بســـــــــم الله الرحمن الرحيم

MEAE – Middle East Institute for Alternative Energy

A member of AECENAR Applied Research Center

www.aecenar.com/institutes/meae

www.temo-ek.de

Construction of the cooling system for the condenser

Construction of condensor

Programming and Integration of Process Control System

Further integration of mechanical parts for Demonstration Power Plant

التقرير **الرابع** لمشروع **TEMO-STPP** (المدة من كانون الثاني الى كانون الاول 2013)

TEMO-STPP: **4th** project report (Jan – Dec 2013)

PART II

PART II

(Process Control System)

Published by:

AECENAR e.V., **http://www.aecenar.com**

Content in short / المحتوى في شكل موجز

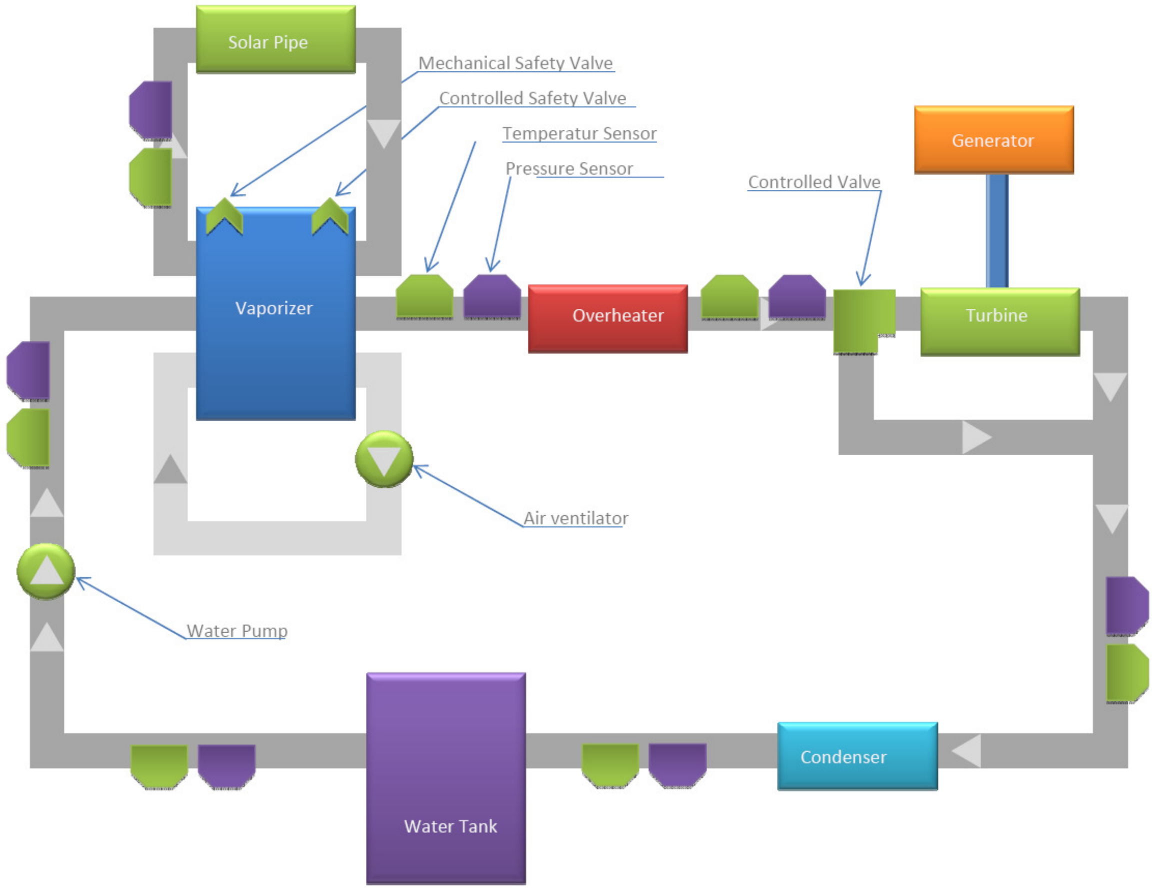
Content / المحتوى

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the Name of God, the Most Merciful

4 نظام التحكمProcess Control System (PCS)

4.1 Test Plant Process Control System - Part 2 (February 2012) - System Design



4.2 Introduction: Installation and putting into operation of a S7 system

A S7-300 SEIMENS PLC was used to control and monitor the plant. The S7-300 is used among the world to control any big industries machine system. The PLC is programed by **STEP7** computer software, and then you can do an interaction between the PLC and the PC using **WinCC** software or any other GUI developed software.

In this part we will programed our PLC using STEP7 and then we will use two ways to interact with PLC and plant system. Part steps:

- Implement S7-300
- Program PLC using STEP7
- Develop WinCC GUI user interface
- System – PLC – Computer Communication
- Develop of second GUI interface choice (using velleman board)

4.3 PLC S7-300

tbd

4.4 Step7 WorkFlow

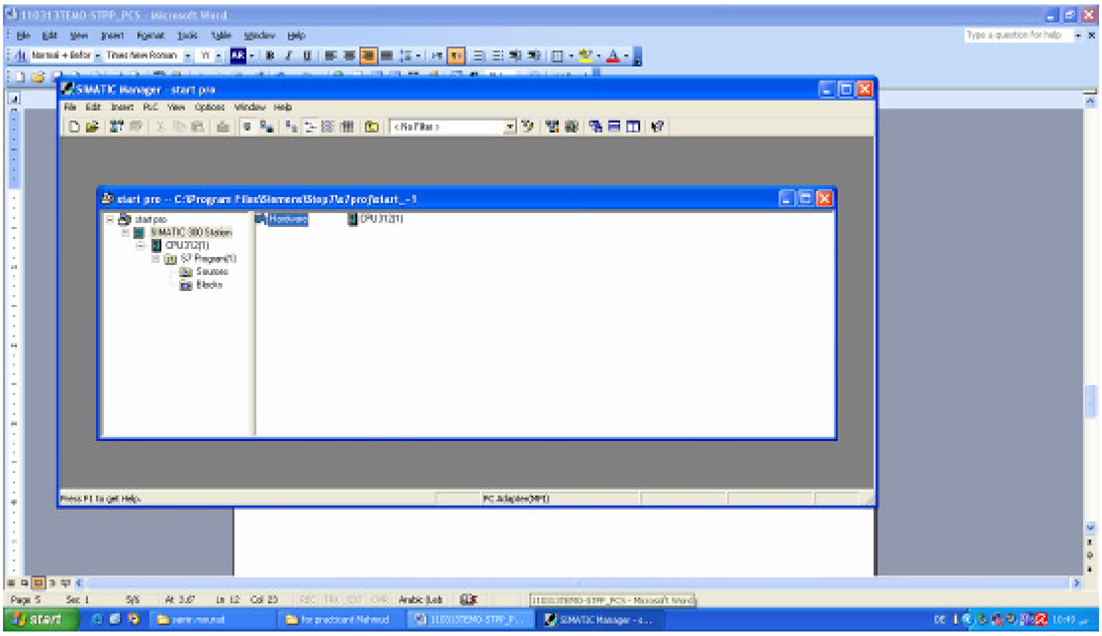
4.4.1 برمجة الـPLC و تطبيق برنامج تعليمي عليها:

بعد توصيل قطع الـ PLC ببعضها حسب الحاجة (يمكنك النظر في أي ملف تعليمي لمعرفة طريقة توصيلها) لا بد أن تعرّف للـ CPU الشكل الذي قمت بجمع الـPLC به و ذلك من خلال برنامج SIMATIC Manager على الشكل التالي:

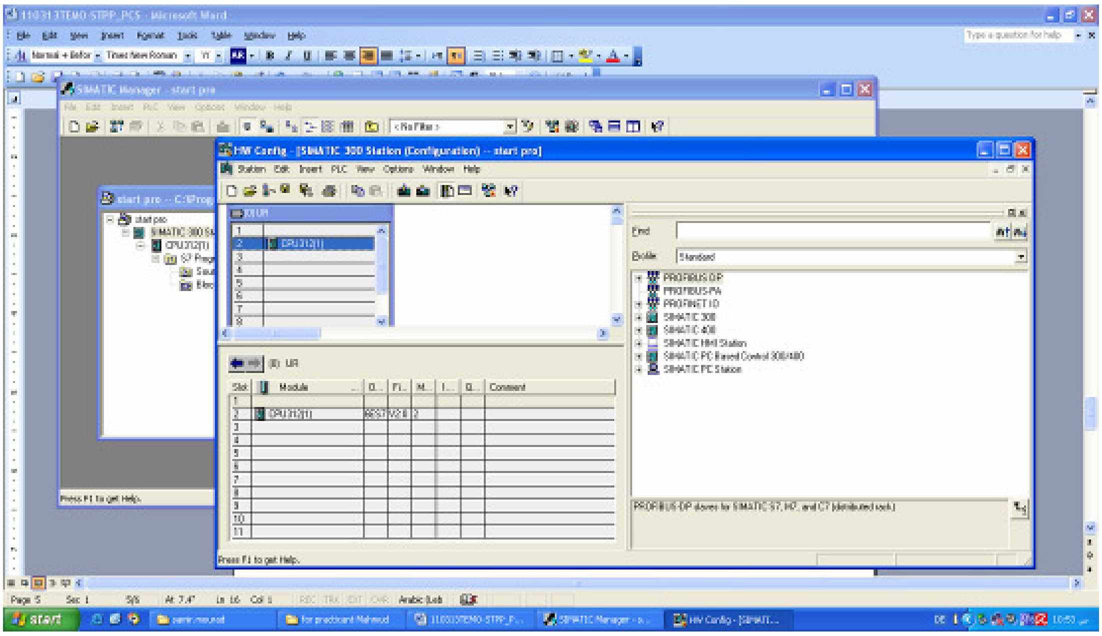
1. أولاً علينا فتح مشروع جديد ('New Project' Wizard) و يتم خلاله إختيار الـ CPU المستخدمة

2. ثانيا بالضغط على SIMATIC 300 station الموجود على يسار الشاشة سيظهر لك خيار الـ Hardware الذي نحتاجه لتعرفت أجزاء الـ PLC للـ CPU

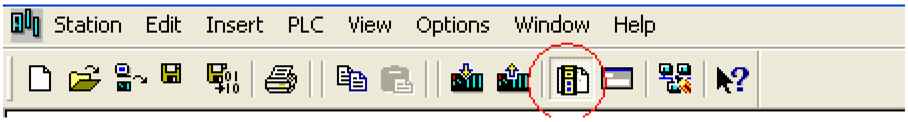
صورة توضح طريقة الدخول على بناء Hardware:



3. بالضغط على خيار Hardware ستظهر لك الشاشة التالية و فيها الـ CPU الذي قمت بأختياره:



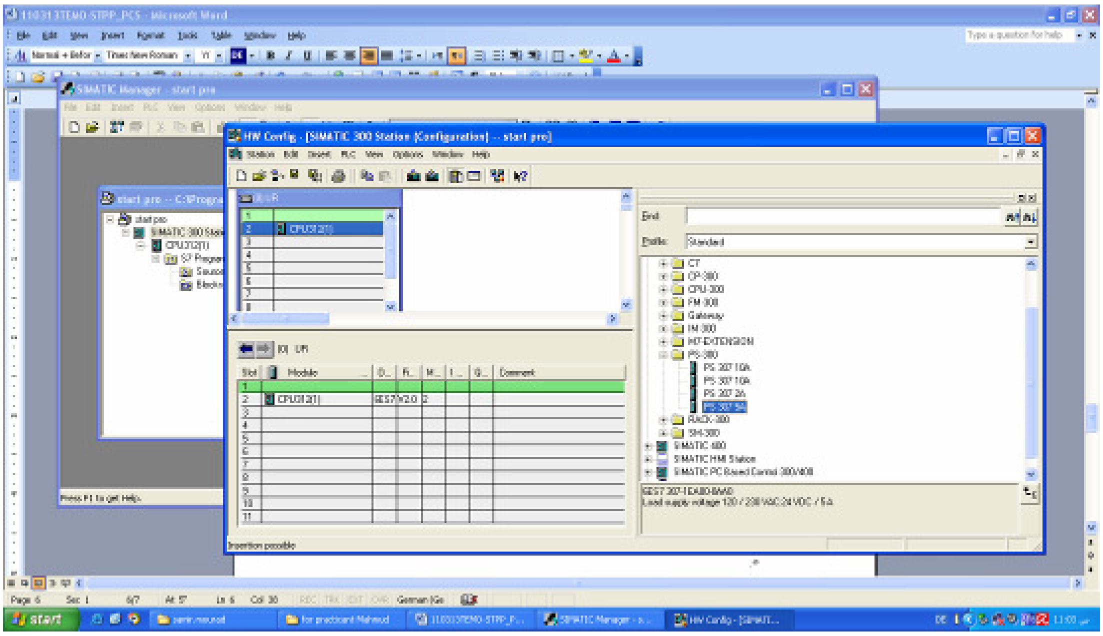
4. الآن علينا أكمال عملية بناء Hadrware الـ PLC من خلال حمل القطع من التسلسل يمين الشاشة و إسقاطها في مكانها يسار الشاشة, في حال لم تجد التسلسل يمكنك عرضه من خلال الضغط على المفتاح التالي:



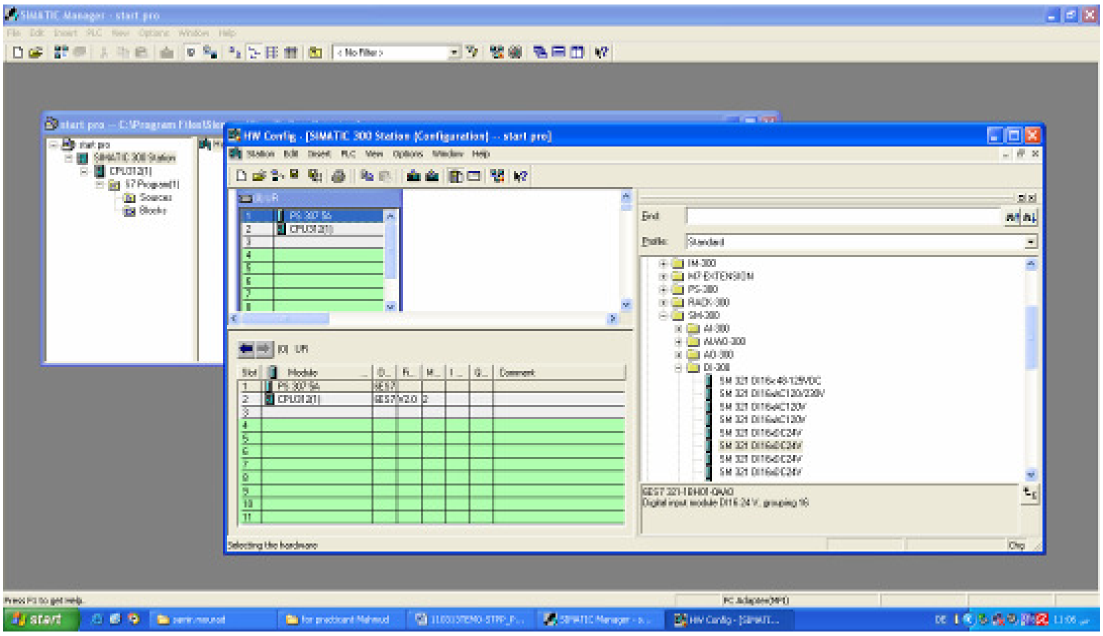
سيظهر لك المكان المناسب القطعة بمجرد الوقوف عليها.

القطع التي سنحتاجها موجودة في قسم SIMATIC 300 من التسلسل علي يمين الشاشة

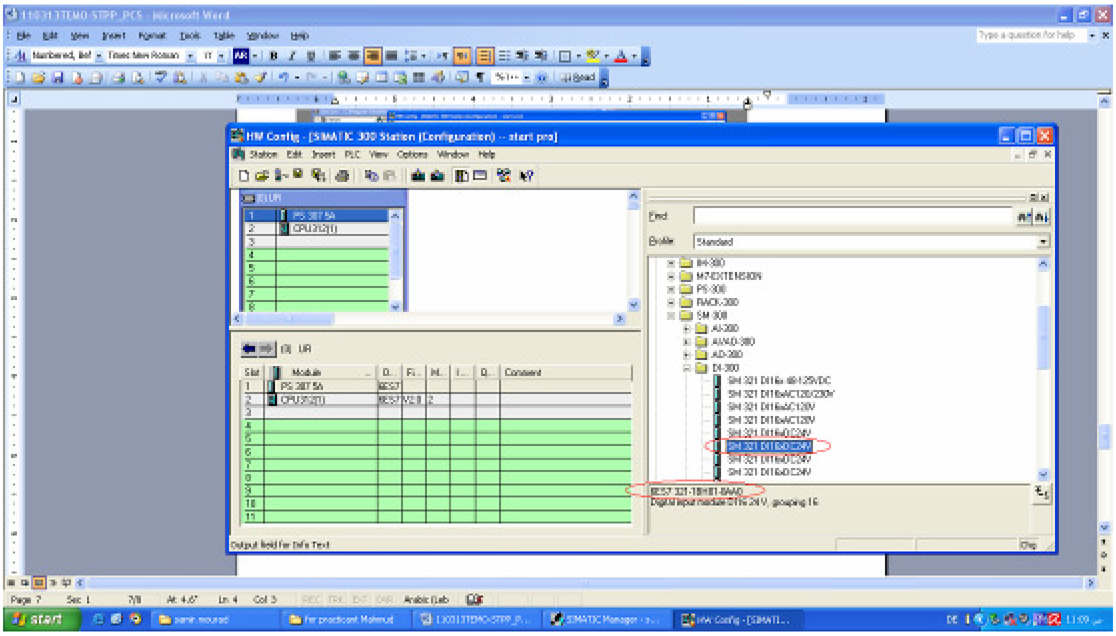
الـ PowerSupply موجودة في قسم PS-300 على الشكل التالي:



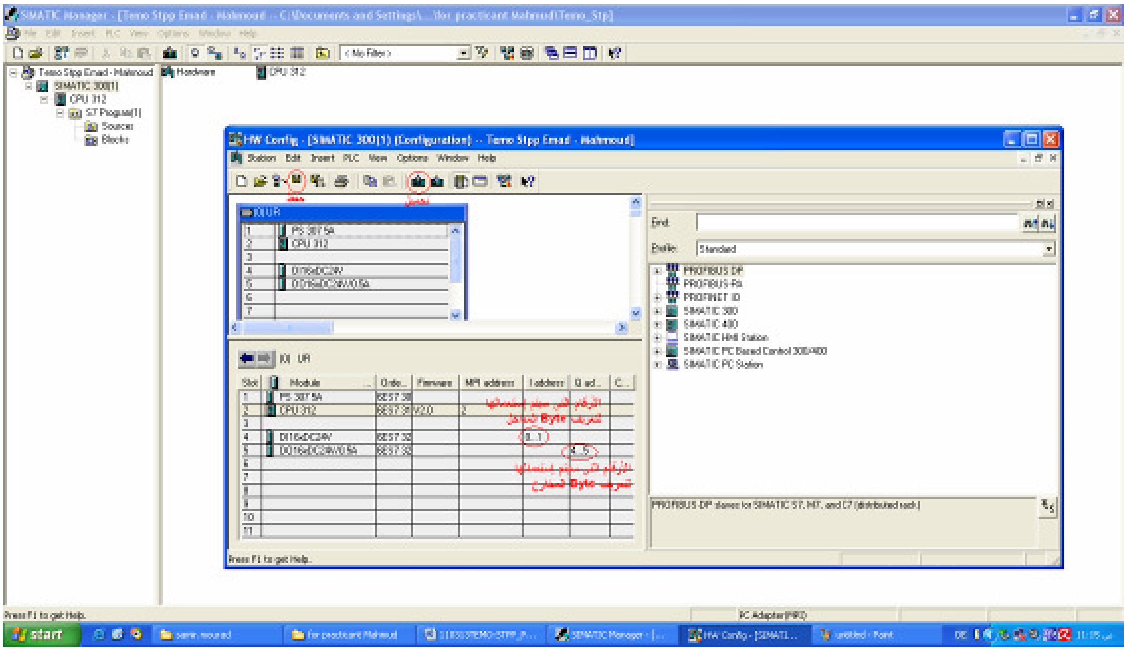
الـ input-output devices موجودة في قسم SM-300 على الشكل التالي:



5. قم بإختيار القطع المناسبة بالتأكد من أسمها و رمزها التسلسلي (أي إختلاف سيمنع البرنامج من العمل) صورة توضيحية

