-56	Lower Alarm Limit in E.U.	Change every channel number.
57-62	Upper Alarm Limit in E.U.	Change every channel number.
63-66	Hysterics Band in E.U.	5%*Maximum value of each channel

Measurement range, engineering unit and limit values (as engineering units) of analog inputs are given in the BYM table. Also hysterics band value of input signal is added. To fill the Columns 12-17 and 18-23 of the P4 Active Power, R4 Reactive Power and F4 Power Factor is necessary to put the theoretical values (the maximum value for P4=3*V*I*cos(F4); The engineering unit of power is kW, etc.). Desired data for automation operation such as "start_ control address (in the 105.module)" is taken from this table to automation codes in appendix B. Two examples have been given about this table at below.

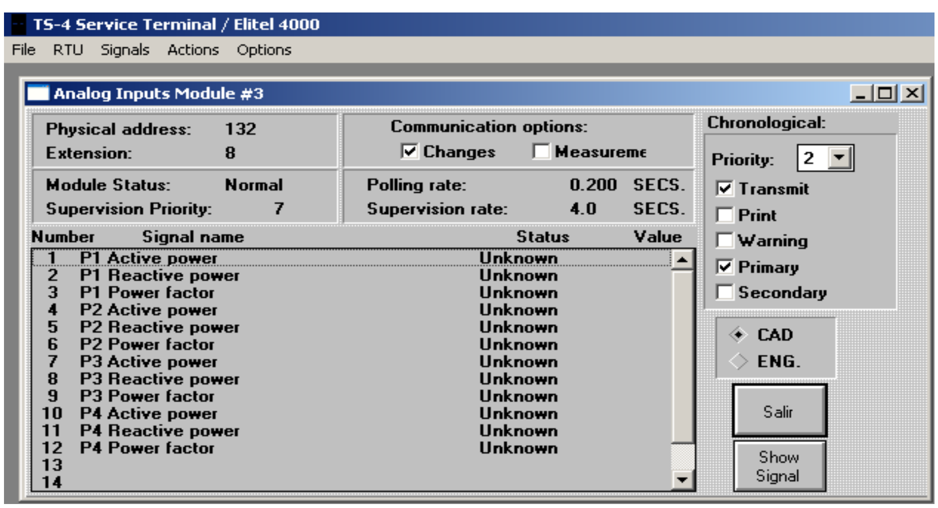


Figure 5.20 A screenshot of the ts-4 service terminal, showing the power values

Example 6:

```
BYM0049    -95.04 95.04 kW
```

The maximum/minimum active powers are determined as P=3*264*120*1=95.04 kW and P=3*264*120*-1=-95.04 kW. 264V is maximum value of single phase voltage; 120A is maximum value of single phase current. These values are consumption of pump1 total active power's (see AYM0049 line in the Appendix A).

Example 7:

```
BYM0095        48  4048      CAD   18435 10000     18435 10000
```

This line is given P2 start control address (see AYM0095 line in the Appendix A). Here "18435" is defined in a decimal code. Status of its converted to the hexadecimal is 4803 (48.module and 3.channel of digital output module). PLC system looks up these lines for start operation.

PYM table is the third channel parameters table and its column descriptions are explained in the below table. These algorithms are defined for RTU (R) configuration. These algorithms are defined for RTU (R) configuration as PYI table.

Table 5.11 PYM table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYM
4-7	Analog input key	1…60 /90...100
13	Algorithm space	(R>>RTU)

Counter Inputs: The digital input module can work with logic relations of inputs in the form of counters. Counter inputs department of the configuration files consist of AYE, and PYE tables.

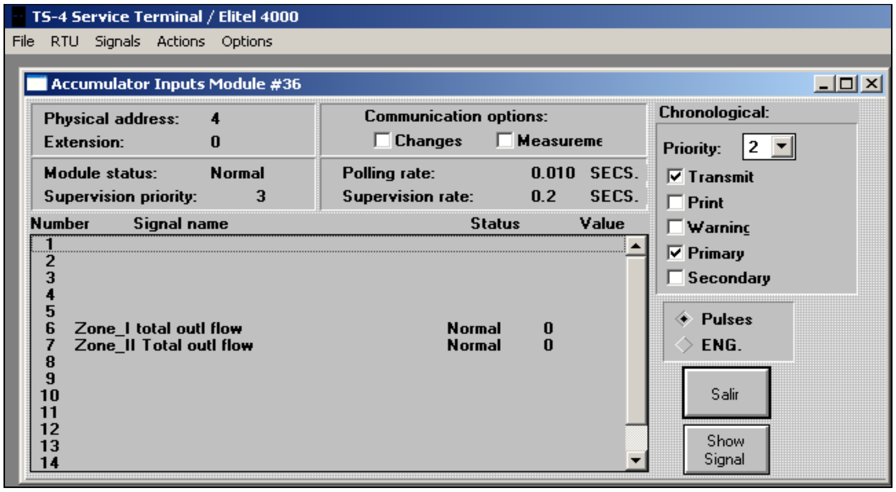


Figure 5.21 A screenshot of the ts-4 service terminal, showing the accumulator inputs

AYE table is the first channel parameters table and its column descriptions are explained in the below table.

Table 5.12 AYE table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYE
4-7	Counter input key	1…10
9-11	Station number	65
13-15	Module number	37-32
17-18	Channel number	1…8-6.7
22	Priority	2
24-53	Channel name	Change every channel number.
55-63	Engineering Units	kWh, kVARh, m3
65-70	Value per Pulse in E.U.	1.0
72-75	Period of historical	2C03-1 hour data storage
77-79	SCADA profile of channel	AEN, REN, TFL

Example 8:

```
AYE0009 065 032 06   2 Zone_I total outl flow         m3            1.0 2C03 TFL   036
```

Calculated total outlet flow pulse is obtained from flow meter hardware. Every pulse means 1 m3 flow. These pulses enter to 32.module-06.channel (32, 6) of digital input module. Counter inputs collect these inputs. Energy is integrated of power in time domain (see PYE table in the Appendix A). PYE table is the second channel parameters table and its column descriptions are explained in the below table.

Table 5.13 PYE table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PYE
4-7	Counter input key	1…10
13	Algorithm Switch	R-> RTU
15-132	RPN Algorithm	RPN Algorithm

Digital Outputs: Digital output signals are used to the pump start and stop control or glow the lamps which indicate running information and stopped information. Outputs are connected between the motor control circuit and the MLS-369 module of RTU as hardware. The module has 16 ports. Digital outputs department of the configuration files consist of PPC, AYC and PYC tables.

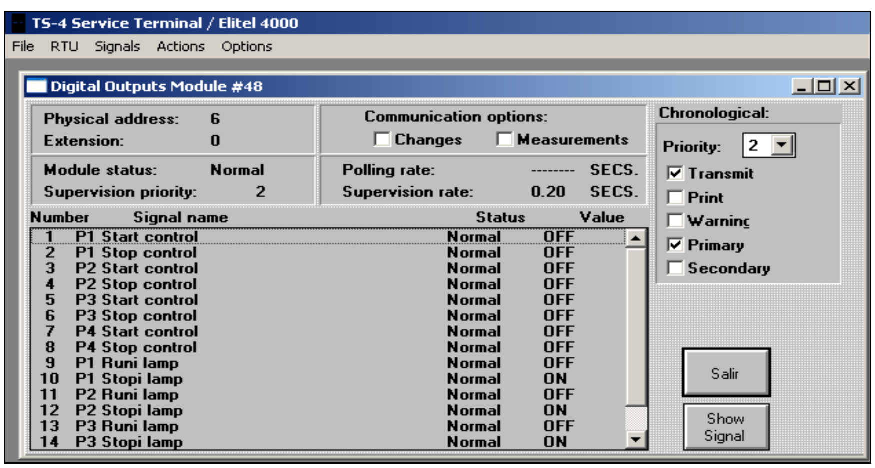


Figure 5.22 A screenshot of the ts-4 service terminal, showing the digital outputs

PPC table is module parameters table and its column descriptions are explained in the below table. Two numbers DO card module have been used for this project and position of the last DO card module is eight in the rack of RTU.

Table 5.14 PPC table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PPC
5-7	Position of the last DO card module	8
9-11	Quantity of DO card modules	2

AYC table is the first channel parameters table and its column descriptions are explained in the below table.

Table 5.15 AYC table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	AYC
4-7	Digital output key	1…32
9-11	Station number	65
13-15	Module number	48-49
17-18	Channel number	1…16
20	Kind of command	S continuous, C pulse commands
22	Command with possible selection	N
28-55	Channel name	Change every channel number.
57-67	Name attached to the active digital output	ON
68-78	Name attached to the inactive digital output	OFF

48DO and 49DO module numbers have been used for this project. Two examples have been given about this table at below.

For example 9:

```
AYC0005 065 048 05 C N     P3 Start control             ON         OFF
```

This station's number is 65 between the SCADA RTUs. It has used 48.Module - 5.Channel number (48, 5) of digital output card. MLS-369's port5 relay contact's variation is sent to MCC control circuit for start. If the contact is open, port5 is '0' (inactive channel>>OFF). So it is normal. If the contact is closed via command, port5 pin is '1' (active channel>>ON). "P3 start control>> ON" message is informed and data is held by MLS-369.

PYC table is the second channel parameters table and its column descriptions are explained in the below table.

Table 5.16 PYC table and its selected parameters

Column numbers	Table Parameters	Entered values
1-3	Table identification	PYC
4-7	Digital output key	1…32
18	Digital Input key associated to this Digital Output	A
20-133	RPN Boolean Expression	Change every channel number

For example 10:

```
AYC0017 065 049 01 S N     Alarm lamp                    ON         OFF    [AYC table]
PYC0017          A LEER(33,2) LEER(33,6) OR LEER(33,10) OR LEER(33,14) OR [PYC table]
```

This station's number is 65 between the SCADA RTUs. It has used 49.Module -1.Channel number (49, 1) of digital output card. If the PYC0017 line is "0", channel1 is "0" (inactive channel>>alarm lamp OFF). So it is normal. If defined any digital input is "1", port1 "1" (active channel>>alarm lamp ON). So alarm lamp will indicate the error. "Alarm lamp>> ON" message is informed and data is held by MLS-369. Alarm lamp's algorithm is written in the RTU configuration software. This line is simply explained in the following schematic.

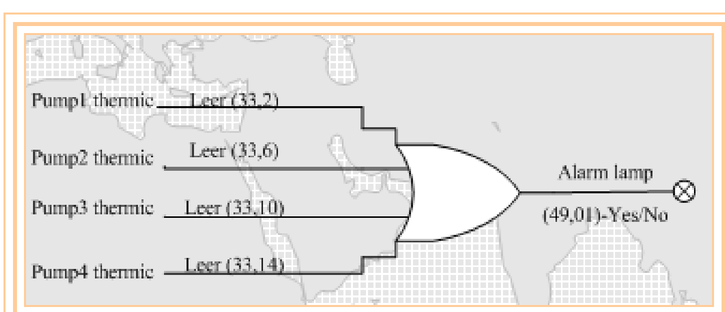


Figure 5.23 Schematic showing the alarm lamp output using logical gates

The TS-4 service terminal for the ELITEL-4000 is software for compatible personal computer which is executed within Windows 95 or later operating environments, and whose purpose is to supply the operator with facilities for the commissioning, problem diagnosis, and the equipment configuration of the ELITEL-4000. It is totally connected to the equipment by means of a serial port. The TS-4 presents useful information for the setting up, tests, installation, and maintenance of the ELITEL-4000 and the installation that it controls. The operator views general types of data as well as specific information for each equipment input or output, including the detected alarms and the diagnostic data or internal errors. It allows the downloading of the configuration and automatism (PLC programs) files from the TS-4 to the ELITEL-4000.

5.2.2.2 Automation Software

The basic purpose of this function is to execute the combinational and sequential automatic controls defined by means of a program that the equipment's user can execute via an easy-to-learn language and adapted to this type of automatic control functions. The language used to define this program is in accordance with the IEC-1131 standards. Automation program is specified activity for working two objects. These objects are those.

- Input and output lines,
- Timer, inner RTU/PLC sources as memory.

Transfers between input/output are made from system program. Defined operations are repeated continuously as numeric. Used variables in the following lines are important for automation software.

- E type variables (Input/output) ,
- C and T type variables (Timer and counter),
- I type variables (General purpose inner memory),
- L type variables (Communication space),
- F type variables (Fixed value space),
- Stack and accumulators,

- X and R type variables (Index and special purpose registers),
- Labels, peripheral units,
- Functions.

Four number modules have been used to perform the automation program. These are specification module, program initiation module, basic cycle program module and user function specification module. Modules are assigned between INI and FIN commands. The automation codes are defined in an ASCII file named "thes" (text file) which may be created with a text editor such as Notepad in the appendix B. ELIBASE program language is used to perform the automation. The details are explained in the Appendix B.

Designed booster station for this project has been worked as RTU or manual (local) system. Selection of system is made by the RTU/manual key on the RTU panel. Starting pumps can be made from start button on panel or start control command from SCADA center's operator at RTU system. It is the responsibility of the RTU to determine the correct start-up procedure. Always take special precautions when starting a pump for the first time. Firstly, special precautions are defined as the stop conditions in the "thes.dat" configuration file. Contents of the conditions are created by the analog/digital information and logical operation. They can be seen by TS-4 service terminal connected to the MPB-463 module of RTU. Each pump's working and stop conditions are shown as five logical inputs. Each pump's controls of the working conditions and their tests can be made by these channels. These inputs begin from the 109 module. The five conditions are those.

```
1. AYI0066 065 109 01 S 0 P1 Min_Max Current_condition     YES        NO
2. AYI0067 065 109 02 S 2 P1 Stop Current_condition        YES        NO
3. AYI0068 065 109 03 S 0 P1 Working_condition             YES        NO
4. AYI0069 065 109 04 S 2 P1 Stop pressure_condition       YES        NO
5. AYI0070 065 109 05 S 2 P1 Stop other_conditions         YES        NO
```

Contents of these conditions are created by the analog/digital information and logical operation in the following lines.

```
1. PYI0066      R LEER(1,2) LEER(1,4) MIN2 LEER(1,6) MIN2 19.0 < LEER(1,2) LEER(1,4)
   MAX2 LEER(1,6) MAX2 68.0 > OR
2. PYI0067      R LEER(109,1) LEER(33,1) AND
3. PYI0068      R LEER(33,1) NOT LEER(31,3) 4.5 < AND LEER(31,5) 1.5 > AND
4. PYI0069      R LEER(31,4) 7.5 >
5. PYI0070      R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,2) OR
```

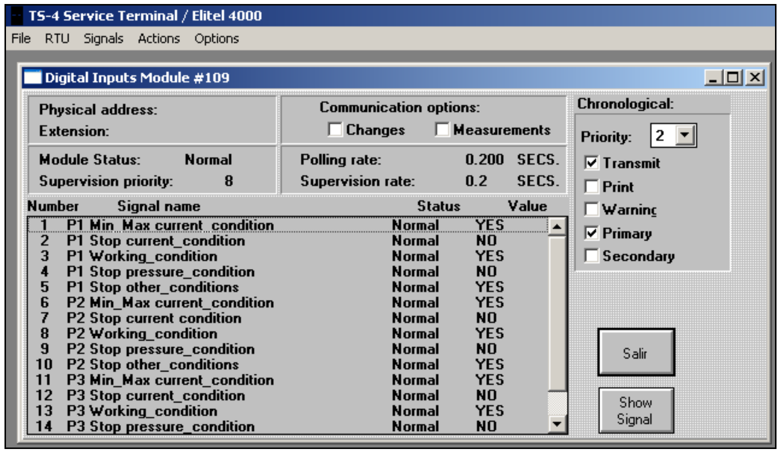


Figure 5.23 A screenshot of the ts-4 service terminal, showing the conditions

PLC automation program controls these conditions for every desired starting pump using 109 and 110 modules. This program does not control the first condition (Min_Max Current_Condition). The first condition (109, 1) is required for utilization of the second condition (109, 2). PLC program is controlled 2 (109, 2), 4 (109, 4) and 5 (109, 5) no “STOP Conditions” for starting the stopped pump. If any channel between these conditions is YES, the pump will not start. Third channel (working condition) is necessary for “Automatism ON”. If the automatism selector is OFF position, PLC program will not use this channel. There is two minute limitation time for stop pressure_conditions. However, five minute limitation time is used for stop current and other conditions. The other time limitations are those.

- 5 min. is required between start commands (5 min. running condition),
- 5 min. is required between stop commands (5 min. stop condition),
- When pressure stop condition is occurred, the limitation time is 2 min. (2 min. stop condition),
- 30 seconds is required to stop the running pump (30 sc. running condition),

- If motor's any STOP condition is YES and this condition continue up thirty seconds, related motor will stop (30 sc. stop condition).

Current and voltage modules start from module 1 and continue up until channel 8, module 2 (2, 8). RTU/Local selector position is identified by channel 1, module 119 (119, 1). Pump's input and output points are defined in the module 105 for controlling by PLC program. These points are given in the following lines.

1. channel : Pump number
2. channel : If it exists; valve number
3. channel : Permission channel address
4. channel : Empty
5. channel : P1 start_control address
6. channel : P1 start_button address……etc

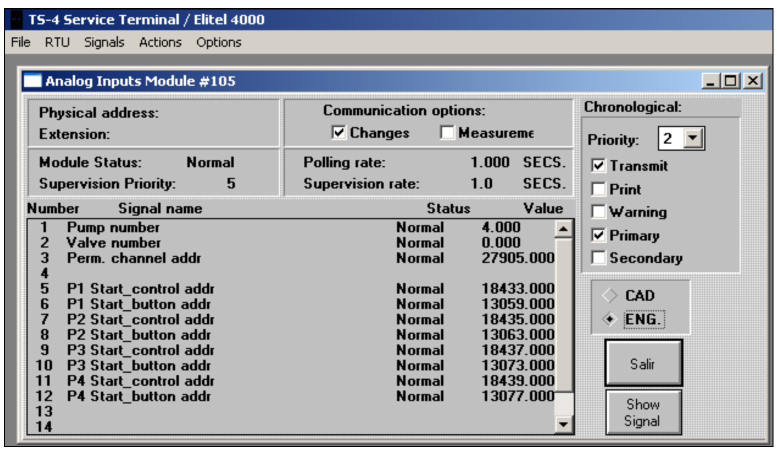


Figure 5.24 A screenshot of the ts-4 service terminal, showing the addresses

Automatism ON/OFF inputs are situated standard in the first and second channel of module 108. Otherwise, pump start/stop commands are given from SCADA which are existed in the module 108. These are those.

1. channel : Automatism OFF
2. channel : Automatism ON
3. channel : P1 start
4. channel : P1 stop…….etc

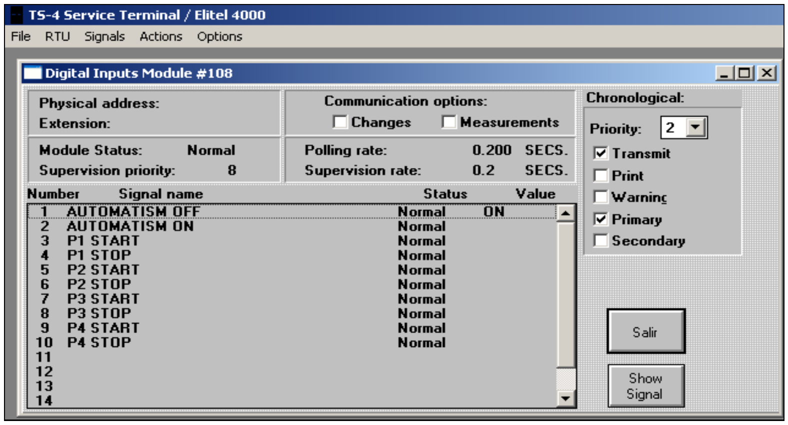


Figure 5.25 A screenshot of the ts-4 service terminal, showing the real outputs

This module is more important for automation software. Because programmable logic controller software is detected from (108, 3)…(108, 10) channels for start/stop pumps. Start/stop operations of pumps from SCADA center or the RTU are actualized via the module 108. These steps are given. Firstly, the software takes receiving the requests (start or stop of pump command) from the module 108. Then, these requests are evaluated with the other conditions such as pressure stop condition by the software. After that, PLC has been decided the operation after this step. Finally, it dictates digital outputs module for desired operation. Figures 5.24 and 5.25 are given the schematics showing the start-stop inner commands using logical gates.

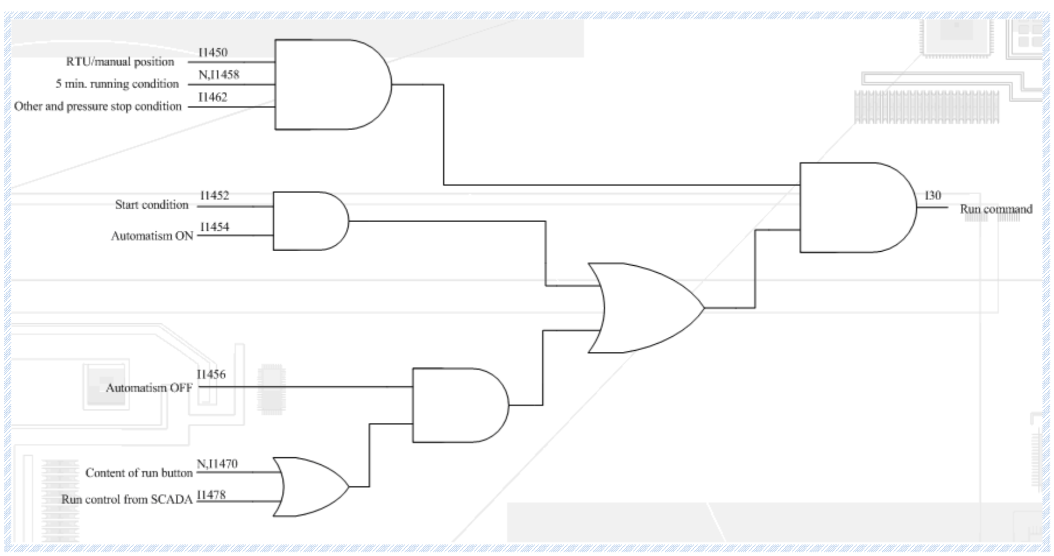


Figure 5.24 Schematic showing the start inner command using logical gates

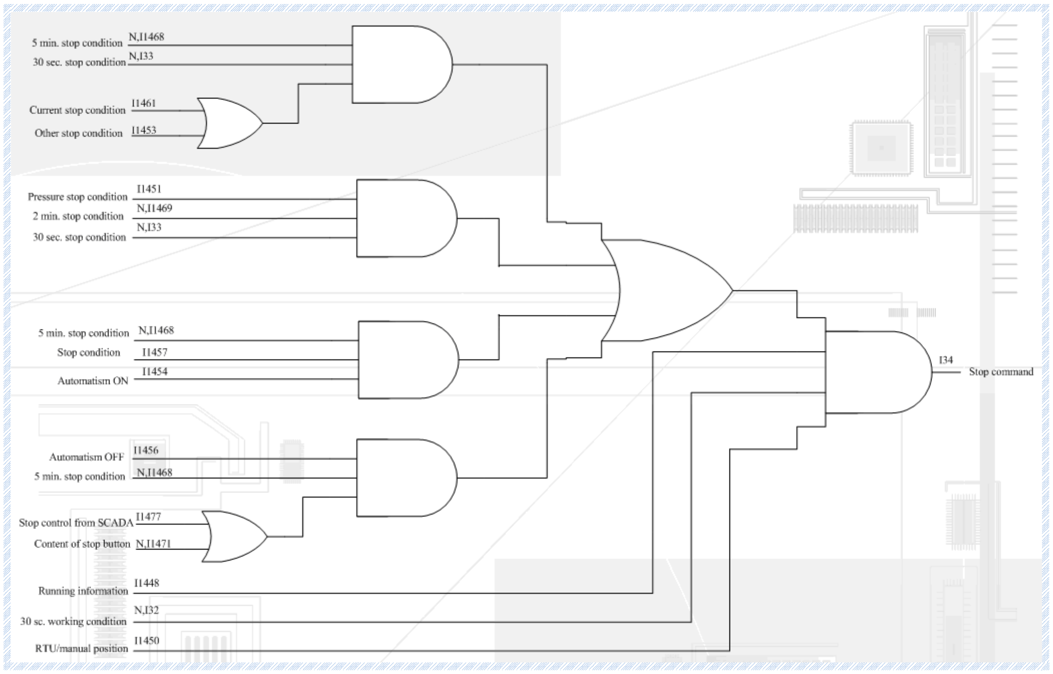


Figure 5.25 Schematic showing the stop inner command using logical gates

CHAPTER SIX
CONCLUSION

This thesis describes an overall automation and control architecture to support the functional aspects of a water distribution system facility and presents the basic knowledge needed to choose technology, design a system, and select a communication method. These descriptions are to be used in the design and implementation of a system that will support the day to day operations of the water distribution.

The distribution system of a waterworks consists of pipes, valves, pumps, and appurtenances used for distributing the water; the tanks and reservoirs used for equalizing pressures and pump discharges; and the costumer service pipes. A distribution system should be designed so that an adequate supply of water is available to the consumers. Water distribution usually involves a large geographic area. In the second chapter of this study, the operation and selection of water distribution equipments, the estimation of water consumption for the selected two zones, and also the designed booster pump station architecture using the estimation are presented.

