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Study and Control of an Industrial Cooling System Based on a Chiller Using TIA Portal

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Dedication

🌹 Dedication (Abdelmounaim)

To my beloved parents, whose endless love, sacrifices, and prayers have always been the light of my journey.

To my family, for their constant encouragement and support.

To my friends, who stood by me through challenges and successes.

I dedicate this work as a token of love, gratitude, and respect.

Dedication

🌹 Dedication (Walid)

To my dear parents, the foundation of my strength and the reason behind my perseverance.

To my brothers and sisters, for their encouragement and inspiration.

To my friends and colleagues, who shared with me the road of learning and achievement.

I dedicate this dissertation in appreciation of their unwavering support.

Abstract

This dissertation presents a comprehensive study of an industrial cooling system using a chiller, addressing both theoretical and practical aspects. The first chapter introduces the fundamental principles of chilled water systems, including thermodynamic laws, refrigeration cycles, and the main components of chillers. The second chapter focuses on industrial control systems, highlighting the role of Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) systems in automation and monitoring, ensuring reliability and energy efficiency. The third chapter presents the practical implementation, where a chiller control system was designed and simulated using the TIA Portal platform. Ladder Logic programming was developed to integrate sensors, pumps, and compressors in a safe and efficient control sequence. This work demonstrates the importance of integrating thermodynamic engineering with modern automation technologies to achieve intelligent, efficient, and reliable industrial cooling systems.

Keywords: Control, Conling System, Chiller, Tia Portal

ملخص

مذكرة التخرج هذه تناولت بالدراسة نظام التبريد الصناعي باستخدام الشيلر، حيث تم التركيز على الجوانب النظرية والعملية لهذا النظام. في الفصل الأول تم عرض المبادئ الأساسية لأنظمة الماء البارد مع التطرق إلى القوانين الترموديناميكية ودورات التبريد المختلفة، إضافة إلى شرح مكونات الشيلر وآلية عمله في التطبيقات الصناعية. أما الفصل الثاني فقد خُصص لدراسة أنظمة التحكم الصناعية، مع إبراز دور الـ PLCو SCADA في أتمتة ومراقبة نظام الشيلر، وما توفره هذه التقنيات من دقة في التشغيل وموثوقية في الأداء. بينما الفصل الثالث انتقل إلى الجانب التطبيقي من خلال تصميم ومحاكاة برنامج تحكم لشيلر باستخدام منصةTIA Portal ، حيث تم بناء شبكات Logic Ladder لربط الحساسات والمضخات والضواغط وفق تسلسل منطقي يضمن الأمان والكفاءة. وبذلك تجمع المذكرة بين الأساس النظري والتحكم الصناعي والتطبيق العملي، مما يبرز أهمية التكامل بين الهندسة الحرارية وتقنيات الأتمتة لتحقيق أنظمة تبريد أكثر ذكاءً وفعالية.

الكلمات المفتاحية: التحكم، نظام التبريد، الشيلر, TiaPortal

Résumé

Ce mémoire de fin d'études a examiné les systèmes de réfrigération industrielle utilisant des refroidisseurs, en se concentrant sur les aspects théoriques et pratiques de ce système. Le premier chapitre a présenté les principes de base des systèmes à eau glacée, en abordant les lois thermodynamiques et les différents cycles de réfrigération. Il a également expliqué les composants des refroidisseurs et leur fonctionnement dans les applications industrielles. Le deuxième chapitre a été consacré à l'étude des systèmes de contrôle industriel, soulignant le rôle des automates programmables (API) et des systèmes SCADA dans l'automatisation et la surveillance des systèmes de refroidissement, ainsi que la précision et la fiabilité opérationnelles qu'ils offrent. Le troisième chapitre a abordé la pratique en concevant et en simulant un programme de contrôle pour un refroidisseur à l'aide de la plateforme TIA Portal. Des réseaux Ladder Logic ont été construits pour connecter capteurs, pompes et compresseurs selon une séquence logique garantissant sécurité et efficacité. La thèse allie ainsi fondements théoriques, contrôle industriel et applications pratiques, soulignant l'importance de l'intégration des technologies de génie thermique et d'automatisation pour obtenir des systèmes de réfrigération plus intelligents et plus performants.

Mots clés: Commande, Système de refroidissement, Chiller, Tia Portal

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Liste of Abbreviation

cp =specific heat at constant

pressure COP =coefficient of

performance

g =local acceleration of gravity

h =enthalpy, kJ/kg

I =irreversibility =irreversibility

rate m =mass =mass flow, kg/s

p =pressure

Q =heat energy, kJ =rate of heat flow, kJ/s

R =ideal gas

constant s

=entropy,

kJ/(kg·K)

S =total entropy

t =temperature, °C

T =absolute temperature,

K u =internal energy

W =mechanical or shaft work =rate of work,

power v =specific volume, m3/kg

V =velocity of fluid

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General Introduction

General Introduction

Chilled Water Systems represent one of the essential components in various industrial, commercial, and infrastructural applications, due to their critical role in ensuring optimal operating conditions and maintaining thermal stability for machines and equipment. With the growing demand for energy efficiency and operational reliability, the integration of these systems with modern control technologies such as Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) has become indispensable. This integration enables precise monitoring of thermal and operational variables, facilitates rapid intervention in case of malfunctions, and enhances system performance while reducing operational costs.

Building on this significance, the present dissertation aims to address the subject of the chiller system from both fundamental and practical perspectives. The first chapter focuses on the thermodynamic principles underlying the system, with a detailed explanation of its operation and the functions of its main components. The second chapter is devoted to the study of industrial control systems, emphasizing the role of PLC and SCADA in the automation of processes and their application in critical systems such as chilled water systems. The third chapter moves towards the practical dimension, where a chiller system was programmed using the TIA Portal platform, highlighting how theoretical concepts can be translated into a real-world application that combines programmed control with intelligent supervision.

<u>Chapter I :</u>

Basics of Chilled Water System

1-Introduction

The cooling circuit plays a vital role in heating, ventilation, and air conditioning (HVAC) systems. Its primary function is to remove indoor heat to maintain a comfortable and controlled environment for occupants or industrial processes, most modern air conditioning systems rely on the vapor compression refrigeration cycle, which consists of four key components: the compressor, condenser, expansion valve, and evaporator. These components work together to transfer heat from the indoor space to the external environment.

Cooling systems in HVAC are typically classified into two main types based on the cooling medium used: water-cooled systems (chilled water systems) and air-cooled systems (direct expansion or DX systems). Engineers select between these systems based on factors such as the nature of the building, climatic conditions, and the availability of energy and water resources. Water-cooled systems are often preferred in large-scale projects due to their high efficiency, while air-cooled systems are commonly used in small to medium applications for their ease of installation and maintenance.[1]

The principles of thermodynamics play a fundamental role in the operation and analysis of refrigeration cycles. They explain how heat energy is transferred from the cooled space to the external environment, primarily through the application of the first and second laws of thermodynamics. These principles establish the relationship between pressure, temperature, and volume within key components such as the evaporator, condenser, and compressor. Understanding these dynamics is essential for optimizing system efficiency, reducing energy consumption, and improving performance indicators like the Coefficient of Performance (COP). Consequently, thermodynamic principles form the foundation for designing reliable and energy-efficient refrigeration systems.

2- Thermodynamic principles:

A thermodynamic system is a region in space or a quantity of matter bounded by a closed surface. The surroundings include everything external to the system, and the system is separated from the surroundings by the system boundaries. These boundaries can be movable or fixed, real or imaginary. The concepts that operate in any thermodynamic system are entropy and energy. Entropy measures the molecular disorder of a system. The more mixed a system, the greater its entropy; conversely, an orderly or unmixed configuration is one of low entropy. Energy has the capacity for producing an effect and can be categorized into either stored or transient forms as described in the following sections. [2]

Stored Energy.

Thermal (internal) energy is the energy possessed by a system caused by the motion of the molecules and/or intermolecular forces.

Potential energy is the energy possessed by a system caused by the attractive forces existing between molecules, or the elevation of the system.

$$PE = mgz \quad (1)$$

Where

m

=mass.

g = local acceleration of gravity.

z = elevation above horizontal reference plane.

Kinetic energy is the energy possessed by a system caused by the velocity of the molecules and is expressed as.

$$KE = mV^2/2 \quad (2)$$ Where

V is the velocity of a fluid stream crossing the system boundary.

Chemical energy is energy possessed by the system caused by the arrangement of atoms composing the molecules.

Nuclear (atomic) energy is energy possessed by the system from the cohesive forces holding protons and neutrons together as the atom's nucleus.

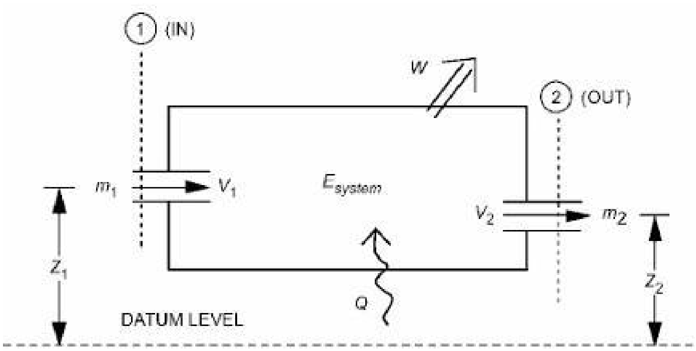
Energy in Transition

Heat (Q) is the mechanism that transfers energy across the boundary of systems with differing temperatures, always toward the lower temperature. Heat is positive when energy is added to the system.

Work is the mechanism that transfers energy across the bound ary of systems with differing pressures (or force of any kind), always toward the lower pressure. If the total effect produced in the system can be reduced to the raising of a weight, then nothing but work has crossed the boundary. Work is positive when energy is removed from the system.

Mechanical or shaft work (W) is the energy delivered or absorbed by a mechanism, such as a turbine, air compressor, or internal combustion engine.

Flow work is energy carried into or transmitted across the system boundary because a pumping process occurs somewhere outside the system, causing fluid to enter the system. It can be more easily understood as the work done by the fluid just outside the system on the adjacent fluid entering the system to force or push it into the system. Flow work also occurs as fluid leaves the system.



FigI.1. Energy Flows in General Thermodynamic System

Flow Work (per unit mass) = pv

Where p is the pressure and v is the specific volume, or the volume displaced per unit mass. A property of a system is any observable characteristic of the system. The state of a system is defined by listing its properties. The most common thermodynamic properties are temperature T, pressure p, and specific volume v or density ρ. Additional thermodynamic properties include entropy, stored forms of energy, and enthalpy. Frequently, thermodynamic properties combine to form other properties. Enthalpy (h), a result of combining properties, is defined as

$$h = u + pv \quad (3)$$

Where u is internal energy per unit mass.

The thermodynamic principles form the foundation for understanding and operating Heating, Ventilation, and Air Conditioning (HVAC) systems. Both the first and second laws of thermodynamics play a crucial role in analyzing and optimizing the performance of these systems. The first law, which represents the principle of energy conservation, is used to assess changes in internal energy and to evaluate the efficiency of heat transfer within system components such as the compressor and evaporator. Meanwhile, the second law determines the direction of heat transfer and establishes theoretical limits on the efficiency of cooling systems, making it essential for calculating the Coefficient of Performance (COP) and identifying thermal losses. Moreover, thermodynamic analysis of refrigeration cycles is vital for the effective design and operation of HVAC systems. The vapor-compression refrigeration cycle represents the practical basis for most applications, while the Carnot cycle provides a theoretical benchmark for maximum possible efficiency. Cycles such as the Lorenz and multi-stage compression cycles highlight the importance of technical advancements to enhance performance in specialized applications. Furthermore, the selection of the appropriate refrigerant—whether pure or azeotropic mixture—has a direct impact on system efficiency and thermal behavior. Therefore, mastering these concepts is essential for conducting accurate engineering analysis of modern HVAC systems.[3]

2.1 **_ First law of thermodynamics:** The first law of thermodynamics is often called the law of the conservation of energy. The following form of the first law equation is valid only in the absence of a nuclear or chemical reaction. Based on the first law or the law of conservation of energy for any system, open or closed, there is an energy balance as

Net Amount of Energy Added to System= Net Increase in Stored Energy of System

Or Energy In – Energy Out = Increase in Energy in System

Ein – Eout =delta E system

Illustrates energy flows into and out of a thermodynamic system. For the general case of multiple mass flows in and out of the system, the energy balance can be written

$$\sum m_{in}\left(u + pv + \frac{V^2}{2} + gz\right)_{in} - \sum m_{out}\left(u + pv + \frac{V^2}{2} + gz\right)_{out} + Q - W = \left[m_f\left(u + \frac{V^2}{2} + gz\right)_f - m_i\left(u + \frac{V^2}{2} + gz\right)_i\right]_{system} \quad (4)$$

Where subscripts i and f refer to the initial and final states, respectively. The steady-flow process is important in engineering applications. Steady flow signifies that all quantities associated with the system do not vary with time. Consequently,

$$\sum_{\substack{\text{all streams}\\ \text{leaving}}} \dot{m}\left(h + \frac{V^2}{2} + gz\right) - \sum_{\substack{\text{all streams}\\ \text{entering}}} \dot{m}\left(h + \frac{V^2}{2} + gz\right) + \dot{Q} - \dot{W} = 0 \quad (5)$$

Where h = u + pv as described in Equation (4). A second common application is the closed stationary system for which the first law equation reduces to

$$Q - W = [m(u_f - u_i)]_{system} \quad (6)$$

Where u is internal energy per unit mass. [3]

2.2- Second law of thermodynamics: The second law of thermodynamics differentiates and quantifies processes that only proceed in a certain direction (irreversible) from those that are reversible. The second law may be described in several ways. One method uses the concept of entropy flow in an open system and the irreversibility associated with the process. The concept of irreversibility provides added insight into the operation of cycles. For example, the larger the irreversibility in a refrigeration cycle operating with a given refrigeration load between two fixed temperature levels, the larger the amount of work required to operate the cycle. Irreversibilities include pressure drops in lines and heat exchangers, heat transfer between fluids of different temperature, and mechanical friction. Reducing total irreversibility in a cycle improves the cycle performance. In the limit of no irreversibilities, a cycle will attain its maximum ideal efficiency. In an open system, the second law of thermodynamics can be described in terms of entropy as

$$dS_{system} = \frac{\delta Q}{T} + \delta m_i s_i - \delta m_e s_e + dI \quad (7)$$

Where

dSsystem=total change within system in time dt during process

δmisi =entropy increase caused by mass entering (incoming)

δmese=entropy decrease caused by mass leaving (exiting)

δQ/T=entropy change caused by reversible heat transfer between system and surroundings

dI=entropy caused by irreversibility (always positive)

$$\delta Q = T[(\delta m_e s_e - \delta m_i s_i) + dS_{sys} - dI] \quad (8)$$

Equation (8) accounts for all entropy changes in the system. Re arranged, this equation becomes

In integrated form, if inlet and outlet properties, mass flow, and interactions with the surroundings do not vary with time, the general equation for the second law is

$$(S_f - S_i)_{system} = \int_{rev} \frac{\delta Q}{T} + \sum (ms)_{in} - \sum (ms)_{out} + I \quad (9)$$

In many applications the process can be considered to be operating steadily with no change in time. The change in entropy of the system is therefore zero. The irreversibility rate, which is the rate of entropy production caused by irreversibilities in the process, can be determined by rearranging Equation (10)

$$\dot{I} = \sum (\dot{m}s)_{out} - \sum (\dot{m}s)_{in} - \int \frac{\dot{Q}}{T_{surr}} \quad (10)$$

Equation (6) can be used to replace the heat transfer quantity.

Note that the absolute temperature of the surroundings with which the system is exchanging heat is used in the last term. If the temperature of the surroundings is equal to the temperature of the system, the heat is transferred reversibly and Equation (11) becomes equal to zero. Equation (11) is commonly applied to a system with one mass flow in, the same mass flow out, no work, and negligible kinetic or potential energy flows. Combining Equations (6) and (11) yields

$$\dot{I} = \dot{m}\left[(s_{out} - s_{in}) - \frac{h_{out} - h_{in}}{T_{surr}}\right] \quad (11)$$

In a cycle, the reduction of work produced by a power cycle or the increase in work required by a refrigeration cycle is equal to the absolute ambient temperature multiplied by the sum of the irreversibilities in all the processes in the cycle. Thus the difference in the reversible work and the actual work for any refrigeration cycle, the oretical or real, operating under the same conditions becomes

$$\dot{W}_{actual} = \dot{W}_{reversible} + T_0 \sum \dot{I} \quad (12)$$

2.3_THERMODYNAMIC ANALYSIS OF REFRIGERATION CYCLES

Refrigeration cycles transfer thermal energy from a region of low temperature TR to one of higher temperature. Usually the higher temperature heat sink is the ambient air or cooling water.

This temperature is designated as T0, the temperature of the surroundings. The first and second laws of thermodynamics can be applied to individual components to determine mass and energy balances and the irreversibility of the components.