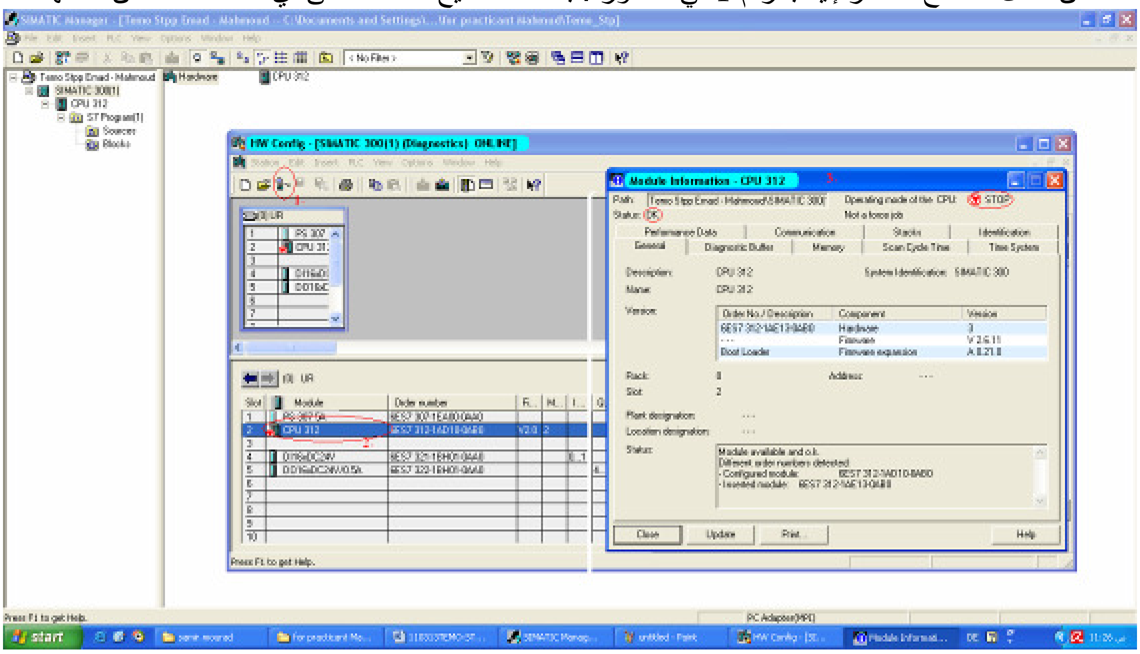


6. بعد إنهاء بناء الـ PLC يتم حفظ العمل ليتم تحميله إلى CPU الـ PLC



7. يجب أن تكون الـ PLC في وضع STOP لتستطيع تحميل البناء عليها

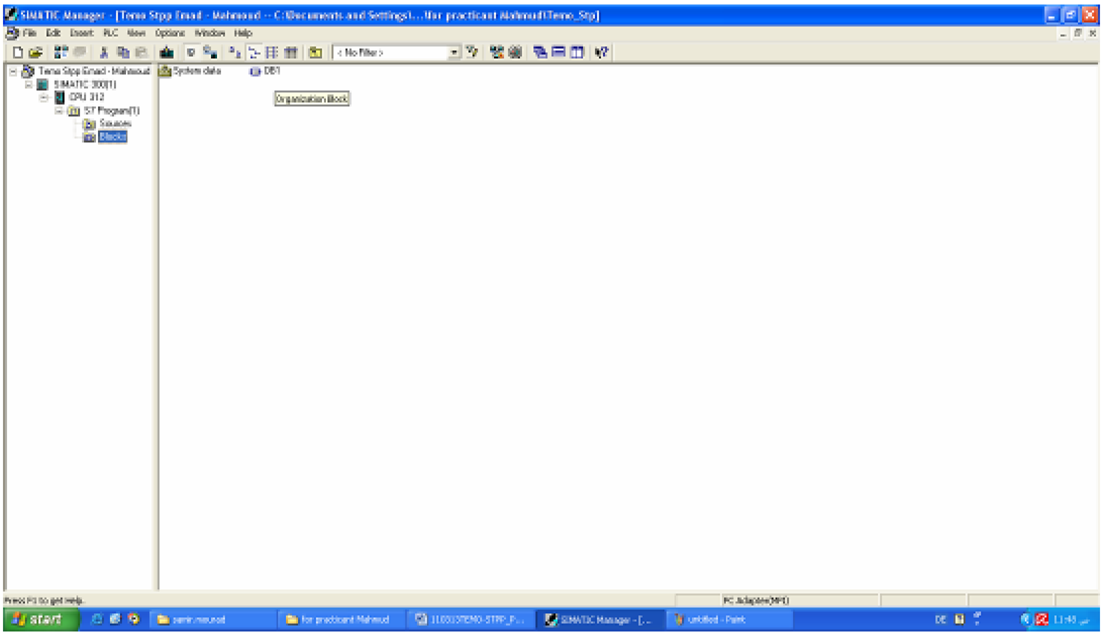
8. للتأكد من توافق البناء من ناحية الـ Software و الـ Hardware قم بنقل حالة الأتصال من Offline إلى Online من خلال المفتاح المشار إليه بالرقم 1 في الصورة. بعدها تستطيع الضغط على أي قطعة للتأكد من حالتها



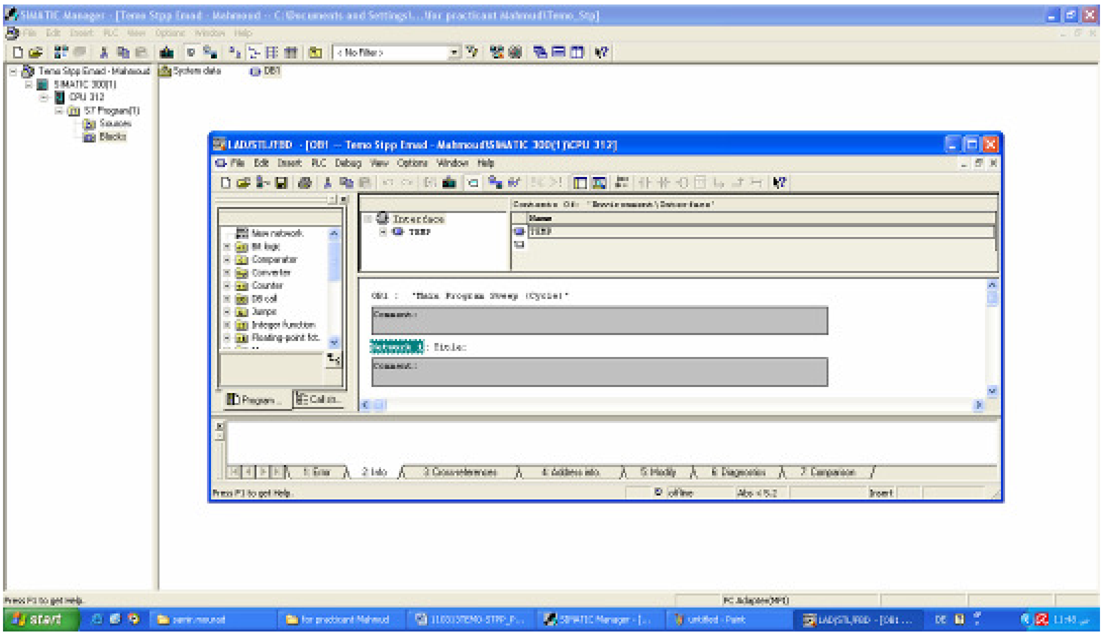
الآن أتممنا عملية تعريف أجزاء الـ PLC للـ CPU . ننتقل الآن إلى برمجتها.

1. أولاً, نفتح ملف OB1 المتحكم (Organization Block) بالـPLC حيث ستتم برمجتها هنا

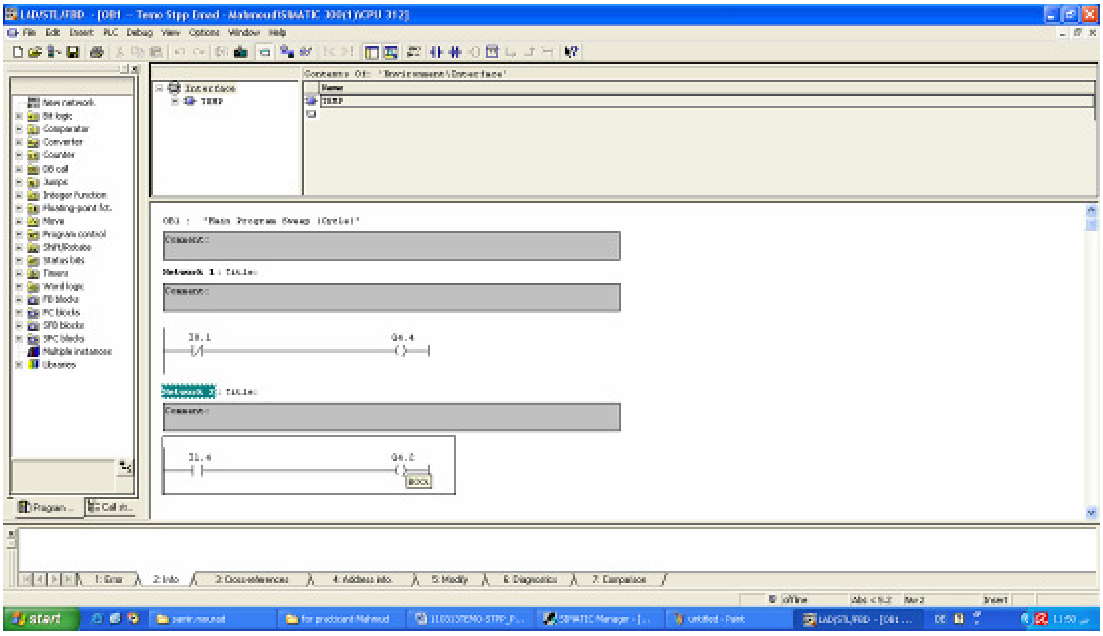
طريقة الولوج للمتحكم(OB1):



شاشة عرض المتحكم(OB1):



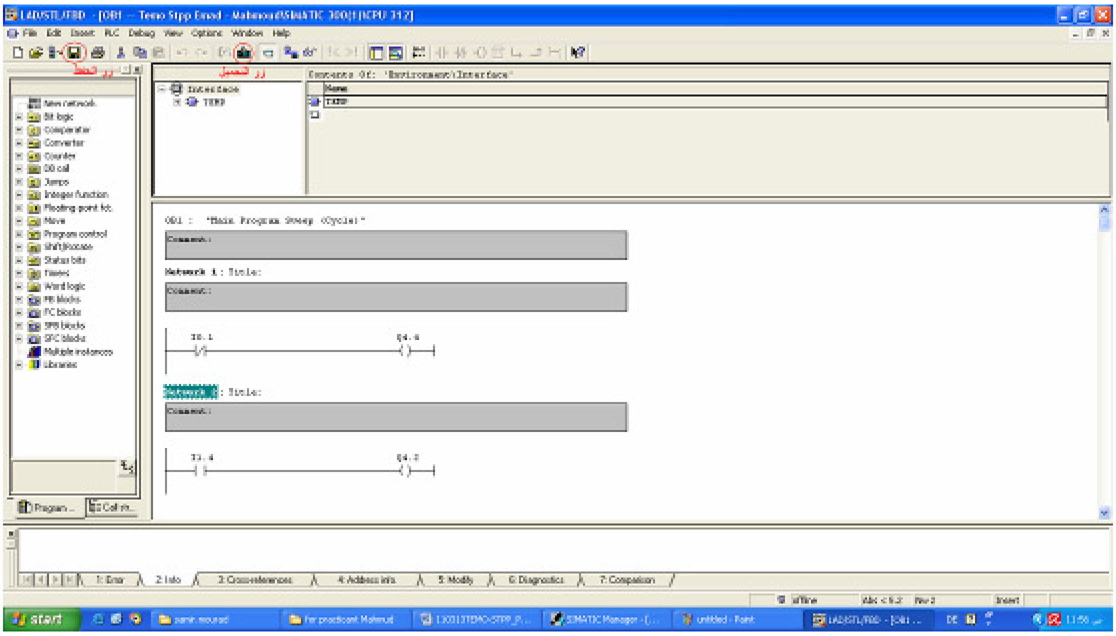
2. و نقوم بكتابة البرنامج البسيط التالي:



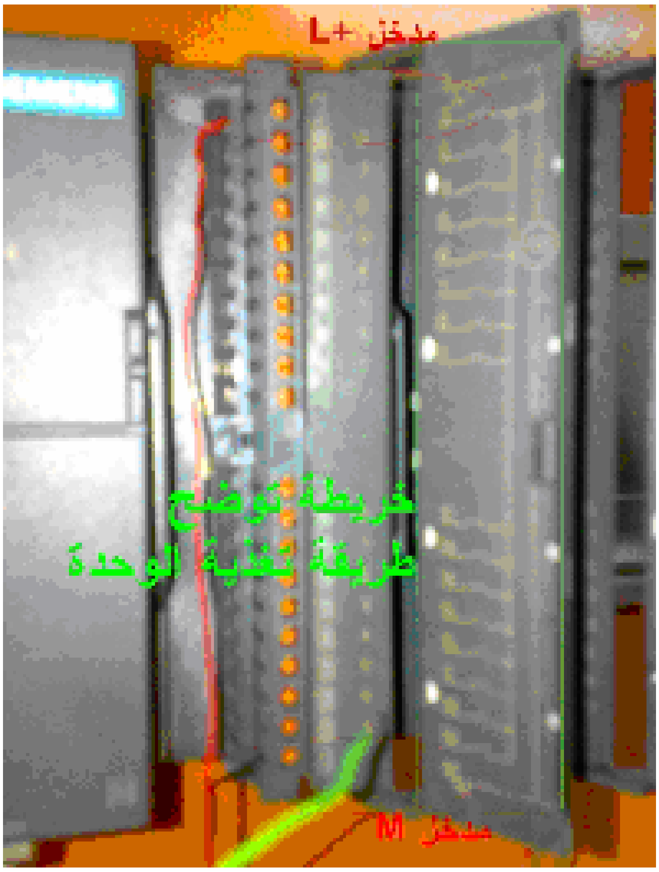
ترجمة البرنامج: - زر المخرج رقم 4.4 يعمل في حال كان مدخل 0.1 حر (V0)