SCADA system is the generic term for the hardware, software, and procedures used to control and monitor these processes, and to manage the accumulated data for later study. SCADA systems consist of one or more remote terminal units (RTU) connected to a variety of sensors and actuators, and relaying information to a master station. In municipal applications, water is often pumped to long distances across extensive areas measured in square miles. To deliver optimum results, remote automation locations must be either tightly coordinated which has presented some challenges in the past with regard to real time data and event evaluation. However, advances in SCADA technology have provided alternatives to traditional approaches to manage these remote sites and helped users to speed implementations up, reduce costs, improve data integrity and resulting distribution processes, and provide significantly ease of accessibility.

Instrumentations which consist of measuring devices for items such as pressure, temperature, flow, current, voltage etc., as well as sensors that indicate the status of equipment and/or facility related items (valves, pumps, security alerts, etc.) are installed at remote field locations. In addition, a typical SCADA application would also normally include certain controllable devices capable of starting/stopping pumps, opening/closing valves, flow rate controller. This study also presents a research on corruptive effects of the cathodic protection system on electromagnetic flowmeter depending on its measuring principle. Experimental measurements are realized on the water distribution pipelines of the Izmir Municipality, Department of Water and Sewage Administration (IZSU) in Turkey and measurement results are given. Experimental results proved that the values measured by the electromagnetic flowmeter (EMF) are affected by cathodic protection system current. Comments on the measurement results are made and precautions to be taken are proposed in the fourth chapter.

This thesis project covers the necessary equipment, hardware, software, electrical installation about connections for the integration of the SCADA system at the potable water production and distribution facilities. Planning SCADA of the water distribution system, required stations for distribution processing, proposed system architecture, system communication, and automation of the booster pump station model which includes the hardware and the software are given in detail in the fifth chapter. The detail of the MCC panels' components (Star/delta starter panels), sensors and ELITEL-4000 RTU hardware configurations to be used for this project are also included. SCADA communication of this project is selected as digital radio system and its standard name is APCO 25. Water distribution station of Izmir Municipality, Department of Water and Sewage Administration's (IZSU), have been built using industry standard hardware and software from ELIOP S.A., providing the designed SCADA systems simulating real-world control applications.

The proposed components to realize the SCADA system are as follows:

- Microprocessor based intelligent RTUs to be installed at the stations,

- A communication network which will provide communication between the center and RTUs, and among the RTUs themselves,
- Instrumentation hardware to be installed at the stations,
- An advanced SCADA software complying with industrial standards, which will run on the supervisory control and monitoring computer,
- A supervisory control and command computer and connected peripherals to be installed at a location identified and allocated by the Administration.

The requirements for such a new SCADA system supported by latest technology are:

- Expandability and flexibility,
- Conformity to international standards,
- High reliability,
- High functionality and high performance,
- High-level human interface.

Many business enterprise use SCADA systems, which is designed by foreigner firms, in turkey. This study demonstrates, the systems like SCADA can also be designed and planned by locally. In a future study, SCADA security, the detail of communication protocols and methods can be considered.

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APPENDIX A: RTU CONFIGURATION SOFTWARE

```
// Thesis SCADA project
// File: Thes.DAT (Model pump station)
// Created by: Serdar GÜNDOĞDU


//***********************DIGITAL INPUTS*******************************************

// PPI Table (Module parameters table for digital inputs)
//
// Digital Inputs
// Columns 1-3   : *- Table Identification.
// Columns 5-7   : *- Position of the first DI Card Module
// Columns 9-11  : *- Quantity of DI Card Modules
// Column 13     : *- Yes/No Repetitive Alarm Filter.
// Columns 15-19 : *- Supervision Period for repetitive Alarms filter.
// Columns 21-25 : *- Upper Threshold to enable the filter.
// Columns 27-31 : *- Lower Threshold to disable the filter.

//******** PPI Table **********************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PPI 5   1   Y 5     20    2


// AYI Table (The first channel parameters table for digital inputs)
//
// The module number for digital inputs must be in [32,33] range.
//
// Columns 1-3   : *- Table Identification.
// Columns 4-7   : *- Digital Input key.
// Columns 9-11  : *- Station Number.
// Columns 13-15 : *- Module number
// Columns 17-18 : *- Channel Number.
// Column 20     : *- Input kind.
// Column 22     : *- Priority.
// Columns 24-53 : *- Channel Text.
// Columns 57-67 : *- Name attached to the active Channel status.
// Columns 68-78 : *- Name attached to the inactive Channel status.

//******** AYI Table **********************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
AYI0001 065 032 01 S 0 Reserved 32 DI 01
AYI0002 065 032 02 S 2 RTU main supply status           NOT        EXIST
AYI0003 065 032 03 S 2 RTU enclosure status           R OPEN       CLOSE
AYI0004 065 032 04 S 2 Reserved 32 DI 04
AYI0005 065 032 05 S 2 Station main entrance status   R OPEN       CLOSE
//AYI0006 CI
//AYI0007 CI
AYI0008 065 032 08 S 2 Zone I outlet flow alarm_1     R ALARM      NORMAL
AYI0009 065 032 09 S 0 Zone I outlet flow alarm _2    R ALARM      NORMAL
AYI0010 065 032 10 S 2 Zone II outlet flow alarm_1    R ALARM      NORMAL
AYI0011 065 032 11 S 0 Zone II outlet flow alarm_2    R ALARM      NORMAL
AYI0012 065 032 12 S 1 Pump1 elec_panel status        R OPEN       CLOSE
AYI0013 065 032 13 S 1 Pump2 elec_panel status        R OPEN       CLOSE
AYI0014 065 032 14 S 1 Pump3 elec_panel status        R OPEN       CLOSE
AYI0015 065 032 15 S 1 Pump4 elec_panel status        R OPEN       CLOSE
AYI0016 065 032 16 S 0 Reserved 32 DI 16

AYI0017 065 033 01 S 2 Pump1                          S RUNI       STOPI
AYI0018 065 033 02 S 2 Pump1 thermic                  R ALARM      NORMAL
AYI0019 065 033 03 F 1 Pump1 start button             B NORMAL     PUSHED
AYI0020 065 033 04 F 1 Pump1 stop button              B NORMAL     PUSHED
AYI0021 065 033 05 S 2 Pump2                          S RUNI       STOPI
AYI0022 065 033 06 S 2 Pump2 thermic                  R ALARM      NORMAL
AYI0023 065 033 07 F 1 Pump2 start button             B NORMAL     PUSHED
AYI0024 065 033 08 F 1 Pump2 stop button              B NORMAL     PUSHED
AYI0025 065 033 09 S 2 Pump3                          S RUNI       STOPI
```

```
AYI0026 065 033 10 S 2 Pump3 thermic                  R ALARM      NORMAL
AYI0027 065 033 11 F 1 Pump3 start button             B NORMAL     PUSHED
AYI0028 065 033 12 F 1 Pump3 stop button              B NORMAL     PUSHED
AYI0029 065 033 13 S 2 Pump4                          S RUNI       STOPI
AYI0030 065 033 14 S 2 Pump4 thermic                  R ALARM      NORMAL
AYI0031 065 033 15 F 1 Pump4 start button             B NORMAL     PUSHED
AYI0032 065 033 16 F 1 Pump4 stop button              B NORMAL     PUSHED

AYI0066 065 109 01 S 0 P1 Min_Max Current_condition     YES        NO
AYI0067 065 109 02 S 2 P1 Stop Current_condition        YES        NO
AYI0068 065 109 03 S 0 P1 Working_condition             YES        NO
AYI0069 065 109 04 S 2 P1 Stop pressure_condition       YES        NO
AYI0070 065 109 05 S 2 P1 Stop other_conditions         YES        NO

AYI0071 065 109 06 S 0 P2 Min_Max Current_condition     YES        NO
AYI0072 065 109 07 S 2 P2 Stop Current_condition        YES        NO
AYI0073 065 109 08 S 0 P2 Working_condition             YES        NO
AYI0074 065 109 09 S 2 P2 Stop pressure_condition       YES        NO
AYI0075 065 109 10 S 2 P2 Stop other_conditions         YES        NO

AYI0076 065 109 11 S 0 P3 Min_Max Current_condition     YES        NO
AYI0077 065 109 12 S 2 P3 Stop Current_condition        YES        NO
AYI0078 065 109 13 S 0 P3 Working_condition             YES        NO
AYI0079 065 109 14 S 2 P3 Stop pressure_condition       YES        NO
AYI0080 065 109 15 S 2 P3 Stop other_conditions         YES        NO

AYI0081 065 109 16 S 0 P4 Min_Max Current_condition     YES        NO
AYI0082 065 110 01 S 2 P4 Stop Current_condition        YES        NO
AYI0083 065 110 02 S 0 P4 Working_condition             YES        NO
AYI0084 065 110 03 S 2 P4 Stop pressure_condition       YES        NO
AYI0085 065 110 04 S 2 P4 Stop other_conditions         YES        NO


// PYI Table (The second channel parameters table for digital inputs)
//
// Columns 1-3   : *- Table Identification.
// Columns 4-7   : *- Digital input Key.
// Columns 13:   : *- Algorithm Space (Remote/SCADA).
// Columns 15-132: *- Algorithm Space for determined channels


//******** PYI Table ************************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PYI0001
PYI0002
PYI0003
PYI0004
PYI0005
//PYI0006
//PYI0007
PYI0008
PYI0009
PYI0010
PYI0011
PYI0012
PYI0013
PYI0014
PYI0015
PYI0016

PYI0017
PYI0018
PYI0019
PYI0020
PYI0021
PYI0022
PYI0023
PYI0024
PYI0025
PYI0026
PYI0027
PYI0028
```

```
PYI0029
PYI0030
PYI0031
PYI0032

//P1 Condition channels
PYI0066     R LEER(1,2) LEER(1,4) MIN2 LEER(1,6) MIN2 19.0 < LEER(1,2) LEER(1,4) MAX2
LEER(1,6) MAX2 68.0 > OR
PYI0067     R LEER(109,1) LEER(33,1) AND
PYI0068     R LEER(33,1) NOT LEER(31,3) 4.5 < AND LEER(31,5) 1.5 > AND
PYI0069     R LEER(31,4) 7.5 >
PYI0070     R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,2) OR

//P2 Condition channels
PYI0071     R LEER(1,8) LEER(1,10) MIN2 LEER(1,12) MIN2 19.0 < LEER(1,8) LEER(1,10)
MAX2 LEER(1,12) MAX2 68.0 > OR
PYI0072     R LEER(109,6) LEER(33,5) AND
PYI0073     R LEER(33,5) NOT LEER(31,3) 4.5 < AND LEER(31,5) 1.5 > AND
PYI0074     R LEER(31,4) 7.5 >
PYI0075     R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,6) OR


//P3 Condition channels
PYI0076     R LEER(1,14) LEER(1,16) MIN2 LEER(2,2) MIN2 30.0 < LEER(1,14) LEER(1,16)
MAX2 LEER(2,2) MAX2 81.0 > OR
PYI0077     R LEER(109,11) LEER(33,9) AND
PYI0078     R LEER(33,9) NOT LEER(31,4) 5.5 < AND LEER(31,5) 1.5 > AND
PYI0079     R LEER(31,3) 8.5 >=
PYI0080     R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,10) OR


//P4 Condition channels
PYI0081     R LEER(2,4) LEER(2,6) MIN2 LEER(2,8) MIN2 30.0 < LEER(2,4) LEER(2,6) MAX2
LEER(2,8) MAX2 81.0 > OR
PYI0082     R LEER(109,16) LEER(33,13) AND
PYI0083     R LEER(33,13) NOT LEER(31,4) 5.5 < AND LEER(31,5) 1.5 > AND
PYI0084     R LEER(31,3) 8.5 >=
PYI0085     R LEER(31,5) LEER(31,6) MIN2 1.0 <= LEER(33,14) OR


//************************ANALOG INPUTS**********************************************

// PPM Table (Module parameters table for analog inputs)
//
// Analog Inputs
// The direction of block block modules for analog inputs must be in [1,31] range.
// To analog inputs 4-20mA, start in 31 module.
// To analogue inputs direct, start in module 1 and go up.
//
// Columns 1-3   : *- Table Identification.
// Columns 5-7   : *- Position of the first 4-20mA AI Module card.
// Columns 9-11  : *- Quantity of 4-20mA AI Module cards.
// Columns 13-15 : *- Position of the first DR AI Module card.
// Columns 17-19 : *- Quantity of Direct AI Module cards.
// Columns 21-22 : *- Time for confirmation of a fast variation.
// Columns 24-25 : *- Noise Factor to start fast AI variation Mode.
// Columns 27-29 : *- Filtering Factor (in units per cent).

//******** PPM Table **********************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PPM 4   1   3   1   10 25 5


// AYM Table (The first channel parameters table for analog inputs)
//
// Columns 1-3   : *- Table Identification.
// Columns 4-7   : *- Analog input key.
// Columns 9-11  : *- Station number.
// Columns 13-15 : *- Module number.
// Columns 17-18 : *- Channel number.
// Columns 20-21 : *- Input Kind: Un, RM, P4, R4, F4.
// Columns 23-24 : *- Input type. mA, DR
```

```
// Column 26     : *- Priority. 1...3
// Columns 28-57 : *- Channel Text.
// Columns 60-63 : *- Historical data storage type (1A04-15 minutes/2A04-1 hours)
// Columns 65-67 : *- SCADA profile of channel


//******** AYM Table ***********************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
AYM0001 065 031 01 Un mA 2 Zone_I outlet flow             1A04 FLW
AYM0002 065 031 02 Un mA 2 Zone_II outlet flow            1A04 FLW
AYM0003 065 031 03 Un mA 2 Zone_I outlet pressure         1A04 PRS
AYM0004 065 031 04 Un mA 2 Zone_II outlet pressure        1A04 PRS
AYM0005 065 031 05 Un mA 2 Tank level_1                   1A04 LEV
AYM0006 065 031 06 Un mA 2 Tank level_2                   1A04 LEV
AYM0007 065 031 07 Un mA 2 P1_Motor temperature           1A04 TMP
AYM0008 065 031 08 Un mA 2 P2_Motor temperature           1A04 TMP
AYM0009 065 031 09 Un mA 2 P3_Motor temperature           1A04 TMP
AYM0010 065 031 10 Un mA 2 P4_Motor temperature           1A04 TMP
AYM0011 065 031 11 Un mA 2 Chlorine                       2A04 CLR
AYM0012 065 031 12 Un mA 0 Reserved 31 AI 12
AYM0013 065 031 13 Un mA 0 Reserved 31 AI 13
AYM0014 065 031 14 Un mA 0 Reserved 31 AI 14
AYM0015 065 031 15 Un mA 0 Reserved 31 AI 15
AYM0016 065 031 16 Un mA 0 Reserved 31 AI 16

AYM0090 065 105 01 Un mA 0 Pump number
AYM0091 065 105 02 Un mA 0 Valve number
AYM0092 065 105 03 Un mA 0 Perm. Channel addr

AYM0093 065 105 05 Un mA 0 P1 Start_control addr
AYM0094 065 105 06 Un mA 0 P1 Start_button addr
AYM0095 065 105 07 Un mA 0 P2 Start_control addr
AYM0096 065 105 08 Un mA 0 P2 Start_button addr
AYM0097 065 105 09 Un mA 0 P3 Start_control addr
AYM0098 065 105 10 Un mA 0 P3 Start_button addr
AYM0099 065 105 11 Un mA 0 P4 Start_control addr
AYM0100 065 105 12 Un mA 0 P4 Start_button addr

AYM0017 065 001 01 RM DR 2 P1 R_Phase voltage             2A04 VLT
AYM0018 065 001 02 RM DR 2 P1 R_Phase current             2A04 CUR
AYM0019 065 001 03 RM DR 2 P1 S_Phase voltage             2A04 VLT
AYM0020 065 001 04 RM DR 2 P1 S_Phase current             2A04 CUR
AYM0021 065 001 05 RM DR 2 P1 T_Phase voltage             2A04 VLT
AYM0022 065 001 06 RM DR 2 P1 T_Phase current             2A04 CUR
AYM0023 065 001 07 RM DR 2 P2 R_Phase voltage                  VOL
AYM0024 065 001 08 RM DR 2 P2 R_Phase current             2A04 CUR
AYM0025 065 001 09 RM DR 2 P2 S_Phase voltage                  VOL
AYM0026 065 001 10 RM DR 2 P2 S_Phase current             2A04 CUR
AYM0027 065 001 11 RM DR 2 P2 T_Phase voltage                  VOL
AYM0028 065 001 12 RM DR 2 P2 T_Phase current             2A04 CUR
AYM0029 065 001 13 RM DR 2 P3 R_Phase voltage                  VOL
AYM0030 065 001 14 RM DR 2 P3 R_Phase current             2A04 CUR
AYM0031 065 001 15 RM DR 2 P3 S_Phase voltage                  VOL
AYM0032 065 001 16 RM DR 2 P3 S_Phase current             2A04 CUR

AYM0033 065 002 01 RM DR 2 P3 T_Phase voltage                  VOL
AYM0034 065 002 02 RM DR 2 P3 T_Phase current             2A04 CUR
AYM0035 065 002 03 RM DR 2 P4 R_Phase voltage                  VOL
AYM0036 065 002 04 RM DR 2 P4 R_Phase current             2A04 CUR
AYM0037 065 002 05 RM DR 2 P4 S_Phase voltage                  VOL
AYM0038 065 002 06 RM DR 2 P4 S_Phase current             2A04 CUR
AYM0039 065 002 07 RM DR 2 P4 T_Phase voltage                  VOL
AYM0040 065 002 08 RM DR 2 P4 T_Phase current             2A04 CUR
AYM0041 065 002 09 RM DR 0 Reserved 7 PAE 1
AYM0042 065 002 10 RM DR 0 Reserved 7 PAE 2
AYM0043 065 002 11 RM DR 0 Reserved 7 PAE 3
AYM0044 065 002 12 RM DR 0 Reserved 7 PAE 4
AYM0045 065 002 13 RM DR 0 Reserved 8 PAE 1
AYM0046 065 002 14 RM DR 0 Reserved 8 PAE 2
AYM0047 065 002 15 RM DR 0 Reserved 8 PAE 3
AYM0048 065 002 16 RM DR 0 Reserved 8 PAE 4
```

```
AYM0049 065 001 01 P4 DR 2 P1 Active power               2A04 AP1
AYM0050 065 001 01 R4 DR 2 P1 Reactive power             2A04 RPW
AYM0051 065 001 01 F4 DR 2 P1 Power factor
AYM0052 065 001 07 P4 DR 2 P2 Active power               2A04 APW
AYM0053 065 001 07 R4 DR 2 P2 Reactive power             2A04 RPW
AYM0054 065 001 07 F4 DR 2 P2 Power factor
AYM0055 065 001 13 P4 DR 2 P3 Active power               2A04 APW
AYM0056 065 001 13 R4 DR 2 P3 Reactive power             2A04 RPW
AYM0057 065 001 13 F4 DR 2 P3 Power factor
AYM0058 065 002 03 P4 DR 2 P4 Active power               2A04 APW
AYM0059 065 002 03 R4 DR 2 P4 Reactive power             2A04 RPW
AYM0060 065 002 03 F4 DR 2 P4 Power factor


// BYM Table (The second channel parameters table for analog inputs)
//
// Columns 1-3   : *- Table Identification.
// Columns 4-7   : *- Analog input Key.
// Columns 12-17 : *- Minimum Value of Analog input.
// Columns 18-23 : *- Maximum Value of Analog input.
// Columns 25-33 : *- Engineering Units.
// Columns 35-40 : *- Lower Warning Limit in E.U.
// Columns 41-46 : *- Upper Warning Limit in E.U.
// Columns 51-56 : *- Lower Alarm Limit in E.U.
// Columns 57-62 : *- Upper Alarm Limit in E.U.
// Columns 63-66 : *- Hysterics Band in E.U.
//
// To fill the Columns 12 to 17 and 18 to 23 of the P4 Active Power, R4 Reactive
// Power and F4 Power Factor is necessary to put the theoretical values. For example;
// the minimum value for a P4 is 80; the maximum value for P4=3*V*I*cos(80); The E.U.
// of Power is W,etc.

//******** BYM Table ***********************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
BYM0001         0   100      l/s      10    80        10   100 5.0
BYM0002         0   100      l/s      10    90        10   100 5.0
BYM0003         0  10.0      bar     4.5   7.0       4.0   7.5 0.5
BYM0004         0  10.0      bar     5.5   8.0       5.0   8.5 0.5
BYM0005         0   5.0       m      0.8   3.8       0.5     40.25
BYM0006         0   5.0       m      0.8   3.8       0.5     40.25
BYM0007         0   100       C        0    80         0    85   5
BYM0008         0   100       C        0    80         0    85   5
BYM0009         0   100       C        0    80         0    85   5
BYM0010         0   100       C        0    80         0    85   5
BYM0011      0.05   2.5      mg      0.8   1.5       0.5     20.13
BYM0012
BYM0013
BYM0014
BYM0015
BYM0016

BYM0090        48  4048      CAD       4 10000         4 10000
BYM0091        48  4048      CAD       0 10000         0 10000
BYM0092        48  4048      CAD   27905 10000     27905 10000

BYM0093        48  4048      CAD   18433 10000     18433 10000
BYM0094        48  4048      CAD   13059 10000     13059 10000
BYM0095        48  4048      CAD   18435 10000     18435 10000
BYM0096        48  4048      CAD   13063 10000     13063 10000
BYM0097        48  4048      CAD   18437 10000     18437 10000
BYM0098        48  4048      CAD   13073 10000     13073 10000
BYM0099        48  4048      CAD   18439 10000     18439 10000
BYM0100        48  4048      CAD   13077 10000     13077 10000

BYM0017         0   264       V      198   242       193   246
BYM0018         0   120       A       31    48        19    68
BYM0019         0   264       V      198   242       193   246
BYM0020         0   120       A       31    48        19    68
BYM0021         0   264       V      198   242       193   246
BYM0022         0   120       A       31    48        19    68
BYM0023         0   264       V      198   242       193   246
BYM0024         0   120       A       31    48        19    68
```

```
BYM0025         0   264       V      198   242       193   246
BYM0026         0   120       A       31    48        19    68
BYM0027         0   264       V      198   242       193   246
BYM0028         0   120       A       31    48        19    68
BYM0029         0   264       V      198   242       193   246
BYM0030         0   120       A       47    64        30    81
BYM0031         0   264       V      198   242       193   246
BYM0032         0   120       A       47    64        30    81

BYM0033         0   264       V      198   242       193   246
BYM0034         0   120       A       47    64        30    81
BYM0035         0   264       V      198   242       193   246
BYM0036         0   120       A       47    64        30    81
BYM0037         0   264       V      198   242       193   246
BYM0038         0   120       A       47    64        30    81
BYM0039         0   264       V      198   242       193   246
BYM0040         0   120       A       47    64        30    81
BYM0041
BYM0042
BYM0043
BYM0044
BYM0045
BYM0046
BYM0047
BYM0048
BYM0049    -95.04 95.04 kW
BYM0050    -95.04 95.04 kVAR
BYM0051         0     1 --
BYM0052    -95.04 95.04 kW
BYM0053    -95.04 95.04 kVAR
BYM0054         0     1 --
BYM0055    -95.04 95.04 kW
BYM0056    -95.04 95.04 kVAR
BYM0057         0     1 --
BYM0058    -95.04 95.04 kW
BYM0059    -95.04 95.04 kVAR
BYM0060         0     1 --


// PYM Table (The third channel parameters table for analog inputs)
//
// Columns 1-3   :* E- Table Identification.
// Columns 4-7   :* E- Analog input key.
// Column 13     :* E- Algorithm space (R>>RTU or S>>SCADA)


//******** PYM Table ************************************************************
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PYM0001
PYM0002
PYM0003
PYM0004
PYM0005
PYM0006
PYM0007
PYM0008
PYM0009
PYM0010
PYM0011
PYM0012
PYM0013
PYM0014
PYM0015
PYM0016

PYM0090     R
PYM0091     R
PYM0092     R

PYM0093     R
PYM0094     R
PYM0095     R
```

```
PYM0096     R
PYM0097     R
PYM0098     R
PYM0099     R
PYM0100     R


PYM0017
PYM0018
PYM0019
PYM0020
PYM0021
PYM0022
PYM0023
PYM0024
PYM0025
PYM0026
PYM0027
PYM0028
PYM0029
PYM0030
PYM0031
PYM0032

PYM0033
PYM0034
PYM0035
PYM0036
PYM0037
PYM0038
PYM0039
PYM0040
PYM0041
PYM0042
PYM0043
PYM0044
PYM0045
PYM0046
PYM0047
PYM0048

PYM0049
PYM0050
PYM0051
PYM0052
PYM0053
PYM0054
PYM0055
PYM0056
PYM0057
PYM0058
PYM0059
PYM0060


//************************COUNTER INPUTS*********************************************

// AYE Table (The first channel parameters table for counter inputs)
//
// Counting Inputs
// The module number for counter inputs must be in [32,47] range.
//
// Columns 1-3   : * E- Table Identification.
// Columns 4-7   : * E- Counter input key.
// Columns 9-11  : * E- Station number.
// Columns 13-15 : * E- Module number.
// Columns 17-18 : * E- Channel number.
// Column  22    : * E- Priority.
// Columns 24-53 : * E- Channel Text.
// Columns 55-63 : * E- Engineering Units.
// Columns 65-70 : * E- Value per Pulse in E.U.
// Columns 72-75 : * E- Period of historical (2C03-1 hour storage)
// Columns 77-79 : * E- SCADA profile of channel
```

```
//******** AYE Table ***********************************************************
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
AYE0001 065 037 01   2 Total P1 Active energy         kWh           1.0 2C03 AEN
AYE0002 065 037 02   2 Total P1 Reactive energy       kVARh         1.0 2C03 REN
AYE0003 065 037 03   2 Total P2 Active energy         kWh           1.0 2C03 AEN
AYE0004 065 037 04   2 Total P2 Reactive energy       kVARh         1.0 2C03 REN
AYE0005 065 037 05   2 Total P3 Active energy         kWh           1.0 2C03 AEN
AYE0006 065 037 06   2 Total P3 Reactive energy       kVARh         1.0 2C03 REN
AYE0007 065 037 07   2 Total P4 Active energy         kWh           1.0 2C03 AEN
AYE0008 065 037 08   2 Total P4 Reactive energy       kVARh         1.0 2C03 REN

AYE0009 065 032 06   2 Zone_I total outl flow         m3            1.0 2C03 TFL   036
AYE0010 065 032 07   2 Zone_II total outl flow        m3            1.0 2C03 TFL   036


// PYE Table (The second channel parameters table for counter inputs)
//
// Columns 1-3    : * E- Table Identification.
// Columns 4-7    : * E- Counter input Key.
// Column 13      : * E- Algorithm Switch. R-> RTU; S-> SCADA;
// Columns 15-132 : * E- RPN Algorithm (If it exists).

//******** PYE Table ***********************************************************
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PYE0001     R INT(3,1)
PYE0002     R INT(3,2)
PYE0003     R INT(3,4)
PYE0004     R INT(3,5)
PYE0005     R INT(3,7)
PYE0006     R INT(3,8)
PYE0007     R INT(3,10)
PYE0008     R INT(3,11)

PYE0009
PYE0010


//************************DIGITAL OUTPUTS********************************************

// PPC Table (Module parameters table for digital outputs)
//
// Digital Outputs
// The module number for digital outputs must be in [48,49] range.
// Columns 1-3    : * E- Table Identification.
// Columns 5-7    : * E- Position of the last DO Card Module.
// Columns 9-11   : * E- Quantity of DO Card Modules.

//******** PPC Table ***********************************************************
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
PPC 8   2


// AYC Table (The first channel parameters table for digital outputs)
//
// Columns 1-3    : * E- Table Identification.
// Columns 4-7    : * E- Digital Output key.
// Columns 9-11   : * E- Station number.
// Columns 13-15  : * E- Module number.
// Columns 17-18  : * E- Channel number.
// Columns 20-21  : * E- Kind of Command. ( S, C,)
// Column 22      : * E- Command with Possible Selection.
// Columns 28-55  : * S- Channel Text.
// Columns 57-66  : * E- Name Attached to active Digital Output.
// Columns 68-76  : * E- Name attached to inactive Digital Output.
```

```
//******** AYC Table ***********************************************************
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
AYC0001 065 048 01 C N     P1 Start control             ON         OFF
AYC0002 065 048 02 C N     P1 Stop control              ON         OFF
AYC0003 065 048 03 C N     P2 Start control             ON         OFF
AYC0004 065 048 04 C N     P2 Stop control              ON         OFF
AYC0005 065 048 05 C N     P3 Start control             ON         OFF
AYC0006 065 048 06 C N     P3 Stop control              ON         OFF
AYC0007 065 048 07 C N     P4 Start control             ON         OFF
AYC0008 065 048 08 C N     P4 Stop control              ON         OFF
AYC0009 065 048 09 S N     P1 Runi Lamp                 ON         OFF
AYC0010 065 048 10 S N     P1 Stopi lamp                ON         OFF
AYC0011 065 048 11 S N     P2 Runi Lamp                 ON         OFF
AYC0012 065 048 12 S N     P2 Stopi lamp                ON         OFF
AYC0013 065 048 13 S N     P3 Runi Lamp                 ON         OFF
AYC0014 065 048 14 S N     P3 Stopi lamp                ON         OFF
AYC0015 065 048 15 S N     P4 Runi Lamp                 ON         OFF
AYC0016 065 048 16 S N     P4 Stopi lamp                ON         OFF

AYC0017 065 049 01 S N     Alarm lamp                   ON         OFF
AYC0018 065 049 02 S N     Reserved 49 DO 2             ON         OFF
AYC0019 065 049 03 S N     Reserved 49 DO 3             ON         OFF
AYC0020 065 049 04 S N     Reserved 49 DO 4             ON         OFF
AYC0021 065 049 05 S N     Reserved 49 DO 5             ON         OFF
AYC0022 065 049 06 S N     Reserved 49 DO 6             ON         OFF
AYC0023 065 049 07 S N     Reserved 49 DO 7             ON         OFF
AYC0024 065 049 08 S N     Reserved 49 DO 8             ON         OFF
AYC0025 065 049 09 S N     Reserved 49 DO 9             ON         OFF
AYC0026 065 049 10 S N     Reserved 49 DO 10            ON         OFF
AYC0027 065 049 11 S N     Reserved 49 DO 11            ON         OFF
AYC0028 065 049 12 S N     Reserved 49 DO 12            ON         OFF
AYC0029 065 049 13 S N     Reserved 49 DO 13            ON         OFF
AYC0030 065 049 14 S N     Reserved 49 DO 14            ON         OFF
AYC0031 065 049 15 S N     Reserved 49 DO 15            ON         OFF
AYC0032 065 049 16 S N     Reserved 49 DO 16            ON         OFF

// PYC Table (The second channel parameters table for digital outputs)
//
// Columns 1-3     : * E- Table Identification.
// Columns 4-7     : * E- Digital Output key.
// Columns 9-12    : * E- Digital Input key associated to this Digital Output.
// Columns 18-80   : * E- RPN Boolean Expression.

//******** PYC Table ***********************************************************
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
------- ---- --- ---------------------------------------------------------------
PYC0001
PYC0002
PYC0003
PYC0004
PYC0005
PYC0006
PYC0007
PYC0008
PYC0009          A LEER(33,1)
PYC0010          A LEER(33,1) NOT
PYC0011          A LEER(33,5)
PYC0012          A LEER(33,5) NOT
PYC0013          A LEER(33,9)
PYC0014          A LEER(33,9) NOT
PYC0015          A LEER(33,13)
PYC0016          A LEER(33,13) NOT

PYC0017          A LEER(33,2) LEER(33,6) OR LEER(33,10) OR LEER(33,14) OR
PYC0018
PYC0019
PYC0020
PYC0021
PYC0022
PYC0023
```