This procedure is illustrated in later sections in this chapter. Performance of a refrigeration cycle is usually described by a coefficient of performance. COP is defined as the benefit of the cycle (amount of heat removed) divided by the required energy input to operate the cycle, or

$$\text{COP} \equiv \frac{\text{Useful refrigerating effect}}{\text{Net energy supplied from external sources}} \quad (13)$$

For a mechanical vapor compression system, the net energy sup plied is usually in the form of work, mechanical or electrical, and may include work to the compressor and fans or pumps, thus

$$\text{COP} = \frac{Q_{evap}}{W_{net}} \quad (14)$$

In an absorption refrigeration cycle, the net energy supplied is usually in the form of heat into the generator and work into the pumps and fans, or

$$COP = \frac{Q_{evap}}{Q_{gen} + W_{net}} \quad (15)$$

In many cases the work supplied to an absorption system is very small compared to the amount of heat supplied to the generator, so the work term is often neglected, Application of the second law to an entire refrigeration cycle shows that a completely reversible cycle operating under the same conditions has the maximum possible Coefficient of Performance. A measure of the departure of the actual cycle from an ideal reversible cycle is given by the refrigerating efficiency:

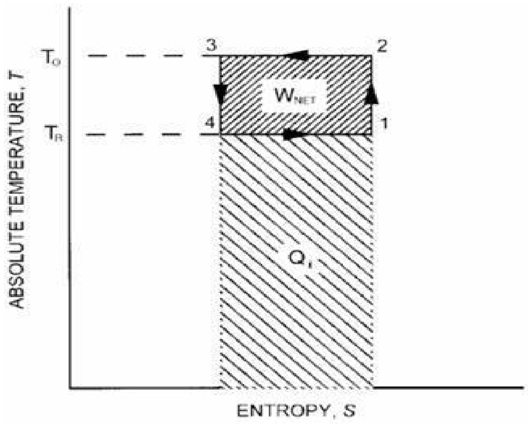
$$\eta_R = \frac{COP}{(COP)_{rev}} \quad (16)$$

The Carnot cycle usually serves as the ideal reversible refrigeration cycle. For multistage cycles, each stage is described by a reversible cycle. [3]

2.4_COMPRESSION REFRIGERATION CYCLES

2.4.1_CARNOT CYCLE

The Carnot cycle, which is completely reversible, is a perfect model for a refrigeration cycle operating between two fixed temperatures, or between two fluids at different temperatures and each with infinite heat capacity, Reversible cycles have two important proper ties: (1) no refrigerating cycle may have a coefficient of performance higher than that for a reversible cycle operated between the same temperature limits, and (2) all reversible cycles, when operated between the same temperature limits,



FigI.2. Carnot Refrigeration Cycle

have the same coefficient of performance, Proof of both statements may be found in almost any textbook on elementary engineering thermodynamics, Figure 3 shows the Carnot cycle on temperature-entropy coordinates. Heat is withdrawn at the constant temperature TR from the region to be refrigerated. Heat is rejected at the constant ambient temperature T0, The cycle is completed by an isentropic expansion and an isentropic compression.

The energy transfers are given by

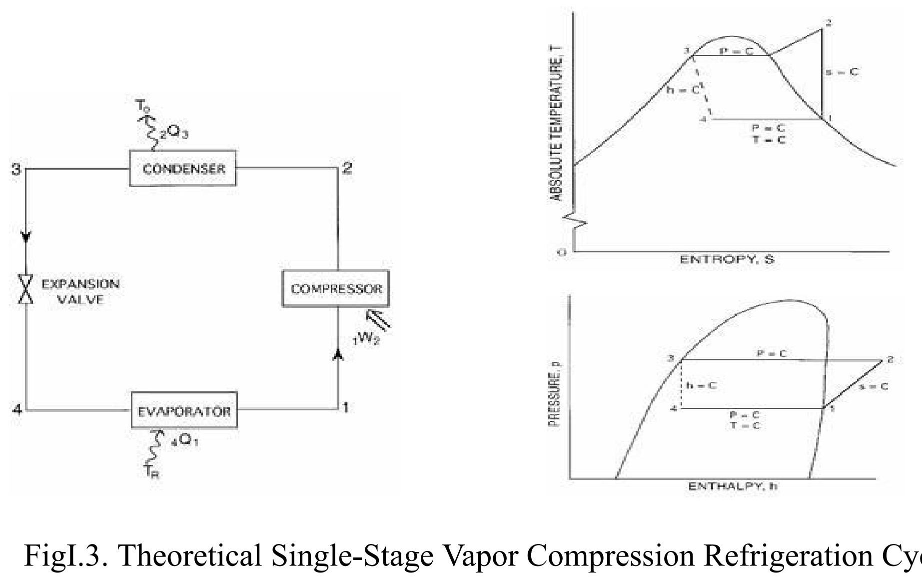
$$\begin{aligned} Q_0 &= T_0(S_2 - S_3) \\ Q_i &= T_R(S_1 - S_4) = T_R(S_2 - S_3) \\ W_{net} &= Q_o - Q_i \end{aligned} \quad (17)$$

Thus, by Equation (15)

$$\text{COP} = \frac{T_R}{T_0 - T_R} \quad (18)$$

2.4.2 _THEORETICAL SINGLE-STAGE CYCLE USING A PURE REFRIGERANT OR AZEOTROPIC MIXTURE

A system designed to approach the ideal model shown in Figure 4 is desirable. A pure refrigerant or an azeotropic mixture can be used to maintain constant temperature during the phase changes by maintaining a constant pressure. Because of such concerns as high initial cost and increased maintenance requirements, a practical machine has one compressor instead of two and the expander (engine or turbine) is replaced by a simple expansion valve. The valve throttles the refrigerant from high pressure to low pressure



FigI.3. Theoretical Single-Stage Vapor Compression Refrigeration Cycle

Shows the theoretical single-stage cycle used as a model for actual systems.

Applying the energy equation for a mass of refrigerant m yields

$$
\begin{aligned}
{}_4Q_1 &= m(h_1 - h_4) \\
{}_1W_2 &= m(h_2 - h_1) \\
{}_2Q_3 &= m(h_2 - h_3) \\
h_3 &= h_4
\end{aligned}
\qquad (19)
$$

The constant enthalpy throttling process assumes no heat transfer or change in potential or kinetic energy through the expansion valve. The coefficient of performance is

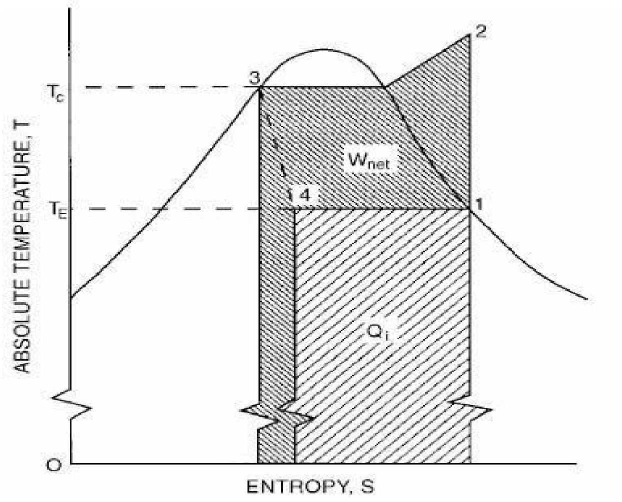
$$\text{COP} = \frac{{}_4Q_1}{{}_1W_2} = \frac{h_1 - h_4}{h_2 - h_1} \qquad (20)$$

The theoretical compressor displacement CD (at 100% volumetric efficiency), is

$$\text{CD} = \dot{m}v_3 \qquad (21)$$

Which is a measure of the physical size or speed of the compressor required to handle the prescribed refrigeration load.

The saturation temperatures of the single-stage cycle have a strong influence on the magnitude of the coefficient of performance. This influence may be readily appreciated by an area analysis on a temperature-entropy (T-s) diagram. The area under a reversible process line on a T-s diagram is directly proportional to the thermal energy added or removed from the working fluid. This observation follows directly from the definition of entropy [see Equation (4)]. In Figure 5 the area representing Qo is the total area under the constant pressure curve between states 2 and 3. The area representing the refrigerating capacity Qi is the area under the constant pressure line connecting states 4 and 1. The network required Wnet equals the difference (Qo − Qi), which is represented by the shaded area shown on Figure 10.



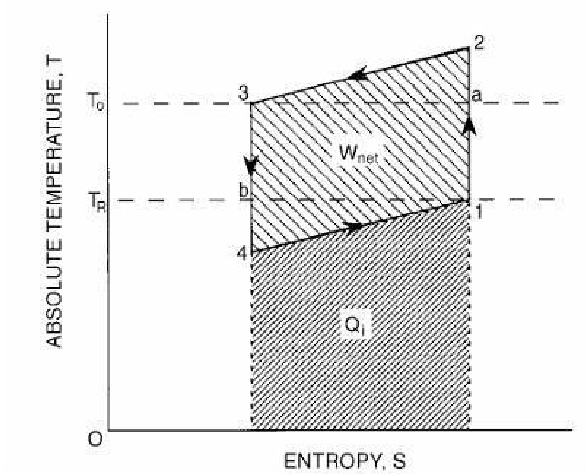
FigI.4. Areas on T-s Diagram Representing Refrigerating Effect and Work Supplied for Theoretical Single-Stage Cycle

Because COP = Qi/Wnet, the effect on the COP of changes in evaporating temperature and condensing temperature may be observed. For example, a decrease in evaporating temperature TE significantly increases Wnet and slightly decreases Qi. An increase in condensing temperature TC produces the same results but with less effect on Wnet. Therefore, for maximum coefficient of perform ance, the cycle should operate at the lowest possible condensing temperature and at the maximum possible evaporating temperature.

2.4.3 _LORENZ REFRIGERATION CYCLE

The Carnot refrigeration cycle includes two assumptions which make it impractical. The heat transfer capacity of the two external fluids are assumed to be infinitely large so the external fluid temperatures remain fixed at T0 and TR (they become infinitely large thermal reservoirs). The Carnot cycle also has no thermal resistance between the working refrigerant and the external fluids in the two heat exchange processes. As a result, the refrigerant must remain fixed at T0 in the condenser and at TR in the evaporator. The Lorenz cycle eliminates the first restriction in the Carnot cycle and allows the temperature of the two external fluids to vary during the heat exchange. The second assumption of negligible thermal resistance between the working refrigerant and the two external fluids remains. Therefore the refrigerant temperature must change during the two heat exchange processes to equal the changing temperature of the external fluids. This cycle is completely reversible when operating between two fluids, each of which has a finite but constant heat capacity. Figure 6 is a schematic of a Lorenz cycle. Note that this cycle does not operate between two fixed temperature limits. Heat is added to the refrigerant from state 4 to state 1, this process is assumed to be linear on T-s coordinates, which represents a fluid with constant heat capacity. The temperature of the refrigerant is increased in an isentropic compression process from state 1 to state 2.

Process 2-3 is a heat rejection process in which the refrigerant temperature decreases linearly with heat transfer. The cycle is concluded with an isentropic expansion process between states 3 and 4. The heat addition and heat rejection processes are parallel so the entire cycle is drawn as a parallelogram on T-s coordinates. A Car not refrigeration cycle operating between T0 and TR would lie between states 1, a, 3, and b. The Lorenz cycle has a smaller refrigerating effect than the Carnot cycle and more work is required. However this cycle is a more practical reference to use than the Car not cycle when a refrigeration system operates between two single phase fluids such as air or water. [3]



FigI.5. Processes of Lorenz Refrigeration Cycle

The energy transfers in a Lorenz refrigeration cycle are as follows, where ΔT is the temperature change of

$$Q_0 = (T_0 + \Delta T/2)(S_2 - S_3)$$
$$Q_i = (T_R - \Delta T/2)(S_1 - S_4) = (T_R - \Delta T/2)(S_2 - S_3)$$
$$W_{net} = Q_0 - Q_R$$

T (22)

the refrigerant during each of the two heat exchange processes.

Thus by Equation (15)

$$\text{COP} = \frac{T_R - (\Delta T/2)}{T_O - T_R + \Delta T}$$

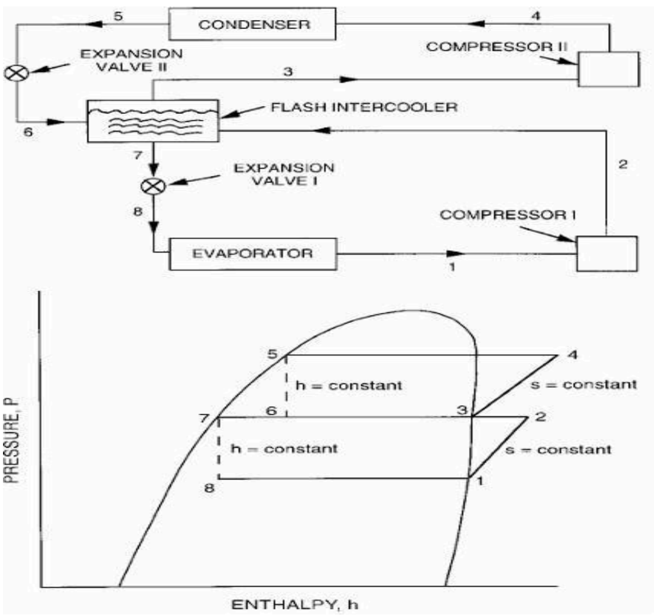
(23)

2.4.4 _MULTISTAGE VAPOR COMPRESSION REFRIGERATION CYCLES

Multistage vapor compression refrigeration is used when several evaporators are needed at various temperatures such as in a supermarket or when the temperature of the evaporator becomes very low. Low evaporator temperature indicates low evaporator pressure and low refrigerant density into the compressor. Two small compressors in series have a smaller displacement and usually operate more efficiently than one

$$COP = \sum Q_i / W_{net} \quad (24)$$

large compressor that covers the entire pressure range from the evaporator to the condenser. This is especially true in refrigeration systems that use ammonia because of the large amount of superheating that occurs during the compression process. The thermodynamic analysis of multistage cycles is similar to the analysis of single-stage cycles. The main difference is that the mass flow differs through various components of the system. A careful mass balance and energy balance performed on individual components or groups of components ensures the correct application of the first law of thermodynamics. Care must also be exercised when performing second law calculations. Often the refrigerating load is comprised of more than one evaporator, so the total system capacity is the sum of the loads from all evaporators. Likewise the total energy input is the sum of the work into all compressors. For multistage cycles, the expression for the coefficient of performance given in Equation 7 should be written as



FigI.6. Schematic and Pressure-Enthalpy Diagram for Dual-Compression, Dual-Expansion Cycle

When compressors are connected in series, the vapor between stages should be cooled to bring the vapor to saturated conditions before proceeding to the next stage of compression. Intercooling usually minimizes the displacement of the compressors, reduces the work requirement, and increases the COP of the cycle. If the refrigerant temperature between stages is above ambient, a simple inter cooler that removes heat from the refrigerant can be used. If the temperature is below ambient, which is the usual case, the refrigerant itself must be used to cool the vapor. This is accomplished with a flash intercooler. Figure 7shows a cycle with a flash intercooler installed. The superheated vapor from compressor I is bubbled through saturated liquid refrigerant at the intermediate pressure of the cycle. Some of this liquid is evaporated when heat is added from the superheated refrigerant. The result is that only saturated vapor at the intermediate pressure is fed to compressor II. A common assumption is to operate the intercooler at about the geometric mean of the evaporating and condensing pressures. This operating point provides the same pressure ratio and nearly equal volumetric efficiencies for the two compressors.[3]

3_The refrigeration cycle

The mechanical vapor-compression–refrigeration cycle is used in many types of HVACR systems. It can be found in all sizes of systems, from small dormitory refrigerators to large industrial chillers. The compression cycle has been used for a diverse range of applications, including air conditioning, commercial refrigeration, and industrial process refrigeration. A thorough understanding of the refrigeration cycle is absolutely essential to working in the HVACR field. Understanding exactly what is supposed to take place at any point in the cycle is necessary for proper system installation, servicing, and troubleshooting. Because we only discuss the mechanical vapor compression–refrigeration cycle throughout this unit, we refer to it as simply the refrigeration cycle for the rest of the unit. [2]

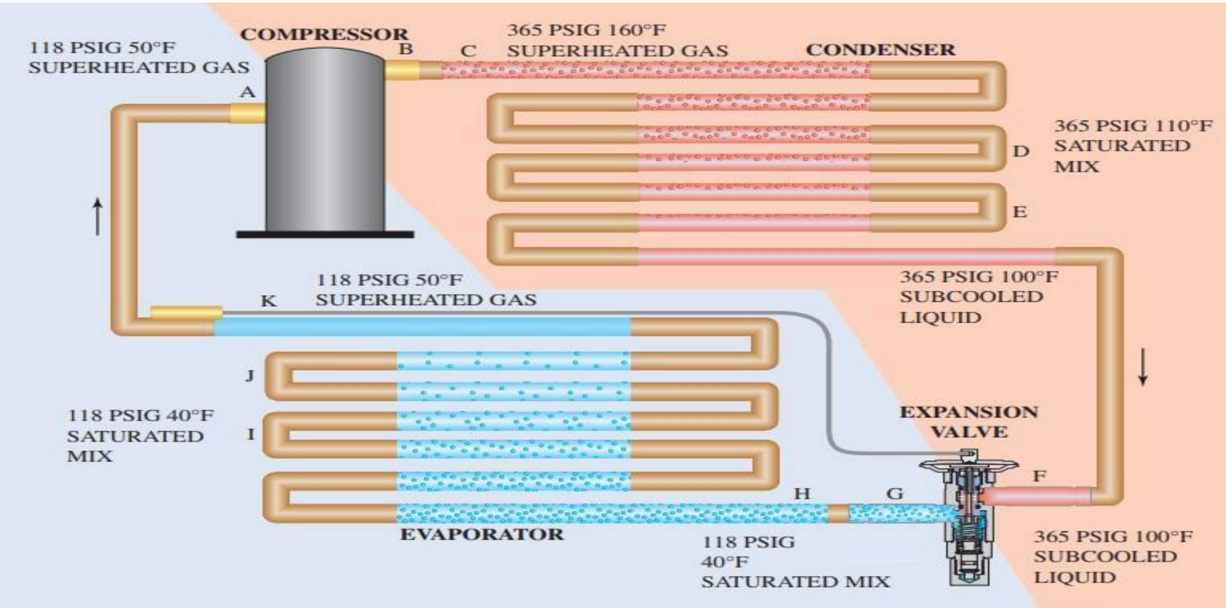


Figure I.7. Basic refrigeration cycle of an R-410A air conditioning system.

3.1_THE COMPRESSOR

The compressor is a mechanical device for pumping refrigerant vapor from the low-pressure evaporator to the high-pressure condenser. The compressor increases the refrigerant pressure and temperature by decreasing the gas volume. The main types of compressors are reciprocating (piston), rotary, centrifugal, screw, and scroll.

Figure I.8. The compressor raises the gas pressure and temperature by squeezing the gas to a smaller volume.

3.2_THE CONDENSER

The condenser is a device for removing heat from the refrigeration system. In the condenser, the vapor at high temperature and high pressure transfers heat through the condenser tubes to the surrounding medium, usually air or water. The first portion of the condenser cools off the superheated gas and lowers its temperature to the saturation point. This part of the condenser is called the de-superheating section. When the temperature of the vapor reaches the saturation temperature, the additional latent heat removed causes condensation of the refrigerant, producing liquid refrigerant. The refrigerant temperature remains the same while it is changing state, the end of the condenser subcools the refrigerant, lowering the refrigerant temperature below the saturation point. This is called the sub cooling section of the condenser. There are three types of condensers: air cooled, water cooled, and evaporative. The air-cooled condenser uses air as the condensing medium, the water-cooled condenser uses water as the condensing medium, and the evaporative condenser uses both air and water.