- زر المخرج رقم 4.2 يعمل في حال كان مدخل 1.4 مفتوح (V24)

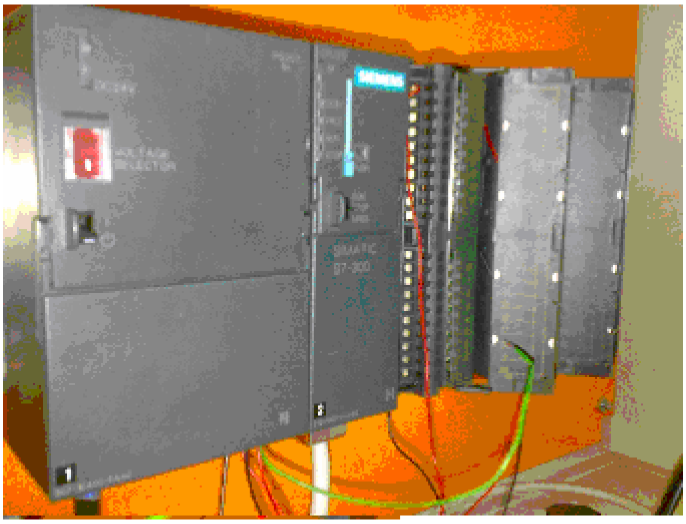
3. أيضاً يتم حفظ البرنامج و تحميله إلى الـ PLC , بالطبع يجب أن تكون الـ PLC في وضع STOP



4. الآن ننتقل إلى جهاز الـ PLC لتغذية مداخل و مخارج الجهاز لتصبح فاعلة و يتم ذلك حسب الخريطة الخاصة بالقطعة صورة توضح طريقة تغذية قطعة المداخل DI:

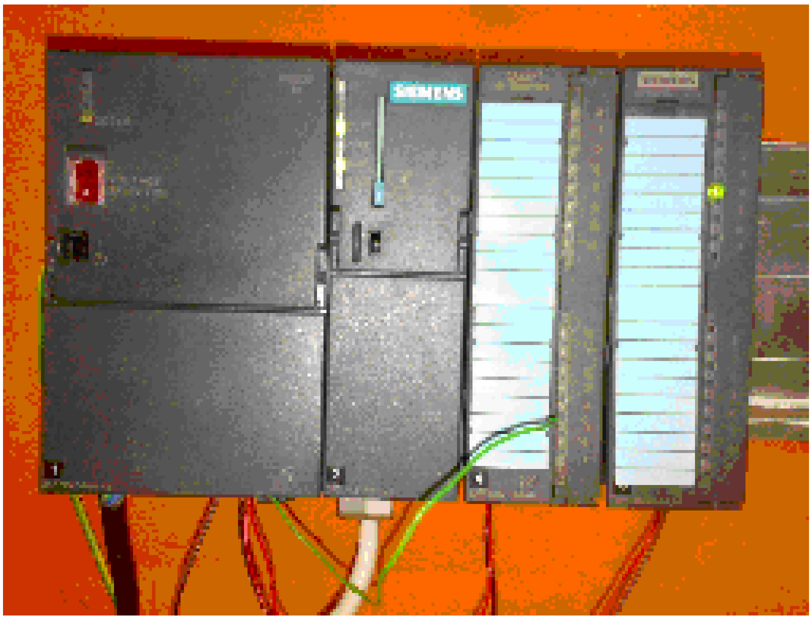


5. إذا و بحسب خريطة التغذية سنحتاج لتغذية المدخل الأول بـ **L+** و المدخل الأخير بـ **M** وسنقوم بتغذيتهم من المغذي الأساسي للـ PLC (PowerSupply) على هذا الشكل:

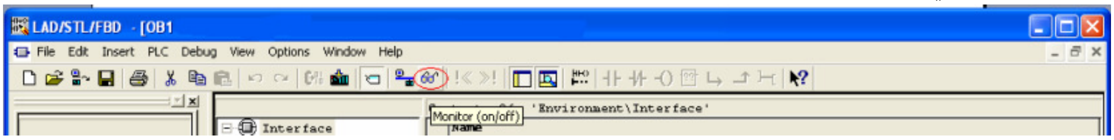


6. الآن أصبح بأمكاننا تشغيل الـ PLC و تجربت العمل, يبدأ التشغيل بمجرد تغير حالة الـ CPU من STOP إلى **RUN**.

بالنتيجة سيعمل زر المخرج **4.4** كما في الصورة التالية و يمكننا تجربت المداخل و التأكد من المخارج ليكون بذلك تم تنفيذ المشروع الأولي التعليمي على الـ PLC.



7. كما يمكن إجراء محاكاة لما يحدث على الـ PLC من خلال برنامج الـ SIMATIC manager و ذلك بتشغيل زر **Monitor** كما في الصورة التالية:



بعد أن أنهينا هذا المشروع التدريبي أصبح بإمكاننا الأنتقال إلى مشارع أكثر تعقيد, أي أصبح بأمكاني تنفيذ مشروعي الذي يخص TEMO-STPP على الـ PLC S7-300

4.4.2 طريقة توصيل profibus

يستخدم الـ profibus لفصل اجزاء الـ PLC إلى جزئين منفصلين بالمكان متصلين بالعمل. يمكّنك الـ Profibus من فصل أجزاء الـ PLC إلى جزئين: الاول متحكم ليوضع في غرفة المراقبة و التحكم و الثاني خاص بالمداخل و المخارج و يكون قريب من الأجزاء التي ستقوم الـ PLC من قراءة و التحكم بأجزائها.

في مشروع TEMO-Stpp تم تقسيم أجزاء الـ Profibus على الشكل المبين في الصورة التالية:

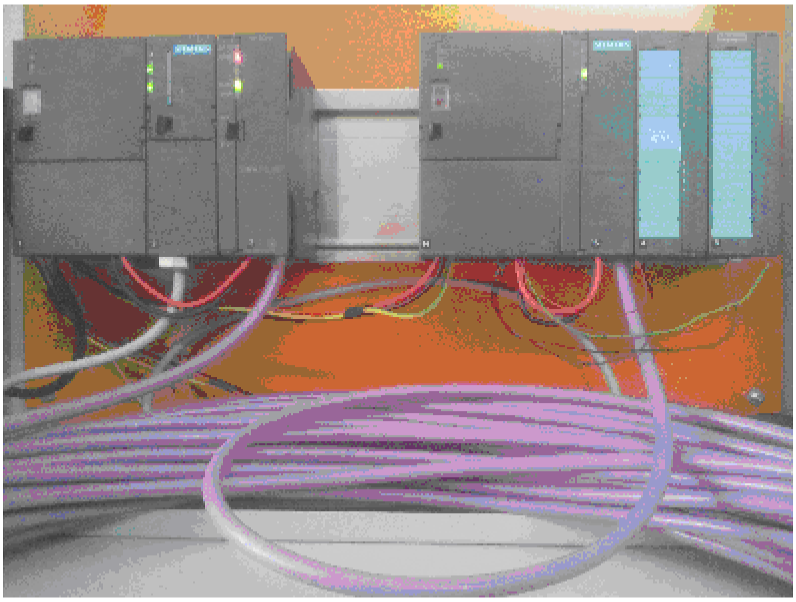


Figure 4.1: S7-300 PROFIBUS NET

الأجزاء المستعملة هي:

Other description	Order Number	Module
Power Supply	6ES7 307-1EA00-0AA0	PS 307 5A
SIMATIC S7-300 V2.6.11 X1 MPI	6ES7 312-1AE13-0AB0	CPU 312
Communication Profibus module SIMATIC NET V5.7	6GK7 342-5DA02-0XE0	CP 342-5
Bus interface module SIMATIC ET 200M Profibus-DP	6ES7 153-1AA03-0XB0	IM 153-1
Digital Input module, grouping 16	6ES7 321-1BH01-0AA0	SM321 DI 16xDC24V
Digital Output module, grouping 8	6ES7 322-1BH01-0AA0	SM322 DO 16Xdc24V/0.5A
Analog input module, 12Bit	6ES7 331-7KB02-0AB0	SM331 AI 2x12BIT

و كالعادة يجب تعريف الـ PLC بالشكل الذي تم توصيل القطع به من خلال الدخول على قسم Hardware, و سنقوم حاليا بتوصيلها حسب الصيغة التي اعتمدناها في جمع الـ PLC المبينة في الصورة 1. من خلال ترجمة صيغة الترتيب المبينة في الصورة 1 إلى HW Config. ستحصل إلى الصورة التالية:

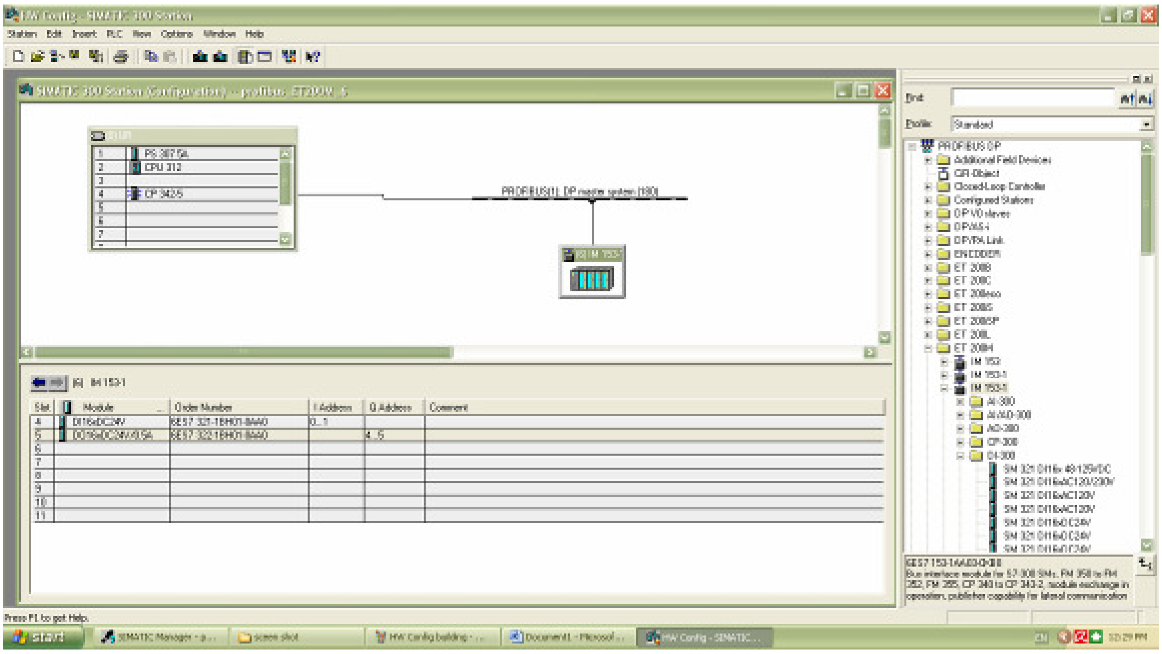


Figure 4.2: HW Config building

تجد الـ module CP 342-5 في هذا العنوان:

SIMATIC 300 > CP 300 > PROFIBUS > CP 342-5

لإضافة الـ DP Slave أي الـ IM 153-1 يجب أولا إضافة POFIBUS master system و ذلك من خلال الضغط بالزرالايمن للفأرة اثناء الوقوف على module CP 342-5 و إختيار Add Master System كما في الصورة التالية:

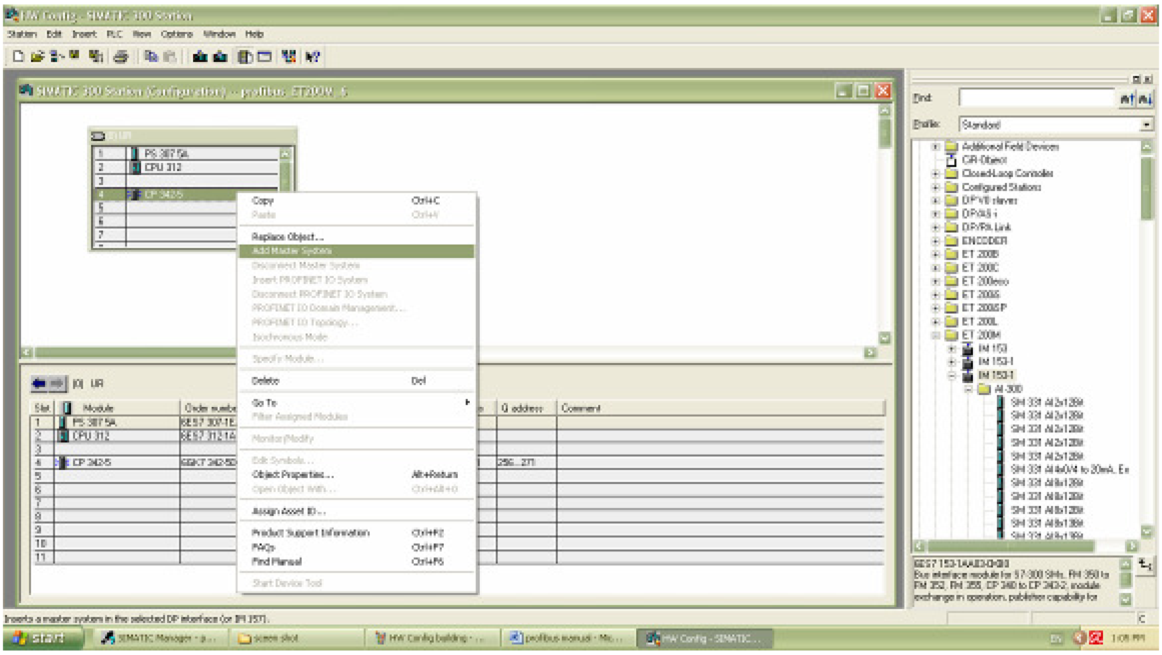


Figure 4.3: HW Config Add Master System

سيطلب منك أن تصله بـ Profibus Network ستقوم بذلك من خلال أتباع الطريقة المبينة في الصورة التالية (انظر الصورة 4) و من ثم تحدد الـ Address للـ master Profibus يفضل أختيار Address = 5 و ما فوق:

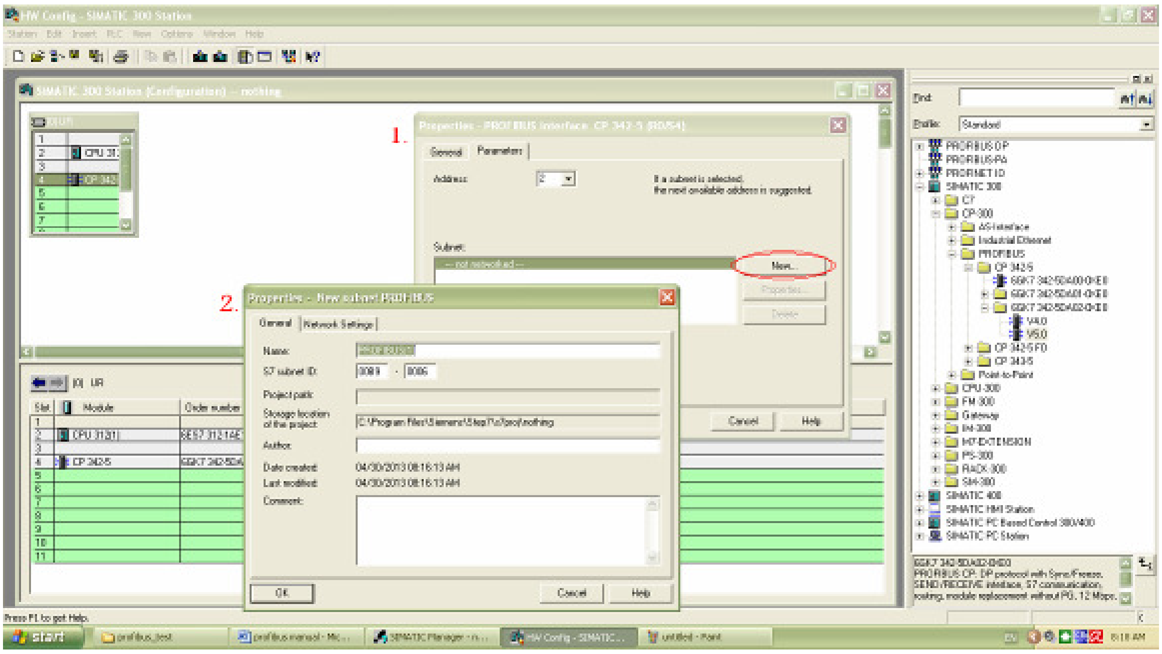


Figure 4.4: HW Config Add Profibus network

ستظهر لك رسالة تبلغك بوجوب نداء الملفين FC1 و FC2 لتستطيع إضافة Profibus system تختار Ok. الآن أصبح بالإمكان إضافة الـ IM 153-1 على الـ Profibus master system من التسلسل التالي:

PROFIBUS DP > ET 200M > IM 153-1 تختار المناسب منها ثم تقوم بالضغط عليه

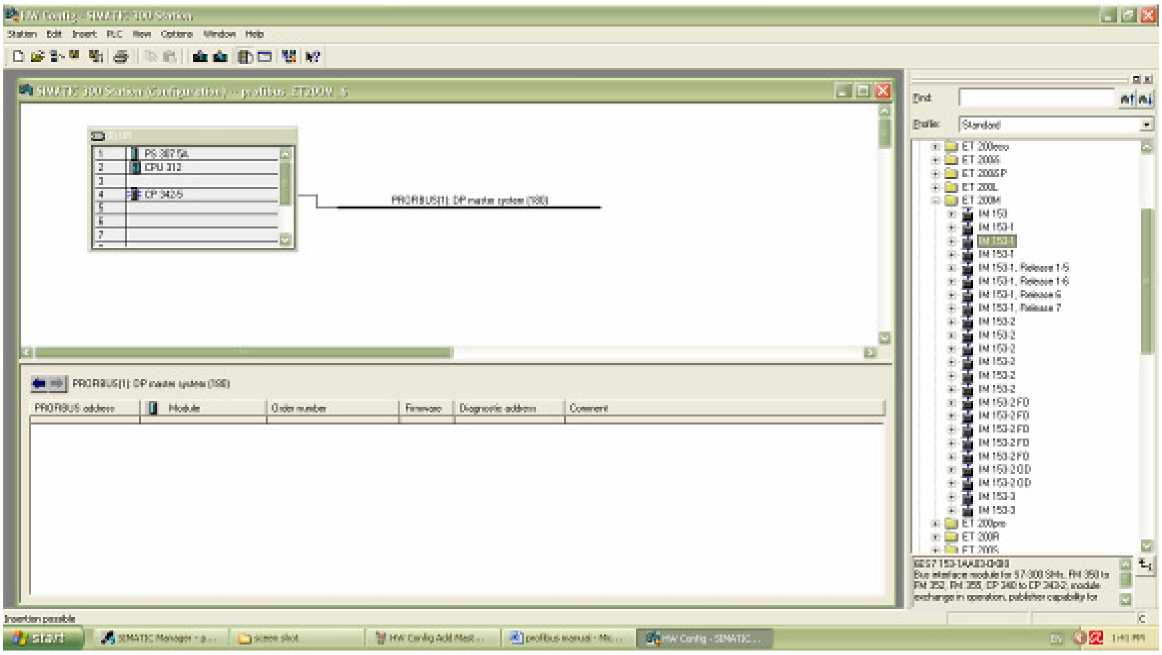
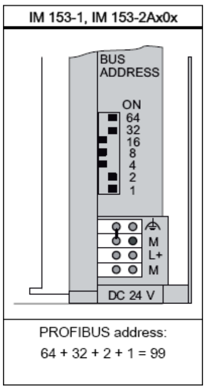


Figure 4.5: HW Config Add IM153-1

و من ثم إختيار address له و موافقته مع الـ Address المضبوط على قطعة الـ IM 153-1 و يكون بالشكل التالي:



بعد ذلك يتم إضافة الأجزاء الموصولة بالـ SIAMTIC NET من القائمة الخاصة بالـ Module IM 153-1 كما في الصورة التالية:

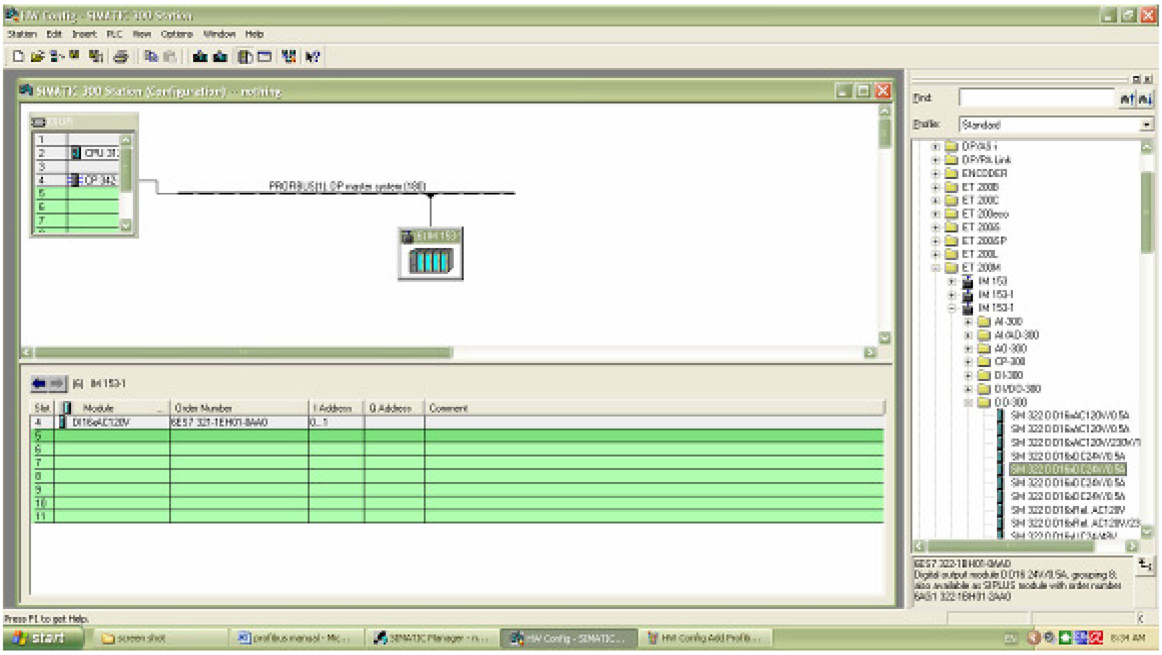


Figure 4.6: HW Config Add Net module

الآن أنهينا العمل على برمجة و تعريف الـ Hardware من خلال برنامج HW config نقوم بحفظ العمل و تحميله على الـ CPU. بعد ذلك أن قمت بالضغط على زر Configure Network (انظر الصورة 7) ستظهر لك التوصيلة بهذا الشكل المبين في الصورة 8:

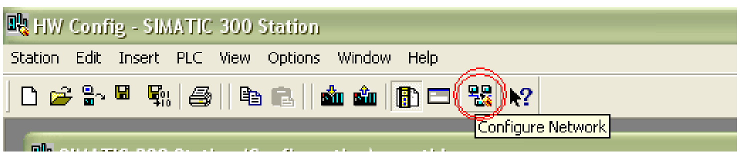


Figure 4.7: Configure Network bottom

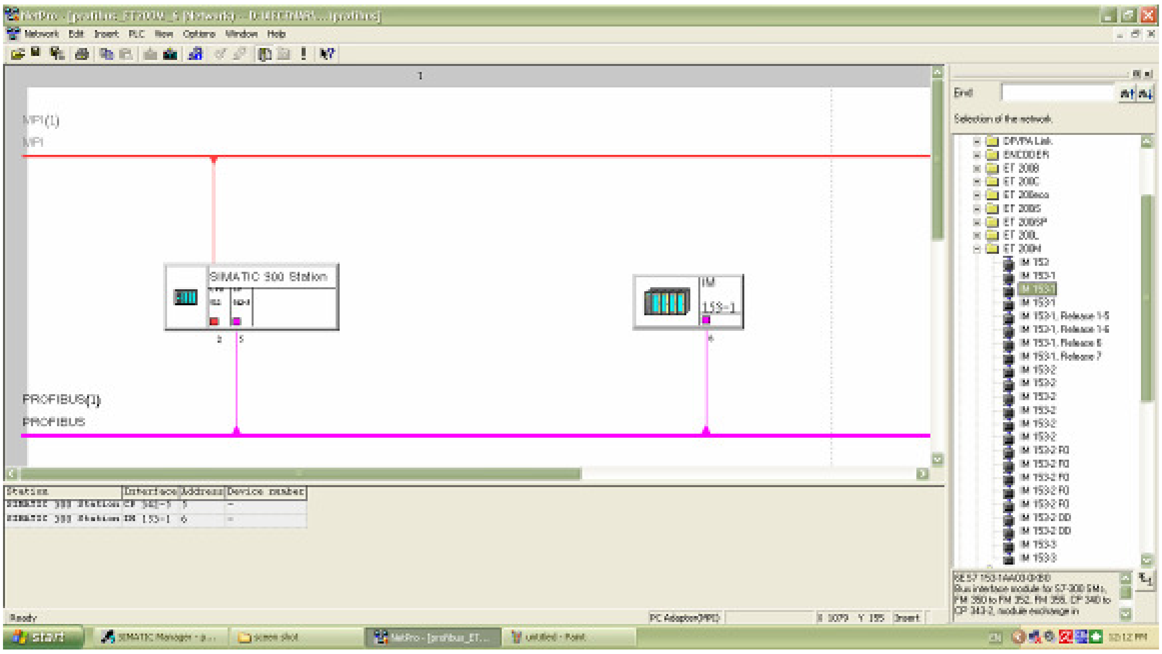


Figure 4.8: NetPro connection

هذه هي طريقة توصيل PROFIBUS الآن أصبح بأمكانك كتابة برنامجك الخاص بمشروعك كالشكل المعتاد. يمكنك مراقبة عمل الـ CPU أو الـ CP 342-5 من خلال أختيار Object properties من قائمة زر الموس اليميني و من ثم Diagnostics و من ثم Run (انظر الصورة 9):

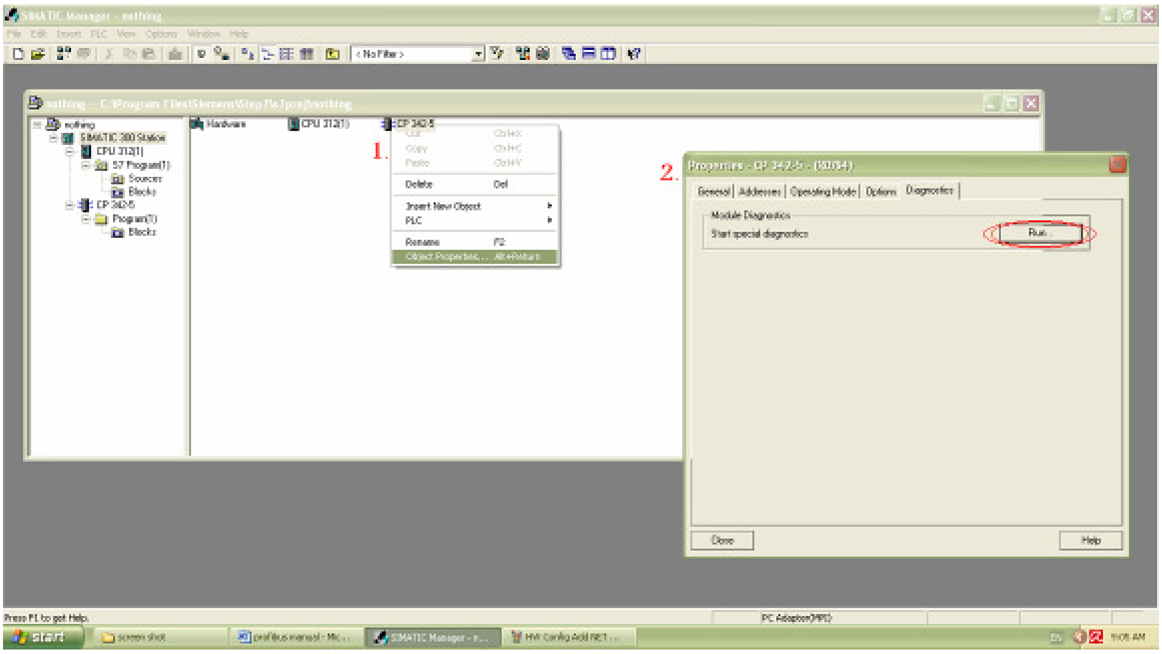


Figure 4.9: open Diagnostics screen

يمكنك مراقبة و معرفت أي معلومات تحتاجها من هنا (انظر الصورة 10):

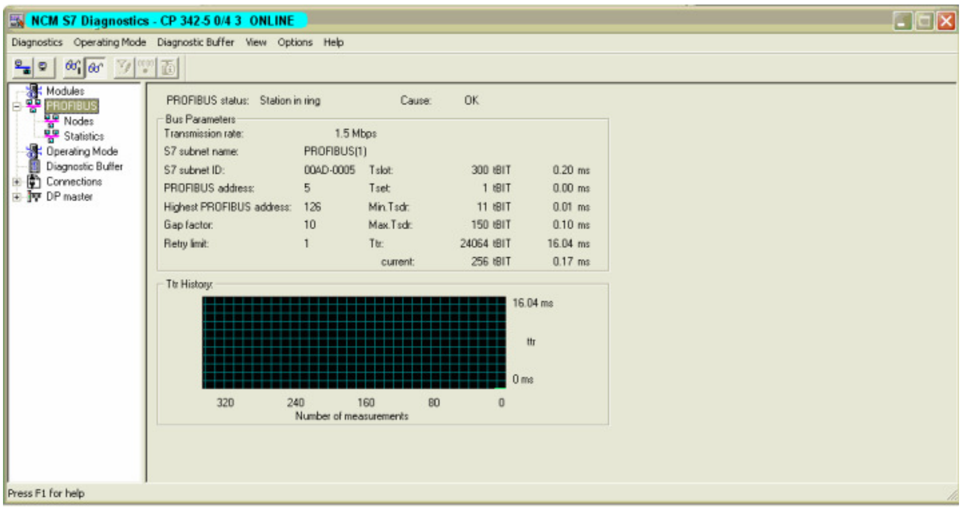


Figure 4.10: Diagnostics screen

Analog input Reading 4.4.3

4.4.3.1 تعريف الـ Analog input module:

تتيح الـ PLC S7-300 امكانية قراءة مداخل متغيرة Analog من خلال إضافة أحدى القطع الخاصة SM 331 AI المتوفرة بعدة أشكال, إخترنا منها AI 2x12Bit لاستعمالها في مشروعنا هذا .

نلاحظ من أسم الـ Module انها تحتوي مدخلين متغيرين Analog يتألف كل منهما من Bit12 أي أن دقة القراءة هي 2"12=4096. من هنا نلاحظ أننا لقراءة المدخل خلال البرمجة لا نقوم باستعماله كـ Bit كما في المداخل العادية Digital input حيث كنا نستعمل المداخل بهذا الشكل I 0.1 أما هنا فلا, لان كل مدخل هو Bit12 اي سنحتاج 2 Byte كون كل Bit8=Byte, و 2 Byte في لغة البرمجة تعني Word1 لذلك يتم تعريف مدخل الـ Analog خلال البرمجة كـ IWxxx مع الإشارة إلى أن الـ xxx هي الرقم المعرف للمداخل.

تظهر الصورة التالية أن Analog module قد حجزت المداخل بين الرقمين 64 و 67 أي أنه سيكون لدينا مدخلين متغيرين هما IW64 و IW66. نلاحظ أننا تجاوزنا الـ 65 و ذلك بسبب أن الـ Word=2Byte لذلك حجز المدخل الأول الـ 64 و الـ 65 و كذالك الامر نفسه بالنسبة للـ 67 حجزت مع الـ 66 (انظر الصورة 1):

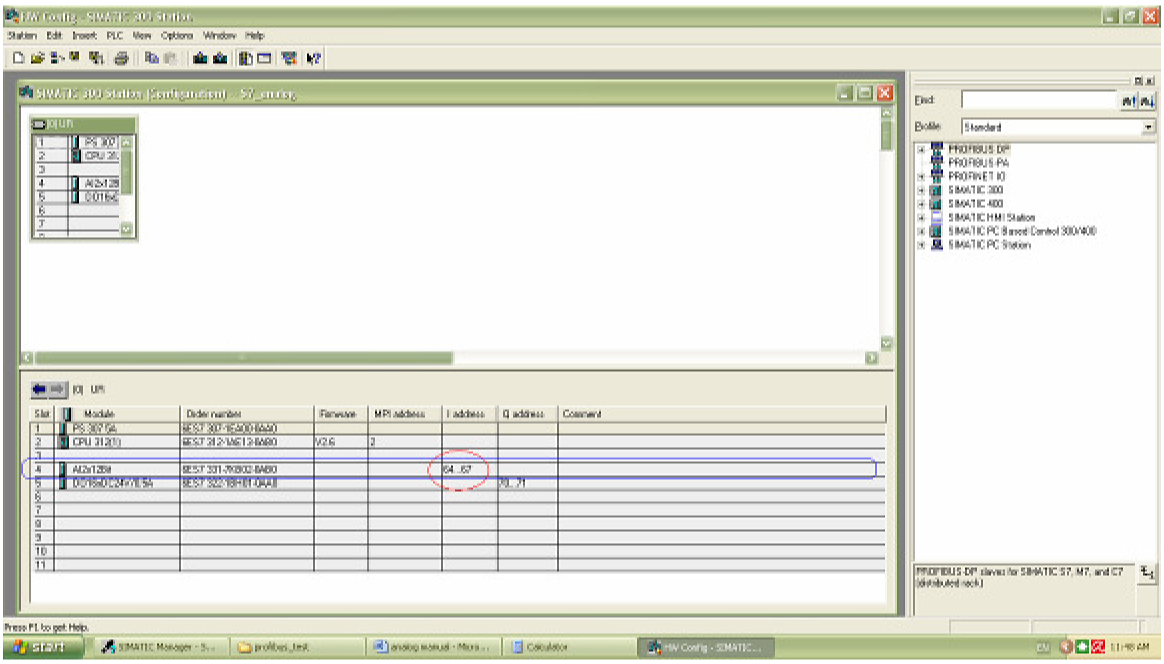


Figure 4.11: I/0 number specification

بعد أن تم بناء بنية الـ PLC كما في الصورة أعلاه نتحول إلى بدء كتابة برنامج الـ LAD الخاص بقراءة المداخل الـ Analog.