PYC0024
PYC0025
PYC0026
PYC0027
PYC0028
PYC0029
PYC0030
PYC0031
PYC0032

APPENDIX B: RTU AUTOMATION SOFTWARE

```
;********Specification module*****************************************************
INI    E                              ;Start line of specification module
;
FIJ    T2,3000                        ;5 min. running condition time
FIJ    T3,300                         ;30 sec. running condition time
FIJ    T4,3000                        ;5 min. stop condition time
FIJ    T5,1200                        ;2 min. stop condition time
;
FIJ    T10,300                        ;30 sec. stop wait (T10)
FIJ    T11,300                        ;30 sec. stop wait (T11)
FIJ    T12,300                        ;30 sec. stop wait (T12)
FIJ    T13,300                        ;30 sec. stop wait (T13)
FIJ    T14,300                        ;30 sec. stop wait (T14)
FIJ    T15,300                        ;30 sec. stop wait (T15)
FIJ    T16,300                        ;30 sec. stop wait (T16)
FIJ    T17,300                        ;30 sec. stop wait (T17)

;
FIJ    F1000,0,1,2,3,4                ;F1000<=0, F1001<=1,…………continued
FIJ    F1005,5,6,7,8,9
FIJ    F1010,10,11,12,13,14
FIJ    F1015,15,16,17,18,19
FIJ    F1020,20,21,22,23,24
FIJ    F1025,25,26,27,28,29
FIJ    F1030,30,31,32,33,34
FIJ    F1035,35,36,37,38,39
FIJ    F1040,40,41,42,43,44
FIJ    F1045,45,46,47,48,49
FIJ    F1050,50,51,52,53,54
FIJ    F1055,55,56,57,58,59
FIJ    F1100,100,101,102,103,104
FIJ    F1105,105,106,107,108,109
FIJ    F1110,110,111,112,113,114
FIJ    F1115,115,116,117,118,119      ;F1115<=115, F116<=116,…………continued
;
FIN    E                              ;End line of specification module
;
;********Program initiation module************************************************
INI    I                              ;Start line of program initiation module
;
FUN    U14,F1001,F1108,F1001          ;Automatism ON/OFF
ENU    0                              ;Reset
SLU    I1454                          ;Automatism ON
SLU    I1456                          ;Automatism OFF
;
FUN    U11,F1105,F1001                ;Pump number (see AYM0090 in the appendix A)
ENN    I520
SLN    I155                           ;Pump number
;
ENN    0                              ;Reset
SLN    I1310                          ;Module address
SLN    I1311                          ;Channel address
;
ENN    0
SLN    I150                           ;Start loop from X5 index >>>0
;
REP    I155                           ;Starting of loop-1 (I155 times repetition)
;
ENN    I150
SUM    1
SLN    I150
SLN    X5                             ;X5<<<I150 <<<I150+1
;
FUN    U8,I150                        ;Go U8-subprogram
;
ENU    0                              ;Reset
SLU    I60,X5                         ;Running factor for each pump
;
ENN    1500
SLN    I40,X5                         ;Running time for each pump
```

```
;
ENU     0                              ;Reset
SLU     I1740,X5                       ;Running time subsidiary factor for each pump
;
REP     F                              ;End of loop-1
;
ENU     0                              ;Reset
SLU     I30                            ;Run inner command
SLU     I34                            ;Stop inner command
;
ENN     2
SLN     I9                             ;First zone's motor number (2)
;
ENN     2
SLN     I10                            ;Second zone's motor number (2)
;
;Condition-times
ENU     1
ENU     0
TMP     T2                             ;5 min. running condition time
SLU     I1999
;
ENU     1
ENU     0
TMP     T3                             ;30 sec. running condition time
SLU     I1999
;
ENU     1
ENU     0
TMP     T4                             ;5 min. stop condition time
SLU     I1999
;
ENU     1
ENU     0
TMP     T5                             ;2 min. stop condition time
SLU     I1999
;
ENU     0                              ;Reset for running and stop conditions
SLU     I1458                          ;5 min. running condition
SLU     I32                            ;30 sc. running condition
SLU     I1468                          ;5 min. stop condition
SLU     I1469                          ;2 min. stop condition
;
FIN     I                              ;End line of program initiation module
;
;********Basic cycle module*********************************************************
INI     C                              ;Start line of basic cycle module
;
FUN     U11,F1119,F1001                ;RTU/Local switch status/U11-subprogram
ENU     I520
SLU     N,I1450                        ;RTU/Local inner variable for each pump
;
FUN     U11,F1108,F1002                ;Automatism ON status
ENU     I520
LYU     N,I1454                        ;Automatism ON inner variable for each pump
SAL     ONN,                           ;If (N,1454) is 0,go ETI ONN.
ENU     1
SLU     I1454                          ;Set Automatism ON inner variable
ENU     0
SLU     I1456                          ;Reset Automatism OFF inner variable
;
FUN     U14,F1000,F1108,F1001          ;Content of 108,1 channel write to 0
;
ETI     ONN
;
FUN     U11,F1108,F1001                ;Automatism OFF status
ENU     I520
LYU     N,I1456                        ;Automatism OFF inner variable
SAL     OFF,                           ;If (N,1456) is 0,go ETI OFF.
ENU     1
SLU     I1456                          ;Set Automatism OFF inner variable
ENU     0
SLU     I1454                          ;Reset Automatism ON inner variable
;
```

```
FUN    U14,F1000,F1108,F1002          ;Content of 108,2 channel write to 0
;
ETI    OFF
;
ENN    0                              ;Reset
SLN    I170
SLN    X14                            ;Index about pump information
SLN    X15                            ;Index about conditions
;
REP    I155                           ;Starting of loop-2 (I155 times repetition)
;
ENN    109
SLN    I109                           ;II109 <<< 109
;
ENN    I170
SUM    1
SLN    I170                           ;I170<<<I170+1
;
FUN    U7,I170                        ;Start and stop conditions (109.-110. module)
;
;Start/stop commands reading from SCADA and button
FUN    U6,I170                        ;U7 subprogram about pump information(33.module)
;
ENN    X14                            ;Index about pump information for each pump
SUM    1
SLN    X14                            ;X14+1 >>> X14 >>> U6
;
ENU    I1444                          ;Content of start button
SLU    I400,X14                       ;I1444 (subprogram)>>>I400 (main program)
;
ENU    I1445                          ;Content of stop button
SLU    I420,X14                       ;I1445 (subprogram)>>>I420 (main program)
;
ENU    I1448                          ;Running information
SLU    I440,X14                       ;I1448 (subprogram)>>>I440 (main program)
;
ENN    X15                            ;Index about conditions for each pump
SUM    1
SLN    X15                            ;U7<<< X15 <<<X15+1
;
ENU    I300,X15                       ;Content of start condition
SLU    I1452                          ;I300 (subprogram)>>>I1452 (main program)
;
ENU    I320,X15                       ;Content of pressure stop
SLU    I1451                          ;I320 (subprogram)>>>I1451 (main program)
;
ENU    I340,X15                       ;Content of other stop
SLU    I1453                          ;I340 (subprogram)>>>I1453 (main program)
;
ENU    I280,X15                       ;Content of current stop
SLU    I1461                          ;I280 (subprogram)>>>I1461 (main program)
;
ENU    I1451                          ;Pressure stop condition
LOU    I1453                          ;Other stop condition
LOU    I1461                          ;Current stop condition
SLU    I1457                          ;Stop cond.(I1451 or I1453 or I1461 >>> 1457)
;
ENU    N,I620,X15                     ;Not of I620
LYU    N,I1457                        ;(Not of I620) AND (Not of I1457)
FLC    I1457                          ;I1457 (Edge input)
TMP    T10,X15                        ;30 sec. stop wait
SLU    I620,X15                       ;Stop output (after 30 sc. waited)
;
ENU    I620,X15
SLU    I33                            ;Stop condition
;
ENU    N,I1451                        ;Not of I451 (Inverse of pressure stop condit.)
LYU    N,I1453                        ;Not of I453 (Inverse of other stop condition)
SLU    I1462                          ;Other-pres. stop.(N,I1451 or N,I1453 >>> 1462)
;
;Line of starting about working
ENU    I400,X15
SLU    I1470                          ;Content of start button
;
```

```
ENN    X15                          ;Proportional pump number loop-(1,2,3,4 pumps)
MUL    2                            ;2*X15
SUM    1                            ;2*X15+1
SLN    I1479                        ;SCADA start channel no (108. Mod.3,5,7,9 chan.)
;
FUN    U11,F1108,I1479
ENU    I520
SLU    I1478                        ;Content of start control from SCADA
;
ENU    I1450                        ;RTU/Local position
LYU    N,I1458                      ;Inverse of 5 min. running condition
LYU    I1462                        ;Other and pressure stop condition
ENU    I1452                        ;Start condition
LYU    I1454                        ;Automatism ON
ENU    I1456                        ;Automatism OFF
ENU    I1478                        ;Start control from SCADA
LOU    N,I1470                      ;Inverse of content of start button
LYU
LOU
LYU
SLU    I30                          ;Start inner command
;
;Reset for SCADA run output
ENU    I1478                        ;Content of start control from SCADA
SAL    SRIZ,                        ;If I1478 is 0,go ETI SRIZ.
FUN    U14,F1000,F1108,I1479        ;Reset***content of (108,1479) channels
ETI    SRIZ
;
;5 min. running condition
ENU    N,I1458                      ;Not of I1458
LYU    N,I30                        ;(Not of I30) AND (Not of I1458)
FLC    I30                          ;Run inner command (Edge input of I30)
TMP    T2                           ;5 min. stop wait
SLU    I1458                        ;5 min. running condition (after 5 min. waited)
;
;30 sc. running condition
ENU    N,I32                        ;Not of I32
LYU    N,I30                        ;(Not of I32) AND (Not of I32)
FLC    I30                          ;Run inner command (Edge input of I30)
TMP    T3                           ;30 sc. stop wait
SLU    I32                          ;30 sc. running condition (after 30 sc. waited)
;
ENU    I30                          ;Start inner command
SAL    PURUN,                       ;If I30 is 0,go ETI PURUN.
;
FUN    U16,X15                      ;Go U16 subprogram for start and stop button
;
;Physical start command
FUN    U15,F1001,I1440,I1441        ;Start button (1440,1441)>>> 1
;
ETI    PURUN
;
FUN    U30                          ;Go U30 subprogram
;
;Line of starting about stopping
ENU    I420,X15
SLU    I1471                        ;Content of stop button
;
ENN    X15                          ;Proportional pump number loop-(1,2,3,4 pumps)
MUL    2                            ;2*X15
SUM    2                            ;2*X15+2
SLN    I1479                        ;SCADA stop channel no (108. Mod.4,6,8,10 chan.)
;
FUN    U11,F1108,I1479
ENU    I520
SLU    I1477                        ;Content of stop control from SCADA
;
ENU    1
SLU    I31                          ;I31 input>>>1 (stop)
FUN    U20                          ;Go U20 subprogram for running time
;
ENU    I440,X15
SLU    N,I1476                      ;Inverse of running information
;
```

```
ENU    N,I1468                      ;Inverse of 5 min. stop condition
ENU    I1461                        ;Current stop condition
LOU    I1453                        ;Other stop condition
LYU
LYU    N,I33                        ;Inverse of 30 sc. stop condition
ENU    N,I1469                      ;Inverse of 2 min. stop condition
LYU    I1451                        ;Pressure stop condition
LYU    N,I33                        ;Inverse of 30 sc. stop condition
ENU    I1454                        ;Automatism ON
LYU    I1457                        ;Stop condition
LYU    N,I1468                      ;Inverse of 5 min. stop condition
ENU    I1456                        ;Automatism OFF
LYU    N,I1468                      ;Inverse of 5 min. stop condition
ENU    I1477                        ;Stop control from SCADA
LOU    N,I1471                      ;Inverse of content of stop button
LYU
LOU
LYU    I1450                        ;RTU/Local position
LYU    I1448                        ;Running information
LYU    N,I32                        ;Inverse of 30 sc. running condition
SLU    I34                          ;Stop inner command
;
;Reset for SCADA stop output
ENU    I1477                        ;Content of stop control from SCADA
SAL    SSIZ,                        ;If I1477 is 0,go ETI SSIZ.
FUN    U14,F1000,F1108,I1479        ;Reset***content of (108,1479) channels
ETI    SSIZ
;
;5 min. stop condition
ENU    N,I1468                      ;Not of I1468
LYU    N,I34                        ;(Not of I34) AND (Not of I1468)
FLC    I34                          ;Stop inner command (Edge input of I34)
TMP    T4                           ;5 min. stop wait
SLU    I1468                        ;5 min. stop condition (after 5 min. waited)
;
;2 min. stop condition
ENU    N,I1469                      ;Not of I1469
LYU    N,I34                        ;(Not of I34) AND (Not of I1469)
FLC    I34                          ;Stop inner command (Edge input of I34)
TMP    T5                           ;2 min. stop wait
SLU    I1469                        ;2 min. stop condition (after 2 min. waited)
;
ENU    I34                          ;Stop inner command
SAL    PUMSTOP,                     ;If I34 is 0,go ETI PUMSTOP.
;
FUN    U16,X15                      ;Go U16 subprogram for start and stop button
;
;Physical stop command
FUN    U15,F1001,I1443,I1442        ;Stop button (1443,1442)>>> 1
;
ETI    PUMSTOP
;
FUN    U32                          ;Go U32 subprogram
;
REP    F                            ;End of loop-2
;
FIN    C                            ;End line of basic cycle module
;
;********User function specification module*****************************************
INI    U6                           ;Start line of U6 subprogram
;
ENN    P1                           ;For pump number loop-(1,2,3,4 pumps)
SLN    X13
;
ENN    I1500,X13
SLN    I1440                        ;Start button input module no (33. module)
SLN    I1443                        ;Stop button input module no (33. module)
RES    1
SLN    I1446                        ;Running information input module no(33. module)
;
;
ENN    I1520,X13
SLN    I1441                        ;Start button input channel no (3,7,11,15)
;
```

```
SUM     1
SLN     I1442                          ;Stop button input channel no (4,8,12,16)
;
SUM     13
SLN     I1447                          ;Running information input channel no (1,5,9,13)
;
CMP     I1447,16                       ;If I1447<16,go ETI RUNI.
SAL     ,RUNI,RUNI
;
ENN     I1447
RES     16
SLN     I1447                          ;1447<<<1447-16
;
ENN     I1446
SUM     1
SLN     I1446                          ;1146<<<1446+1
;
ETI     RUNI
;
FUN     U11,I1443,I1442                ;Content of stop button module and channel
ENU     I520
SLU     I1445                           ;I1445 (subprogram)>>>I420 (main program)
;
FUN     U11,I1446,I1447                ;Content of running information mod. and channel
ENU     I520
SLU     I1448                          ;I1448 (subprogram)>>>I440 (main program)
;
FUN     U11,I1440,I1441                ;Content of start button module and channel
ENU     I520
SLU     I1444                          ;I1444 (subprogram)>>>I400 (main program)
;
FIN     U6                             ;End line of U6 subprogram
;
;*********************************************************************************
INI     U7                             ;Start line of U7 subprogram
;
ENN     P1                             ;For pump number loop-(1,2,3,4 pumps)
SLN     X12
;
ENN     P1
MUL     5                              ;5*P1
RES     3                              ;5*P1-3
SLN     I171                           ;Current stop condition channel no
;
CMP     I171,16                        ;If I171<16,go ETI CSTO.
SAL     ,CSTO,CSTO
;
ENN     I171
RES     16
SLN     I171                           ;171<<<171-16
;
ENN     I109
SUM     1
SLN     I109                           ;109<<<109+1
;
ETI     CSTO
;
FUN     U11,I109,I171
ENU     I520
SLU     I280,X12                       ;Current stop condition module and channel
;
ENN     P1
MUL     5                              ;5*P1
RES     2                              ;5*P1-2
SLN     I171                           ;Start condition channel no
;
ENN     109
SLN     I109                           ;I109<<<109
;
CMP     I171,16                        ;If I171<16,go ETI STCO.
SAL     ,STCO,STCO
;
ENN     I171
RES     16
```

```
SLN    I171                          ;171<<<171-16
;
ENN    I109
SUM    1
SLN    I109                          ;109<<<109+1
;
ETI    STCO
;
FUN    U11,I109,I171
ENU    I520
SLU    I300,X12                      ;Start condition module and channel
;
ENN    109
SLN    I109                          ;I109<<<109
;
ENN    P1
MUL    5                             ;5*P1
RES    1                             ;5*P1-1
SLN    I171                          ;Pressure stop condition channel no
;
CMP    I171,16                       ;If I171<16,go ETI PSTO.
SAL    ,PSTO,PSTO
;
ENN    I171
RES    16
SLN    I171                          ;171<<<171-16
;
ENN    I109
SUM    1
SLN    I109                          ;109<<<109+1
;
ETI    PSTO
;
FUN    U11,I109,I171
ENU    I520
SLU    I320,X12                      ;Pressure stop module and channel
;
ENN    109
SLN    I109                          ;I109<<<109
;
ENN    P1
MUL    5                             ;5*P1
SLN    I171                          ;Other stop condition channel no
;
CMP    I171,16                       ;If I171<16,go ETI OSTO.
SAL    ,OSTO,OSTO
;
ENN    I171
RES    16
SLN    I171                          ;171<<<171-16
;
ENN    I109
SUM    1
SLN    I109                          ;109<<<109+1
;
ETI    OSTO
;
FUN    U11,I109,I171
ENU    I520
SLU    I340,X12                      ;Other stop condition module and channel
;
FIN    U7                            ;End line of U7 subprogram
;
;*********************************************************************************
INI    U8                            ;Start line of U8 subprogram
;
ENN    P1                            ;I150 (Pump number loop)-(1,2,3,4 pumps)
MUL    2                             ;2*P1
SUM    3                             ;2*P1+3
SLN    I160                          ;Control channel no(5,7,9,11)
;
ENN    105
SLN    I1305                         ;Control module no (1305 < 105)
;
```

```
ENN    P1
SLN    X11
;
FUN    U11,I1305,I160               ;(105,5)-(105,7)-(105,9)-(105,11) channels
FUN    U9,I520
ENN    I1310
SLN    I1400,X11                    ;Control module no [18433....(DECIMAL)>48]
ENN    I1311
SLN    I1420,X11                    ;Control channel no [18433....(DECIMAL)>1-3-5-7]
;
ENN    I160
SUM    1
SLN    I160                         ;Button channel no (6,8,10,12)
;
FUN    U11,I1305,I160               ;(105,6)-(105,8)-(105,10)-(105,12) channels
FUN    U9,I520
ENN    I1310
SLN    I1500,X11                    ;Button module no [13059....(DECIMAL)>33]
ENN    I1311
SLN    I1520,X11                    ;Button channel no [13059...(DECIMAL)>3-7-11-15]
;
FIN    U8                           ;End line of U8 subprogram
;
;*************************************************************************************
INI    U9                           ;Start line of U9 subprogram
;
ENN    P1
SLN    I1311                        ;Module and channel-combined
;
ENB    9,I1311
SLB    1,I1310
ENB    10,I1311
SLB    2,I1310
ENB    11,I1311
SLB    3,I1310
ENB    12,I1311
SLB    4,I1310
ENB    13,I1311
SLB    5,I1310
ENB    14,I1311
SLB    6,I1310
ENB    15,I1311
SLB    7,I1310
ENB    16,I1311
SLB    8,I1310
;
ENU    0
SLB    9,I1311
SLB    10,I1311
SLB    11,I1311
SLB    12,I1311
SLB    13,I1311
SLB    14,I1311
SLB    15,I1311
SLB    16,I1311
;
ENN    I1311
CONV   BCD,BIN
SLN    I1311                        ;Separated-channel no
;
ENN    I1310
CONV   BCD,BIN
SLN    I1310                        ;Separated-module no
;
FIN    U9                           ;End line of U9 subprogram
;
;*************************************************************************************
INI    U11                          ;Start line of U11 subprogram
;
ENN    0                            ;Reset
SLN    I520                         ;Pump number
;
ENN    0
ENN    P1                           ;Module number (for example;105)
```

```
ENN    P2                             ;Channel number (for example;1)
FUN    S12,I520                       ;Data read from physical and logical channel
;
FIN    U11                            ;End line of U11 subprogram
;Content of(Module number, Channel number)channel write to I520 variable
;*********************************************************************************
INI    U14                            ;Start line of U14 subprogram
;
ENN    0
ENN    P2                             ;Module number (for example;108)
ENN    P3                             ;Channel number (for example;1)
ENN    P1                             ;Written number (for example;1)
FUN    S13                            ;Data send to logical channel
;
FIN    U14                            ;End line of U14 subprogram
;Content of(Module number-P2, Channel number-P3)channel write to P1.
;*********************************************************************************
INI    U15                            ;Start line of U15 subprogram
;
ENN    0
ENN    P2                             ;Module number
ENN    P3                             ;Channel number
ENN    P1                             ;Written number
FUN    S14                            ;Data send to physical channel
;
FIN    U15                            ;End line of U15 subprogram
;Content of(Module number-P2, Channel number-P3)channel write to P1.
;*********************************************************************************
INI    U16                            ;Start line of U16 subprogram
;
ENN    P1
SLN    X13
;
ENN    I1400,X13                      ;Start and stop button control module no
SLN    I1440                          ;Start button input module no (33. module)
SLN    I1443                          ;Stop button input module no (33. module)
;
ENN    I1420,X13                      ;Start and stop button control channel no
SLN    I1441                          ;Start button input channel no (3,7,11,15)
;
SUM    1
SLN    I1442                          ;Stop button input channel no (4,8,12,16)
;
FIN    U16                            ;End line of U16 subprogram
;
;*********************************************************************************
INI    U20                            ;Start line of U20 subprogram for running time
;
ENU    I31
SAL    ,TIMALT                        ;If I31 is 1,go ETI TIMALT.
;
ENN    R19                            ;Real-time hour
MUL    60                             ;(60*R19)
SUM    R18                            ;Real-time minute (60*R19+R18)
SLN    I40,X15                        ;Running time for each pump (R18>>>I40)
;
ETI    TIMALT
;
FIN    U20                            ;End line of U20 subprogram
;
;*********************************************************************************
INI    U30                            ;Start line of U30 subprogram
;
ENU    I1740,X15
SLU    I1740                          ;Running time subsidiary factor for each pump
;
ENU    I440,X15                       ;Running information
LYU    N,I1740                        ;(N,I1740) AND (I440)
SAL    JMPA,                          ;If (N,I1740) AND (I440) is 0,go ETI JMPA.
;
ENU    0
SLU    I31                            ;I31 input >>>0 (stop)
FUN    U20                            ;Go U20 subprogram for running time
;
```

