Tikrit Journal of Engineering Sciences (2022) 29 (3): 1-14
DOI: http://doi.org/10.25130/tjes.29.3.1

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

College of Engineering

TJES Tikrit Journal of Engineering Sciences

Design and implementation of Evaporative Cooler Automation system at Erbil/Perdawd Power Plant

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Keywords:

Embedded Automation System; Evaporative Cooler; PLC; SCADA; S7 APP

A R T I C L E I N F O

Article history:

Received	07 June 2022
Accepted	05 Aug. 2022
Available online	11 Aug. 2022

Citation: Ameen ASH, Sinjari AM. Design and implementation of Evaporative Cooler Automation system at Erbil/Perdawd Power Plant. Tikrit Journal of Engineering Sciences 2022; 29(3): 1- 14. http://doi.org/10.25130/tjes.29.3.1

A B S T R A C T

The Automation design and implementation of any industrial system are very complex pieces of technology. Many systems and components work simultaneously to fulfil a significant operation and control of the system process. The existing evaporative cooler system panel is based on the conventional relay system and has many drawbacks. It takes time and is difficult for people to reach; it could endanger human life and damage machinery. It operates entirely manually and has little to no remote capabilities. Any harm or failure to the electrical panel, the motors, or the instrumentation results in a system shutdown and a loss of power production without giving the control room any prior notice. An automated control system is the natural next step for such a system to eradicate these problems. The Proposal is to implement an automation system designed and implemented by using S7- 1215C Siemens CPU for controlling and WinCC RT advanced as HMI and SCADA approach for monitoring. The programming software is Totally integrated Automation (TIA) Portal V15 software and is used for monitoring the configuration file. Programming style is the ladder while web-server capabilities are initialized for using the wireless protocol with mobile device App S7 for operating and monitoring the system. This paper proposed an innovative automation design and implementation for the gas turbine evaporative cooler system at Erbil/Perdawd combined cycle power plant. The experimental results show that the proposed embedded automation control system is very flexible and simple for controlling and monitoring the evaporative cooler.

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تصميم وتنفيذ نظام التشغيل الآلي للمبرد التبخيري في محطة توليد كهرباء أربيل / بيرداود

اسعد صابر حمد امين ، احمد محمد سناجري قسم الهندسة الكهربائية / كلية الهندسة / جامعة صلاح الدين / أربيل - العراق.

الخلاصة

يعد تصميم وتنفيذ الأتمتة لأي نظام صناعي من القطع التكنولوجية المعقدة للغاية. تعمل العديد من الأنظمة والمكونات في وقت واحد لتحقيق عملية كبيرة والتحكم في عملية النظام. تعتمد لوحة نظام المبرد التبخيري الحالية على نظام الترحيل التقليدي ولها العديد من العيوب. يستغرق الأمر وقتًا ويصعب على الناس الوصول إليه؛ يمكن أن يعرض حياة الإنسان للخطر ويتلف الآلات. إنه يعمل يدويًا بالكامل ولديه قدرات قليلة أو معدومة عن بُعد. يؤدي أي ضرر، أو عطل باللوحة الكهربائية، أو المحركات، أو الأجهزة إلى إيقاف تشغيل النظام وفقدان إنتاج الطاقة دون إعطاء غرفة التحكم أي إشعار مسبق. نظام التحكم الآلي هو الخطوة الطبيعية التالية لمثل هذا النظام للقضاء على هذه المشاكل. يتمثل الاقتراح في تنفيذ نظام أتمتة تم تصميمه وتنفيذه باستخدام S7- 1215C Siemens CPU للتحكم و WinCC RT المتقدم كنهج HMI و SCADA للمراقبة. برنامج البرمجة هو برنامج Portal V15 متكامل تمامًا للأتمتة (TIA) ويستخدم لمراقبة ملف التكوين. أسلوب البرمجة هو السلم بينما يتم تهيئة إمكانيات خادم الويب لاستخدام البروتوكول اللاسلكي مع تطبيق الجهاز المحمول S7 لتشغيل النظام ومراقبته. اقترحت هذه الورقة تصميمًا آليًا مبتكرًا وتنفيذًا لنظام التبريد التبخيري للتوربينات الغازية في محطة توليد الكهرباء ذات الدورة المركبة في أربيل / بيرداود. أظهرت النتائج التجريبية أن نظام التحكم الآلي المدمج المقترح مرن للغاية وبسيط للتحكم في المبرد التبخيري ومراقبته.

الكلمات الدالة: نظام الأتمتة المدمج، المبرد التبخيري، PLC و SCADA، S7 APP .

1. INTRODUCTION

Due to the rise in power demand and technological advancement, there have been more requests in recent years from the industrial sector and power plants to enhance power quality, efficiency, automation operation, and protective devices. Remote monitoring and control of industrial systems have grown more important. It is used to correctly and forcefully eliminate threats to human life. An embedded automation system is a system that consists of software embedded in hardware. It can be programmable or non-programmable, depending on the application which need. The important features of embedded automation systems are speed, size, power, reliability, accuracy, and adaptability [1]. The gas turbine is one of the turbines used to generate power. Gas fuel is utilized as the combustion fuel. It is made up of a lot of main components and supporting systems. A gas turbine has a filter house air intake system, an axial air compressor, a combustion chamber, a turbine, an exhaust system, and a generator. The air inlet filter system, which is used to feed the gas turbine with the filtered and cleaned airflow and to reduce the compressor air inlet acoustical level, is one of the essential parts of the gas turbine [2]. The turbine efficiency and power output decrease during high ambient temperatures. The air volume that moves through the compressor is the same at the constant speed, but the mass flow will change. The temperature and air density are opposite of each other [3]. Because hot air has less density on hot days, there is less mass flow, which results in lower gas turbine power production. However, on cold days, there is a greater mass flow and more density in the air, which improves efficiency and production. Increasing one °C of air inlet temperature causes to decrease of 1% in power output [4]. Different techniques are devised to overcome the effect of the weather change on turbine power output and increase the turbine performance and power output during the hot air season. The evaporative cooler techniques were developed to directly cool the air inlet to the gas turbine engine [5]. The Evaporative cooler panel is currently installed and designed based on a traditional relay system; the board is installed in a high location, requiring the operator to climb the escape ladder higher than 10 meters. The current design has no communication between the evaporative cooler system and gas turbine parameters such as MW, IGV, and inlet ambient temperature. The automation system design and implementation are required to overcome the above issues. Industrial system automation and control are done using the FATEK PLC and LabVIEW software instead of the SCADA system; the embedded control and monitoring system are implemented with the lower-cost PLC and SCADA system [6]. The metro station's automation control was designed using PLC and SCADA to decrease system errors, avoid human life and material damage and increase transportation speed. Furthermore, it has improved the network flexibility and traffic control change due to traffic variation change [7]. The TIA PORTAL and SIEMENS S7-1200 CPU 1214C are used in designing and implementing the Yaw control system in wind generation [8], the syrup production line [9] and the ethanol rectification process [10]. The authors for [11] proposed implementing an automation system for a shell and tube heat exchanger, and they used PLC, SCADA, OPC and LabVIEW. PID method on