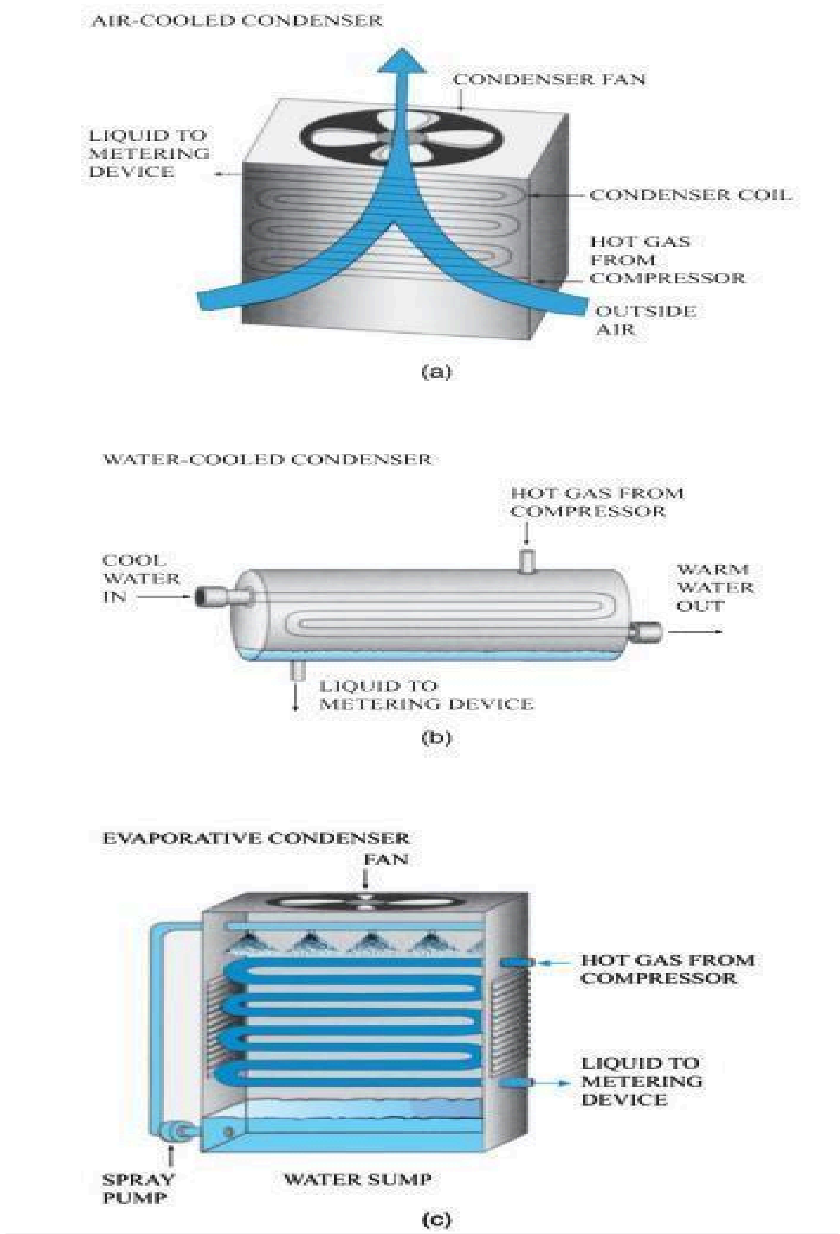


Figure I.9. Condensers: (a) air cooled; (b) water cooled; (c) evaporative condenser, also called a sump.

3.3_ THE EVAPORATOR

The evaporator is a device for absorbing heat into the refrigeration system. In the evaporator, the saturated refrigerant absorbs heat from its surroundings and boils into a low-pressure vapor. Refrigerant enters the evaporator from the metering device as a saturated mixture. The saturated liquid turns to saturated vapor as the refrigerant travels through the evaporator. The refrigerant is superheated in the evaporator or cooling coil is fabricated from metals such as copper or aluminum or both. These metals are selected because of their good thermal conductivity. Although there are many variations and modifications of evaporators, there are three basic types of construction: bare pipe, finned tube, and plate On finned tube evaporators, the tubing is interconnected by aluminum fins that serve to both direct the airflow through the coil and increase heat transfer by increasing the surface area of the evaporator, Like condensers, evaporators can be forced air or natural draft. Most evaporators operate below the dew point of the air being cooled. This causes water to condense on them. [4]

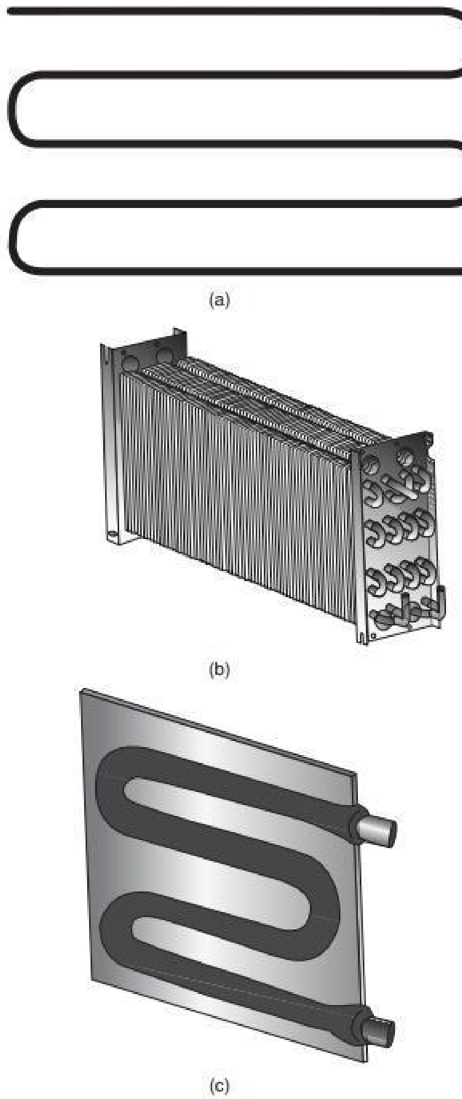


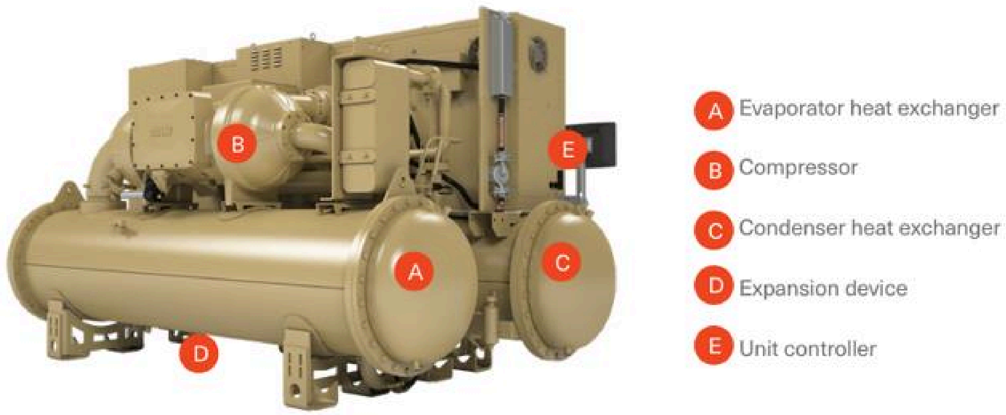
Figure I.10. Different types of evaporators; (a) bare pipe; (b) finned tube; (c) plate.

3.4_ Chilled water system

Chilled water system is a central cooling system that uses water as a medium to absorb and transfer heat. Water is chilled by a chiller and then circulated through pipes to air handling units or fan coil units, where it absorbs heat from the building spaces. The warmed water is then returned to the chiller to be cooled again, completing the cycle. These systems are commonly used in large commercial and industrial buildings for efficient and centralized climate control.

3.5_ Chiller

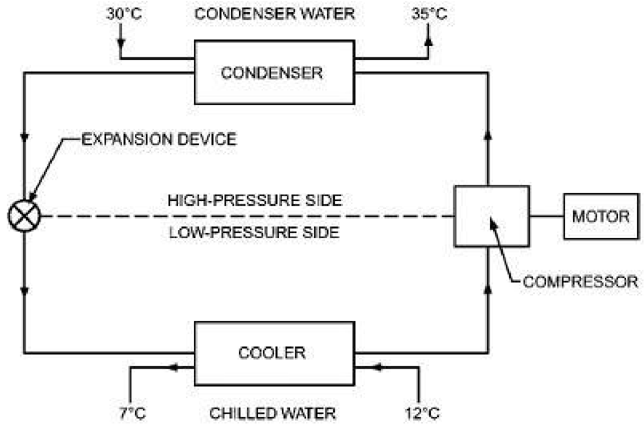
A chiller is a mechanical device used to remove heat from a liquid via a vapor-compression or absorption refrigeration cycle.



FigI.11. chiller

3.6_ Basic Chiller

The refrigeration cycle of a basic chiller is shown in Figure 1. Chilled water enters the cooler at 12°C, for example, and leaves at 7°C. Condenser water leaves a cooling tower at 30°C, enters the con denser, and returns to the cooling tower near 35°C. Condensers may also be cooled by air or evaporation of water. This system, with a single compressor and one refrigerant circuit with a water-cooled con denser, is used extensively to chill water for air conditioning because it is relatively simple and compact. [5]



FigI.12. Equipment Diagram for Basic Liquid Chiller

3.7_ PRINCIPLES OF OPERATION

1. Cooling Demand Is Detected

The building's control system detects a need for cooling—either due to rising indoor temperatures or a scheduled set point and signals the chiller to start operating.

2. Chiller Activates the Refrigeration Cycle

Inside the chiller, the refrigeration cycle begins. The compressor draws in low-pressure refrigerant vapor and compresses it into a high-pressure, high-temperature gas.

3. Heat Rejection in the Condenser

The hot refrigerant gas flows to the condenser, where it releases heat to the surrounding environment. This is done through air (air-cooled chiller) or water (water-cooled chiller via a cooling tower). The refrigerant condenses into a high-pressure liquid.

4. Pressure Drop at the Expansion Valve

The high-pressure liquid refrigerant passes through an expansion valve, where its pressure drops suddenly. This causes a reduction in temperature, preparing it to absorb heat.

5. Heat Absorption in the Evaporator

The cold refrigerant enters the evaporator, where it comes into contact with the chilled water loop. It absorbs heat from the water, causing the refrigerant to evaporate back into a gas. At the same time, the water is cooled and circulated through the building.

6. Chilled Water Distribution

The chilled water is pumped through a network of insulated pipes to air handling units (AHUs) or fan coil units (FCUs), where it absorbs heat from indoor air. This cools the space.

7. Return Water and Cycle Repeats

The now warmed water returns to the evaporator to be cooled again, while the refrigerant vapor returns to the compressor to begin a new cycle.[8]

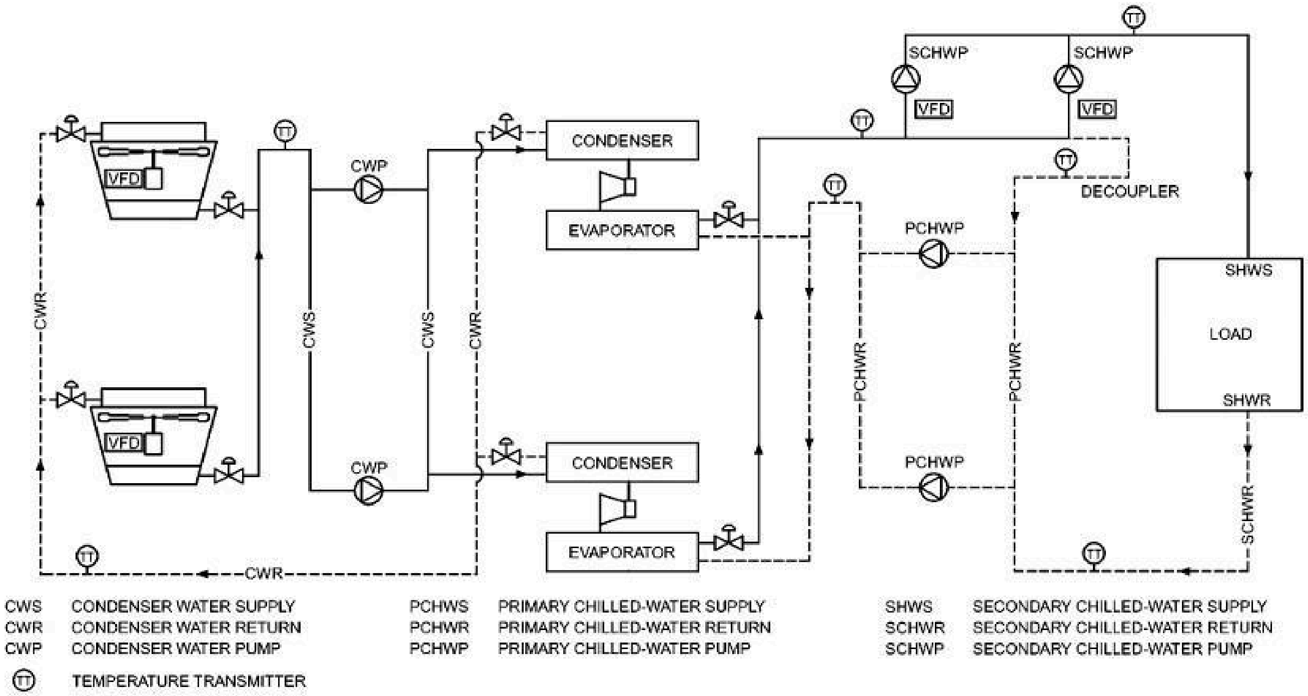
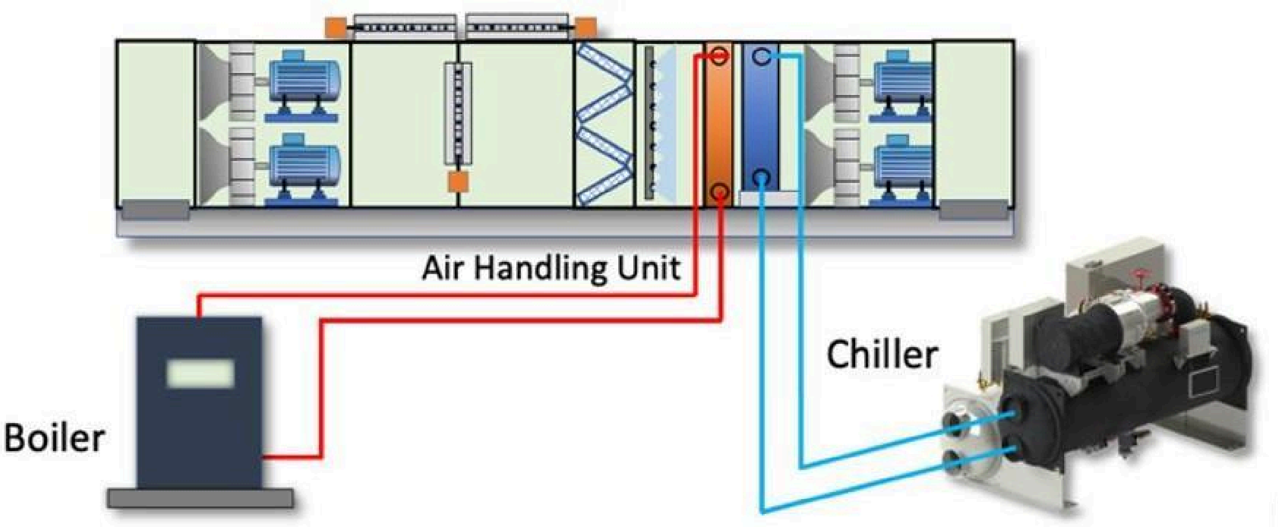


Fig.I.13. Primary/Secondary Pumping Chilled-Water System

A Variable Frequency Drive (VFD) is an electronic device that controls the rotational speed of an electric motor by adjusting the frequency and voltage of its power supply. In chiller systems, a VFD is typically integrated with compressors, pumps, or fans to modulate their operating speed according to the actual cooling demand. This dynamic control reduces energy consumption, minimizes mechanical stress, and enhances overall system efficiency, especially under partial load conditions.

3.8_ AIR-HANDLING UNITS

An Air Handling Unit (AHU) is a central device in mechanical air-conditioning systems designed to condition and distribute indoor air through processes such as cooling, heating, humidification, or dehumidification. In chiller-based systems, the AHU is directly connected to the chilled water circuit, where the cold water produced by the chiller is circulated through the cooling coils of the unit. As air passes over these coils, it is cooled before being distributed to different zones via ductwork. Thus, the AHU serves as the primary interface between the chilled water system and the end-user environment, ensuring thermal comfort, energy efficiency, and indoor air quality.



FigI.14. Air handling unit whit chiller

4_ Conclusion: By examining the fundamental principles of thermodynamics and their application to the chiller system, it becomes clear that the operation of a chiller is essentially governed by the laws of energy and heat transfer. The chiller removes unwanted heat from the indoor environment and rejects it to the outside through a well-defined refrigeration cycle. This makes it one of the most effective engineering solutions for ensuring thermal comfort while enhancing energy efficiency in modern buildings and facilities.

Chapter II:

PLC and SCADA System

1- Introduction

In industrial automation systems, the Programmable Logic Controller (PLC) plays a central role in ensuring the safe, reliable, and efficient operation of machinery and processes. This chapter introduces the fundamental concepts of PLCs, their architecture, and their operational principles. It also highlights the importance of PLCs in the automation and control of chiller systems, with a focus on how these controllers can be programmed and integrated using Siemens' TIA Portal software. A deep understanding of PLCs is essential before delving into the design and implementation of a fully automated chiller control system.

1_The Importance of Control in Chilled Water Systems through PLC

Efficient control in chilled water systems is a fundamental requirement to ensure reliable operation, energy savings, and optimal performance of HVAC applications. A chilled water system typically involves multiple components such as chillers, pumps, cooling towers, and heat exchangers, which must operate in harmony to maintain desired temperature and flow conditions. Without proper control, these systems can suffer from energy losses, unstable operation, and reduced equipment lifespan.