4.4.3.2 كتابة برنامج قراءة الـAnalog :

بداية أود التنويه إلا أن برنامج الـ SIMATIC Manager يوفر إمكانية إضافة بلوكات مبرجة و جاهزة للأستخدام يمكن الإستفادة منها أثناء كتابة البرامج (انظر الصورة 2). سنستخدم بعضها في برنامجنا.

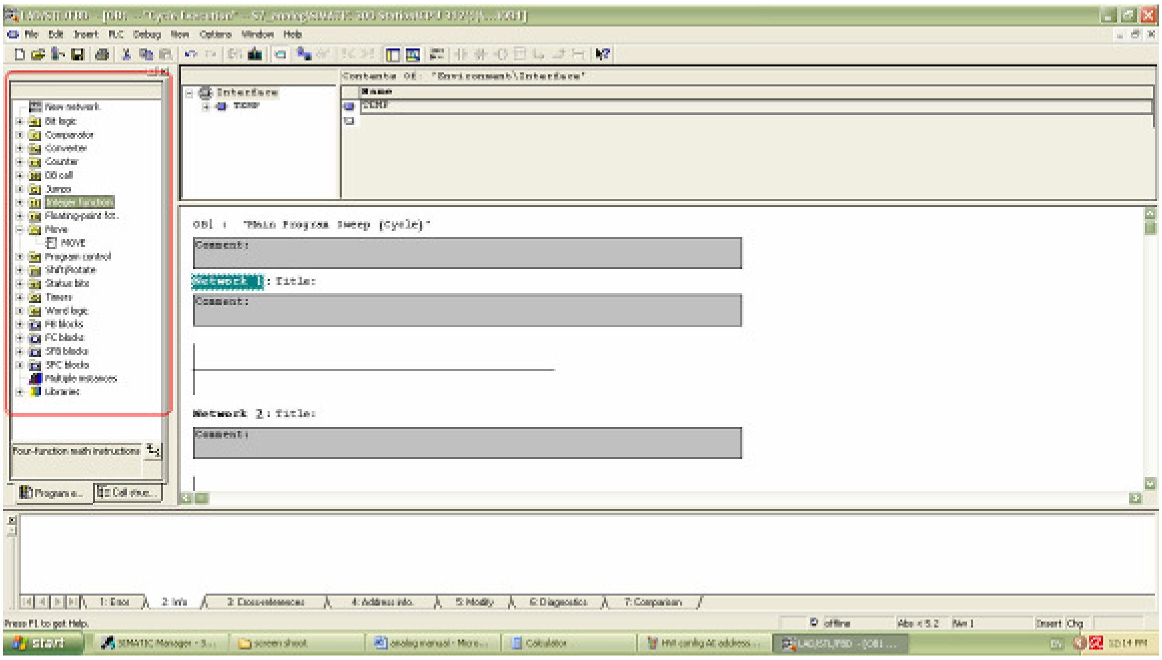


Figure 4.12: order librery

البلوكات المستخدمة (Blocks used) :

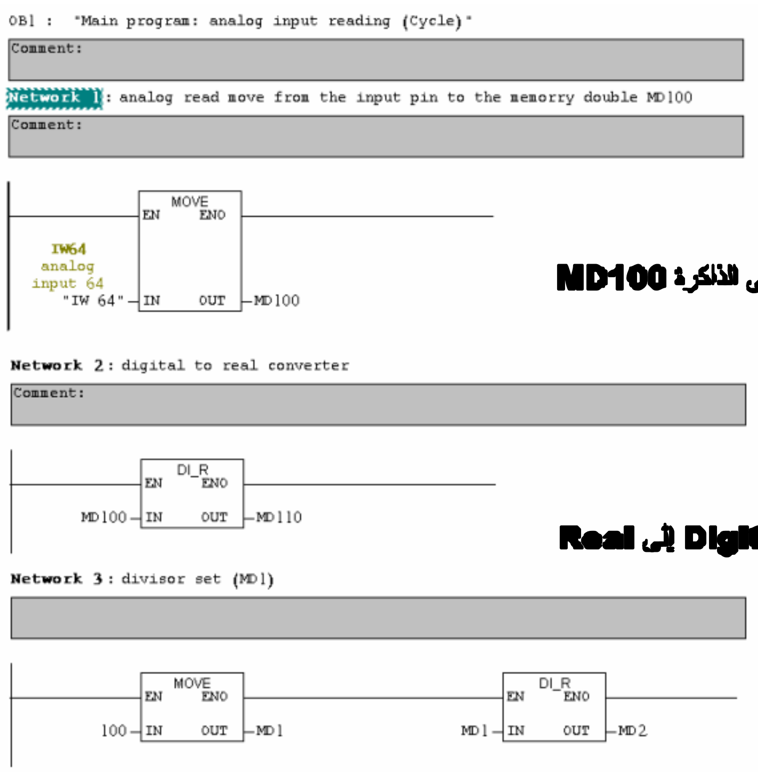
- **MOVE:**
  تقوم بنقل بيانات من موقع إلى آخر, يتم أستدراجها من قسم Move.
- **:DI_R (Digital to Real converter)**
  تقوم بتحويل البيانات إلى أرقا م حقيقية, أي من Hexadecimal إلى Decimal, يتم إستدراجها من قسم Converter.
- **:DIV_R (Real Division)**
  تقوم بقسمة الدخل الأول على الثاني, يتم أستدراجها من قسم Floating-point function.
- **:LT_R (CMP < R compare real number, true if less than)**
  تقوم بفحص أن كان الدخل الاول أصغر من الدخل الثاني أو لا, تستدرج من قسم Comparator.
- **:GE_R (CMP >= R compare real number, true if greater than or equal)**
  تقوم بفحص إن كان الدخل الاول أكبر أو يساوي الدخل الثاني أو لا, تستدرج أيضاً من قسم Comparator.

نقاط حفظ البيانات في الـ CPU الـ PLC:

تحتوي ال CPU على عدد من نقاط حفظ البيانات التي يمكن إستخدامها لحفظ البيانات المؤقته خلال البرنامج, يشار إليها بحرف M مصحوباً مع حرف ثاناً يدل على نوع هذه الذاكرة مع رقم يدل على العنوان أو فقط مصحوباً مع رقم في حال كان المراد أستخدامها لحفظ Bit واحدة فقط.

- M: تشير إلى ذاكرة لـ Bit واحدة فقط. تستخدم: **M x.y** (x و y تدلنا على عنوان الذاكرة).
- MB: تشير إلى ذاكرة لـ Byte. تستخدم بهذا الشكل: **MB x** (x يدل على عنوان الذاكرة).
- MW: يشير إلى ذاكرة لـ Word. تستخدم: **MW x** (x يدل على عنوان الذاكرة).
- MD: يشير إلى ذاكرة لـ Double Word. تستخدم: **MD x** (x يدل على عنوان الذاكرة).

بنية البرنامج:



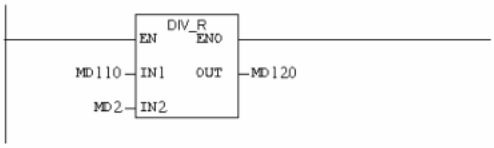
هذه الشبكة تقوم بنقل الرقم المقروء من IW64 إلى الذاكرة MD100

هذه الشبكة تقوم بتحويل محتوى الذاكرة من Digital إلى Real

هذه الشبكة تقوم بجعل MD1=100 و MD2=Real100

Network 4: division network to minimize the real number

Comment:



هذه الشبكة تقوم بقسمة الـ IN1 على الـ IN2 و تحتفظ في MD120

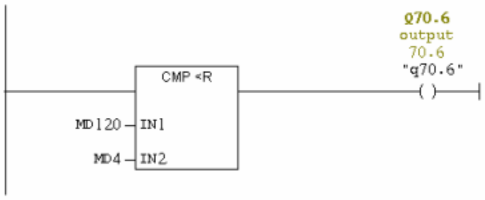
Network 5: comperator set MD3

Comment:

هذه الشبكة تقوم بجعل MD3=50 و MD4=Real50

Network 6: comparision network 1

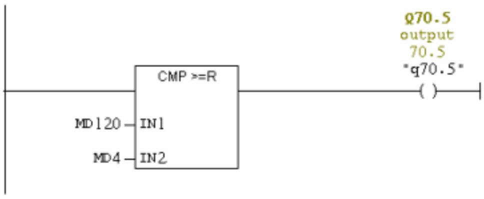
Comment:



هذه الشبكة تقوم بمقارنة, إذا نجحت تشغل Q70.6

Network 7: comparision network 2

Comment:



هذه الشبكة تقوم بمقارنة, إذا نجحت تشغل Q70.5

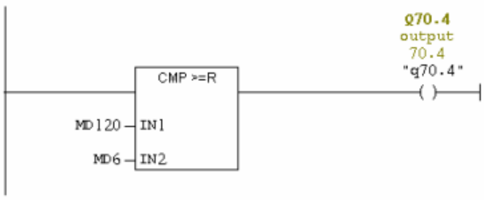
Network 8: comperator set MD5

Comment:

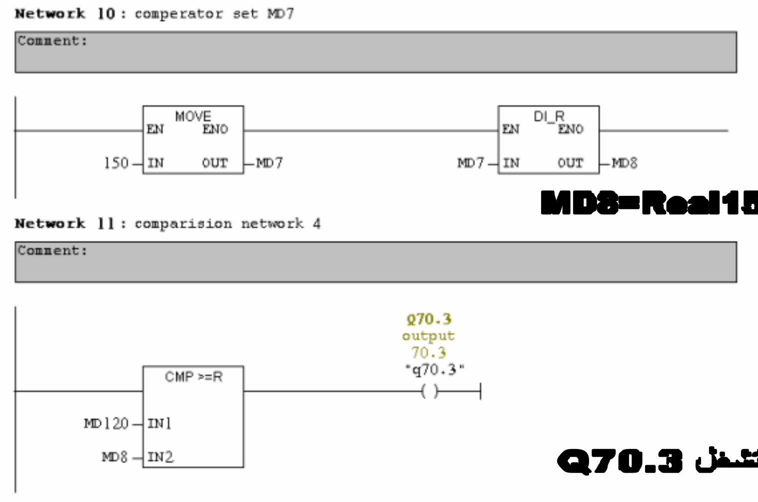
هذه الشبكة تقوم بجعل MD5=100 و MD6=Real100

Network 9: comparision network 3

Comment:

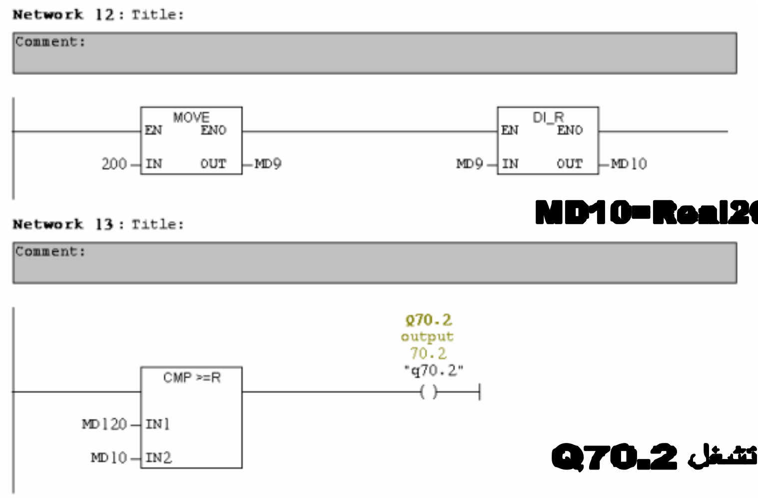


هذه الشبكة تقوم بمقارنة, إذا نجحت تشغل Q70.4



هذه الشبكة تقوم بجعل MD7=150 و MD8=Real150

هذه الشبكة تقوم بمقارنة, إذا نجحت تشغل Q70.3



هذه الشبكة تقوم بجعل MD9=200 و MD10=Real200

هذه الشبكة تقوم بمقارنة, إذا نجحت تشغل Q70.2

بعد الإنتهاء من هذا البرنامج نقوم بتحميله على الـ CPU لتجربته. لتجربة البرنامج نحتاج إلى مصدر طاقة كهربائية متغيرة من 0 إلى 10 Volt.