Allen Bradley MicroLogix 1200C PLC and RSView-32 and LabVIEW for SCADA is used. The PLC and SCADA are used for the automation system of smart farming and automatic toll monitoring system [12, 13]. In [14], the control system for the windscreen washer filling machine using Allen Bradley PLC and LabVIEW software is proposed as a SCADA system. A computerized system for continuously monitoring important parameters in the transformer such as current, voltage, distribution transformer winding temperature, energy, the oil level in the tank, load shedding, Energy consumption, and loss detection in the distribution system. The PLC and the SCADA system measure and send all mentioned parameters to the responsible engineer. The alarm goes to the assigned mobile link during any power loss abnormality [15]. All issues related to controlling and monitoring the evaporative cooler system in the proposed automation system are fixed. The system will be operated and monitored from the control room via the SCADA system. However, it can be monitored and operated through smart devices anywhere in the area. And the system will be controlled via PLC to prevent unwanted outcomes.

2.OVERVIEW OF EVAPORATIVE COOLER SYSTEM

The Evaporative cooler system is a new system installed on the gas turbine air inlet system in Erbil/Perdawd combined cycle power plant. It evaporates the air inlet to the compressor and combustion area. The advantage of this system is to improve efficiency and increase the gas turbine power output. The evaporative cooling system is contained four-level switches to control the water tank level. Two conductivity meters to control and monitor the water quality to protect the mechanical parts from damage due to inadequate water quality. Both functions are controlled through the current relay panel system by opening and closing the inlet filling solenoid valve and a bleed-off solenoid valve, as illustrated in Fig. 1.

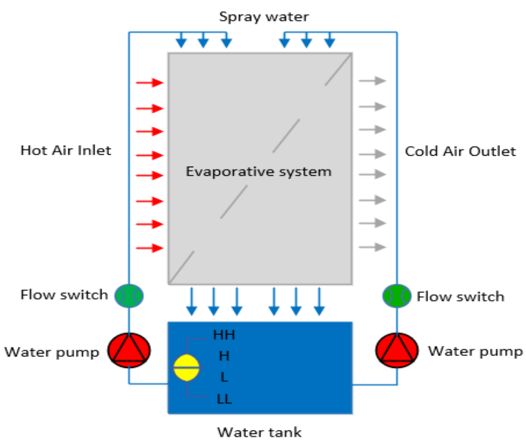


Fig. 1. Evaporative cooler system.

On the existing control panel, several LEDs indicate the status of the system components such as level, conductivity high, abnormal flow alarms, system and water pump 1&2 status...etc. Furthermore, some digital and analogue measurements include conductivity, dewpoint, and relative humidity. There is a selector switch for selecting manual or remote operation of the system and a selector for selecting pump 1 or 2. Also, there are pushbutton-type switches for reset faults and lamp tests. The biggest problem in The Evaporative cooler panel is designed based on a traditional relay system. The panel is installed in a high location, requiring the operator to climb the escape ladder higher than 10 meters. The current design has no communication between the evaporative cooler system and gas turbine parameters such as MW, IGV, and inlet ambient temperature. System operation is entirely manual and depends on human action, and it's the system highly prone to human error. Any failure in the system equipment can't be monitored. Water quality can't be monitored, and it may cause significant turbine parts damage, such as corrosion in the air compressor and combustion zones. Henceforth, the embedded automation control system for evaporative cooler system is accomplished by designing and implementing the monitoring and controlling system based on PLC and SCADA systems. In the first step, the PLC programming is proposed. TIA Portal software is used to program the ladder logic and network system for PLC and downloaded to the CPU. For SCADA and HMI monitoring systems, the WinCC Runtime Advanced software was used to design the graphic interface system and proposed all components for an evaporative cooler in one graphic for easy monitoring and controlling system. The wireless remote monitoring system is also provided using the S7 APP mobile application, which works on iOS and Android. This proposed design helps the operator to understand quickly and monitor all systems. The start and stop pushbuttons on the proposed graphic operate the system by clicking the pushbutton. Also, an alarm page shows all active alarms for digital and analogue signals that facilitate the controlling of an evaporative cooler and cause to reduce human interaction and error space in the operating system.

3.EVAPORATIVE COOLER SYSTEM OPERATION SEQUENCE

The operation sequence of the evaporative cooler system is explained in the below flow chart Fig. 2. The system logic is designed according to the flow chart sequence of events and conditions mentioned in the flow chart. The flow chart represents the automatic and manual control operation for the operation status and sequences, startup operation, reset faults, check the status, and monitor the operation sequence.

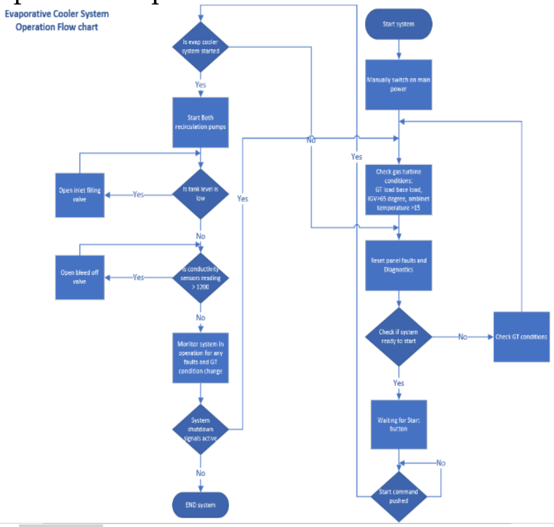


Fig. 2. evaporative cooler system operation sequence flow chart

Initially, before powering up the evaporative cooler system panel, the operator should check the system for any identified issues or wrong status. Also, optionally can check the previous data log to see if there are any outstanding faults to be rectified. After that operator should energize the main power switch manually to provide the system AC power, some conditions should be in an 'OK' state to give startup permission to the system: GT load status should be baseload, IGV angle should be more than 65 degrees, and ambient air temperature should be more than 10 °C. If any error or faults become active or are shown on the system or any of the above conditions are not ok, it shows on the HMI, the operator should reset faults manually or on the proposed HMI system, and for the above GT, condition it should satisfy the condition after that try to start system. The system will be ready to start when all conditions permit and there are no faults or errors. If the system is not ready to start, the operator should re-check all GT conditions and reset the faults on the system, and action must be repeated until the system is ready to start. After that, the operator will start the system by selecting the 'start' push button or clicking on the start button on the proposed SCADA system. The system will start it is sequence; however, the above conditions should be repeated if it's not started. If the evaporative cooler system is started, both water recirculation pumps will recirculate water and spray it on the media. The pump is protected by two water flow switches, which trip the pump if it detects low flow in the line. If the low level is active during system operation, the inlet filling valve will be active and fill the water tank. It's continuously open till the high-high level alarm is active. If the conductivity reaches a high alarm (more than 1200 µS/cm), the bleed-off valve will open to drain the water in the tank and fill the tank with the new low conductivity water. The system will continue operating until one GT condition changes to 'Not Ok'. It would mean that once the deactivation condition activates, such as if GT is out of baseload, if the IGV is less than 65 degrees or if the ambient temperature reaches lower than 10 °C degrees. And also, if any of the below faults are active, the system will shut down. These include conductivity reaching more than 5000 µS/cm, low tank level alarm active, and abnormal water flow. During occurring above abnormal conditions and faults operator should check the cause of the fault and restart the system to operation after clearing faults.