The integration of Programmable Logic Controllers (PLCs) provides a robust and flexible solution for managing chilled water systems. PLCs offer high reliability, real-time monitoring, and advanced automation capabilities, making them ideal for handling complex processes. Through the use of PLCs, operators can achieve precise regulation of chilled water temperature, flow rate, and pressure, ensuring that cooling loads are met efficiently while minimizing energy consumption.

Moreover, PLC-based control enables seamless communication with supervisory systems such as SCADA, allowing for remote monitoring, data logging, and fault diagnostics. This not only improves operational efficiency but also facilitates predictive maintenance and reduces unplanned downtime. In modern smart buildings and industrial facilities, PLC-driven chilled water control systems contribute significantly to sustainability goals by optimizing energy usage and enhancing overall system reliability.

In conclusion, implementing PLC control in chilled water systems is not only a technical enhancement but also a strategic investment. It ensures operational stability, improves energy efficiency, and supports the growing demand for intelligent building management systems.

2_What is a PLC

Programmable Logic Controllers (PLC) are often defined as miniature industrial computers that contain hardware and software used to perform control functions. More specifically, a PLC would be used for the automation of industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or food processing. They are designed for multiple arrangements of digital and analog inputs and outputs with extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. A PLC will consist of two basic sections: the central processing unit (CPU) and the Input/Output (1/0) interface system.[6]

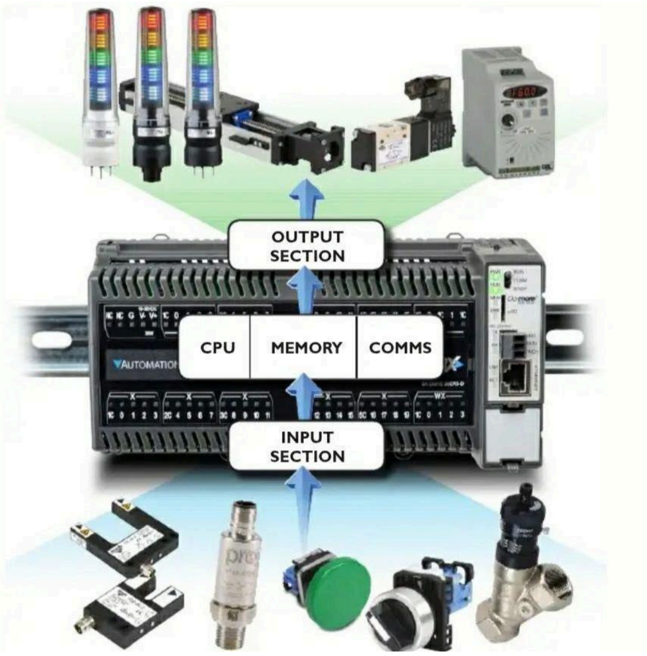


Fig II.1. Automat programmable industrial

The CPU controls all system activity primarily through its processor and memory system. The CPU consists of a microprocessor, memory chip and other integrated circuits to control logic, monitoring and communications. The CPU has different operating modes. In programming mode the CPU will accept changes to the downloaded logic from a PC. When the CPU is placed in run mode it will execute the program and operate the process. Input data from connected field devices (e.g., switches, sensors, etc.) is processed, and then the CPU "executes" or performs the control program that has been stored in its memory system. Since a PLC is a dedicated controller it will process this one program over and over again. The time it takes for one cycle through the program is called scan time and happens very quickly (in the range of 1/1000th of a second, depending on your program). The memory in the CPU stores the program while also holding the status of the I/O and providing a means to store values.

The input/output system is physically connected to field devices and provides the interface between the CPU and its information providers (inputs) and controllable devices (outputs). After the CPU processes the input data (input scan), it will then make any needed output changes after executing the user program (output scan). There are four basic steps in the operation of all PLCs: Input Scan, Program Scan, Output Scan, and Housekeeping. These steps continually take place in a repeating loop. Input Scan-Detects the state of all input devices that are connected to the PLC Program Scan-Executes the user created program logic Output Scan-Energizes or de energizes all output devices that are connected to the PLC Housekeeping - Includes communicating with programming devices and performing internal diagnostics.

Typical PLCs have a wide range of 1/0 modules available to accommodate all kinds of sensors and output devices. For example, discrete input modules can be used to detect object presence or events with devices such as proximity or photoelectric sensors, limit switches and pushbuttons. Discrete output modules can control "ON/OFF" loads such as motors, lights, and solenoid valves. Analog input modules can accept signals from process instrumentation such as flow, pressure, temperature and level transmitters. These modules can interpret the signal and present a value within a range determined by the devices' electrical specifications. Analog outputs will command loads that require a varying control signal, such as panel meters, variable frequency drives or analog flow valves. Many PLCs also offer specialized modules such as high-speed 1/0 or motion control, and serial or Ethernet communications. The greatest benefit of automating with a Programmable Logic Controller is the ability to repeat or change and replicate the operation or process while collecting and communicating vital information. Those making the buying decisions for Programmable Controller applications can have very different needs. Cost, power, speed, and communication are a few of the many considerations when choosing the right PLC for the job.

3_Selection of the Programmable Logic Controller (PLC) in Chiller Systems

The selection of an appropriate Programmable Logic Controller (PLC) for chiller systems is a critical factor in ensuring reliable operation and efficient control. This choice must be guided by several technical and operational considerations that directly influence system performance.

First, it is essential to determine the number of input and output (I/O) points required according to the system components to be controlled, such as pumps, compressors, valves, and sensors for temperature, pressure, and flow. The more complex the system and the higher the number of variables, the greater the need for a PLC with scalable and expandable I/O capabilities.

Second, processing capacity and response time play a decisive role, since chiller systems involve dynamic variables that require real-time processing. This is particularly relevant when implementing advanced control strategies such as PID algorithms or when integrating with energy management systems.

Third, the chosen PLC should support standard industrial communication protocols such as Modbus, BACnet, or Profibus, in order to facilitate seamless integration with Supervisory Control and Data Acquisition (SCADA) systems or Building Management Systems (BMS).

Furthermore, the environmental conditions must be taken into account, including humidity, high temperatures, and vibrations, which are often present in mechanical rooms and central cooling plants. Finally, the availability of technical support, ease of maintenance, and compatibility with the expertise of the engineering team are crucial factors. Widely used systems such as Siemens S7-1200 or Schneider Modicon are considered reliable and flexible solutions, offering robust performance and long-term maintainability.

Based on these criteria, the selection of the PLC should aim to ensure optimal integration with the chiller system while balancing performance, reliability, and future scalability.

4_PLC Architecture:

A typical PLC consists of the following modules or boards, mounted on a common physical support and electrical interconnection structure known as the rack. A typical PLC rack configuration is shown in the diagram in Figure II.6 [7]

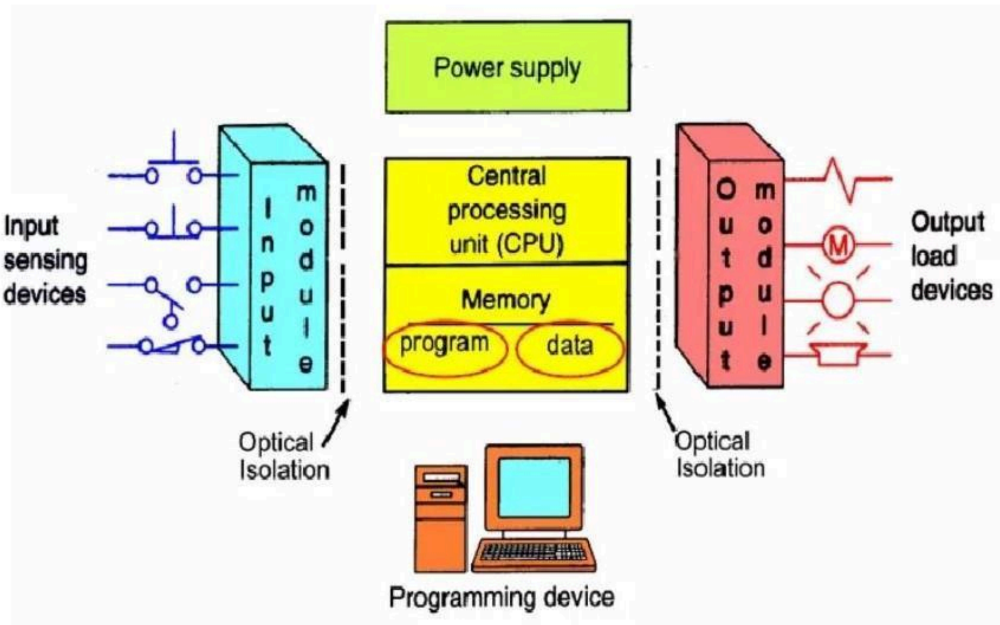


Fig II.2. Plc architecture

Power Supply The power supply converts the utility power supply voltage, such as 120 VAC or 125 VDC, to the signal-level voltage used by the processor and other modules.

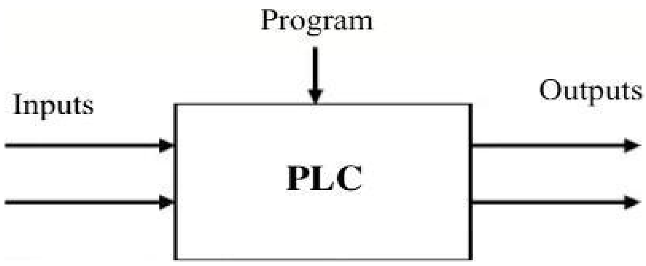
Processor The processor contains the microprocessor that performs control functions and calculations, as well as the memory required to store the program.

Input-Output: These modules provide the means to connect the processor to on-site devices. Communications: Communications modules are compatible with a wide range of industrial network connection standards. These allow the transfer of digital data between PLCs and to other systems. Some types of PLCs have integrated communications capabilities with the processor, rather than using separate modules.

Communications Media and Protocols: The most commonly used communications media are wired, coaxial, fiber optic, and radio. The most common open communication protocols are Ethernet, Ethernet/IP, and DeviceNet. "Open" systems generally provide "plug and play" devices in which the system software automatically recognizes and communicates with any compatible device connected to it. Other widely accepted open protocols are Modbus, Profibus, and ControlNet.

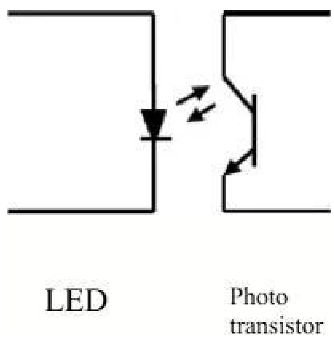
Redundancy: Many PLCs can be configured for redundancy, in which one processor acts as a mirror (bucket) of the others. This arrangement often requires the addition of a redundancy module, which provides status confirmation and control assertion between the processors.

A PLC is a microprocessor-based controller with multiple inputs and outputs. It uses a programmable memory to store instructions and carry out functions to control machines and processes,



FigII.3. Inputs and Outputs

The PLC inputs give it information about the machine or process that it is controlling. These are typically switches and sensors. The switches are connected to an input module that provides the interface between the switches or sensors and the PLC.

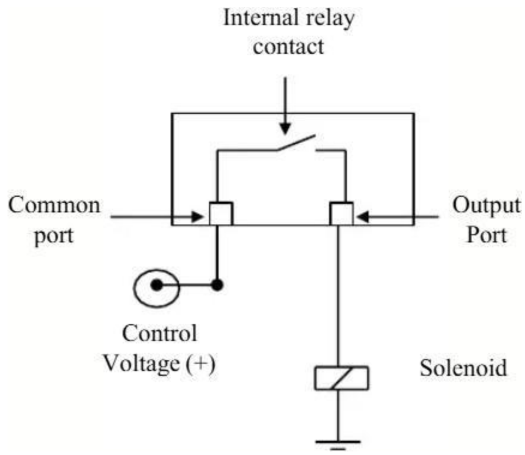


FigII.4. Input module circuits have opto-isolators to protect the internal PLC circuitry from damage.

The PLC outputs are connected directly or indirectly (e.g. through a relay) to actuator controls. Examples include solenoids on directional control valves, motors, motor contactors, alarms and warning lights.

There are three main types of output module:

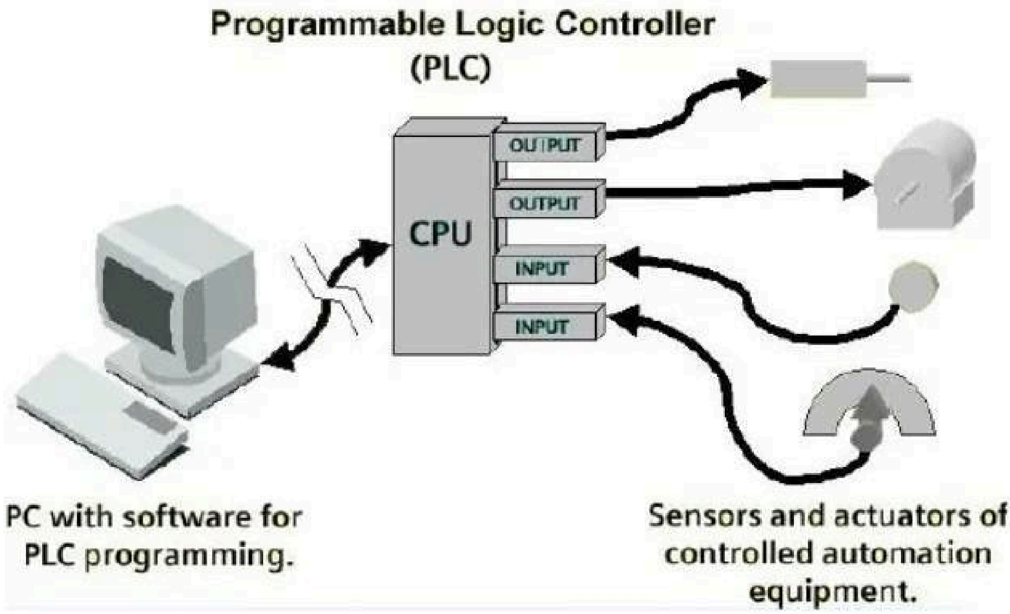
Relay (volt-free): The signal from the PLC operates a relay within the output module connecting the control voltage to the output port and hence to the actuator.



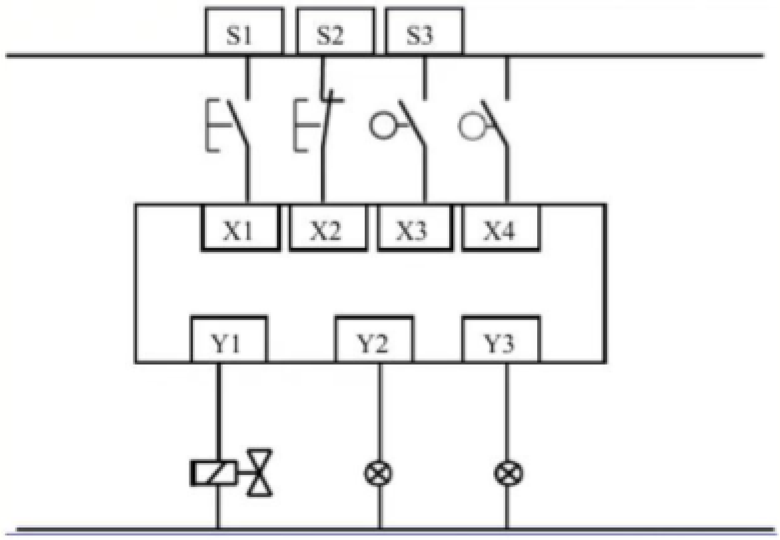
FigII.5. Relay (volt-free)

Transistor: A transistor is used to switch on the output. This is faster than a relay output but is only suitable for low power direct current applications.

Triac: This solid state device is used for switching alternating current devices. It requires some form of over current protection [8]



FigII.6. plc connections



FigII.7. plc wire diagrame

5_Network Protocols

The wiring diagram in Fig 1.5 shows the inputs and outputs connected directly (hard wired) to the PLC. The devices shown are on/off or digital in nature but the signal to the PLC is analog. Many commonly used devices conform to a 4-20 mA standard whereby signals of 4mA and 20mA form respectively the minimum and maximum values of an analog signal.

With analog devices, a separate cable needs to be run between the end device and the control system because only a single analog signal can be represented on the circuit. The 4-20 mA standard is slowly being replaced by network or fieldbus communications. Fieldbus is a multi-drop digital two-way communication link between intelligent devices. Fieldbus allows the connection of a number of sensors all located in the same area to the same cable, Fieldbus comes in many varieties depending on the manufacturer and application. Examples include ASibus, Profibus, Devicenet and Modbus.

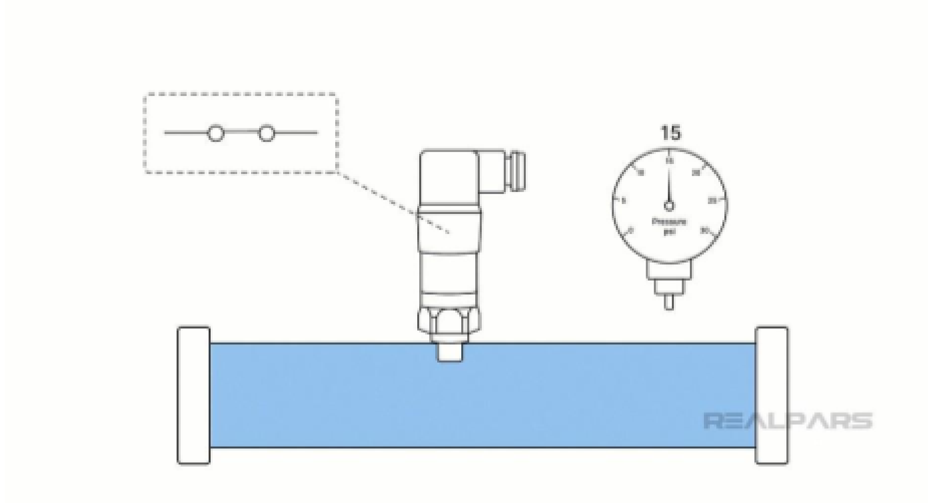
6_Digital signal

The digital part is easy. A digital signal has only two possible conditions: ON or OFF, YES or NO, UP or DOWN, ONE or ZERO.