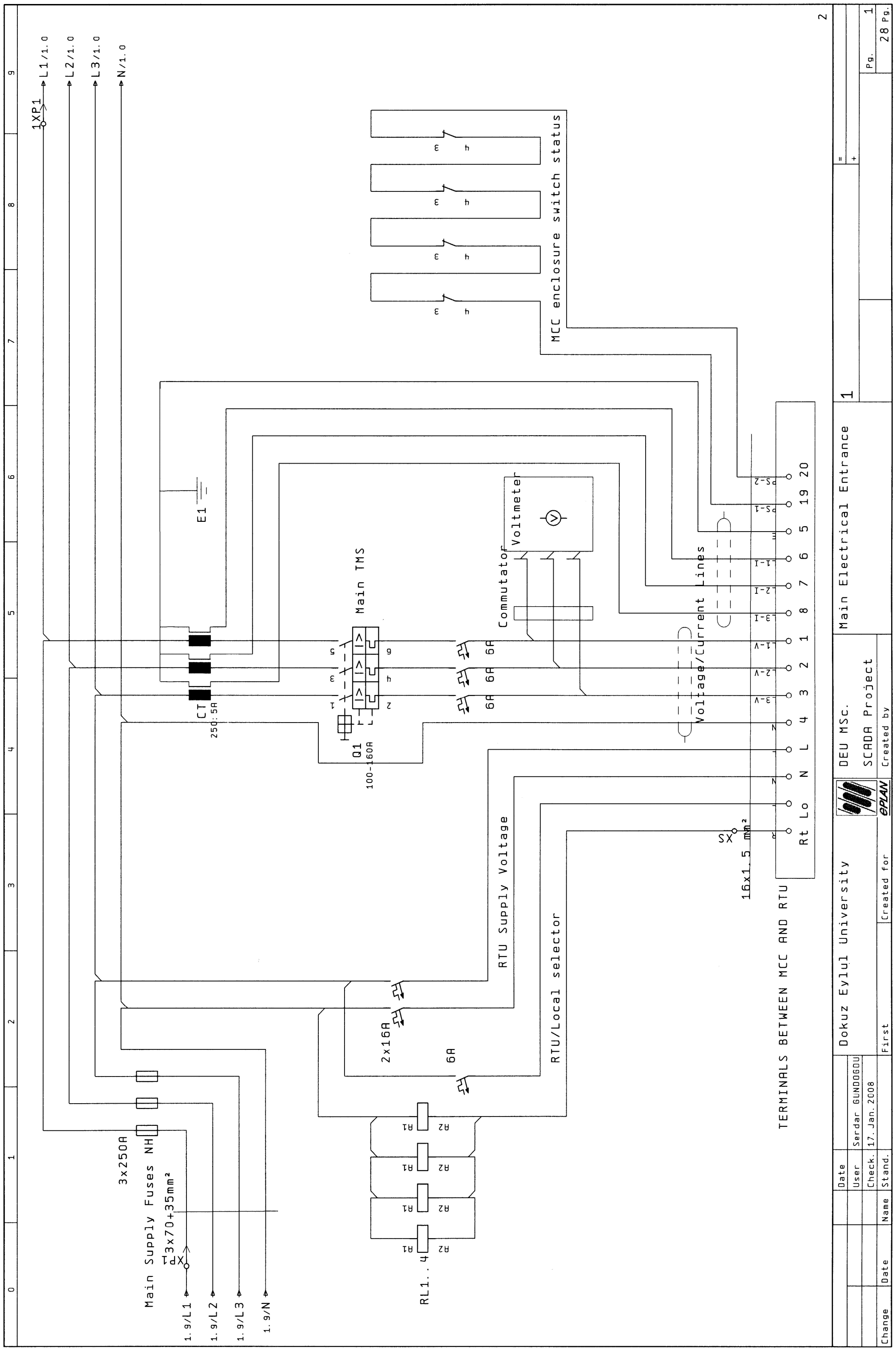
```
ENU    1
SLU    I1740,X15                    ;I1740 input >>>0
;
ETI    JMPA
;
FIN    U30                          ;End line of U30 subprogram
;
;*********************************************************************************
INI    U32                          ;Start line of U32 subprogram
;
ENU    I1740,X15
SLU    I1740                        ;Running time subsidiary factor for each pump
;
ENU    N,I440,X15                   ;Inverse of running information
LYU    I1740                        ;(I1740) AND (N,I440)
SAL    STTT,                        ;If (I1740) AND (N,I440) is 0,go ETI STTT.
;
ENN    1500
SLN    I40,X15                      ;I1500>>>I40 running time
;
ENU    0                            ;Reset
SLU    I60,X15                      ;I60 input (running factor)>>>0
;
ENU    0                            ;Reset
SLU    I1740,X15                    ;I1740 input (Run. time subsidiary factor)>>>0
;
ETI    STTT
;
FIN    U32                          ;End line of U32 subprogram
;*********************************************************************************
```

LIST OF THE USED COMMANDS FOR THE PROJECT

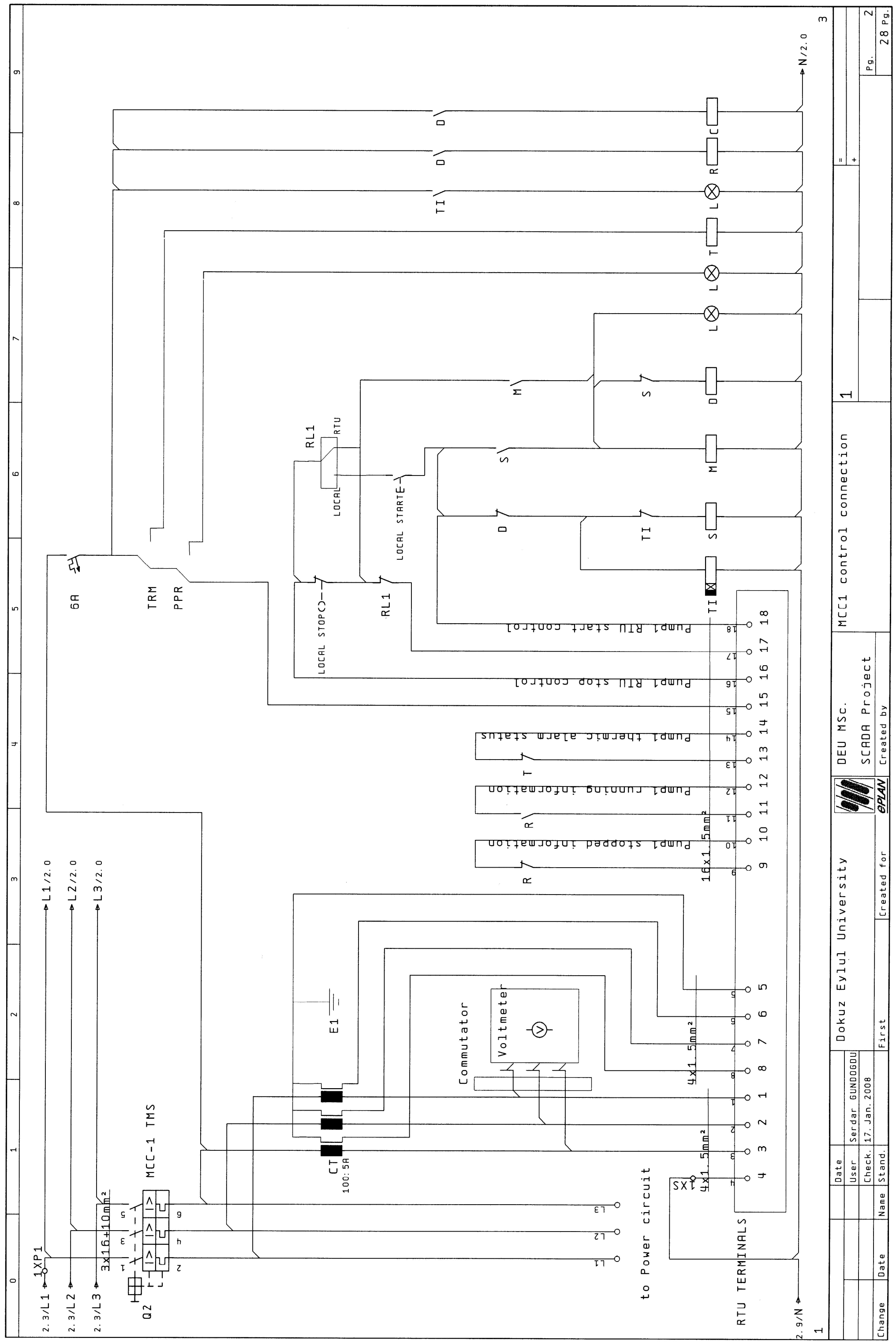
INI : Initiation command for modules
INI : Final command for modules
FIJ : Specification command of constant and limit (timer an counter) values
ETI : Description command of label
REP : Repetition command
ENU : Logical input
ENN : Numerical input
SLU : Logical output
SLN : Numerical output
FLC : Edge input
LYU : Logical AND operation
LOU : Logical OR operation
N   : Logical NOT operation
TMP : Control command of timer
SUM : Operation of numeric summation
RES : Operation of numeric subtraction
MUL : Operation of numeric multiplication
CMP : Operation of numeric comparison
ENB : Bit input to variables
SLB : Bit output to variables
R19 : Real-time meter (as hour)
R18 : Real-time meter (as minute)
FUN : Call command of user (U) and system (S) function
SAL : Jump command according as logical conditions