4.PROPOSED EMBEDDED AUTOMATION SYSTEM FOR EVAPORATIVE COOLER

The proposed design of the evaporative cooler automation embedded control system is in hardware and software form. The detail of the proposed hardware system is demonstrated below Fig. 3. The proposed design ensures a real-time monitoring and controlling system for the air inlet gas turbine system's evaporative cooler system. The evaporative cooler automation embedded control system consists of several components: the power supply, which provides a DC voltage to all other components. CPU as a controller for the processing system and AI for monitoring and controlling analogue data. HMI Wincc monitors and operates the system, and the WIFI Router, internet, and mobile S7 APP use wireless remote configuration monitoring and control system.

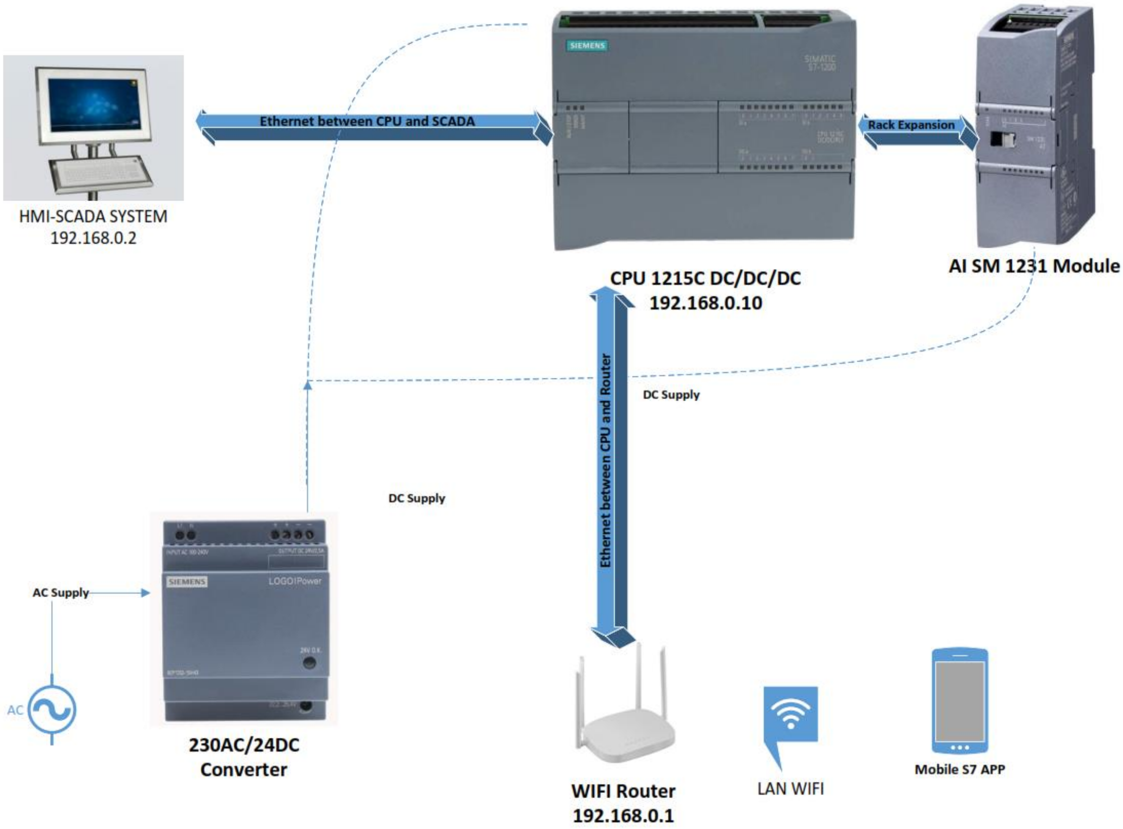


Fig. 3. Proposed control system hardware topology

4.1 CPU 1215C

The S7-1200 Controller is afforded the flexibility and influence to control widespread devices in the automation system. It has flexibility in the configuration and powerful instructions. The S7-1200 is the best solution for controlling a wide range of applications. The CPU is combined from all required components, making it a powerful controller such as a microprocessor, power supply, I/O Circuit, compact PROFINET, and ethernet port to communicate with the computer and HMI. The CPU module used in the proposed design for controlling and monitoring the evaporative cooler system is CPU 1215C DC/DC/DC. It is a compact CPU, DC/DC/DC (power supply voltage/input voltage/output voltage). It consists of 14x DI at 24V DC; 10 DO at 24V DC; 0.5A. The Inputs are a quantity of 2 AI 0-10 V DC and 2 AO 0-20 mA. These Capabilities are sufficient for this application Fig. 4.

Fig. 4. hardware system

4.2 Analog input module

In addition to the CPU, analogue inputs are more than the desired CPU analogue inputs because of the evaporative cooler system. The CPU has two analogue inputs, but the evaporative cooler has 6 analogue inputs. The CPU expanded by adding the analogue inputs to the control system. the analogue input that used in the proposed work is AI SM1231 with part number 6ES7231-4HF32-0XB0. It has 8 AI.

4.3 Scada system

The proposed SCADA (Supervisory Control and Data Acquisition) or called HMI (Human Machine Interface) for the evaporative cooling system, is the WinCC RT Advanced, it is computer-based software which is installed with the TIA Portal Software. In the WinCC, RT Advanced can design the graphical HMI to operate the machine Fig. 5. It can display the sequence of events, alarms, trends, measurement readings, and device status. Furthermore, it can show process events to be acknowledged by the operator, logging measured values and alarms, and showing the current data processing. And the manager of users and their capability access.