Let’s look at a pressure switch, a digital field device that operates at a specific pressure of 15 psi.

This means the switch is OPEN at pressures below 15 psi and CLOSED at pressures above 15 psi.

We can connect this switch to a digital PLC input with a bit of simple wiring.



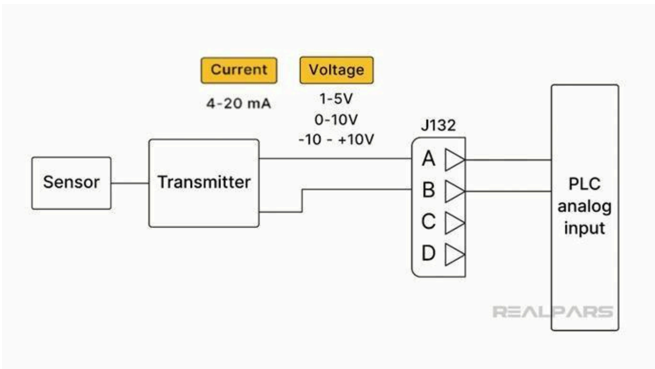
FigII.8. pressure switch

7_Analog input signals

At PLC voltage and current analog input signals and where they originate.

Typical voltage signals include 1 to 5 volts, 0 to 10 volts, and -10 to +10 volts.

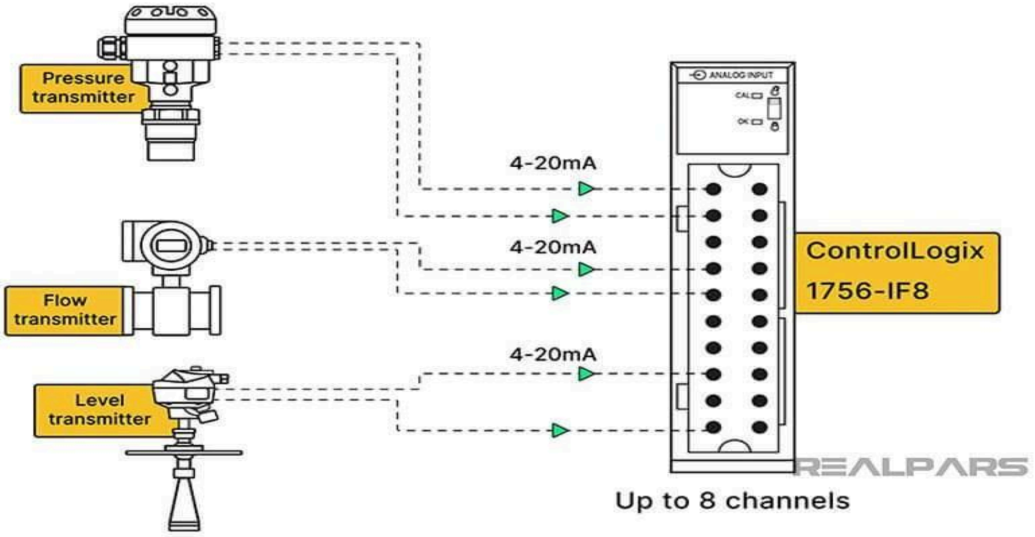
The most commonly used analog signal is a 4 to 20 mA current. [9]



FigII.9. Analog input signals

PLC analog input modules

We can also use the same analog input module for flow and level measurement! Why? Because the 4 to 20mA signal can represent any variable.



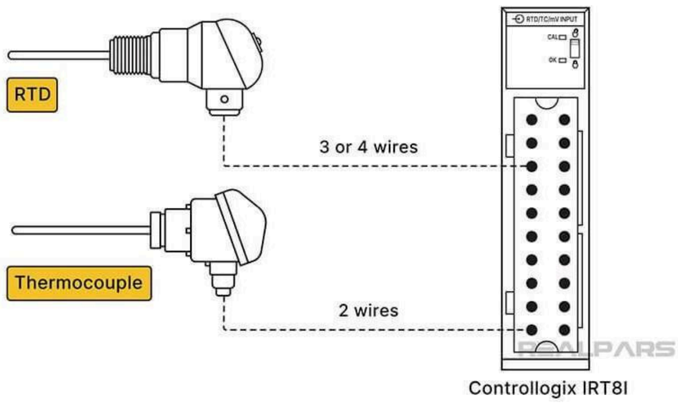
FigII.10. the Allen Bradley ControlLogix 1756-IF8 analog input module can connect up to 8 channels or input loops.

8_Direct sensor connections

Resistance Temperature Detectors (RTDs) or Thermocouples are used for most industrial temperature sensing. As illustrated earlier, temperature sensors can be connected to a transmitter, producing an analog signal of 4 to 20 mA, representing a temperature range.

RTDs and thermocouples

RTDs and thermocouples can be directly connected to a PLC analog input module such as the Allen Bradley Controllogix IRT8I eliminating the need for a transmitter. This type of connection has pros and cons.



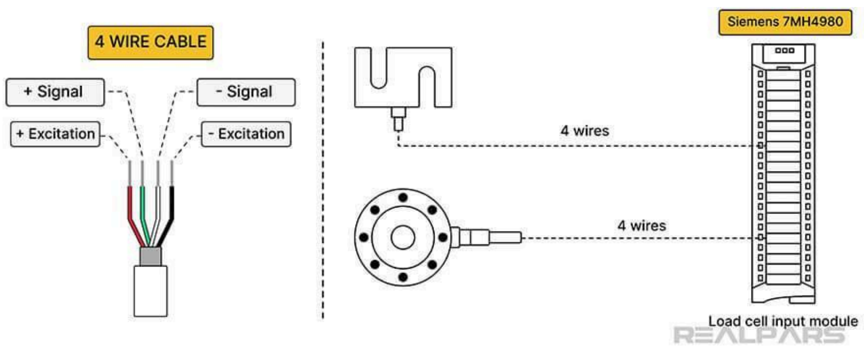
FigII.11. PLC analog input module with RTD

The RTD changes resistance with a temperature change, and a thermocouple produces a change in voltage with a temperature change. Issues with wire length between the RTD and the module and differing temperatures between the thermocouple sensing location and the module need attention.

Load cells and analog input module

Let’s discuss the Siemens 7MH4980, an analog input module connecting directly to a load cell. This type of module is often called a load cell input module.

Load cells come in different shapes and sizes depending upon their application. But, they all have at least four wires. Two wires are for excitation, and two are for the resulting signal.

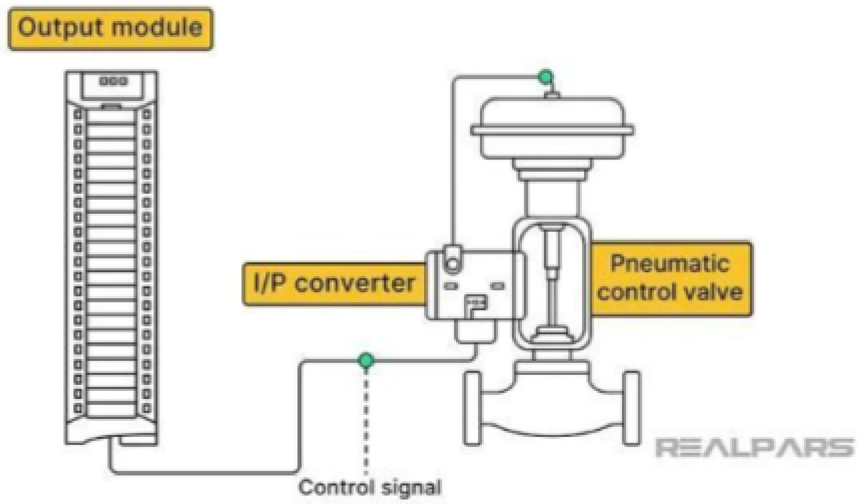


FigII.12. PLC analog input module with RTD

PLC analog output modules

Analog PLC Outputs control devices such as actuators, motors, and control valves. Usually, the module itself does not provide the drive for the controlling device, only the control signal.

Pneumatic valve is operated by a Current-to-Pressure Converter, or I/P converter that receives an analog control signal from a PLC output module.



FigII.13. pneumatic valve is operated by a Current-to-Pressure Converter, or I/P converter that receives an analog control signal from a PLC output module.

Just like on the input side of the PLC, typical output voltage signals include 1 to 5 volts, 0 to 10 volts, and -10 to +10 volts. The most commonly used analog output signal is a 4 to 20 mA current.

An example of a typical analog output module is the Allen-Bradley Controllogix 1756-OF8, which can control eight separate voltage or current devices.

9_Scada system

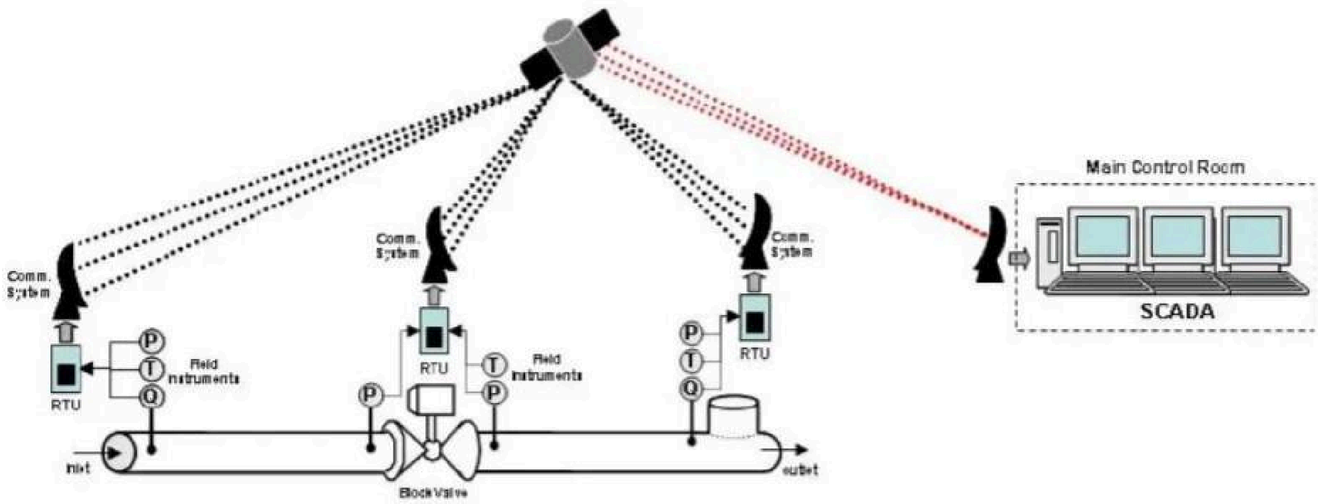
Supervisory control and data acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controllers and discrete PID controllers to interface to the process plant or machinery. The operator interfaces which enable monitoring and the issuing of process commands, such as controller set point changes, are handled through the SCADA supervisory computer system. However, the real-time control logic or controller calculations are performed by networked modules. which connect to the field sensors and actuators.

The SCADA concept was developed as a universal means of remote access to a variety of local control modules, which could be from different manufacturers allowing access through standard automation protocols. In practice, large SCADA systems have grown to become very similar to distributed control systems in function, but using multiple means of interfacing with the plant. They can control large-scale processes that can include multiple sites, and work over large distances. It is one of the most commonly-used types of industrial control systems, however there are concerns about SCADA systems being vulnerable to cyberwarfare/cyberterrorism attacks,

10_The SCADA System for pipelines.

The SCADA system at the Main Control Room receives all the field data and presents it to the pipeline operator through a set of screens or Human Machine Interface, showing the operational conditions of the pipeline. The operator can monitor the hydraulic conditions of the line, as well as send operational commands (open/close valves, turn on/off compressors or pumps, change setpoints, etc.) through the SCADA system to the field.[10]

To optimize and secure the operation of these assets, some pipeline companies are using what is called "Advanced Pipeline Applications", which are software tools installed on top of the SCADA system, that provide extended functionality to perform leak detection, leak location, batch tracking (liquid lines), pig tracking, composition tracking, predictive modeling, look ahead modeling, and operator training.



FigII.14. SCADA System for pipelines.

11_Functional levels of a manufacturing control operation

The key attribute of a SCADA system is its ability to perform a supervisory operation over a variety of other proprietary devices.

The accompanying diagram is a general model which shows functional manufacturing levels using computerised control.

Level 0 contains the field devices such as flow and temperature sensors, and final control elements, such as control valves.

Level I contains the industrialised input/output (1/0) modules, and their associated distributed electronic processors.

Level 2 contains the supervisory computers, which collate information from processor nodes on the system, and provide the operator control screens.

Level 3 is the production control level, which does not directly control the process, but is concerned with monitoring production and targets. Level 4 is the production scheduling level.

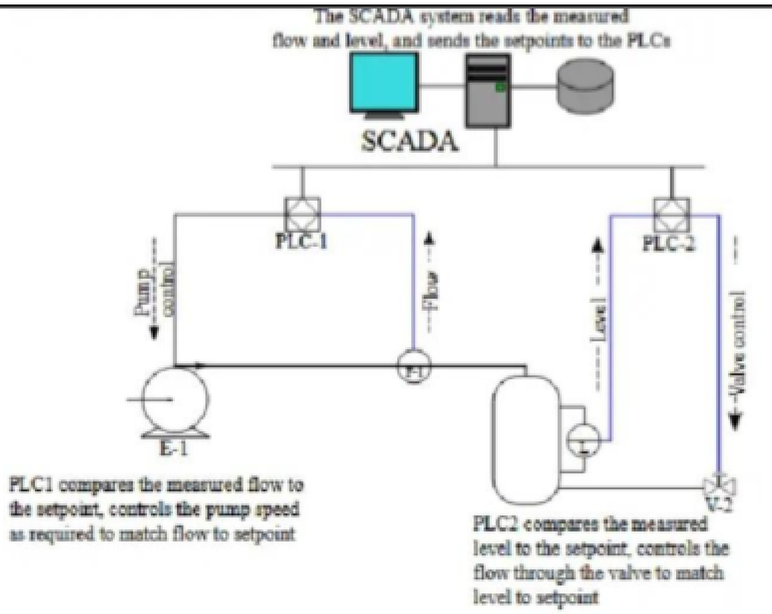
Level 1 contains the programmable logic controllers (PLCs) or remote terminal units (RTUs).

Level 2 contains the SCADA software and computing platform. The SCADA software exists only at this supervisory level as control actions are performed automatically by RTUs or PLCs. SCADA control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process to a set point level, but the SCADA system software will allow operators to change the set points for the flow. The SCADA also enables alarm conditions, such as loss of flow or high temperature, to be displayed and recorded. A feedback control loop is directly controlled by the RTU or PLC, but the SCADA software monitors the overall performance of the loop.

Levels 3 and 4 are not strictly process control in the traditional sense, but are where production control and scheduling takes place.

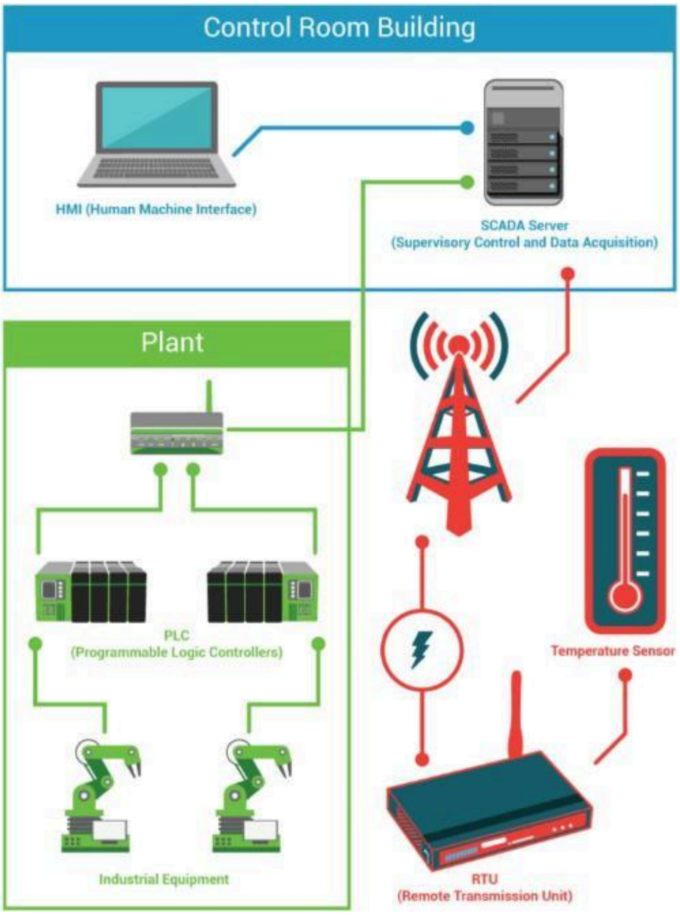
Data acquisition begins at the RTU or PLC level and includes instrumentation readings and equipment status reports that are communicated to level 2 SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI (Human Machine Interface) can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a historian, often built on a commodity database management system, to allow trending and other analytical auditing.

SCADA systems typically use a tog database, which contains data elements called tags or points, which relate to specific instrumentation or actuators within the process system according to such as the Piping and instrumentation diagram. Data is accumulated against these unique process control equipment tag references.