APPENDIX C: HARDWARE CONFIGURATION OF THE SYSTEM

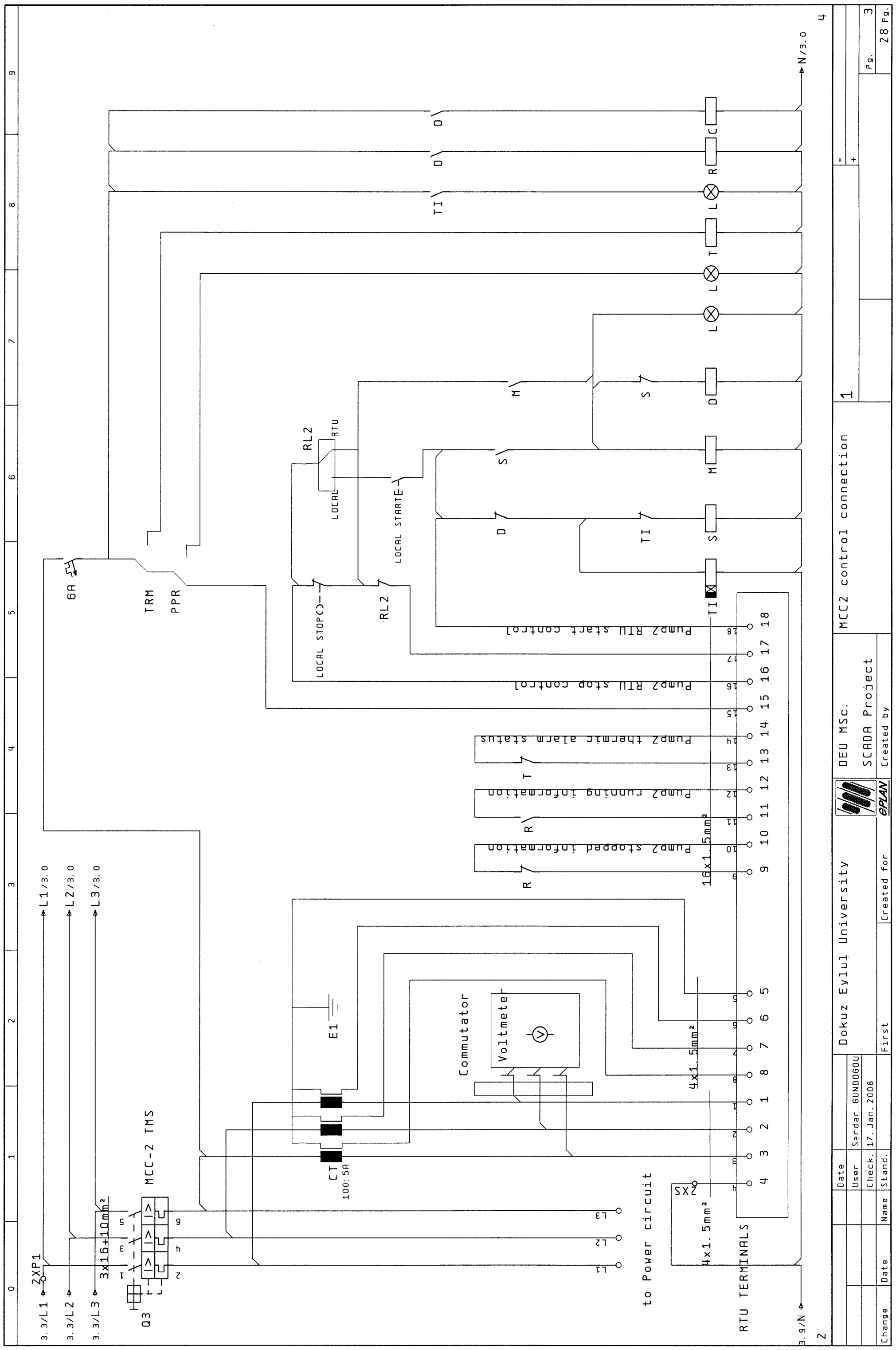
1.) Main Electrical Entrance Drawing



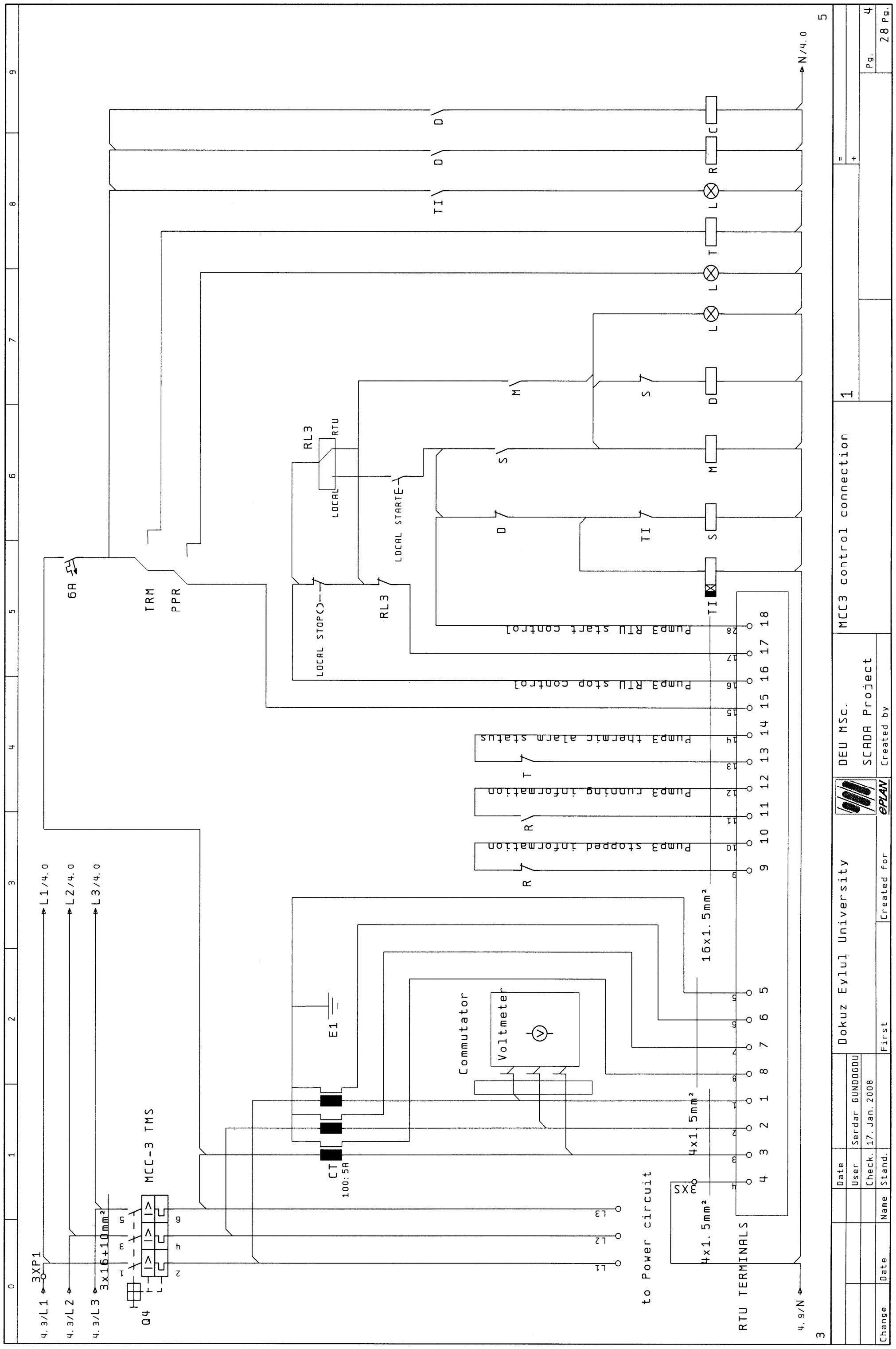
2.) MCC-1 Control Connection Drawing



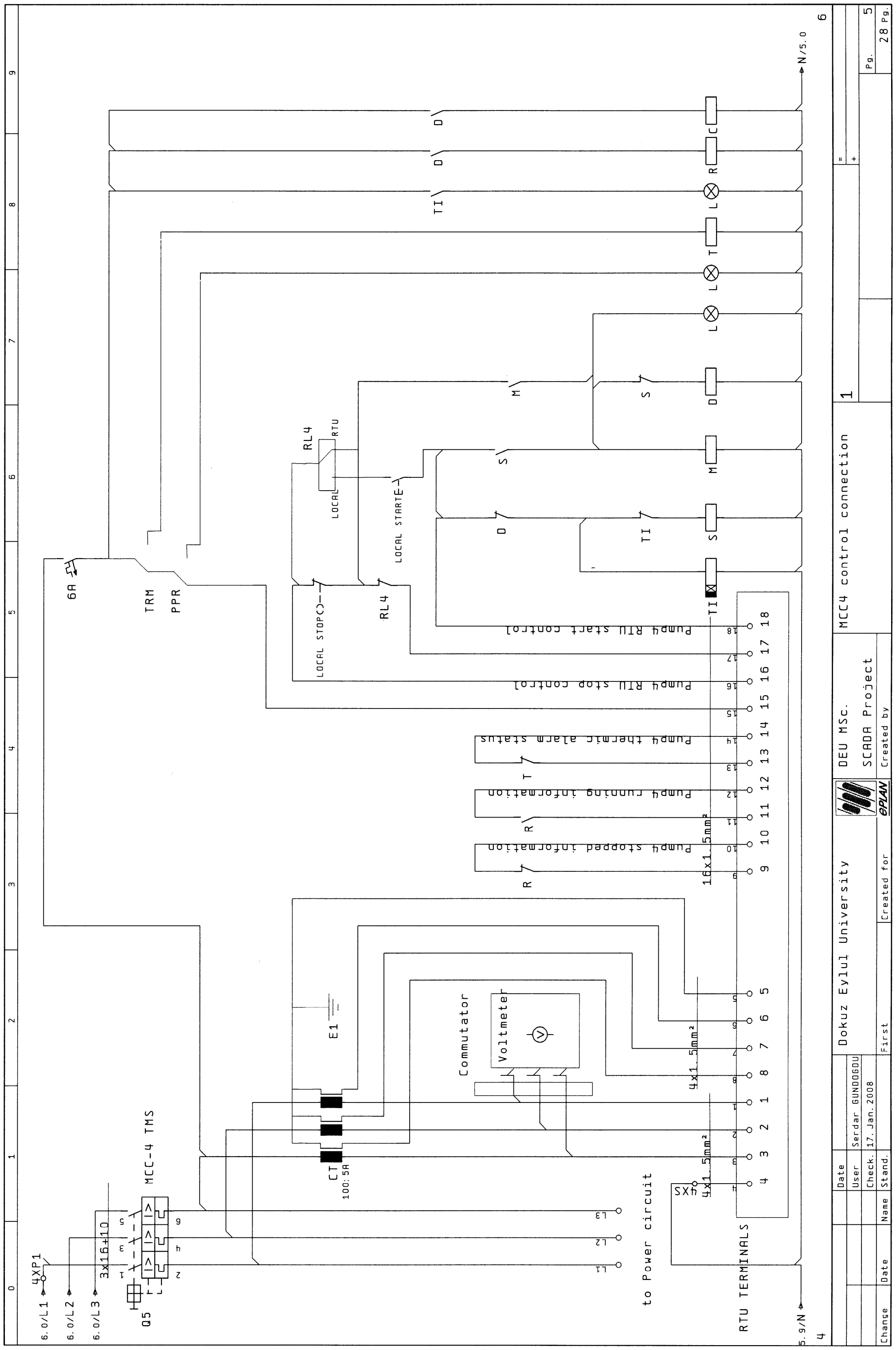
3.) MCC-2 Control Connection Drawing



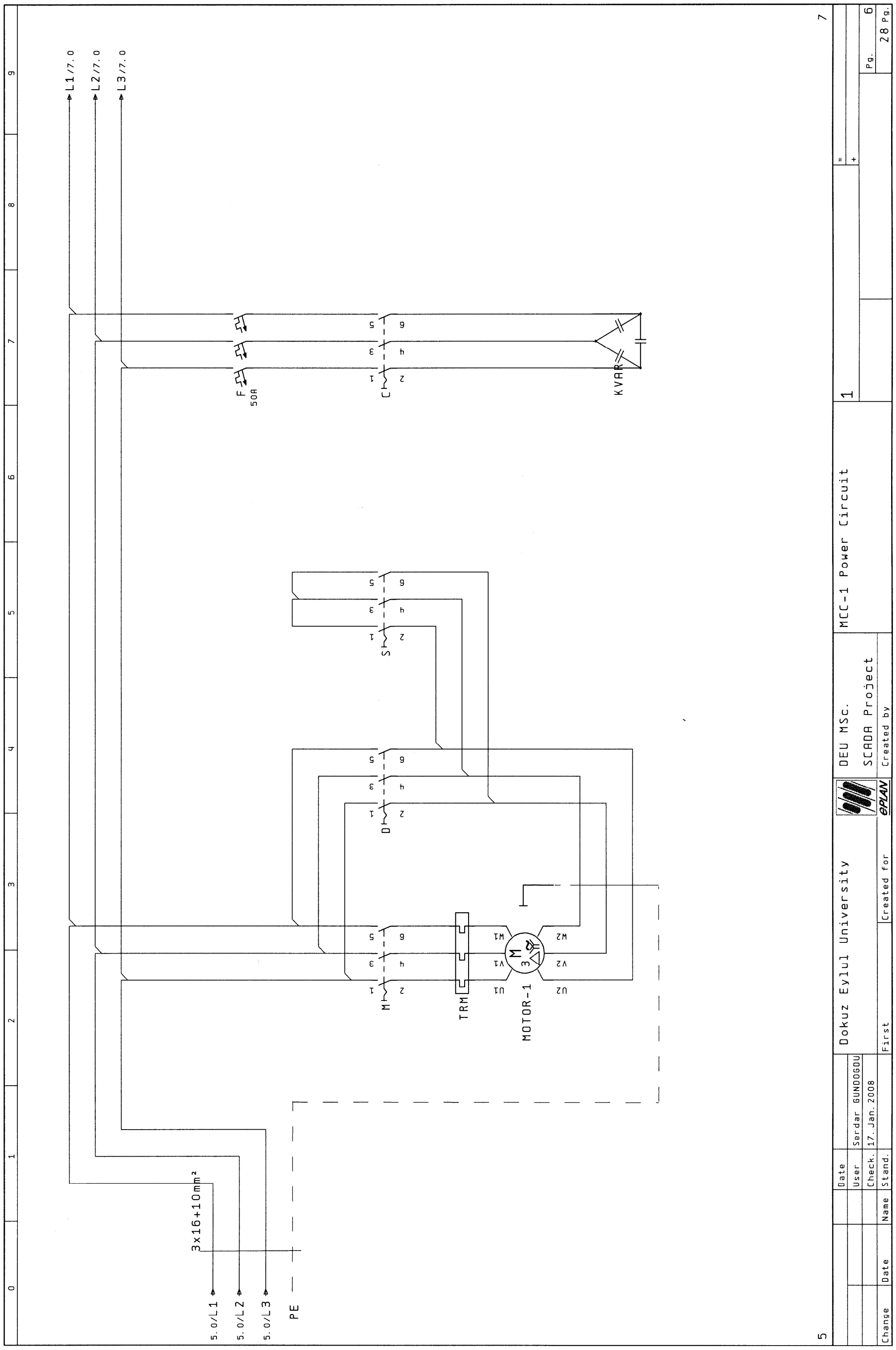
4.) MCC-3 Control Connection Drawing



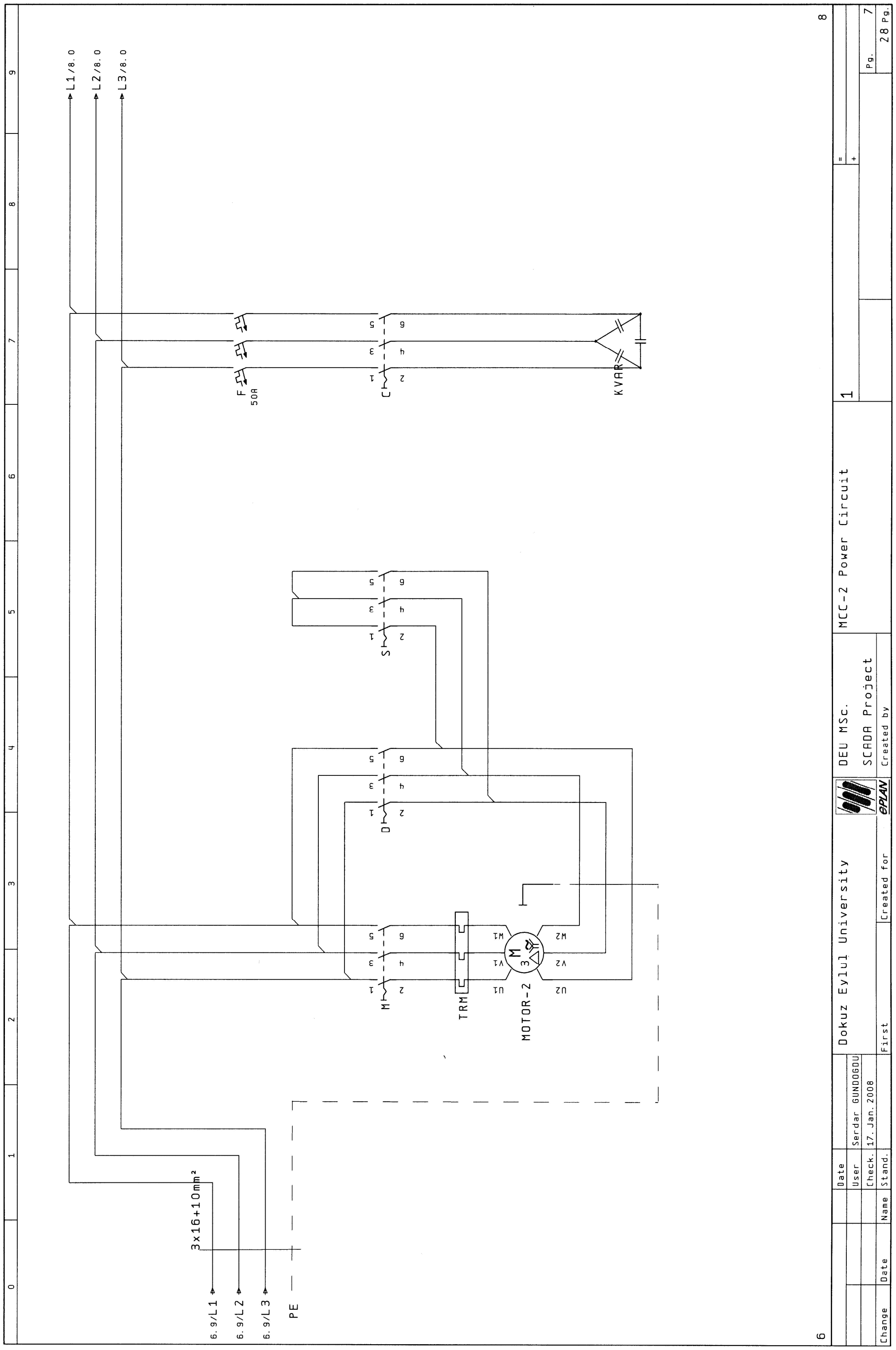
5.) MCC-4 Control Connection Drawing



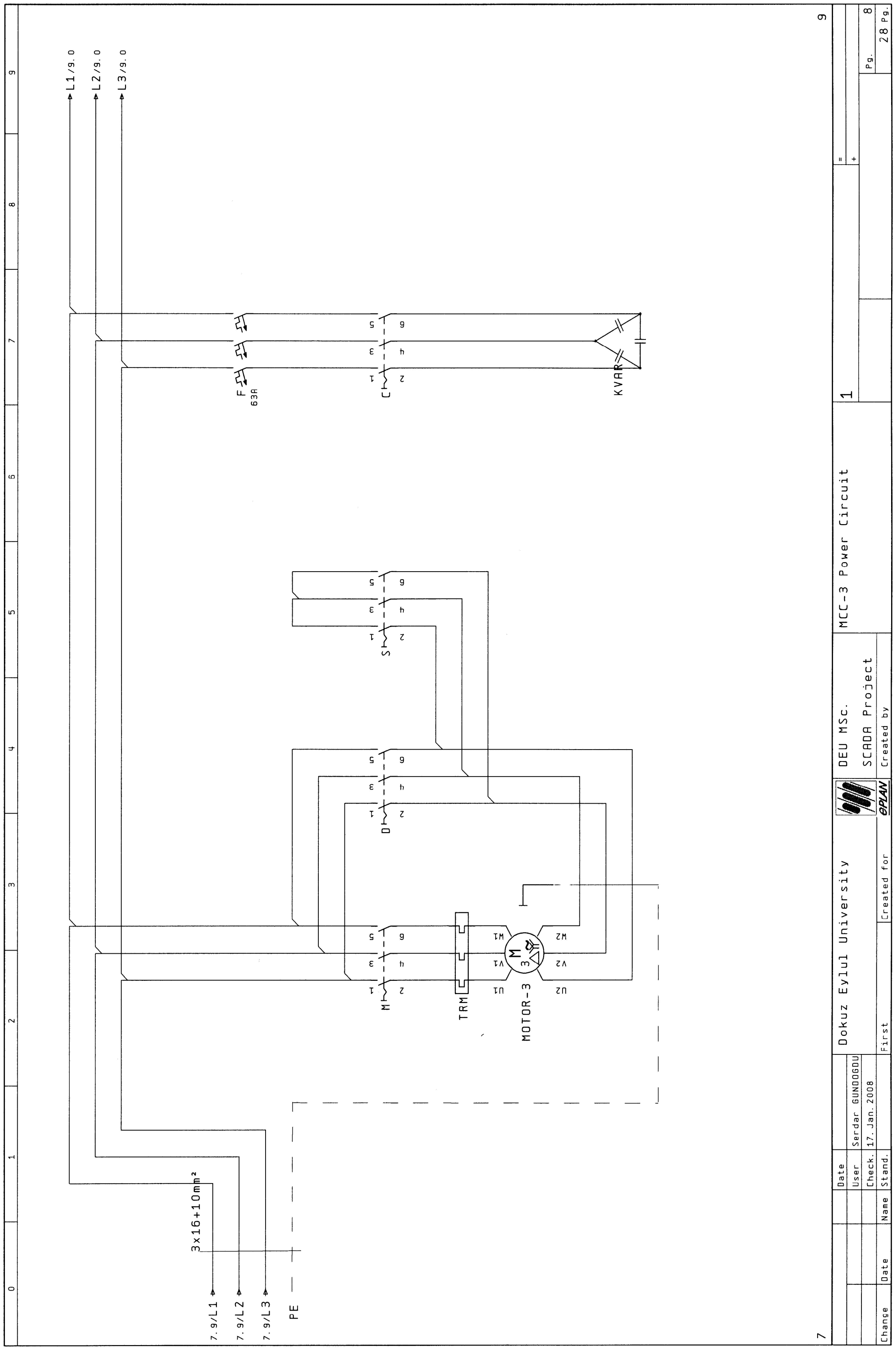
6.) MCC-1 Power Circuit Drawing



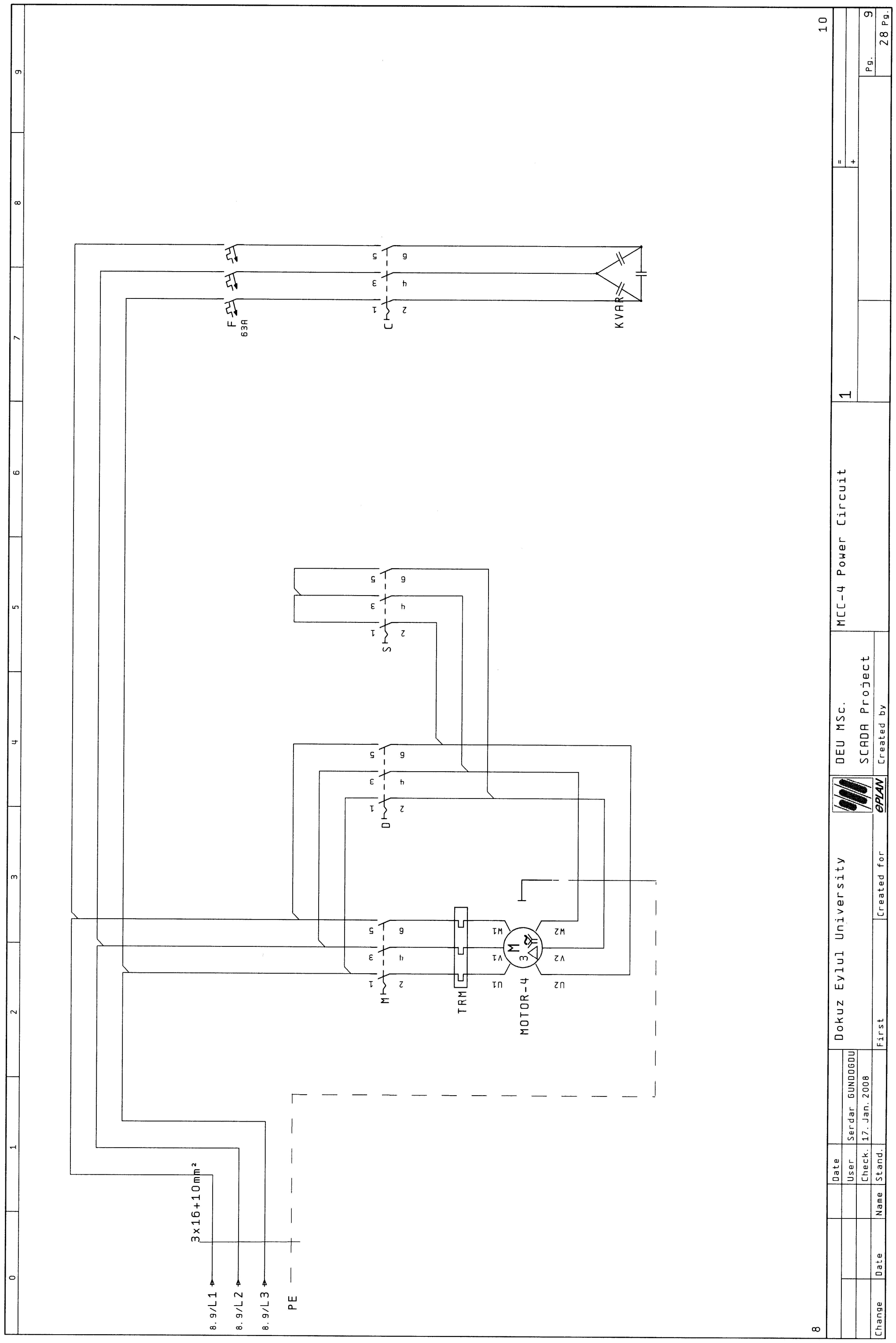
7.) MCC-2 Power Circuit Drawing



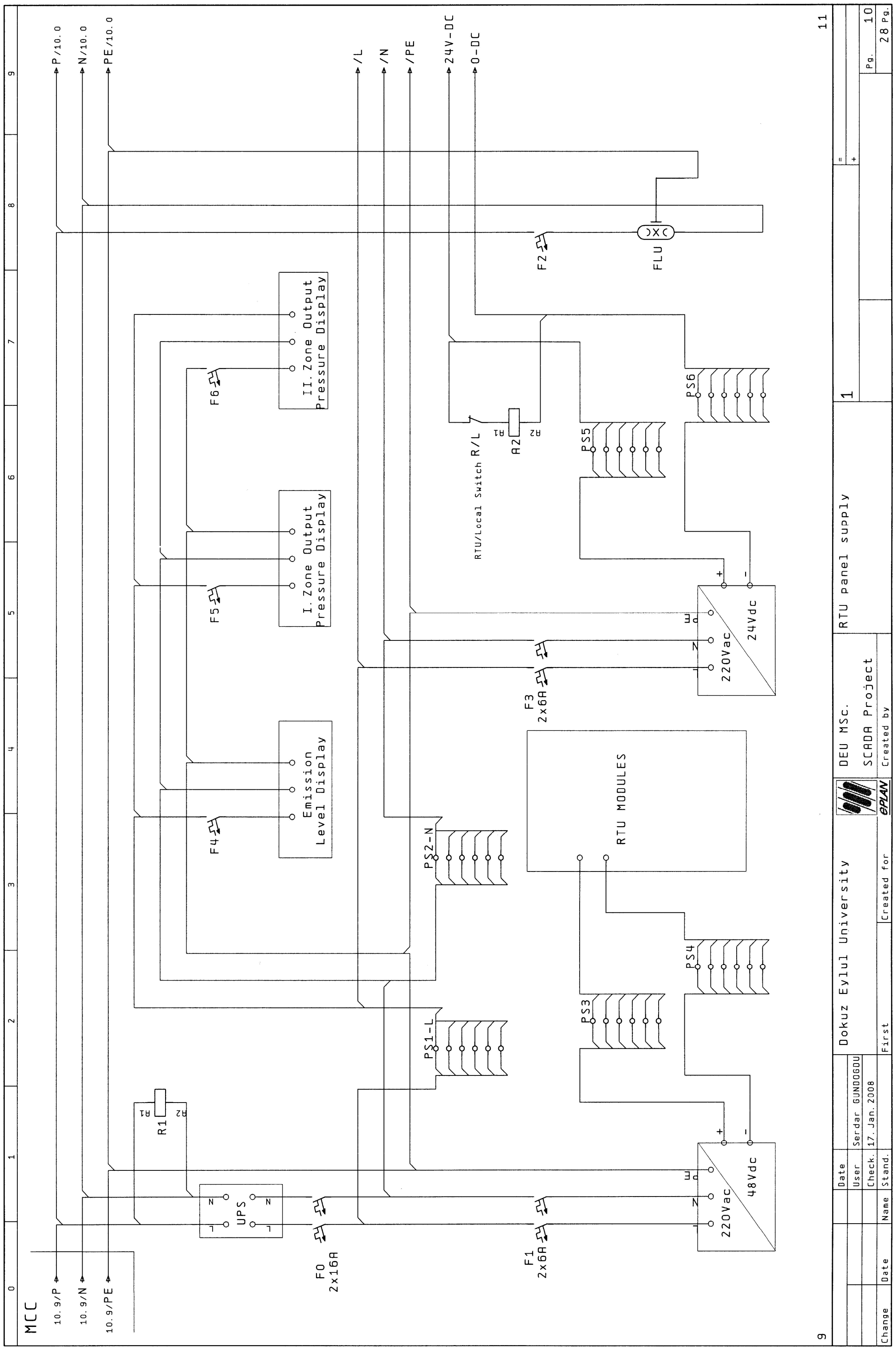
8.) MCC-3 Power Circuit Drawing



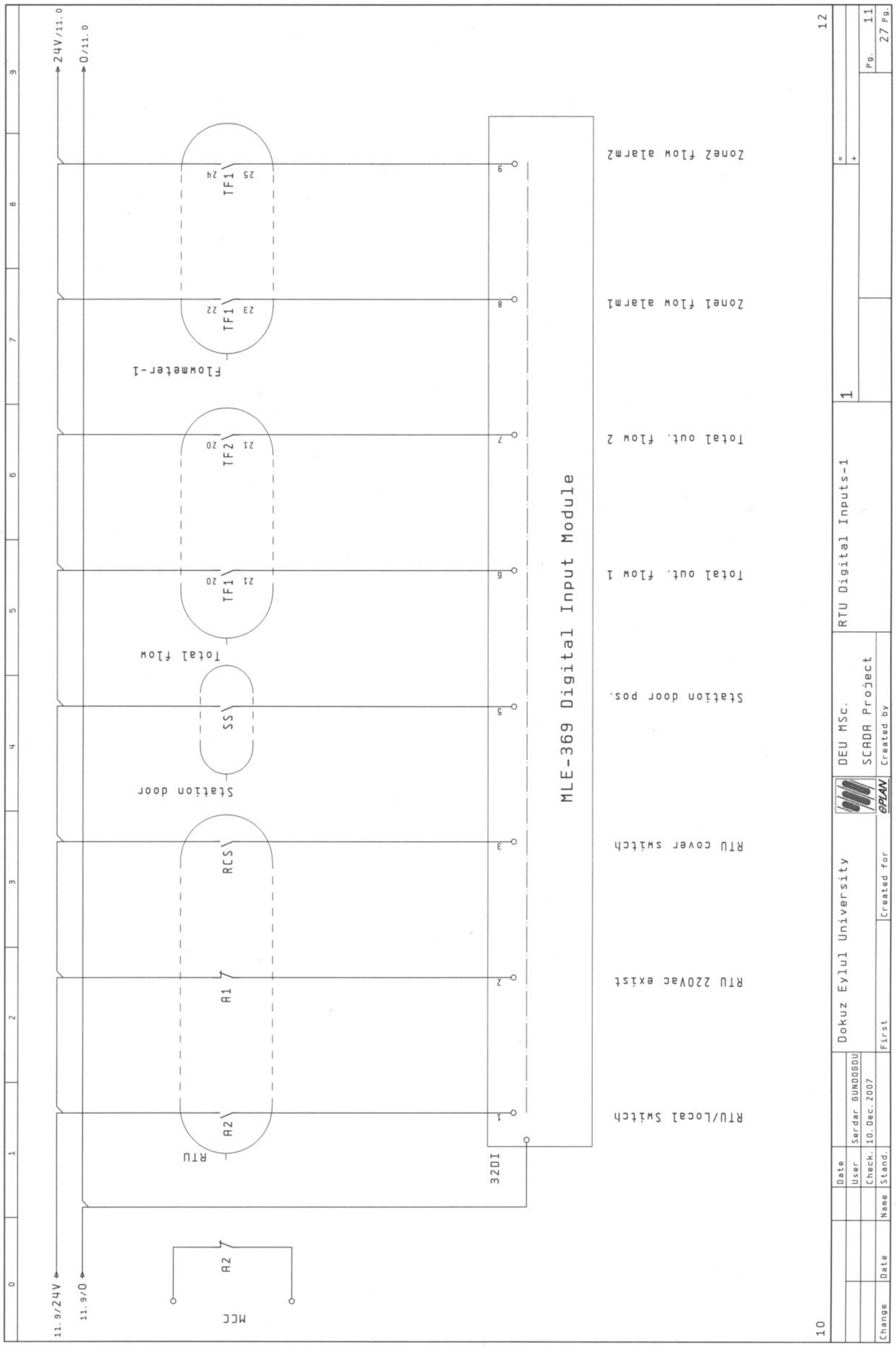
9.) MCC-4 Power Circuit Drawing



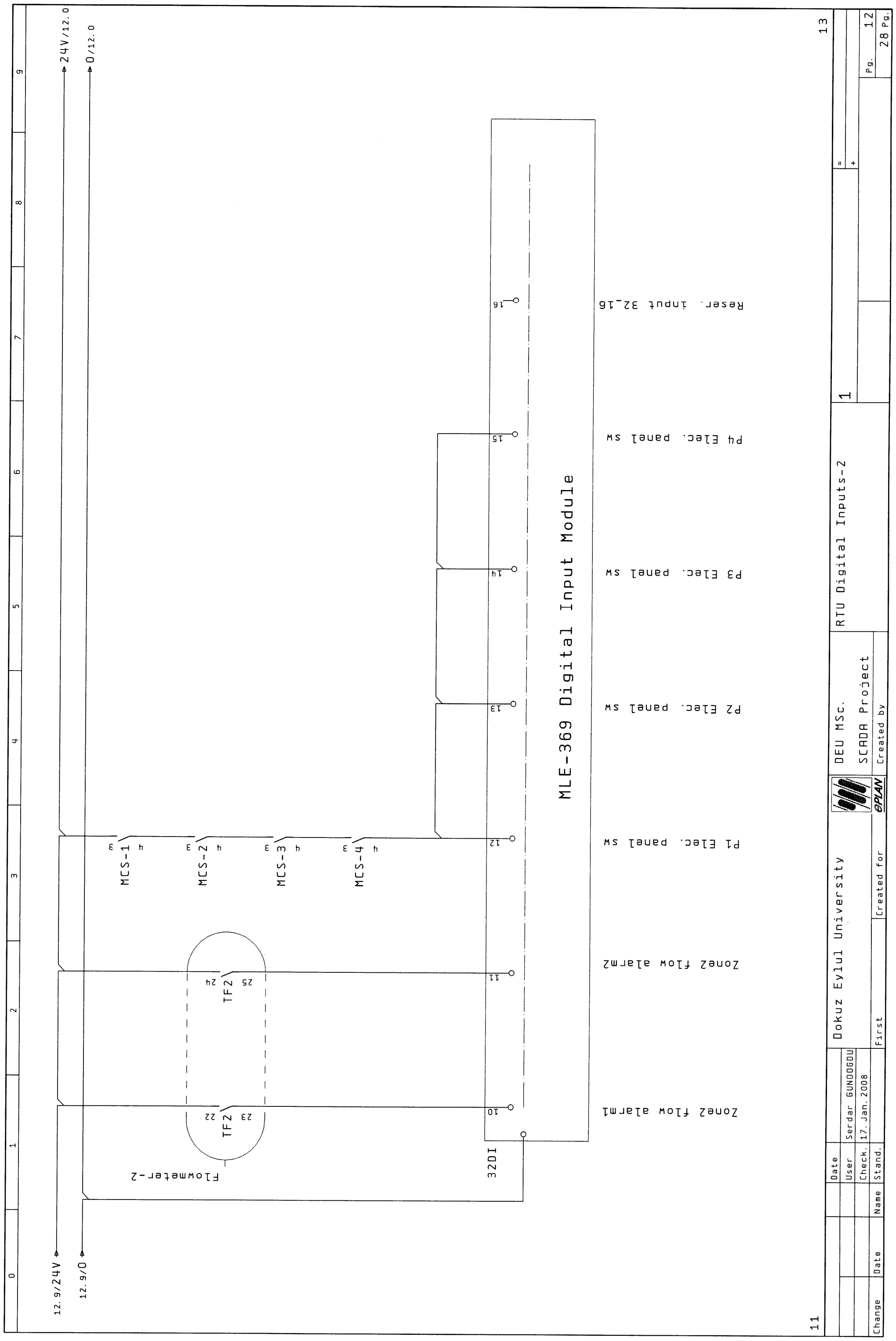
10.) RTU Panel Supply Drawing



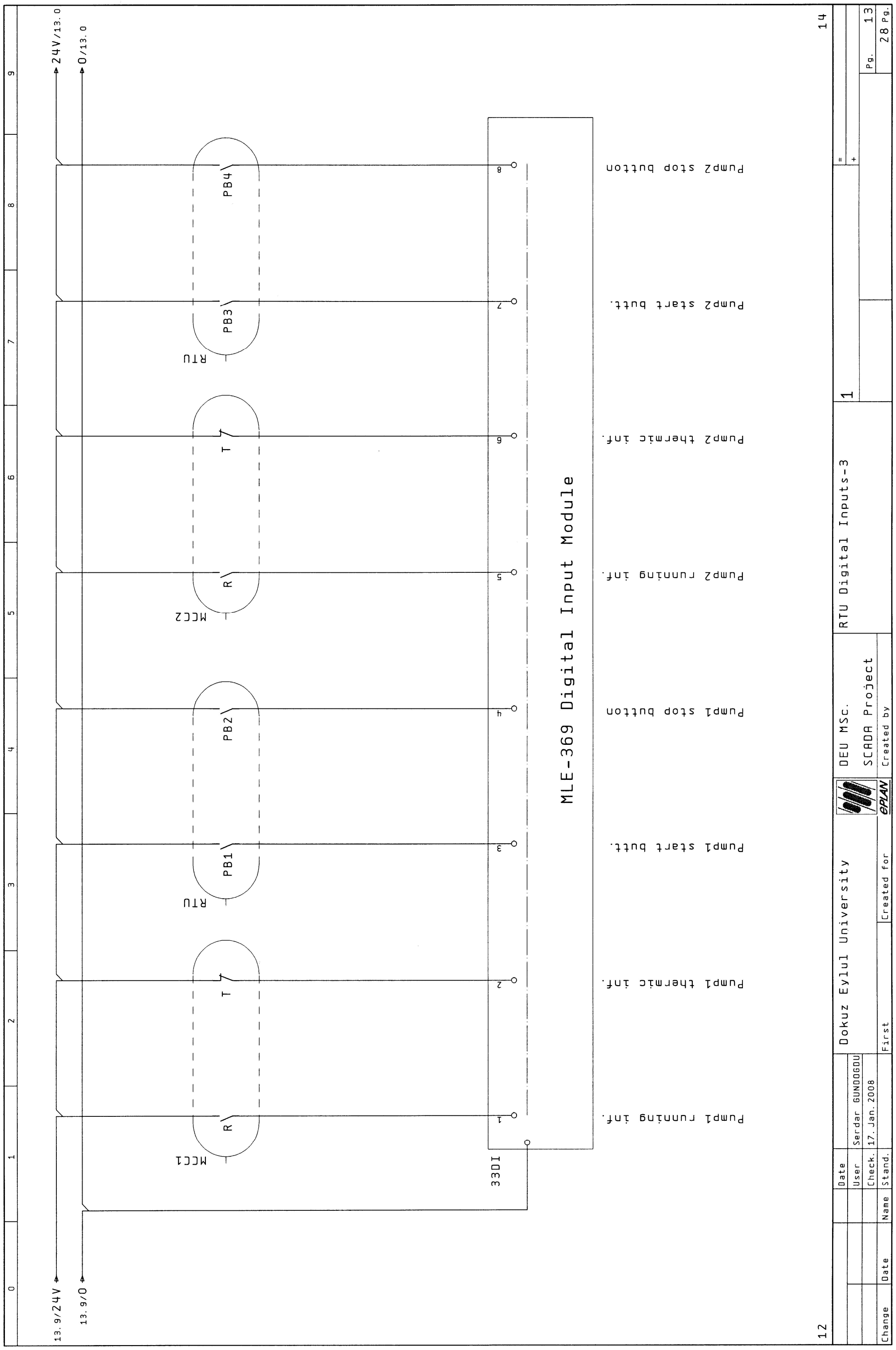
11.) RTU Digital Inputs-1 Drawing



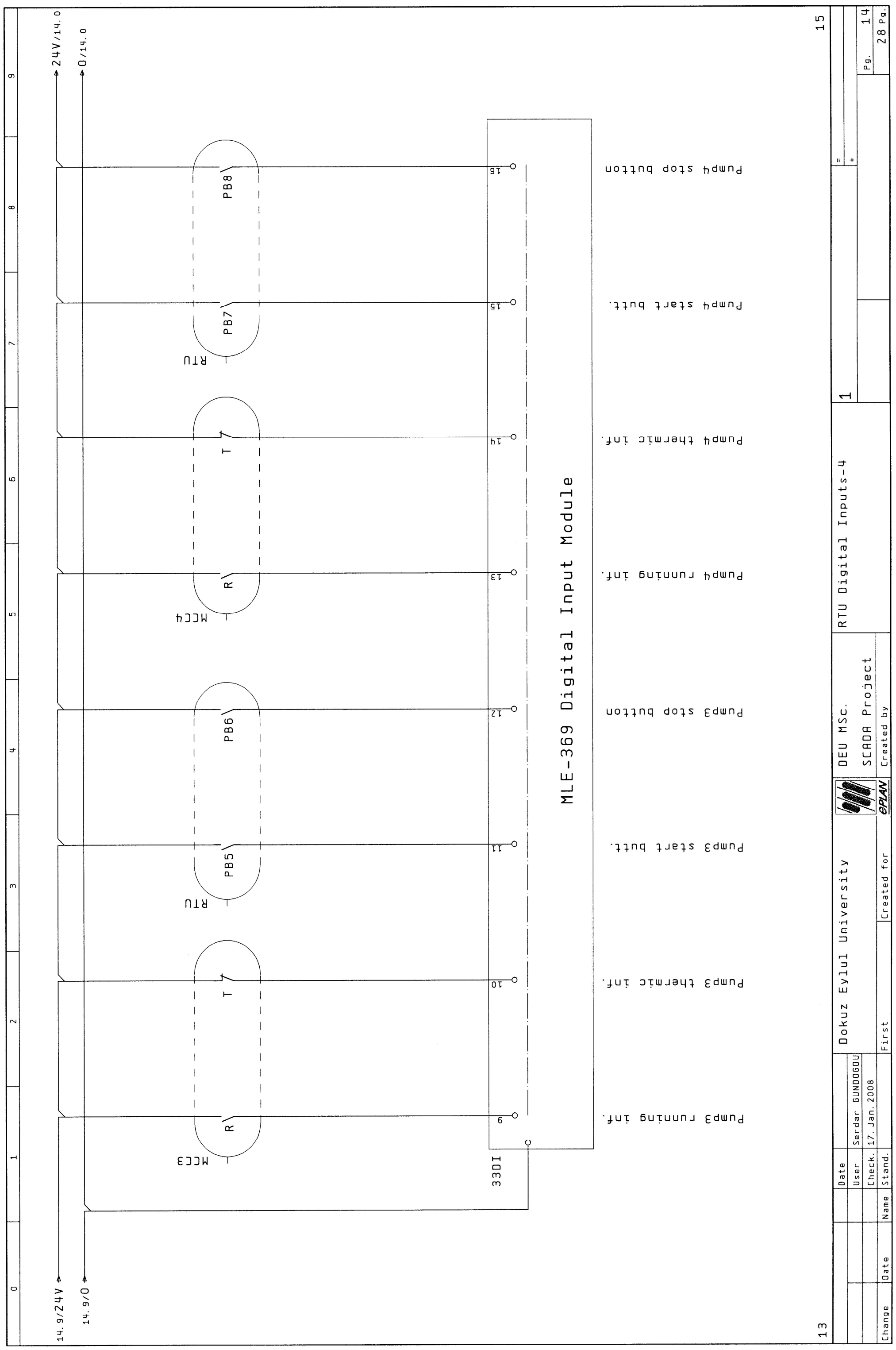
12.) RTU Digital Inputs-2 Drawing



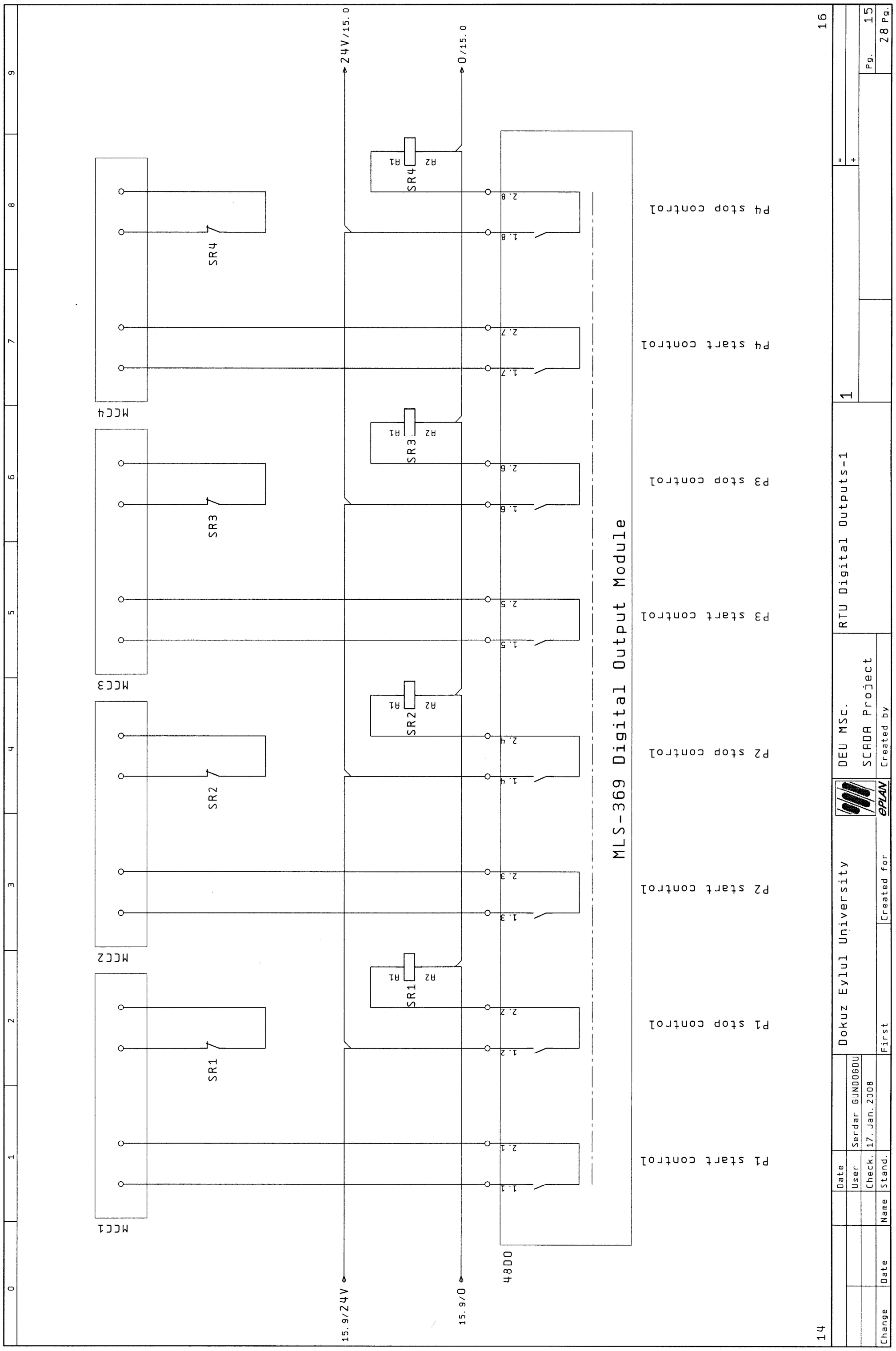
13.) RTU Digital Inputs-3 Drawing



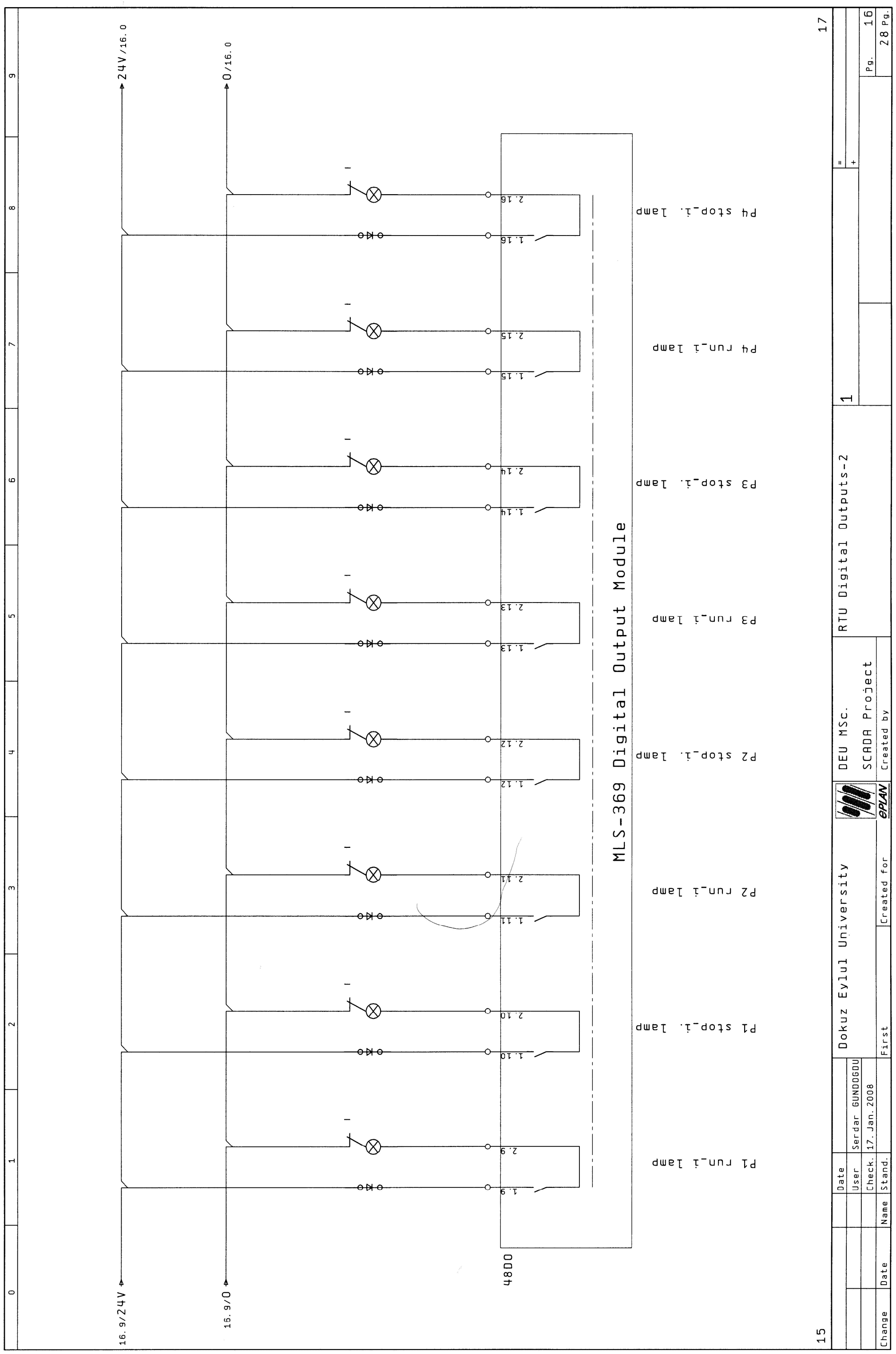
14.) RTU Digital Inputs-4 Drawing



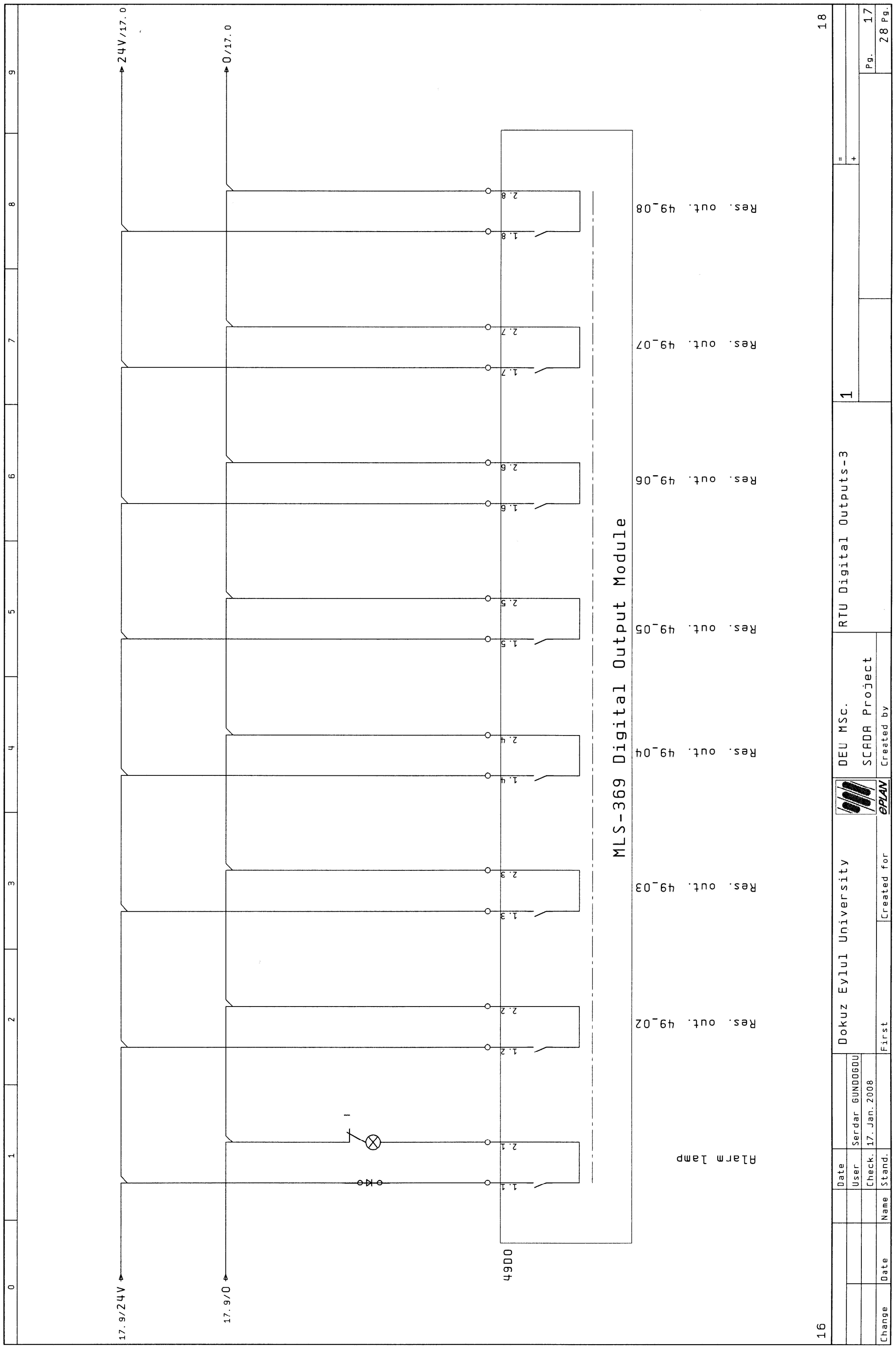
15.) RTU Digital Outputs-1 Drawing



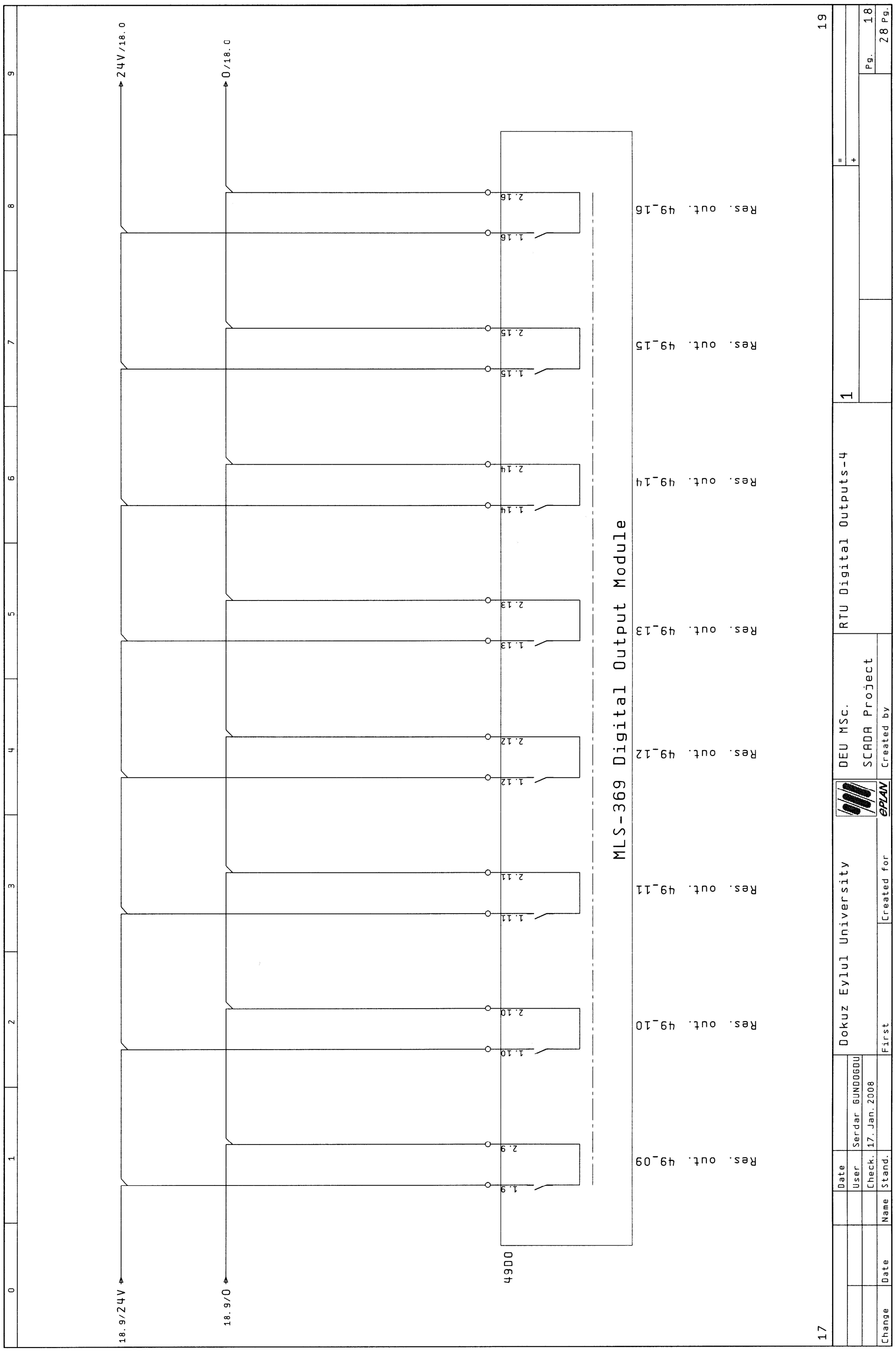
16.) RTU Digital Outputs-2 Drawing



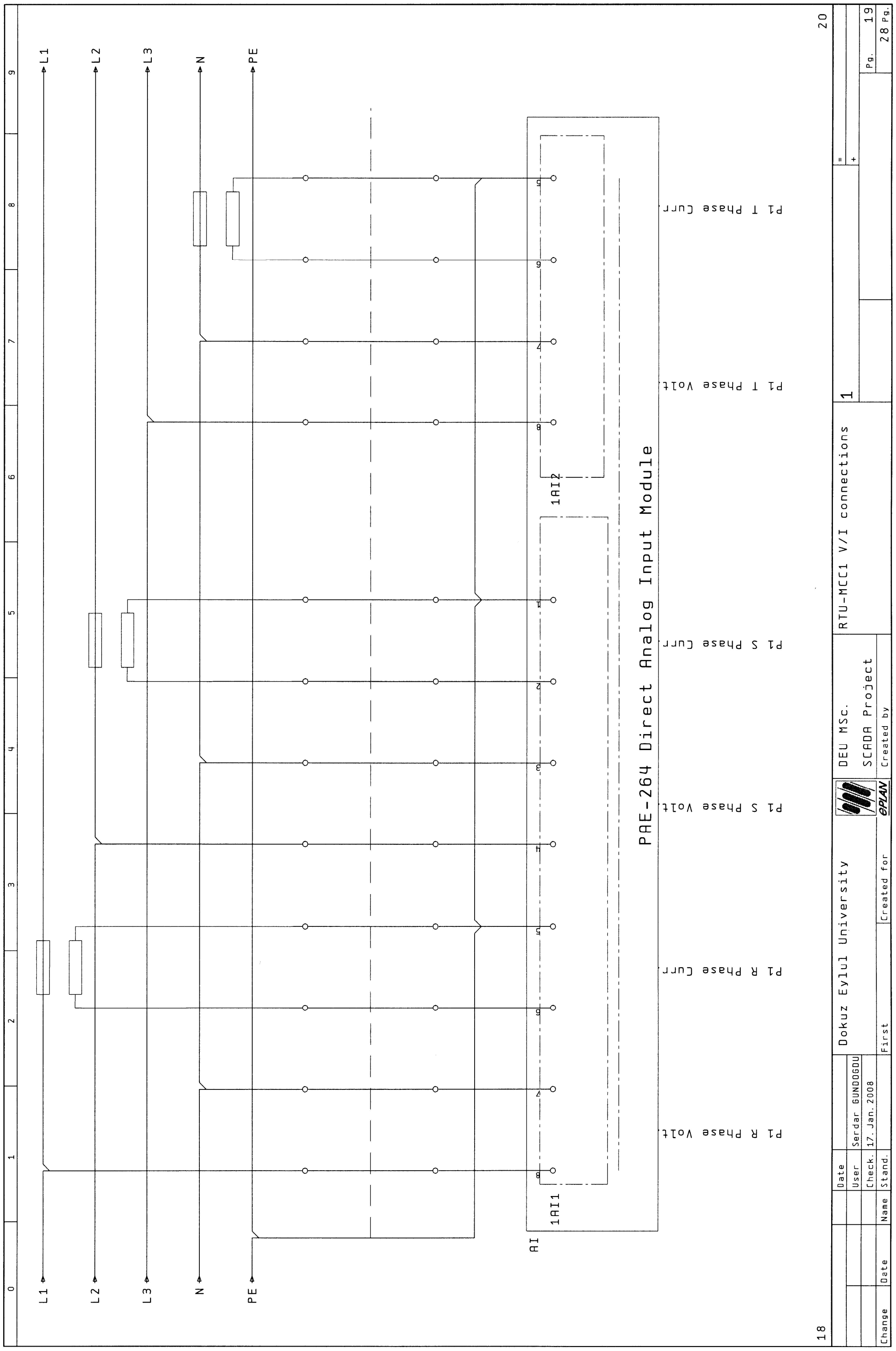
17.) RTU Digital Outputs-3 Drawing



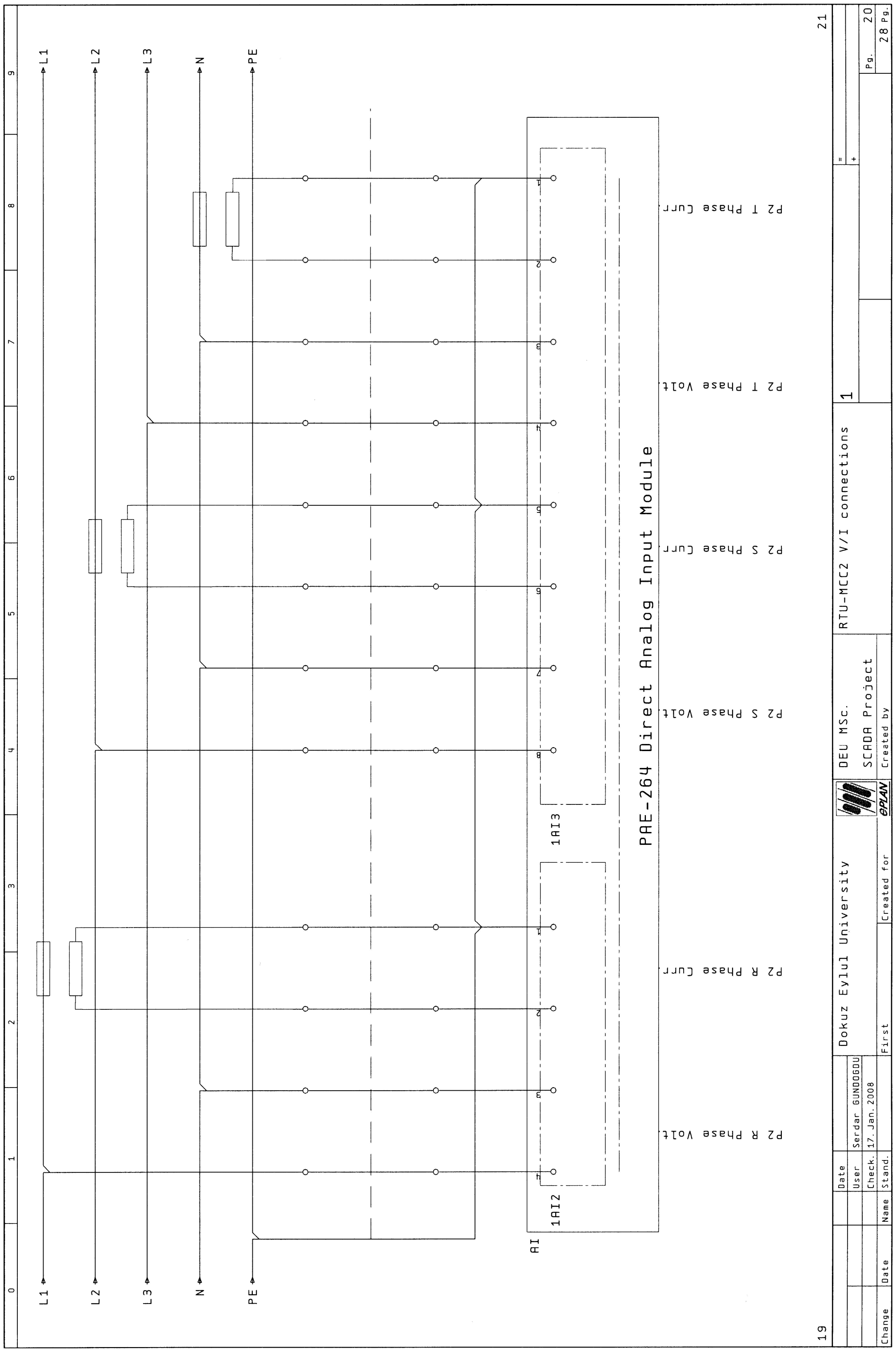
18.) RTU Digital Outputs-4 Drawing



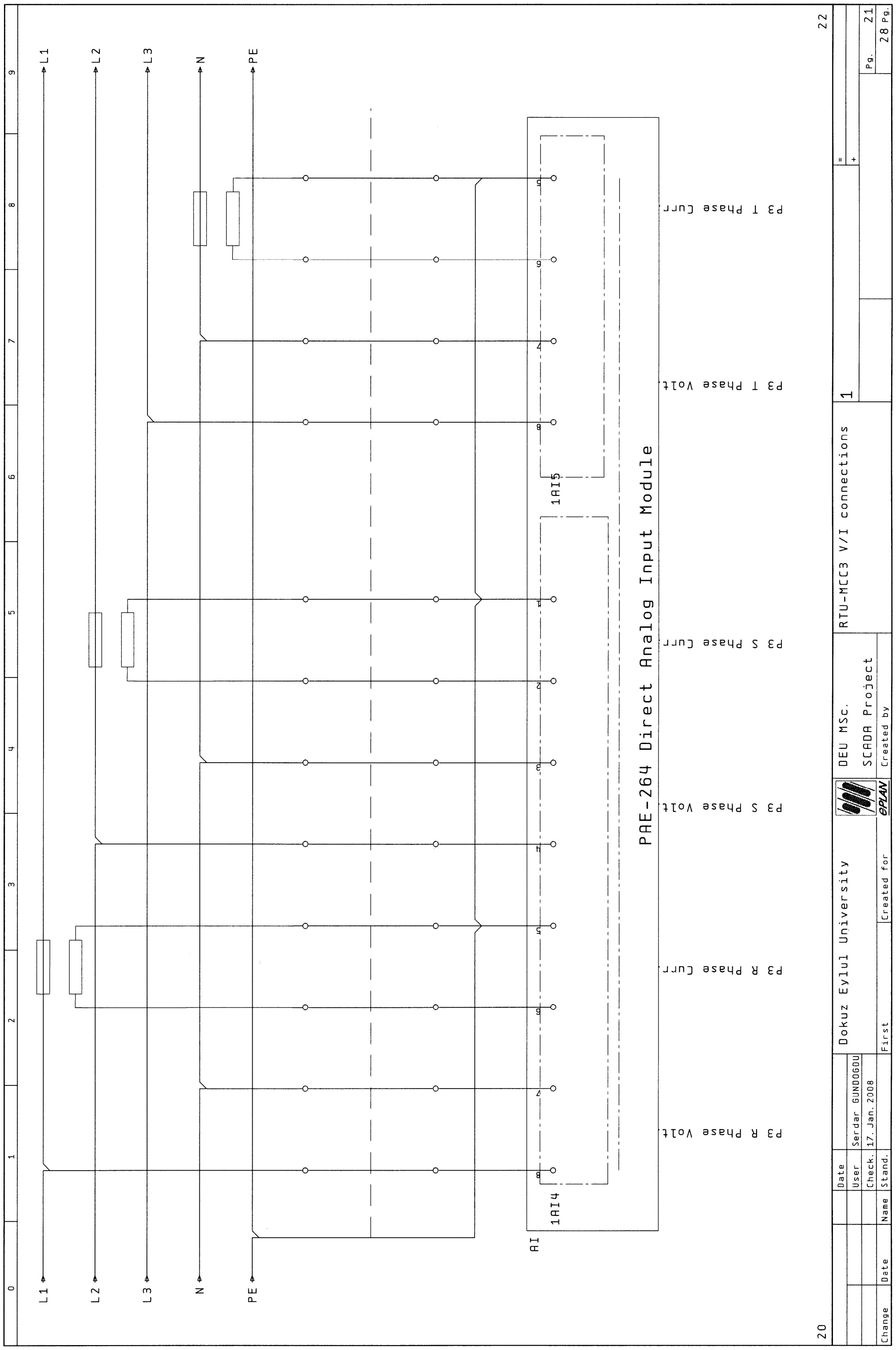
19.) RTU-MCC1 V/I Connections Drawing



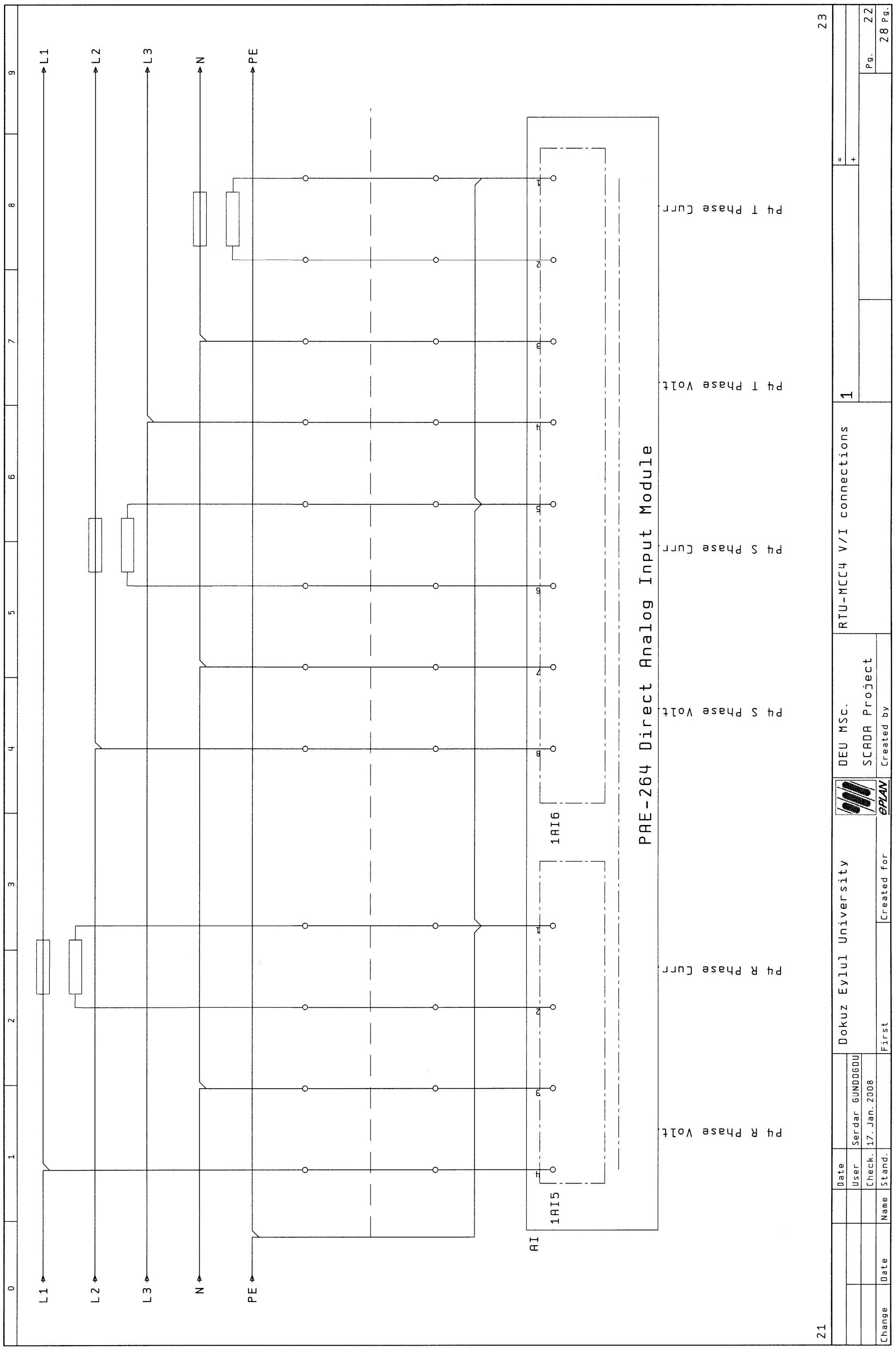
20.) RTU-MCC2 V/I Connections Drawing



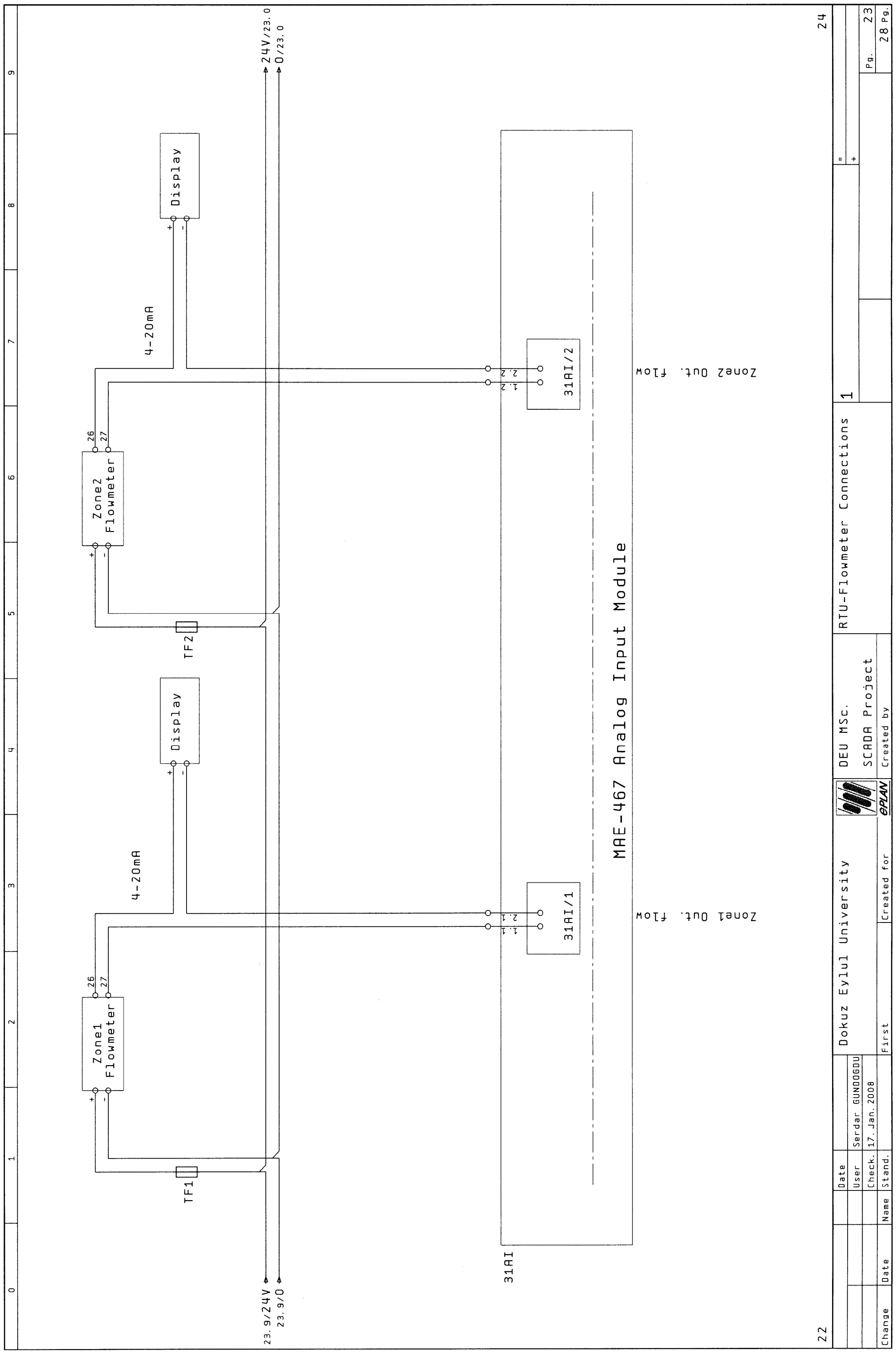
21.) RTU-MCC3 V/I Connections Drawing



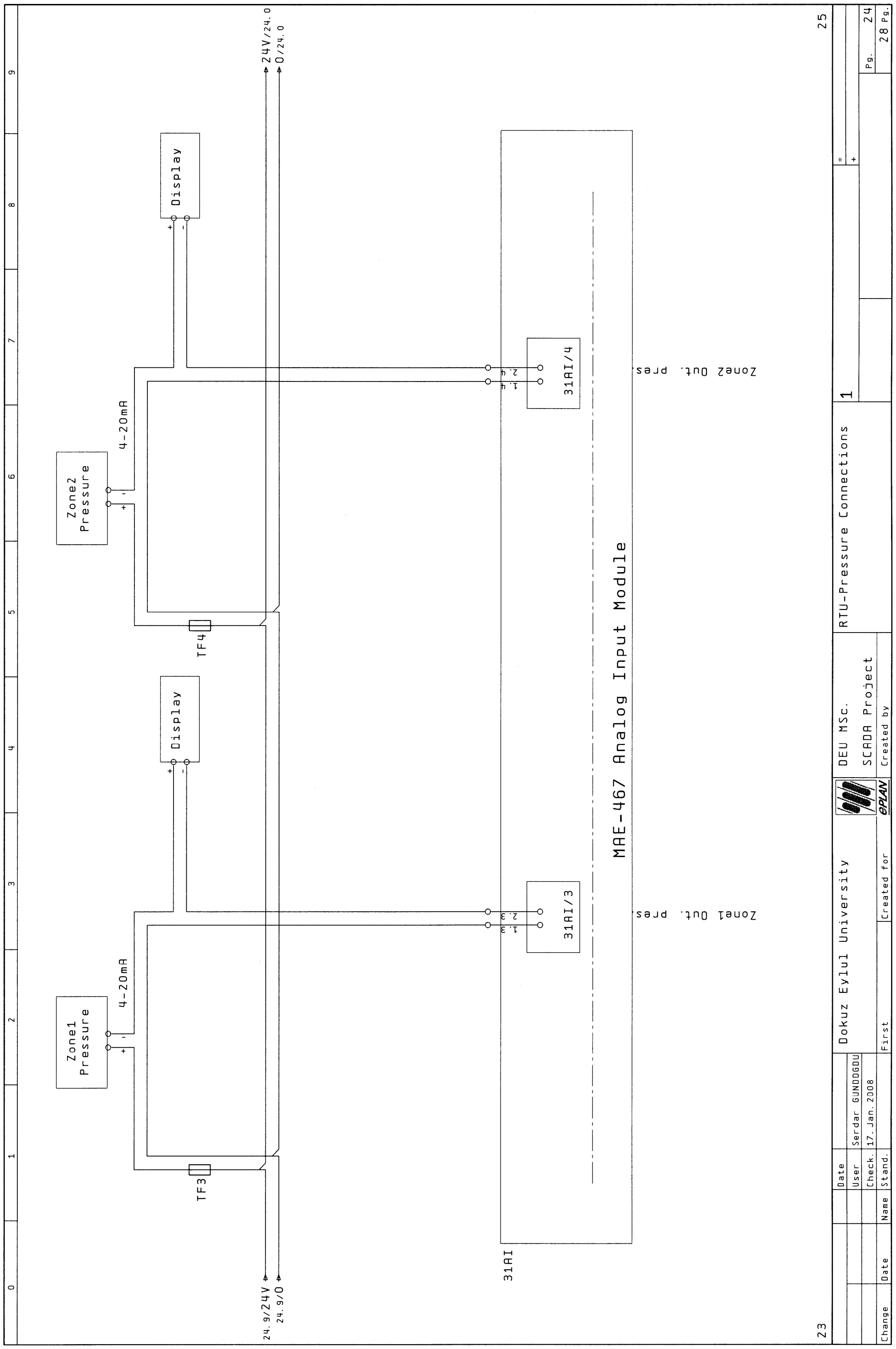
22.) RTU-MCC4 V/I Connections Drawing



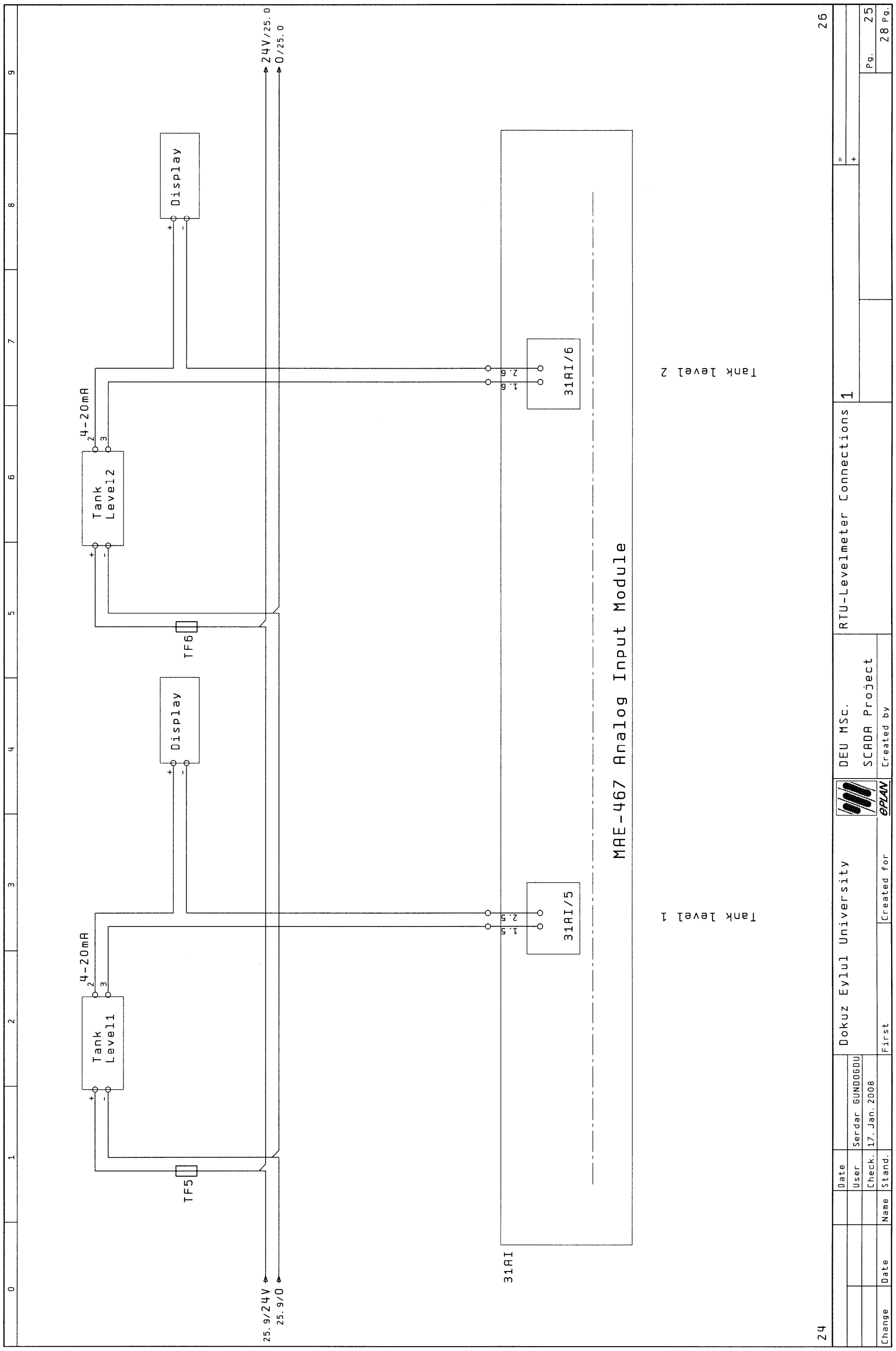
23.) RTU-Flow meter Connections Drawing



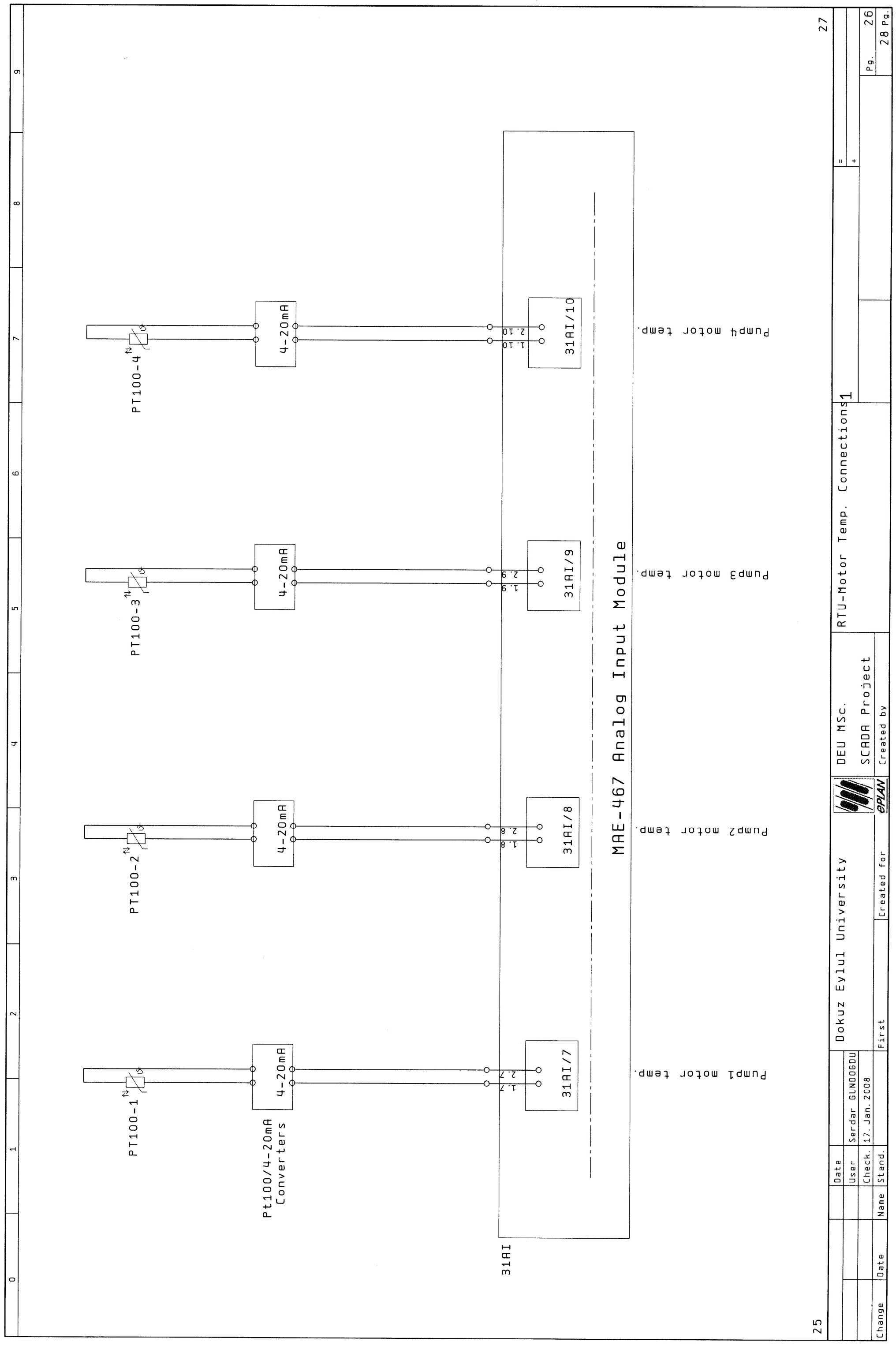
24.) RTU-Pressure meter Connections Drawing



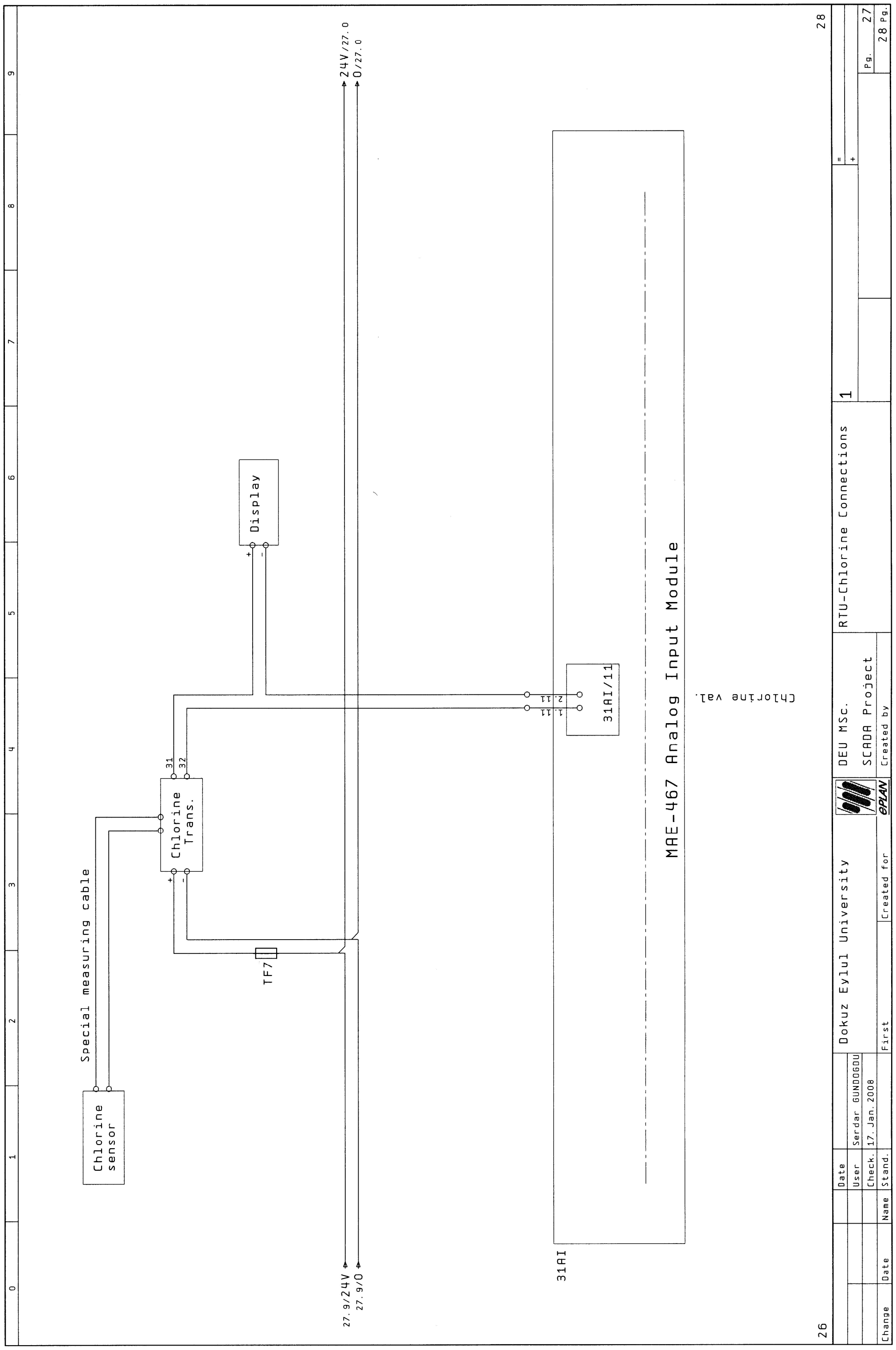
25.) RTU-Level meter Connections Drawing



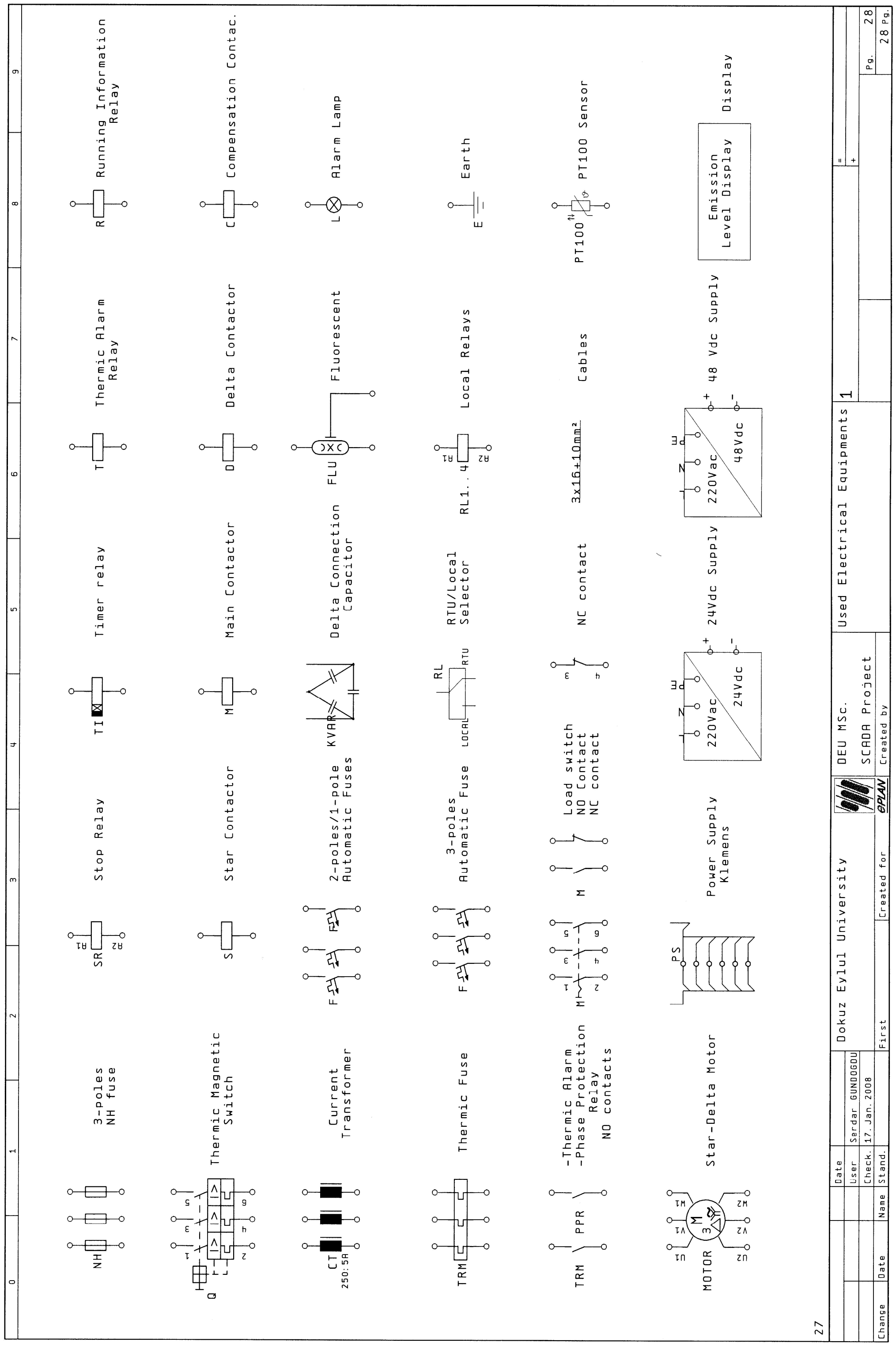
26.) RTU-Motor Temperature meter Connections Drawing