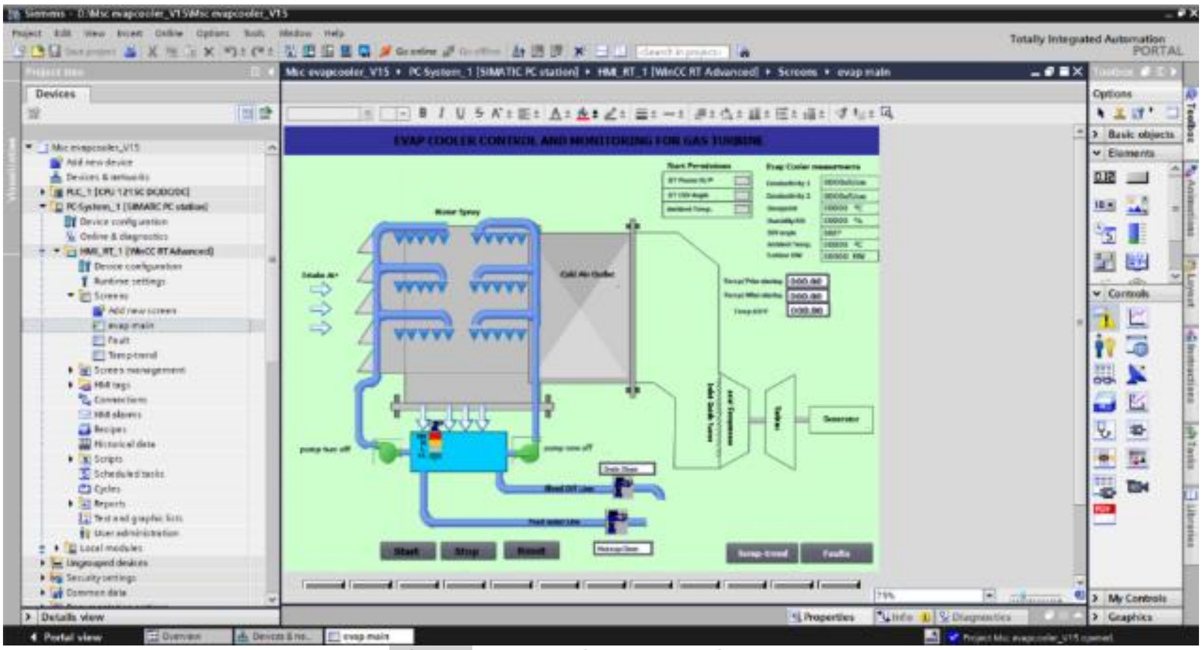


Fig. 5. Proposed main graphic page

4.4 Simatic tia portal

The Simatic TIA Portal is the Integrated Automation Portal used to program and configure the PLC control system components. It's prepared to complete the entire designed process with the capability of programming CPU and I/O, communication module, and SCADA-HMI. A representative automation system includes A PLC used to control the process and an HMI device used to operate and visualize the process [16]. There are several advantages to using TIA PORTAL, such as easy use, configuration and visualization of data, easy operation and loading of data, and easy editing of HMI pages and programming concepts.

4.5 Remote wireless network

It consists of two main parts, which are hardware and software:

4.5.1 wireless network router

The wireless network router transforms the wired network from the CPU to the wireless network. After setup, the required configuration on the CPU regarding webserver accessibility of the wireless router should be initialized. This will require the CPU to be connected to the device via ethernet cable. Then the computer or mobile device will connect to the router through a cable or wireless network to configure the router settings. In the proposed controlling and monitoring system for the evaporative cooler system, the Tp-link 300Mbps wireless N router is used [17].

4.5.2 simatic s7 mobile device application

S7 APP is a specific mobile application that works with IOS and Android operating systems. It's used to support the user to connect the mobile smart devices to the S7-1200 or other siemens products through the wireless local area network. This application allows users to connect to the s7-1200 system, adjust the parameters within the control pages, and monitor equipment such as analogue or digital devices. The tags can add to the variable list to monitor; the total number of tags is limited to 50 tags. Furthermore, the users can change CPU operating mode, read diagnostics, and view elements in the trend [18].

5. EXPERIMENTAL RESULTS

The implementation for the proposed design consists of:

5.1 Hardware implementation

The hardware implementation includes all hardware systems for the proposed system, such as PLC, SCADA, and S7 APP. The central part for controlling an evaporative cooler system is a PLC, which works as the heart of the control system. It consists of a power supply, CPU, and one analogue input extension Fig. 6.

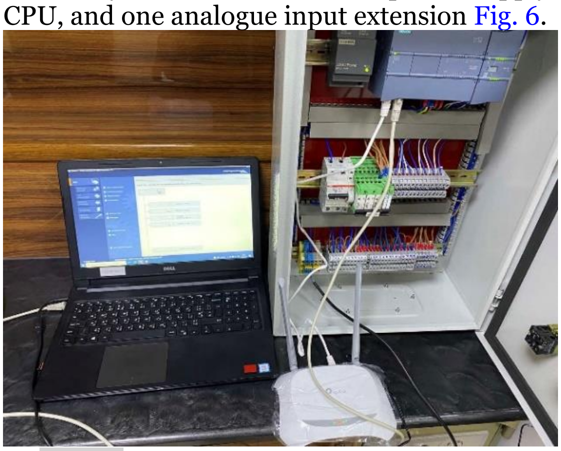


Fig. 6. complete system implementation

CPU input/output signal mapping and wiring diagram represented in Fig.7, it shows the electrical wiring diagram for evaporative cooler system design, the inputs show all 12 digital input sensors' status, and the outputs are 3 digital output relays. Also, the DC power supply connection is represented.

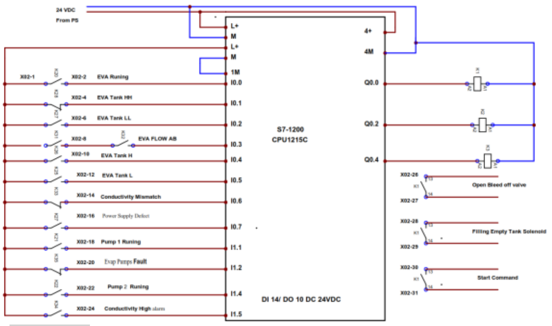


Fig. 7. CPU input and output wiring diagram

furthermore, the analogue input module signal mapping and wiring diagram illustrated in Fig.8, it is consisting of all analogue inputs which presented in the prototype.

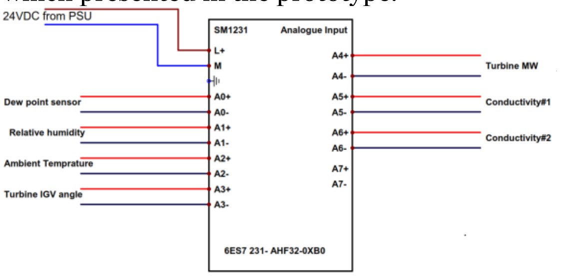


Fig.8 analogue input module wiring diagram

The SCADA or HMI system is a human-machine interface that monitors and operates the evaporative cooler system. It's a graphic page that shows all parameters. They consist of WinCC RT Advanced software installed on the PC, communicating and exchanging data by ethernet cable. The webserver in the proposed paper consists of the Wireless network router, which connects to the CPU by ethernet cable, and the SIMATIC application S7 APP, which is installed on the mobile device and connected with the router wireless network [19].