FigII.15. Schematic overview showing control level 0 and 1 and 2

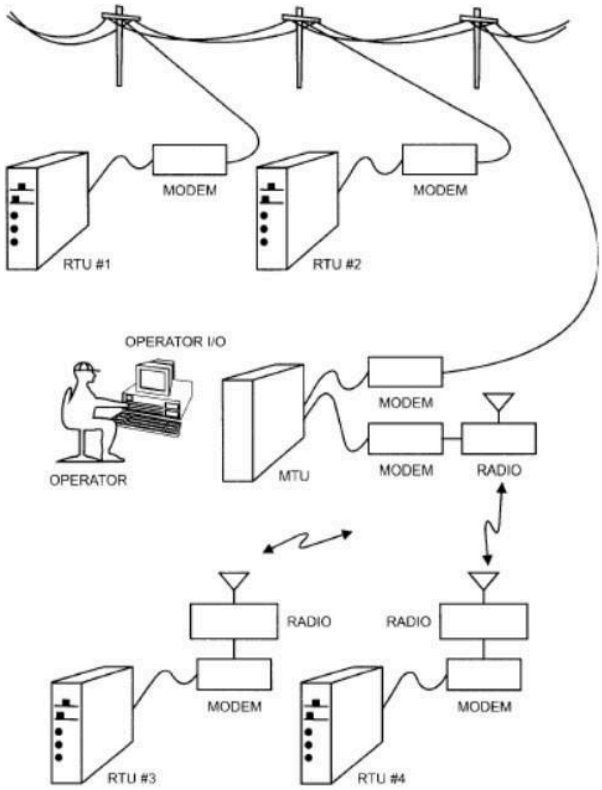
SCADA is a system for obtaining real-time data from both Remote Terminal Units (RTUs) or other communication sources in the field, so that network operators allow supervision of network operations and control of breaker equipment load from a distance (remote operation).[11]



FigII.16. scada system architecture

12_SCADA System working:

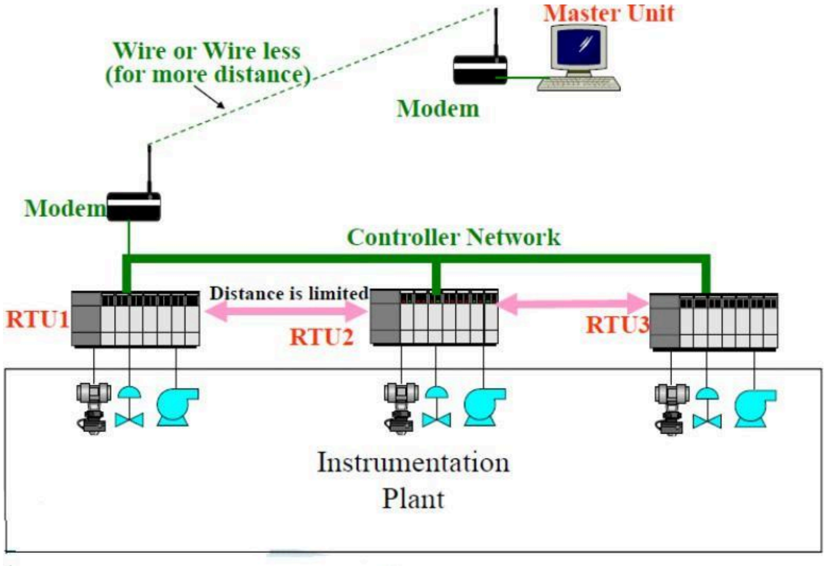
Most control actions are performed automatically by remote terminal units ("RTUs") or by programmable logic controllers ("PLCs").



FigII.17. RTU wire connection

PLC controls the industrial process, but the SCADA system can enable operators to change the setpoints and alarm conditions.

Data acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. [12]



FigII.18. RTU process

Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls.

In order to allow trend and other analytical auditing, data can also be supplied to a historian, often based on a commodity database management system.

13_HMI (Human Machine Interface)

Human Machine Interface is a computer equipment as a link between humans and the system, where the operator can directly monitor and command the elements that are in the electrical substations that enter the system scada.

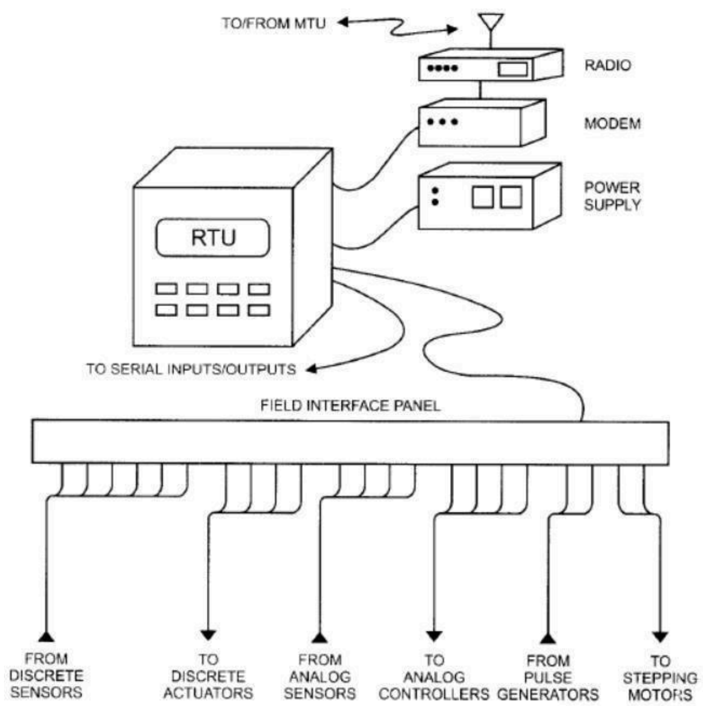
FigII.19. human interface machine

In addition it can also store data and system information in real time to be used as further analysis material. The functions of the HMI are as follows:

- View / monitor the condition of the distribution system.
- Enter or change data.
- Navigate between SCADA functions.
- Monitor and control the Distribution Network System equipment.
- Monitor and control the distribution network system configuration.

14_Remote Terminal Unit (RTU)

RTU is also referred to as Remote Station, which is a device placed in a substation in the form of a processor that functions as a receiver, processor and forwards information from the equipment being monitored and sends it to the master station or receives instructions from the master station.



FigII.20. RTU configuration

15_Conclusion:

The integration of PLC and SCADA in a chiller system represents a crucial step toward achieving intelligent and comprehensive control that ensures high efficiency, precise operation, and easy monitoring. While the PLC provides fast and reliable control of key variables such as flow, temperature, and pressure, the SCADA system offers an advanced supervisory interface for performance monitoring and remote fault diagnosis. This synergy not only enhances system reliability but also improves energy efficiency and reduces operational and maintenance costs.

Chapter III:

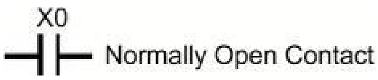
Chiller System Simulink by TIA Portal

1_Introduction:

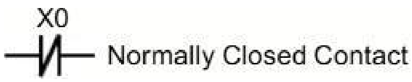
PLCs are special computers designed to operate in the industrial environment with wide ranges of ambient temperature and humidity. They have a number of different programming languages which include Ladder logic, Mnemonic instructions, and Sequential Function Charts. Ladder logic is the main programming method used for PLC's. It is a graphical language which has been developed to mimic relay logic. The decision to use the relay logic diagrams was a strategic one. By selecting ladder logic as the main programming method, the amount of retraining needed for engineers and tradespeople was greatly reduced.

2_Ladder logic and mnemonic programming

The instructions from a ladder diagram, mnemonic, or SFC are translated to machine code that can be stored in the PLC memory. Each horizontal rung on the ladder in a ladder program represents a line in the program and the entire ladder gives complete program in "ladder language". There are three basic symbols used in ladder logic.



The first one is NO NC contacts NO contact is an instruction that tells the processor to look at a specific bit in its RAM memory. If the bit is 1, the instruction is true, and if it is 0, the instruction is false. The determining factor in choosing which bits in its memory to look at is the address. It could be some auxiliary bit (M), a timer contact (T), a counter contact (C), a state bit (S), or it might be connected to an external input (X).

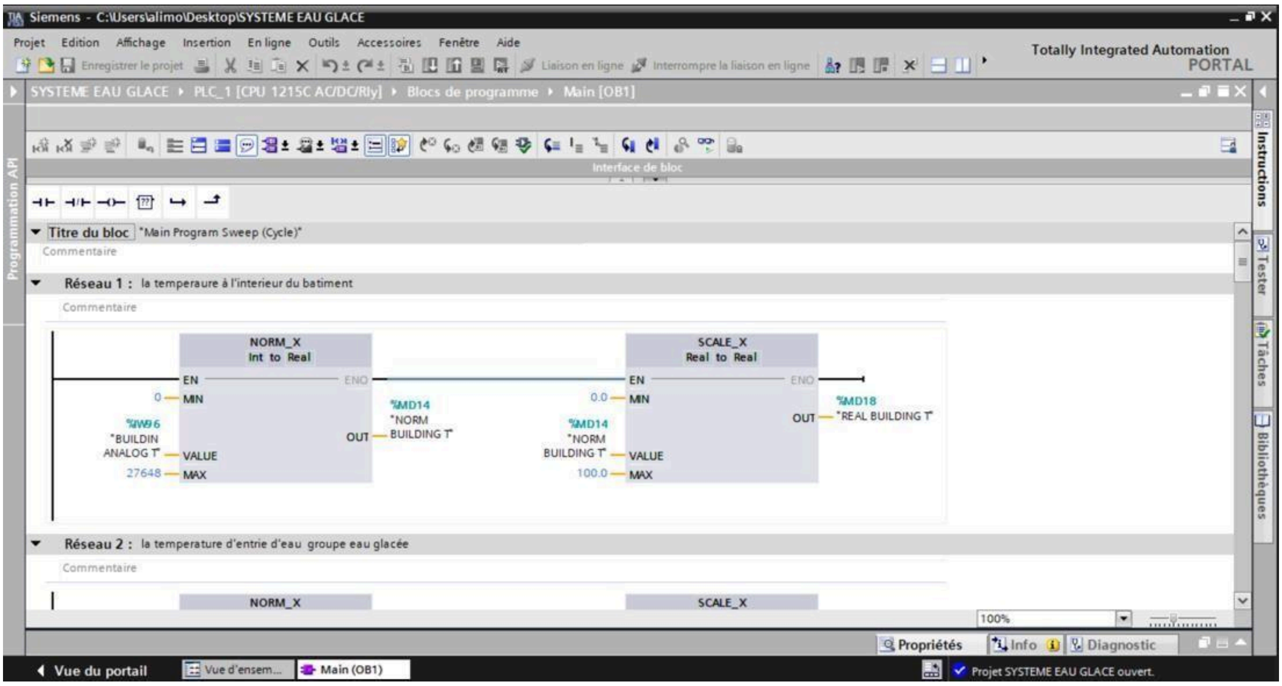


NC contact plays the same role as the previous one, except that if the bit addressed is 1. the instruction is false and if it is 0, the instruction is true.

The second symbol is output: for outputting to the output module. If the instructions to the left on its rung have a true path to the leftmost vertical rail, then the PLC will set the bit to which it is referenced via the address to 1. If no complete true path is available, it will set the bit to 0.

3_Simulation chilled water system

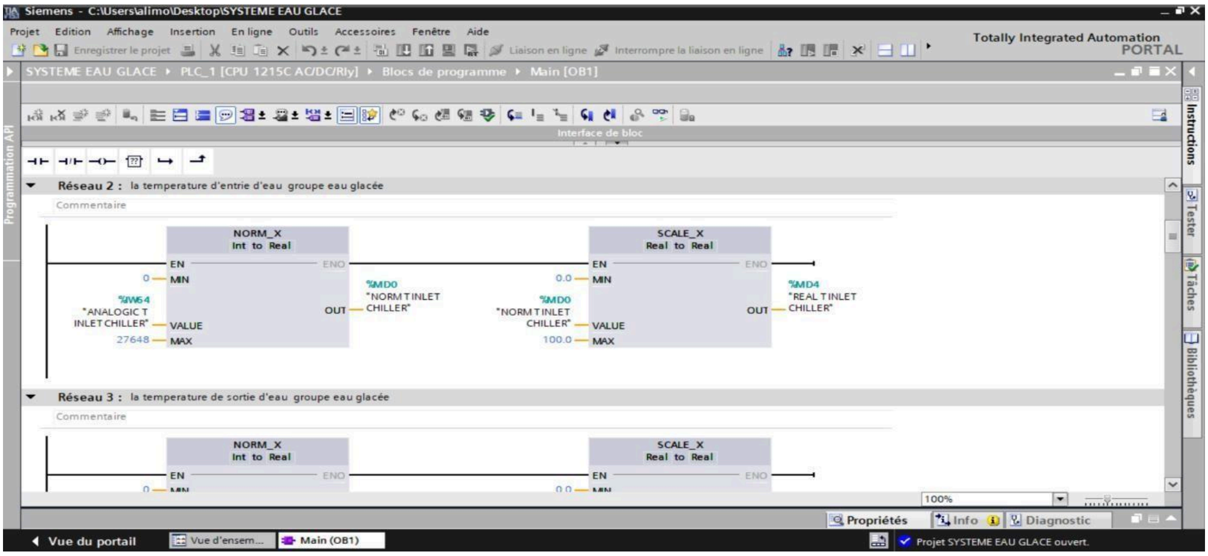
In this section, the various PLC-programmed networks that ensure safe operation and efficient control of a Chilled Water System are presented and analyzed. This software design aims to process signals from sensors, calculate basic temperature values, and then implement control logic associated with starting, stopping, and protecting equipment.



FigIII.1. Network 1: Measuring and Processing the Building Temperature

* Input `%IW96`: Analog signal from the temperature sensor (raw value).
* NORM_X block: Converts the raw value (0 → 27648) into a normalized range (0.0 → 1.0).
* SCALE_X block: Converts the normalized value into a real temperature (0.0 → 100.0 °C).
* Result: The actual building temperature is stored in %MD18 as "REAL BUILDING T", to be used later for monitoring or control.

In short: this network converts the sensor's electrical signal into a readable temperature in °C.

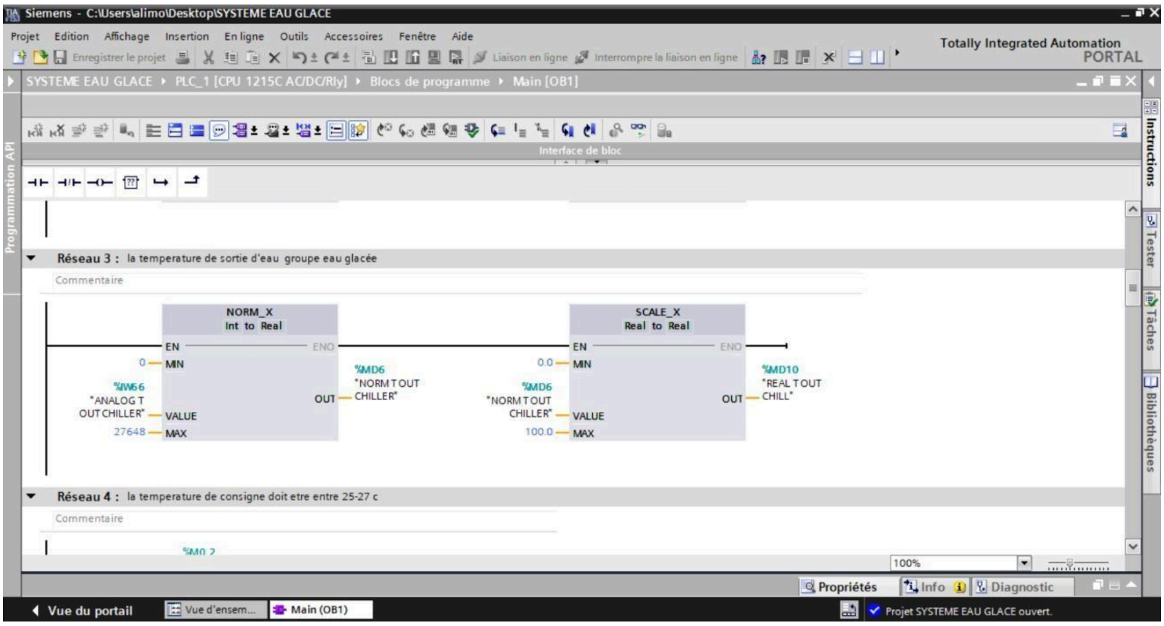


FigIII.2. Network 2: Chilled Water Inlet Temperature Reading

In this section, the analog input signal coming from the temperature sensor of the chilled water inlet is read. The block NORM_X performs a normalization: it converts the raw PLC value (0 to 27648) into a relative value (0.0 → 1.0).

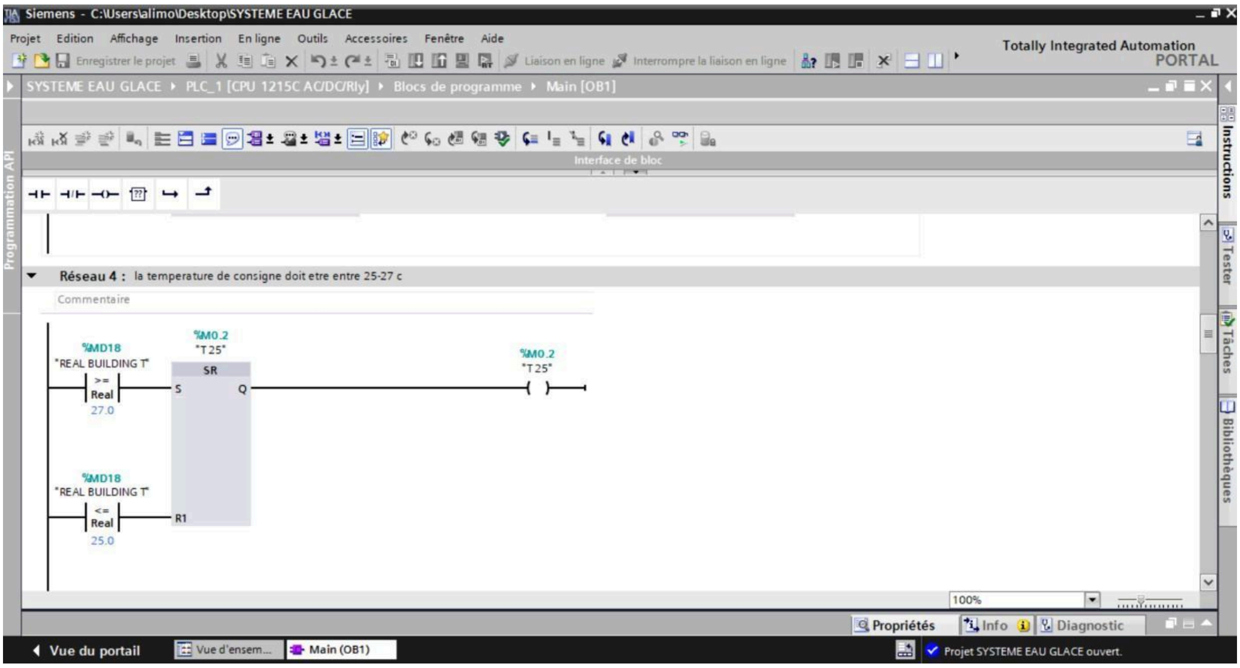
Then, the SCALE_X block transforms this normalized value into a real temperature value (°C) within the range 0.0 → 100.0.