27.) RTU-Chlorine meter Connections Drawing

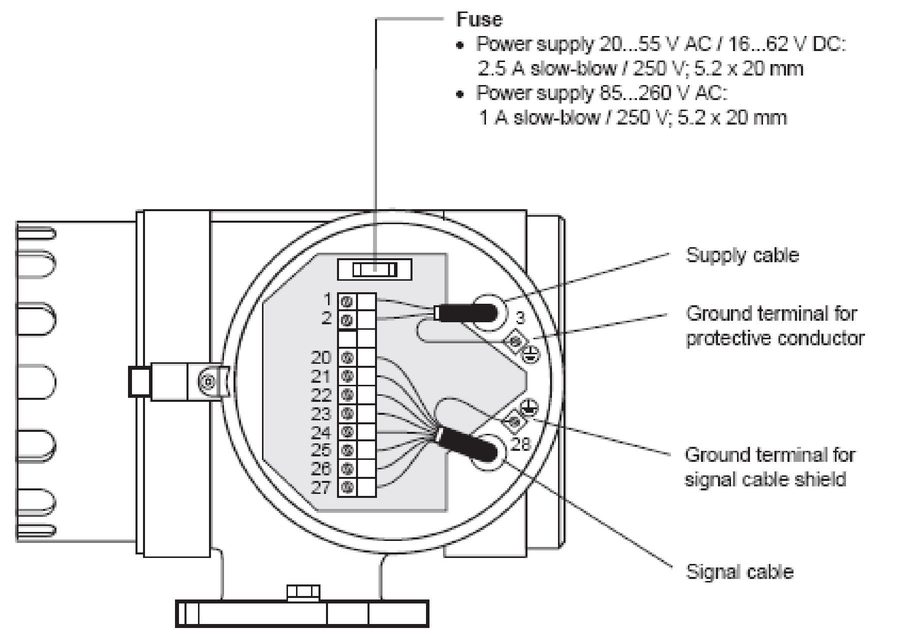


28.) Used Electrical Equipments Description Drawing



APPENDIX D: TRANSMMITTER CATALOGS OF USED SENSORS

1.) Electrical Connection Transmitter of Promag 33-Flow meter



The input and outputs are galvanically separated from the power supply and from each other.

“HART” version		
3	Ground connection (protective earth)	
1 2	L1 N for AC power supply	L+ L– for DC power supply
20 (+) 21 (–)	Pulse / Frequency output	active/passive, f_{max} = 10 kHz active: 24 V DC, 25 mA (max. 250 mA/20 ms) passive: 30 V DC, 250 mA
22 (+) 23 (–)	Alarm output (Relay 1)	can be configured max. 60 V AC / 0.5 A AC; max. 30 V DC / 0.1 A DC
24 (+) 25 (–)	Status output (Relay 2)	can be configured max. 60 V AC / 0.5 A AC; max. 30 V DC / 0.1 A DC
26 (+) 27 (–)	Current output	active, 0/4...20 mA, R_L < 700 Ω (with HART: R_L ≥ 250 Ω)
28	Ground connection (screening of signal cable)	

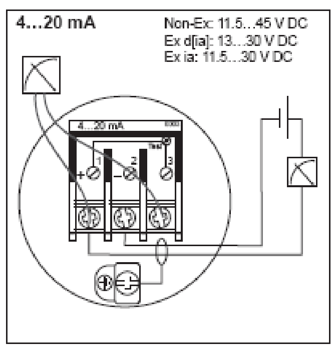
2.) Electrical Connection Transmitter of Cerabar S-Pressure meter

Electrical Connection

Wiring 4…20 mA

The two-wire cable is connected to screw terminals (wire cross section 0.5…2.5 mm²/ AWG 20…13) in the connecting compartment.

- For the connecting line, we recommend you use a twisted, screened two-core cable.
- Supply voltage:
  - Non-Ex: 11.5…45 V DC
  - Ex d[ia]: 13…30 V DC
  - Ex ia: 11.5…30 V DC
- Internal protection circuits against reverse polarity, HF interference and overvoltage peaks (see Technical Information TI 241F "EMC Guidelines").
- Test signal: The output current can be measured between terminal 1 and 3 without interrupting the process measurement.



Electrical connection:
Cerabar S for all versions with 4…20 mA

Wiring PROFIBUS-PA

The digital communication signal is transmitted to the bus using a two-wire connecting cable. The bus cable also carries the power supply.

- Supply voltage:
  - Non-Ex: 9…32 V DC
  - Ex ia: 9…24 V DC
- Bus cable: For the connecting line, we recommend you use a twisted, screened two-core cable. The following specifications must be observed when using the FISCO model (explosion protection):