5.2 Software implementation

The software implementation includes all software and configuration system for the proposed system, such as TIA Portal CPU 1215C program blocks, SIMATIC PC station HMI screens, S7 APP view page, variables, and trends. In general, the implementation can be summarized as follows; TIA Portal Software Implementation: It gives a full access to the configuration of an automation control system. It's easy and friendly software Fig.9. In the project view, it is possible to add a new project in our proposed system named Msc evapcooler_V15. Inside the new project tree, two primary devices were added. The first one is PLC_1 which consists of CPU1215C and AI 1231. The second device is PC_system_1 which in the proposed system is WinCC RT Advanced.

Each used device is configured according to the proposed hardware system. When the configuration for the PLC_1 device is completed, a compile button in the top toolbar can be added to verify the new configuration. The download button is used to download new configurations to the device once all configurations are defined from the software and PC to the CPU.

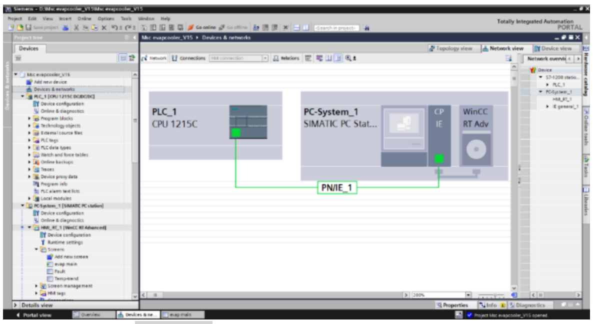


Fig.9. TIA Portal software

PLC Program for Evaporative Cooler System: The PLC program blocks consist of one OB (OB1). The proposed program structure is a linear program that places all the networks and program instructions into the OB called (OB 1). The OB consists of 23 networks written following ladder logic's evaporative cooler operation procedure as indicated in Fig.10. The program networks are tested and modified several times until reaching the last version. The detail of the ladder logic program is shown in Appendix – A.

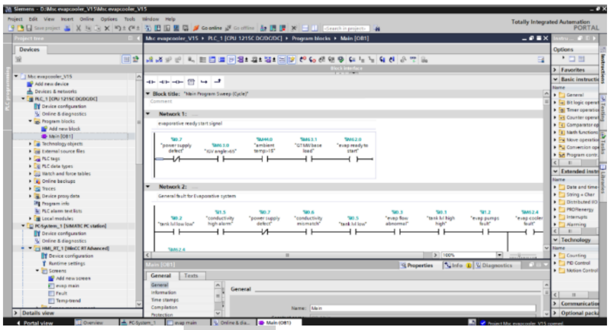


Fig.10. OB program

SCADA-HMI Screens for Evaporative Cooler System: The SCADA-HMI is the tool for communication or interface between the machine control system and the human or responsible operator Fig. 11. The SCADA-HMI exchanges data with the PLC Control system by the ethernet cable, can configure the graphical pages which show all system components and requirement for monitoring and operating system. The proposed work for the SCADA-HMI system is WinCC RT Advanced, the Windows-based software. It can show the complete system component, digital signal status, PB, and analogue measurement status. Moreover, the trends, alarm and fault pages, and diagnostics can be monitored and displayed on this system.

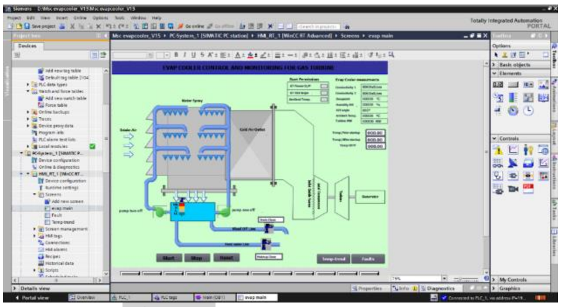


Fig. 11. SCADA main page

Simatic S7 APP For remote control: The Simatic S7 APP for mobile devices can connect to the PLC control system through a wireless network router. the operator can monitor and operate the evaporative cooler remotely from his mobile device and a specific distance Fig. 12.

Fig. 12. S7 APP main pages

The proposed S7 APP can monitor several parameters, and most SCADA accessibility is available in this mobile device application. It consists of three main pages: Station info, Variables, and Diagnostics Buffer.

6.DISCUSSION

Before connecting the proposed system to a real evaporative cooler system in Erbil Perdawd Combined Cycle Power Plant, all hardware and software processes are completed. There is a method for testing the S/W and H/W systems of PLC, SCADA systems, and S7 APP. The PLC and SCADA hardware system is tested through forcing and running the simulation, which can monitor the simulated data in the CPU. The system can perform a simulated test by running a simulation model and integrating the PLC and SCADA systems. Furthermore, the S7 mobile device application also can be tested by connecting the device with the WIFI network router, which can do the actual test from a remote location to see how the mobile device can monitor, operate and control the real PLC. Installing the proposed automation embedded system and connecting the system to the natural evaporative cooler system at Erbil/Perdawd combined cycle power plant can test and prove the last integration system between hardware and software systems. The evaporative cooling system can start successfully, and the PLC, SCADA, and S7 Mobile device APP can work without any problem. The proposed system proved to work with high efficiency in a real-time system. All issues mentioned in the problem statement section can be overcome after installing the proposed system, proving that the evaporative cooler system can be controlled and monitored based on the PLC and SCADA systems. It can control fully automatically based on the proposed logic diagram in the PLC to operate the system, and it can work without any human attendance in the operating system. It is designed to monitor all operation requirements in the evaporative cooler on the SCADA-HMI. The full range of data for the evaporative cooler system is displayed on the SCADA-HMI, which includes alarm, diagnostic, trend, and any other status for the system. Moreover, remotely the operator can monitor and operate the system from his mobile device by using the S7 APP, which can monitor and control the entire system. A Wifi router was installed and connected to the CPU via ethernet cable. Configure the requirements of the webserver on the CPU configuration page. Throughout comparing the proposed automation system for design and implementation of the evaporative cooler system with the nearby previous works [20]. Table 1 is detailed the comparison between this work and nearby related work for the automation system.