The final result is stored in variable %MD4 under the name REAL T INLET CHILLER, which represents the actual inlet water temperature.



FigIII.3 Network 3: Chilled Water Outlet Temperature Reading

This network is very similar to the previous one, but here the focus is on reading the outlet water temperature of the chiller.again, NORM_X and SCALE_X are used to convert the analog signal into a real temperature value.The result is stored in another variable %MD8 named REAL T OUTLET CHILLER.The purpose of this network is to obtain precise inlet and outlet temperature values, which will later be used to calculate the temperature difference (ΔT).



FigIII.4. Network 4: Setpoint Temperature Control (25–27 °C)

This network controls the building temperature (REAL BUILDING T) so that it remains between 25°C and 27°C.

If the temperature rises above 27°C → the Set (S) output is activated, meaning that cooling is switched on.

If the temperature drops below 25°C → the Reset (R) output is triggered, which stops the cooling.

This method is called Hysteresis Control, and it prevents frequent on/off cycling of the chiller when the temperature is near the setpoint.

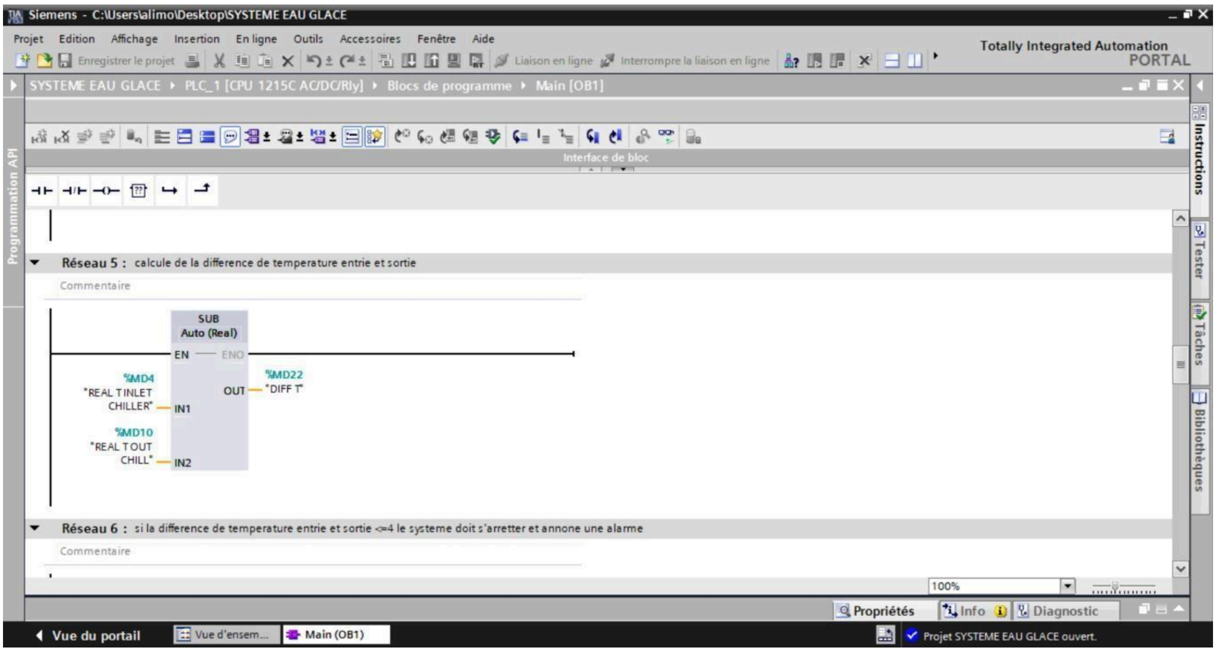


Fig III.5. Network 5: Calculating the Temperature Difference (Chiller Inlet/Outlet)

`%MD4`: Water temperature at the chiller inlet.

`%MD10`: Water temperature at the chiller outlet.

SUB (Real) block: Performs IN1 – IN2, i.e., (Inlet Temperature – Outlet Temperature).

Result: Stored in `%MD22` under the tag "DIFF T".

✦ In short: this network calculates the temperature difference to be used for monitoring and fault detection.

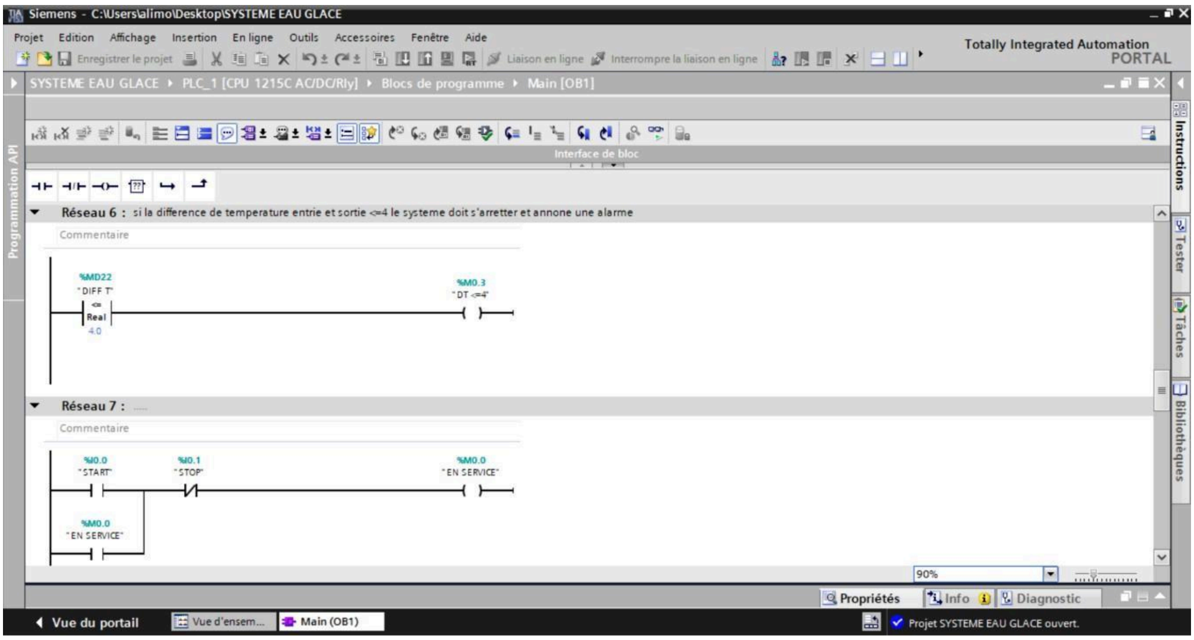


Fig III.6. Network 6 and 7: Start/Stop Command

This is the basic operating control network of the system.

When the START button (%I0.0) is pressed and the STOP button (%I0.1) is not active, the bit EN

SERVICE (%M0.0) is set.

Once “EN SERVICE” is activated, the system remains in operation until the STOP button is pressed. This logic is known as a Latch circuit (Start/Stop memory) and is widely used in industrial automation to safely start and stop equipment manually.

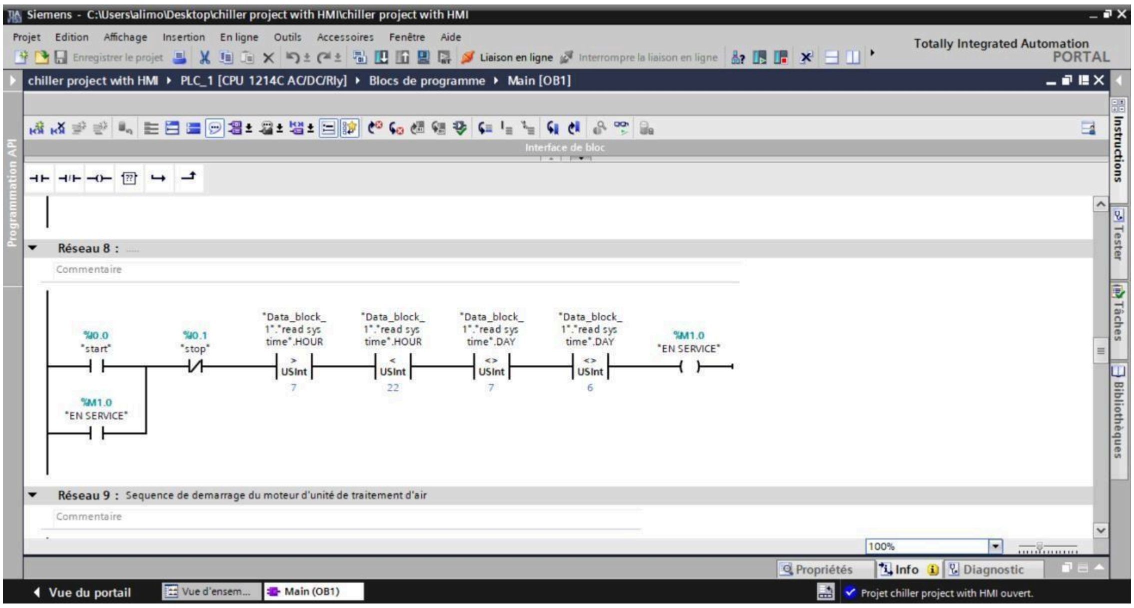


Fig III.7. Network 8

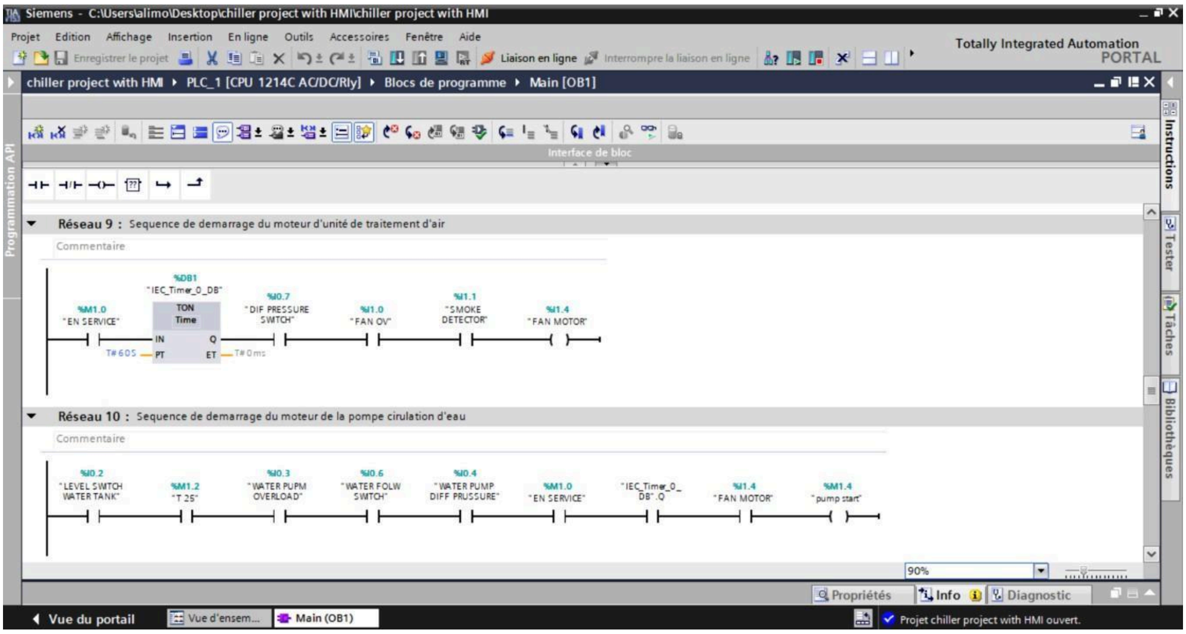


Fig III.8. Network 9: Air Handling Unit Fan Motor Start-up Sequence

Main condition: `%M0.0 "EN SERVICE"` = the system is in service mode.

Then, TON Timer waits 60 seconds before allowing the fan motor to start.

Additional safety conditions:

`%I0.7 "DIF PRESSURE SWITCH"`: differential pressure switch confirms airflow.

`%I1.1 "SMOKE DETECTOR"`: no smoke detected (safety condition).

If all conditions are met ⇒ output `%Q1.4 "FAN MOTOR"` is activated.

✦ In short: the AHU fan motor starts only after a 60-second delay and if all safety conditions are met.

Network 9: Water Circulation Pump Start-up Sequence

* Required conditions to start the pump:

1. `%I0.2 "LEVEL SWITCH WATER TANK"`: sufficient water level in the tank.
2. `%M0.2 "T ≥ 25°C"`: temperature higher than 25°C (cooling demand).
3. `%I0.3 "WATER PUMP OVERLOAD"`: no overload fault.
4. `%I0.6 "WATER FLOW SWITCH"`: water flow is present.
5. `%I0.4 "WATER PUMP DIFF PRESSURE"`: differential pressure is correct.
6. `%M0.0 "EN SERVICE"`: system in service mode.
7. Timer from Network 8 is active.

* If all conditions are satisfied ⇒ output `%M0.4 "pump start"` is activated, and the pump runs.

✦ In short: the circulation pump operates only if water is available, the temperature is high enough, the flow and pressure are correct, and no faults are detected.

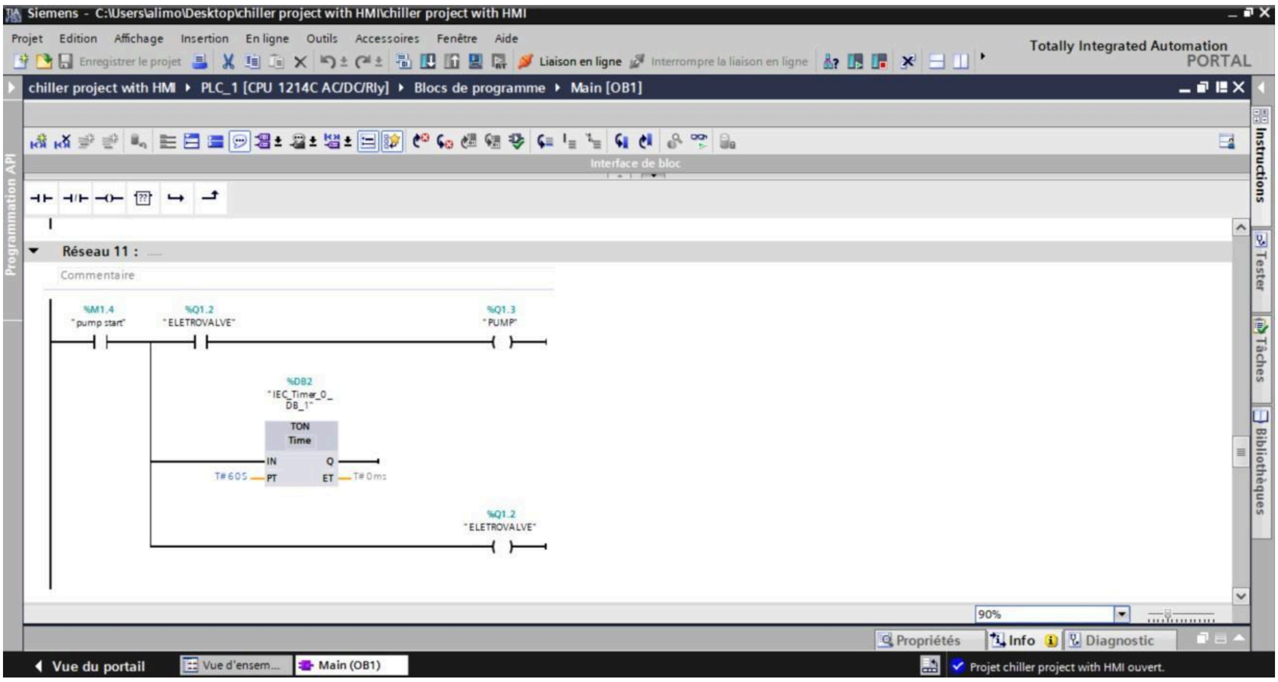


Fig III.9. Network 11 – Pump & Valve Start + 60s Timer

- Inputs:
  - `M0.4` → Pump Start (command to start the pump).
  - `Q1.2` → Electro valve (water valve).
- Operation:
  - When the pump start command is given, the pump (Q1.0) and electro valve (Q1.2) are activated.

  - o At the same time, a TON timer starts with PT = 60 seconds.
- Purpose:
  - o To ensure that water circulation is established for 60 seconds before the compressor is allowed to start.
  - o After 60s, the timer output (Q) will be used in the compressor start sequence (Network 11)

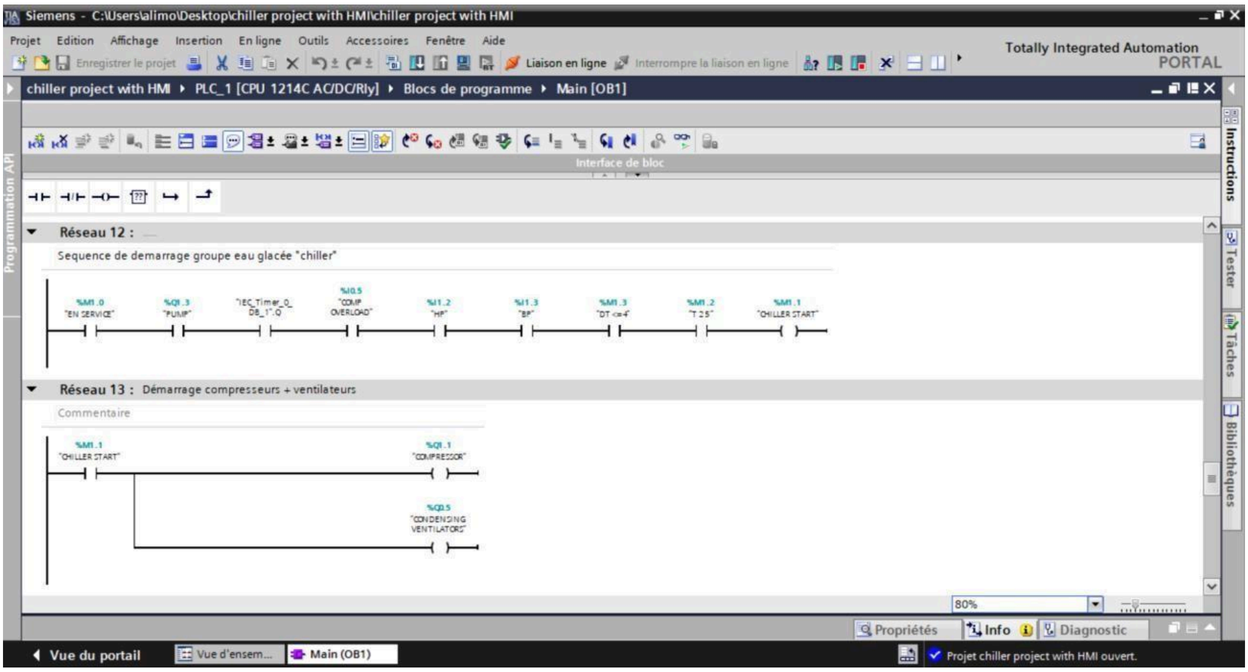


Fig III.10. Network 12.13 – Compressor Start Sequence (Chiller Start)

- Conditions required to start the chiller compressor:
  1. `M0.0` → En Service (system is in service).
  2. `Q1.0` → Pump running (confirmation that pump is on).
  3. **`IEC_Timer_0_DB1.Q` → Timer done (60s elapsed).**
  4. `I0.5` → Comp Overload (compressor overload protection – must be OK).
  5. `I1.2` → HP (high-pressure protection – must be OK).
  6. `I1.3` → BP (low-pressure protection – must be OK).
  7. `M0.3` → $\Delta T \leq 4$ (temperature difference condition – ensures cooling demand).
  8. `M0.2` → $T \geq 25°C$ (temperature above setpoint – requires cooling).
- Result:
  - o If all conditions are satisfied, coil `M0.1 = Chiller Start` is energized.