  - Loop resistance (DC) 15…150 Ω/km
  - Inductance 0.4…1 mH/km
  - Capacitance 80…20 nF/km

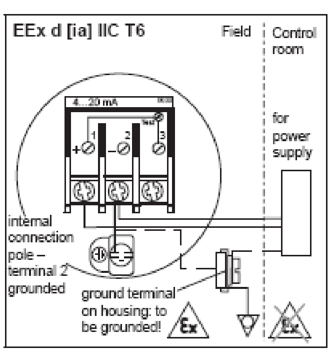
Instructions on connecting and grounding the network are given in BA 198F "Project Instructions for PROFIBUS-PA" as well as PROFIBUS-PA specifications.

Wiring Foundation Fieldbus

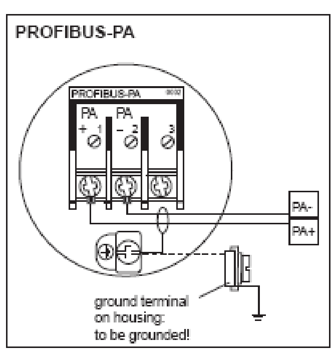
The digital communication signal is transmitted to the bus using a two-wire connecting cable. The bus cable also carries the power supply.

- Supply voltage:
  - Non-Ex: 9…32 V DC
  - Ex ia: 9…24 V DC
  - Ex d: 9…32 V DC
- Bus cable: For the connecting line, we recommend you use a twisted, screened two-core cable. Further information on the type of cabling to be used can be found in the FF specification or in IEC 61158-2.

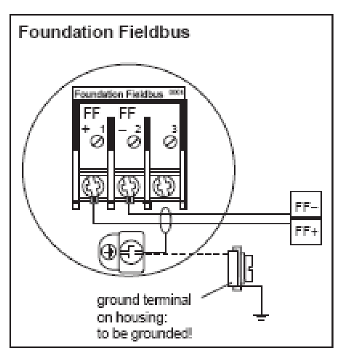
Further information on connecting and grounding the network is given at the Internet address "http://www.fieldbus.org".



Electrical connection:
Cerabar S for version with flameproof enclosure
PMC 731 - I □ □□ □ □ □ □□ □



Electrical connection:
Cerabar S for all versions with PROFIBUS-PA
(Reversed polarity has no effect on function.)



Electrical connection:
Cerabar S for all versions with Foundation Fieldbus
(Reversed polarity has no effect on function.)

3.) Electrical Connection Transmitter of Deltapilot S-Level meter

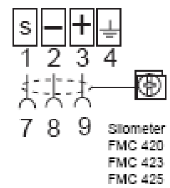
Electrical Connection

① Electronic Insert FEB 11/FEB 11 P

An analogue signal (0.2…1.2 mA) from the FEB 11/FEB 11 P is transmitted along a three-wire cable to the evaluating unit.

- Calibration: at the evaluating unit in the control room or control cabinet.
- Cable resistance max. 25 Ω per wire.
- The housing must be grounded when using the FEB 11 P electronic insert with overvoltage protection.

① FEB 11/FEB 11 P



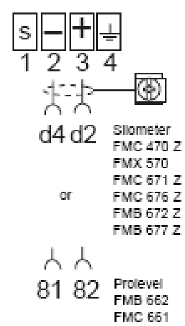
② Electronic Insert FEB 17/FEB 17 P

An interference-free PFM signal (pulse frequency approx. 200 Hz to 1200 Hz) from the FEB 17/FEB 17 P is transmitted to the evaluating unit.

- Calibration: at the evaluating unit. If the density and level of the medium is known, then calibration can be carried out without filling the vessel.