Table 1
Comparison between the proposed design and nearby previous work

Features	The proposed design	Nearby previous work
System and application used	Evaporative cooler for gas turbine air inlet filter	Gas Bottle spray coating system
PLC used	CPU1215C DC/DC/DC	CPU1212C AC/DC/RLY
SCADA and HMI	Wincc RT advanced used all-controlling and monitoring functions such as a pushbutton, analogue value, valve/motor status for analogue and digital for digital I/O.	Wincc RT advanced used with only such as pushbutton and indicate status for digital I/O.
Webserver uses	included	Not include
Remote auto operation	S7 APP from smart device	Not included
Alarm, faults and diagnostics	Alarm and diagnostics page included with HMI	Not included
Calculations and efficiency used	The temperature and MW calculation done	Not included

During testing the proposed system, can monitor the power output and temperature effect of the evaporative running as shown in Table 2 the data can be monitored automatically via mobile APP or SCADA HMI. In the proposed work, when the evaporative cooler enters to operate the generator, the output power increases according to decreasing the ambient air inlet temperature. In the proposed SCADA, there is a block diagram for finding the temperature changing before and after the evaporative cooler enters into operation; for the power output in the trend data, can find the power output in the natural evaporative system on gas turbines in Erbil/Perdawd combined cycle power plant. According to the data collected during the summer season, when the evaporative cooler is out of service and when entering, the evaporative cooler operates at an ambient temperature of more than 41˚C Fig. 13.

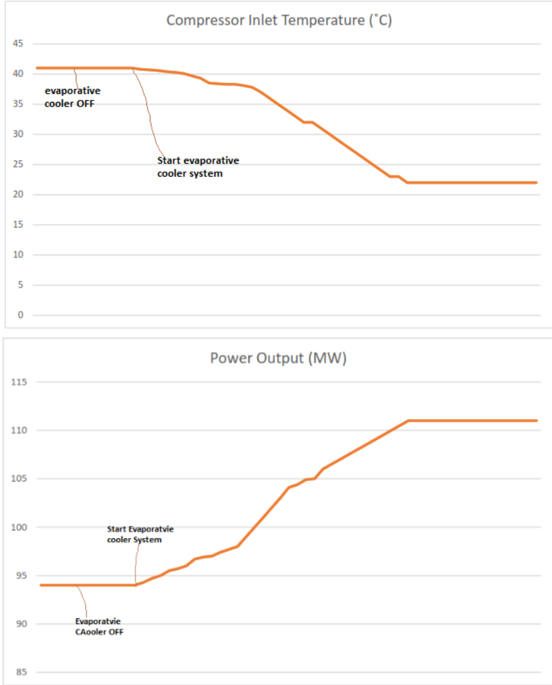


Fig. 13. compressor inlet temperature and power output curve before and after evaporative cooler running

The result illustrates the effect of the evaporative cooler on the air inlet temperature, decreasing from 41 ˚C to 22 ˚C.

Temperature decrease= T before evap start−T after evap start… (1)

Temperature decrease =41-22 =19 ˚C

The decrease in the air inlet temperature to the compressor and hot gas path area directly affects the air mass flow and density. For these reasons, the generator power output will gradually increase per temperature decrease.

MW increase= MW after Evap Start – MW before Evap Start … (2)

=111 – 94 = 17 MW (improvement)

From the power output improvement, it can be found the performance of the evaporative cooler improves output and thus increases the ratio of power, which shows to be (13.6%).

Table 2
Evaporative effect on temperature and power output

Compressor air inlet temperature (˚C)	Load affected by temperature (MW)	Evaporative status
37 ˚C	99 MW	Off
40 ˚C	95 MW	Off
42 ˚C	93 MW	Off
37 ˚C	99 MW	On
35 ˚C	100 MW	On
32 ˚C	101 MW	On
28 ˚C	105 MW	On
25 ˚C	108 MW	On
23 ˚C	109 MW	On
21 ˚C	111 MW	On

7.CONCLUSION

In the last era, the automation embedded control system was widely spread and used due to rapid development in the technology field and industrial section. Using the automation embedded system and the remote-control system enabled the researcher to search for and develop a new program and technique to control and monitor the industrial control system from remote areas. There is a growing need for better power quality, efficiency, automated operation, and protection devices from the industrial sector and power plants. This paper proposes an enhanced automation embedded control system based on the PLC and the SCADA for the evaporative cooler system at the Erbil-Perdawd combined cycle power plant. Due to the advantages of the proposed design and implementation by changing from the original relay-based design, the owner will contribute a total of 10% extra for device cost. This indicates that an automation-based design will be the more advantageous approach from a financial and operational standpoint when accounting for the produced MW improvement, which is approximately 14% of the GT power output efficiency. Additionally, a PLC-based design uses the fewest possible apparatuses and the most readily available, least expensive components on the local market. It has fewer mechanical and replacement components in addition to it is high resilience and prolonged operating life, which results in lower downstream costs. Therefore, the whole cost will go down. Furthermore, the experimental results and investigations indicate that the proposed automation embedded control system is very flexible, simple for controlling and monitoring the evaporative cooler for air inlet, and safe and easy to operate.

NOMENCLATURE

GT: Gas Turbine
CC: Combined Cycle
IGV: Inlet Guide Vanes
MW: Mega Watt
PLC: Programmable Logic Controller
SCADA: Supervisory Control and Data Acquisition
PC: Personal Computer
CPU: Central Processing Unit
TCP: Transmission Control Protocol
IP: Internet Protocol
GSM: Global System for Mobile Communication
TIA: Totally Integrated Configuration
HMI: Human Machine Interface
AC: Alternating current
DC: Direct Current
EN: Enable
OB: Organization Block
FC: Function
DB: Data Block
LAD: Ladder Language
LED: Light Emitting Diode
PB: Push Button
I: Input
Q: Output
W: Word
IW: input Word
PSU: power supply unit
I/O: input and output
NO: normally open
NC: normally close
APP: Application
µS: micro siemens
LAN: Local Area Network
AI: Analog Input
AO: Analog Output
DI: Digital Input
DO: Digital Output

APPENDIX – A

The ladder logic program for the evaporative cooler control system:

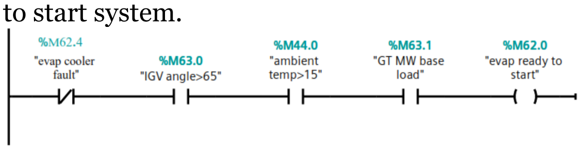
Main [OB1]

Main Properties							
General							
Name	Main	Number	1	Type	OB	Language	LAD
Numbering	Automatic						
Information							
Title	"Main Program Sweep (Cycle)"	Author		Comment		Family	
Version	0.1	User-defined ID					

Name	Data type	Default value	Comment
▼ Input			
Initial_Call	Bool		Initial call of this OB
Remanence	Bool		=True, if remanent data are available
Temp			
Constant			

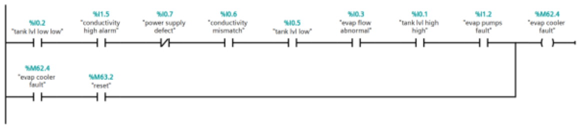
Network 1: evaporative cooler ready to start signal

The evaporative cooler ready signal is programmed. The system will check if the evaporative cooler fault is not active, GT IGV angle is more than 65-degree, ambient temperature is more than 10 °C degree and GT mode at baseload. The Control system permits to start system.