In short: Network 11 is the safety and logic check before running the compressor. It guarantees water flow, time delay, and ensures there are no faults (overload, high/low pressure) while there is a real demand for cooling.

Network 12 – Compressor Output

- Input:
  - o Contact `M0.1` (Chiller Start).
- Output:
  - o Coil `Q1.1 = Compressor`.
- Purpose:
  - o Once all conditions are met and `M0.1` is set, the compressor is energized.

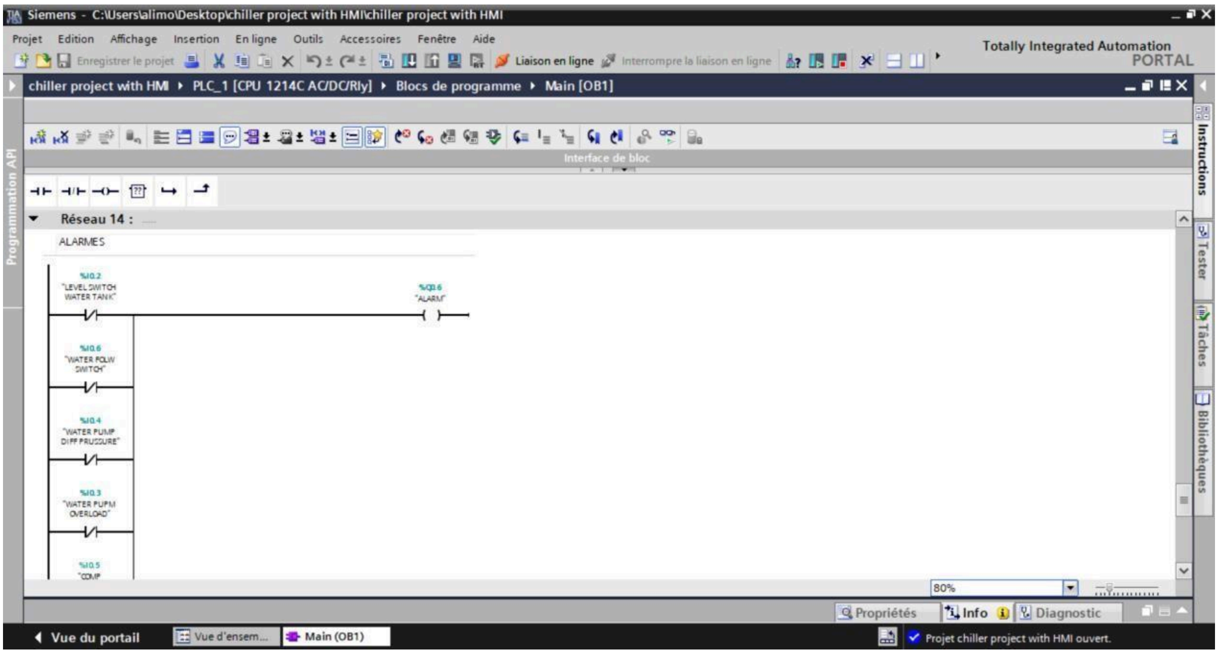


Fig III.11. Network 14 – Alarms

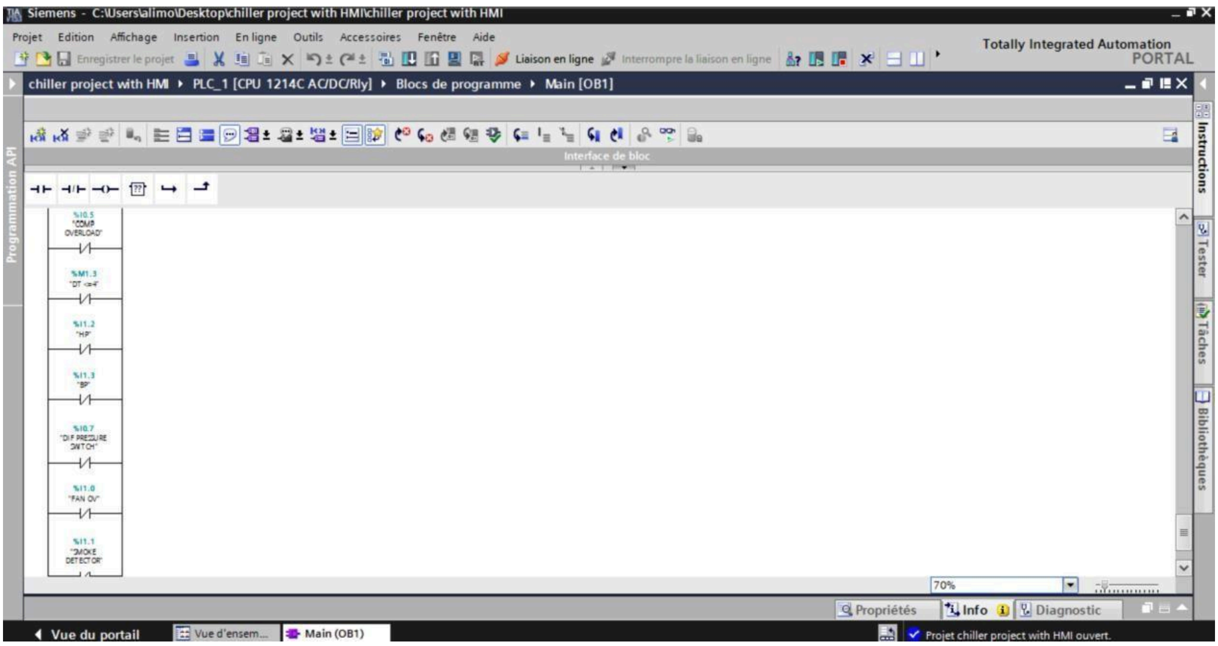


Fig III.12. Network 14.1 – Alarms

In this project, a customized HMI interface for a chiller system was designed and programmed with the objective of enhancing monitoring, control efficiency, and maintenance operations. The developed interface provides real-time visualization of key operational parameters such as temperatures, pressures, and flow rates, in addition to displaying the status of major components including the compressor, pumps, and heat exchangers. The HMI also integrates diagnostic functionalities that support faster decision-making, improve energy management, and reduce downtime.

This work is based on industrial control principles and was developed using the TIA Portal environment, following safety standards and usability guidelines. The result is a fully integrated HMI system that contributes to higher operational efficiency, improved reliability, and a smoother interaction between the operator and the chiller system in a realistic industrial environment.

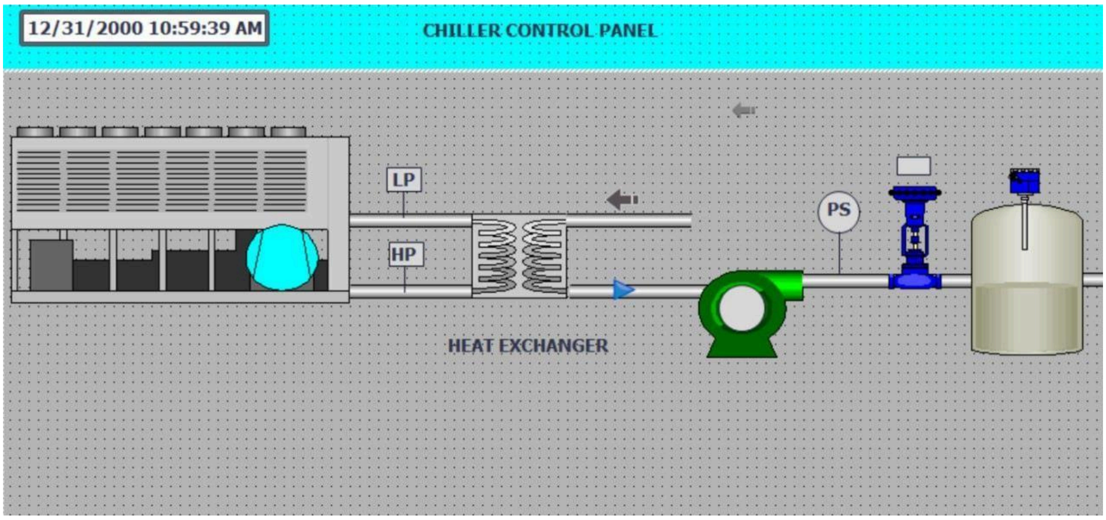


Fig III.13. chiller panel

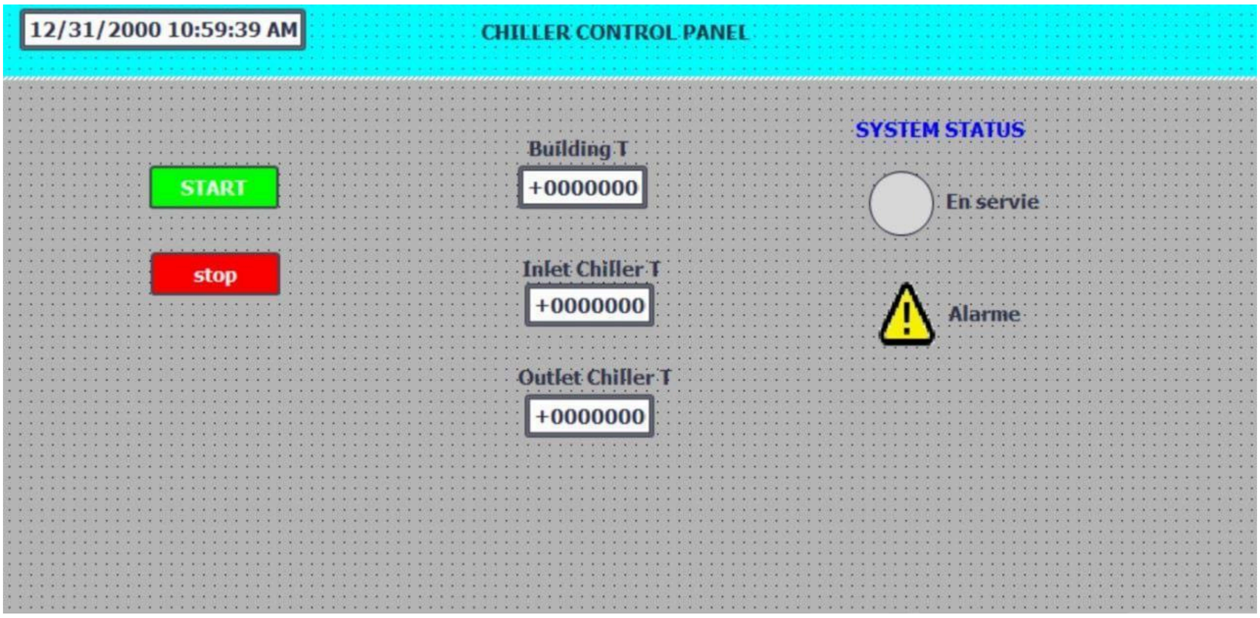


Fig III.14. chiller control panel

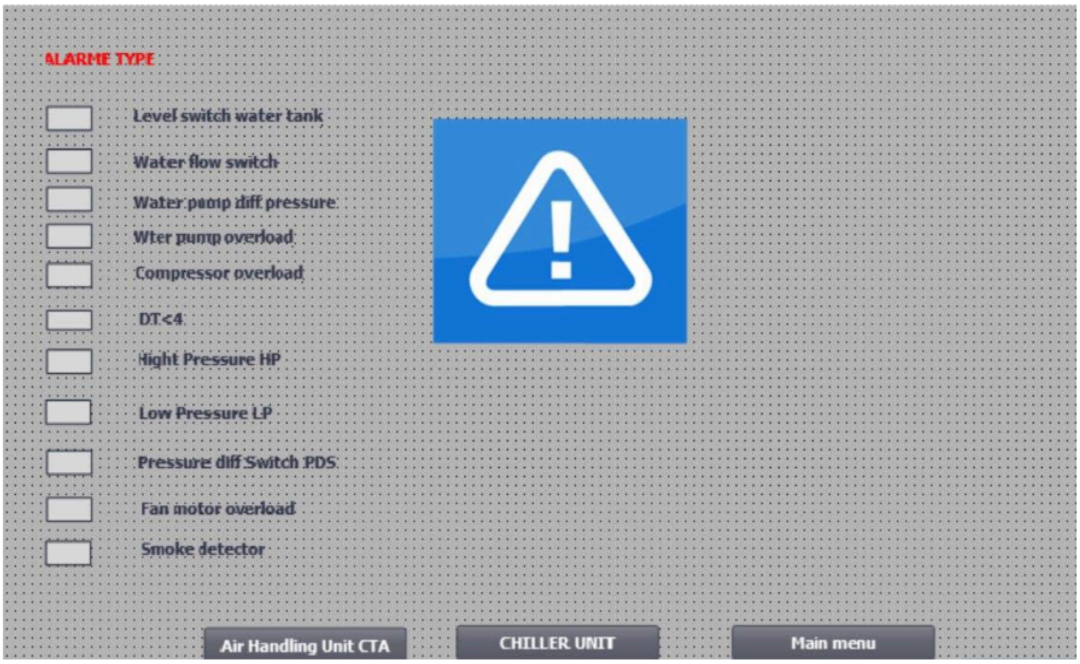


Fig III.15. Chiller alarms panel

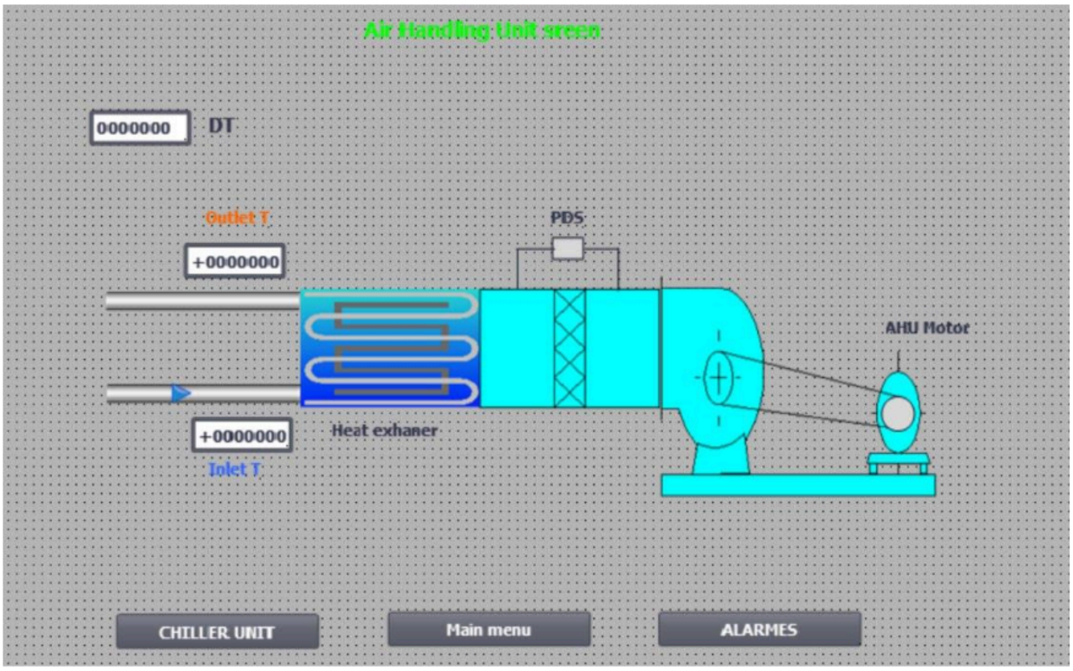


Fig III.16. Air handling unit panel

4_Conclusion:

This chapter has demonstrated that programming a chiller system using TIA Portal is a fundamental step to ensure precise and continuous control of its different components, such as compressors, pumps, valves, and sensors. The platform enables the development of an integrated control logic through PLC programming, as well as the design of HMI/SCADA interfaces for operation and monitoring, thereby enhancing both efficiency and reliability. Furthermore, the use of simulation within TIA Portal plays a crucial role in testing and validating the control program before real implementation, which minimizes errors and improves the overall performance of the chilled water system.

General Conclusion

General Conclusion

Through this dissertation, the chiller system has been comprehensively analyzed, starting from its fundamental principles to the practical aspects of programming. The study has shown that a chiller is not merely a cooling device, but rather an integrated system that requires a solid understanding of thermodynamics as well as a precise knowledge of modern industrial control methods. The results further revealed that the integration of PLC and SCADA technologies into chiller management provides significant opportunities for improving performance, minimizing breakdowns, and achieving energy savings, which ultimately enhances the reliability and sustainability of industrial operations.

On the practical side, the implementation of a chiller control model using TIA Portal has demonstrated the importance of automation in facilitating operation and supervision. This work provides a practical foundation that can be extended to the development of more advanced and complex systems in the future. Therefore, this dissertation not only contributes at an academic and theoretical level but also adds practical value by bridging the gap between refrigeration principles and industrial automation, offering a pathway toward smarter and more efficient control solutions in the industrial sector.

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