- The housing must be grounded when using the FEB 17 P electronic insert with overvoltage protection.

Note: For operation with Silometer FMC 470 switch off pulse width detection.

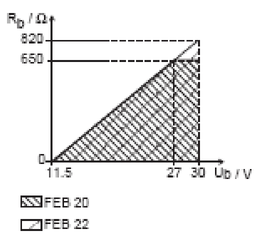
② FEB 17/FEB 17 P



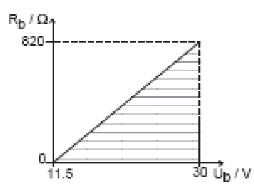
③ Smart Electronic Inserts FEB 20/FEB 20 P; FEB 22/FEB 22 P

A digital communication signal and a analogue 4…20 mA signal are simultaneously transmitted without any mutual interference.

- Power supply voltage: 11.5 V_{DC}…30 V_{DC}
- The housing must be grounded when using the FEB 20 P/FEB 22 P electronic insert with overvoltage protection.

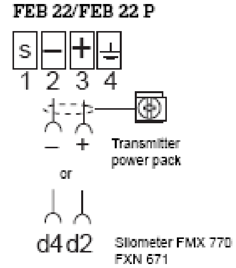


Graph showing load of FEB 20/22 with communication; min. R_b=250 Ω



Graph showing load of FEB 20/22 without communication

③ FEB 20/FEB 20 P FEB 22/FEB 22 P

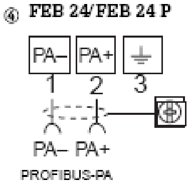


④ PROFIBUS-PA FEB 24/FEB 24 P

The digital communication signal is transmitted along a two-wire cable at the bus. This bus cable also carries the power supply.

- Power supply voltage:
  non-EEx: 9 V_{DC}…32 V_{DC}
  EEx: 9 V_{DC}…24 V_{DC} (1.2 W)
- Bus cable: When installing for the first time, twisted screened two-wire cable should be used with the following specifications:
  - loop resistance (DC) 15...150 Ω/km
  - inductance per unit length 0.4...1 mH/km
  - capacitance per unit length 80...200 nF/km
- The housing must be grounded when using the FEB 24 P electronic insert with overvoltage protection.

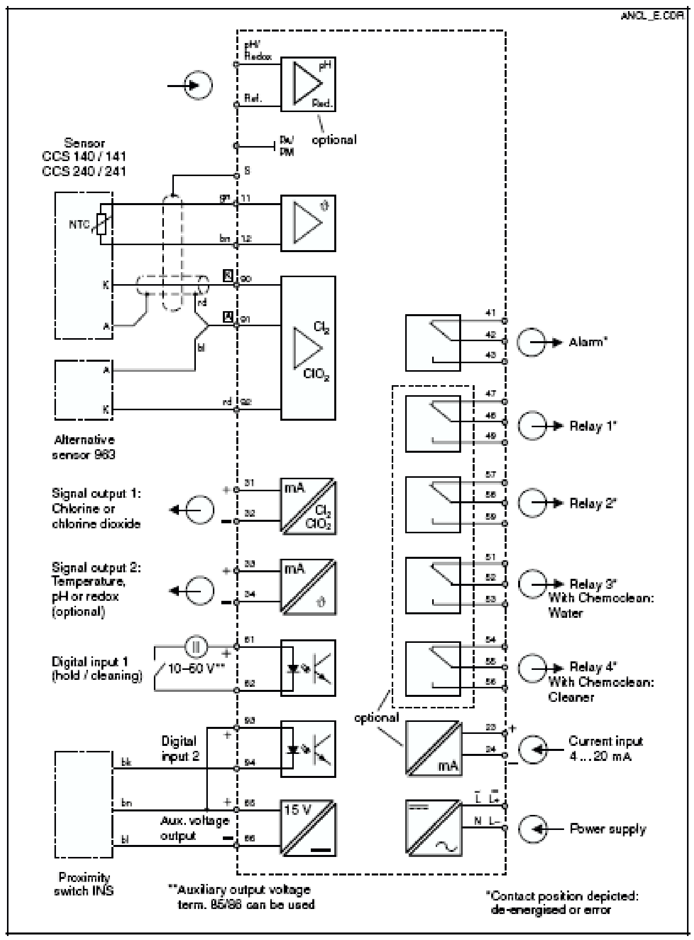
④ FEB 24/FEB 24 P



4.) Electrical Connection Transmitter of CCS 140-Chlorine sensor

Electrical connection

All connections to the panel-mounted instrument CCM 223 are made on terminal strips or by means of the BNC connector on the rear.
On the field instrument CCM 253 all the wires are connected to terminals in the separate wiring compartment of the transmitter. In case of service, all the wiring can remain in place; only the modules are replaced. Dismantling the transmitter and rewiring are no longer necessary.



Electrical connection of Liquisys M CCM 223 / 253