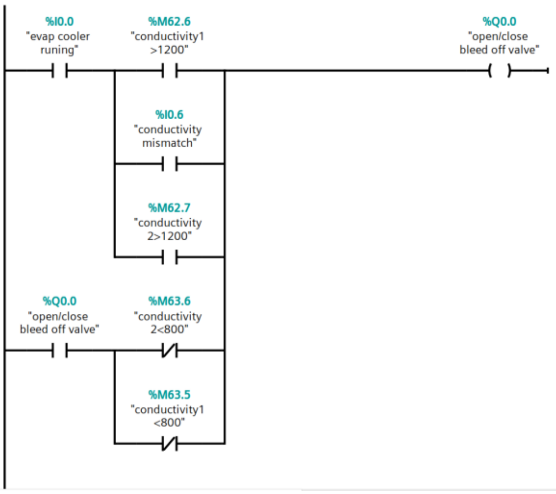
Network 2: general fault on evaporative cooler system

The general fault will be active for the evaporative cooler when any of the below signal active



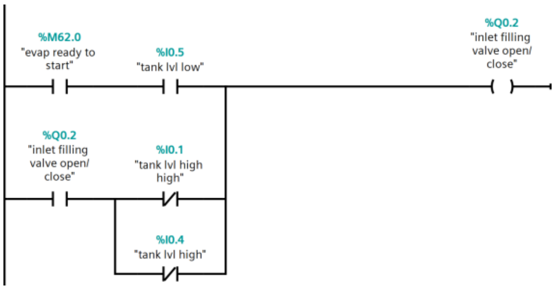
Network 3: open/ close the bleed-off/drain tank solenoid valve

The logic for opening and closing the bleed-off solenoid valve active is shown below the network. When the evaporative cooler runs, if the conductivity sensor reads more than 1200 µS/cm, the valve will open, and at 800 µS/cm, it will close.



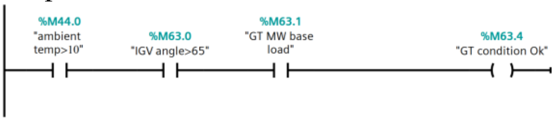
Network 4: open/ close the inlet filling tank solenoid valve

The logic for active opening and closing of the inlet filling solenoid valve is shown in the network below. When the evaporative cooler is ready to start, if the tank level is a low-low alarm or low is active valve will open, and when the tank level is high or high-high alarm active, it will close.



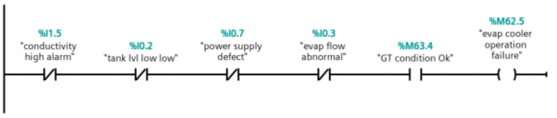
Network 5: gas turbine pre-conditions for starting evaporative cooler

To start the evaporative cooler, there should be below condition active to get the system ready. GT should be at base load, IGV angle should be more than 65 degrees, and ambient temperature more than 10 °C.



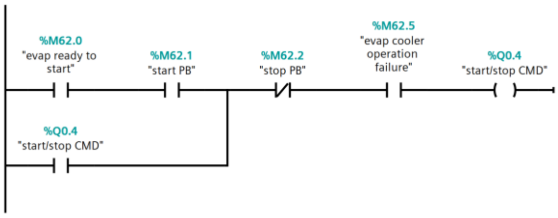
Network 6: evaporator cooler system failure

During system operation, the evaporative cooler system will shut down if any of the below networks are active.



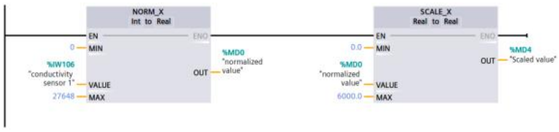
Network 7: evaporative cooler system starts or stop commands

When the system is ready to start and start, PB pushed but stopped PB not pushed and the shutdown signal not active the system will start. During operation, if stop PB is pushed or one of the shutdowns signals is active, the system will stop.



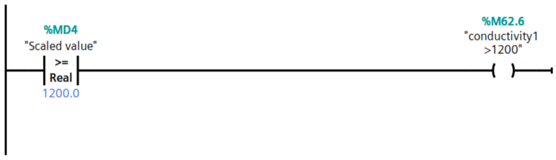
Network 8: conductivity sensor 1 measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input conductivity sensor 1.



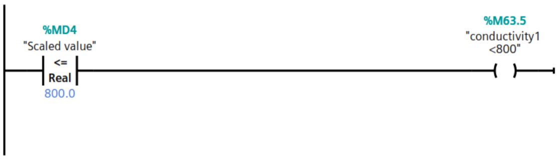
Network 9: Conductivity Sensor 1 high alarm

The compare value instruction was used to compare the analogue input conductivity sensor1 with the specific value. If the conductivity sensor 1 reading is greater than or equal to 1200 µS/cm, the alarm conductivity high alarm will remain active.



Network 10: Conductivity Sensor 1 high alarm reset

The compare value instruction was used to compare the analogue input conductivity sensor1 with the specific value. If the conductivity sensor 1 reads less than or equal to 800 µS/cm, the alarm conductivity high alarm will reset to close the bleed-off valve.

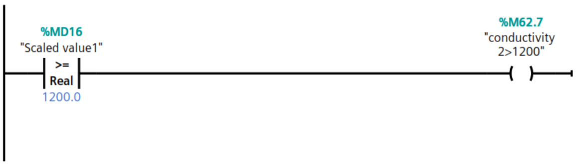


Network 11: conductivity sensor 2 measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input conductivity sensor 2.

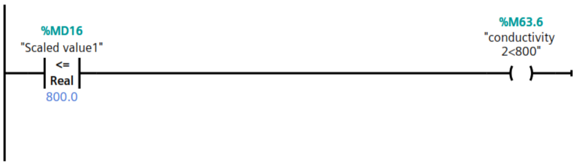
Network 12: Conductivity Sensor 2 high alarm

The compare value instruction was used to compare the analogue input conductivity sensor2 with the specific value. If the reading is more than or equivalent to 1200 µS/cm, the alarm conductivity high alarm will remain active.



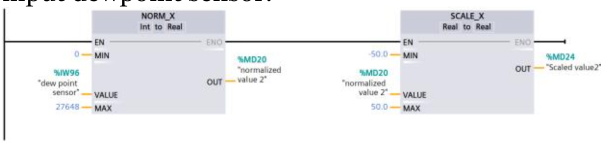
Network 13: Conductivity Sensor 2 high alarm reset

The compare value instruction was used to compare the analogue input conductivity sensor1 with the specific value. If the conductivity sensor 2 reads less than or equal to 800 µS/cm, the alarm conductivity high alarm will reset to close the bleed-off valve.



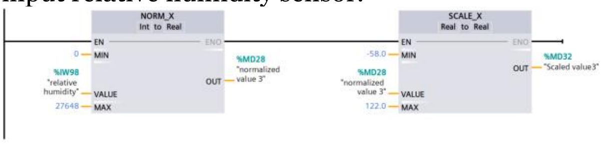
Network 14: Dewpoint sensor measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input dewpoint sensor.



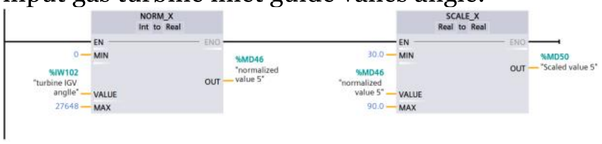
Network 15: relative humidity sensor measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input relative humidity sensor.



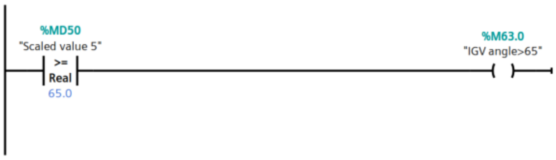
Network 16: gas turbine inlet guide vanes angle

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input gas turbine inlet guide vanes angle.



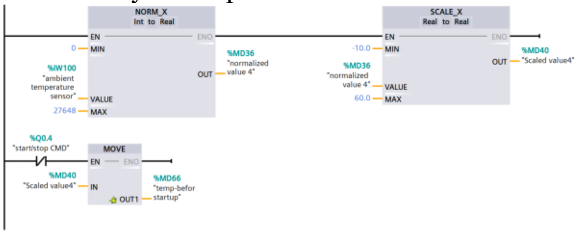
Network 17: IGV angle permission for starting evap. cooler system

The compare value instruction compares the analogue input IGV angle with the specific value. If the IGV angle reading exceeds or exceeds 65, it will permit an evaporative cooler system to start.



Network 18: ambient temperature measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input gas turbine ambient inlet temperature. The move instruction moves to find the temperature before starting evaporative cooler to see the system's performance.

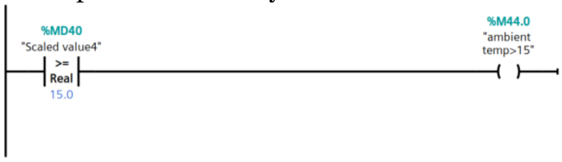


Network 19: the effect of the evaporative cooler on the ambient inlet temperature.

The SUB and ABS instruction used to find the temperature before and after starting the evaporative cooler to see the system's performance.

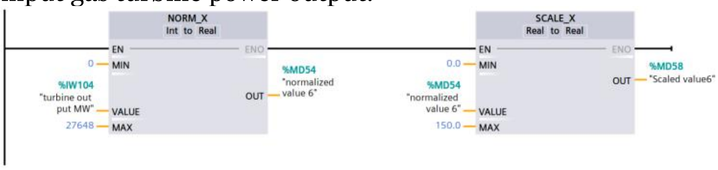
Network 20: ambient temperature permission for starting evap cooler system

The compare value instruction compares the analogue input ambient temperature with the specific value. If the ambient temperature reading exceeds or exceeds 10°C, it will permit an evaporative cooler system to start.



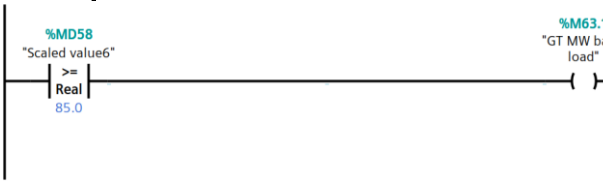
Network 21: gas turbine power output measurement

It contains NORM_X instruction and SCALE_X instruction which are used for normalizing and scaling the reading of analogue input gas turbine power output.



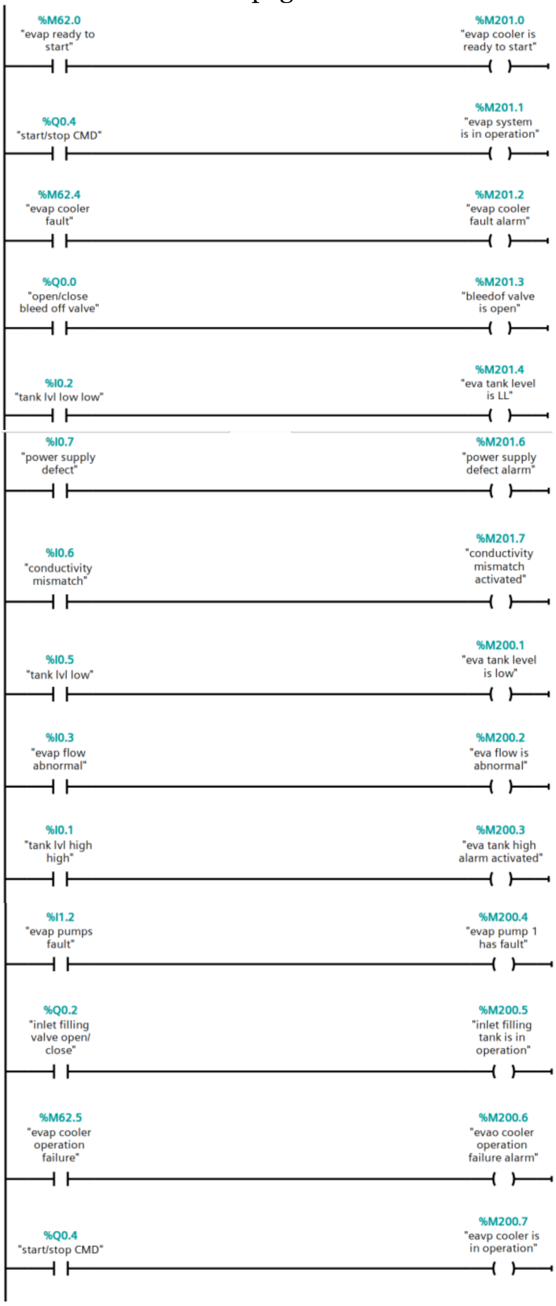
Network 22: turbine power output permission for starting evap cooler system

The compare value instruction was used to compare the analogue input power output MW with the specific value to find the GT load mode, to give permission to start the evaporative cooler system.



Network 23: evaporative cooler system alarms

It configures all alarms to show on the SCADA-HMI alarm and fault pages.



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