يتم توصيل الـ PLC و تغذيتها مع مدخل الـ Analog كما في الصورة التالية :

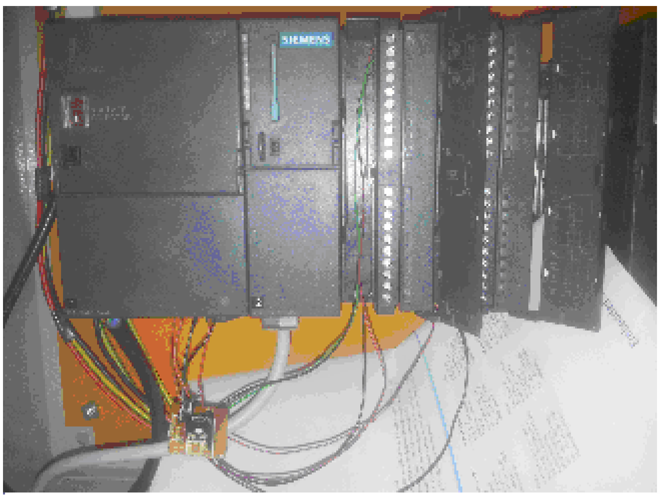


Figure 4.13: PLC Analog input connection

ستجد على باب الـ Module من الخلف طريقة تغذيتها بالطاقة و مكان المداخل أو المخارج المجهزة (انظر الصورة 14).

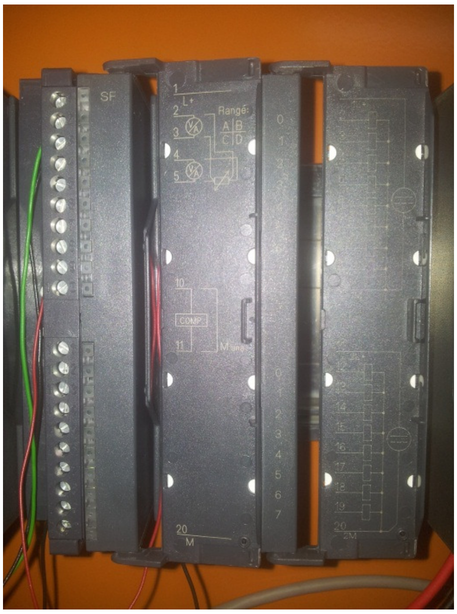


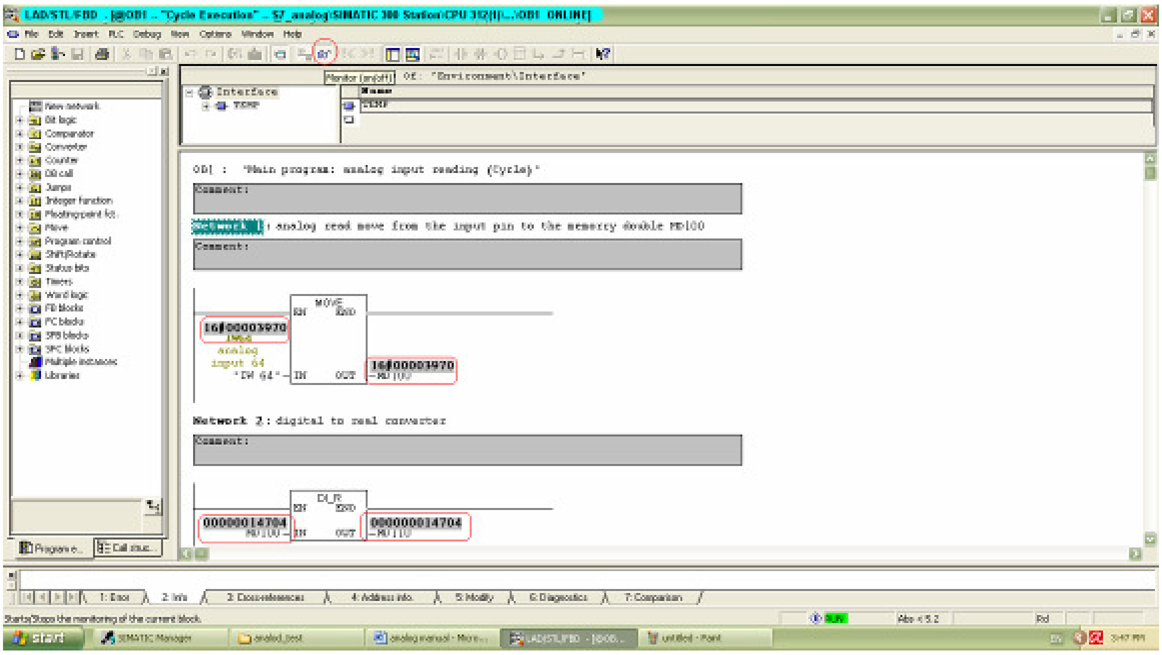
Figure 4.14: module connection MAP

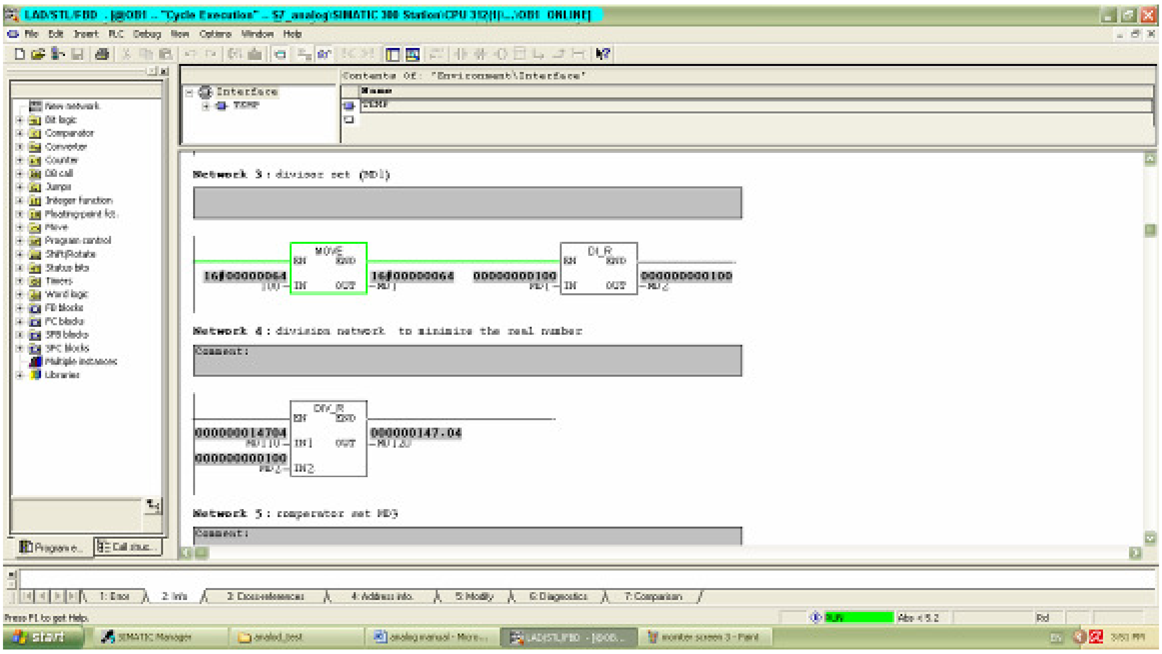
أن كنت قد نجحت في توصيل و تعريف و برمجة الـ PLC كما يجب, إذا تكون قد نجحت في تمثيل حجم الطاقة الموجودة على مدخل الـ Analog على أزرار مخارج الـ Output كما في الصور التالية:

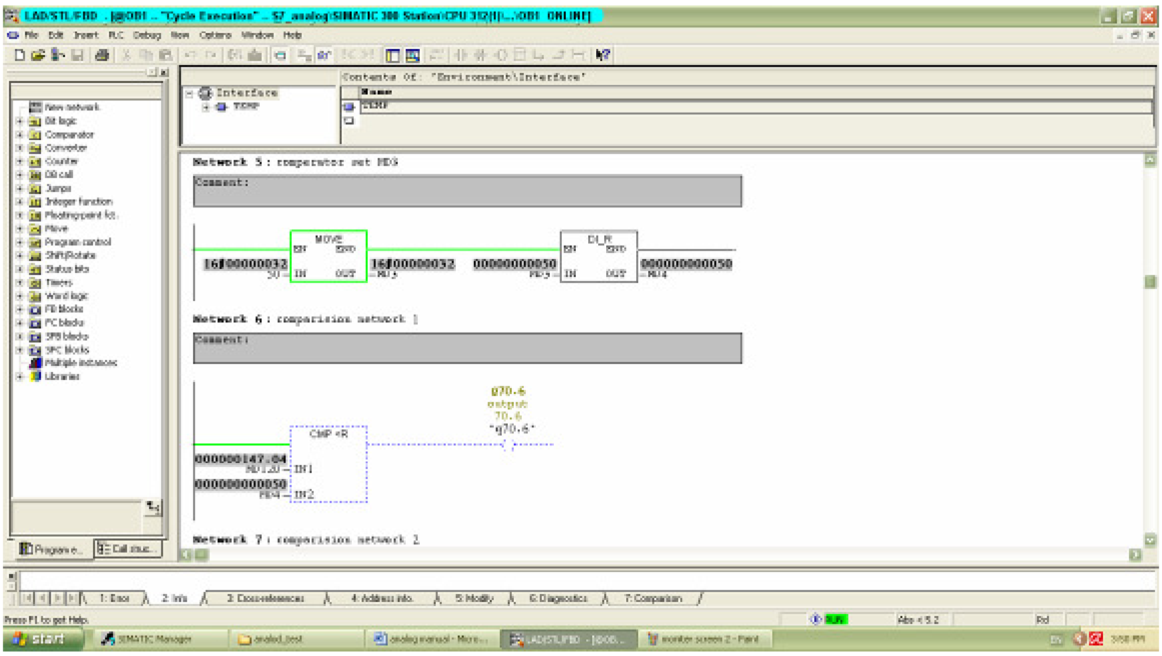
Figure 4.15: analog voltage on output PIN

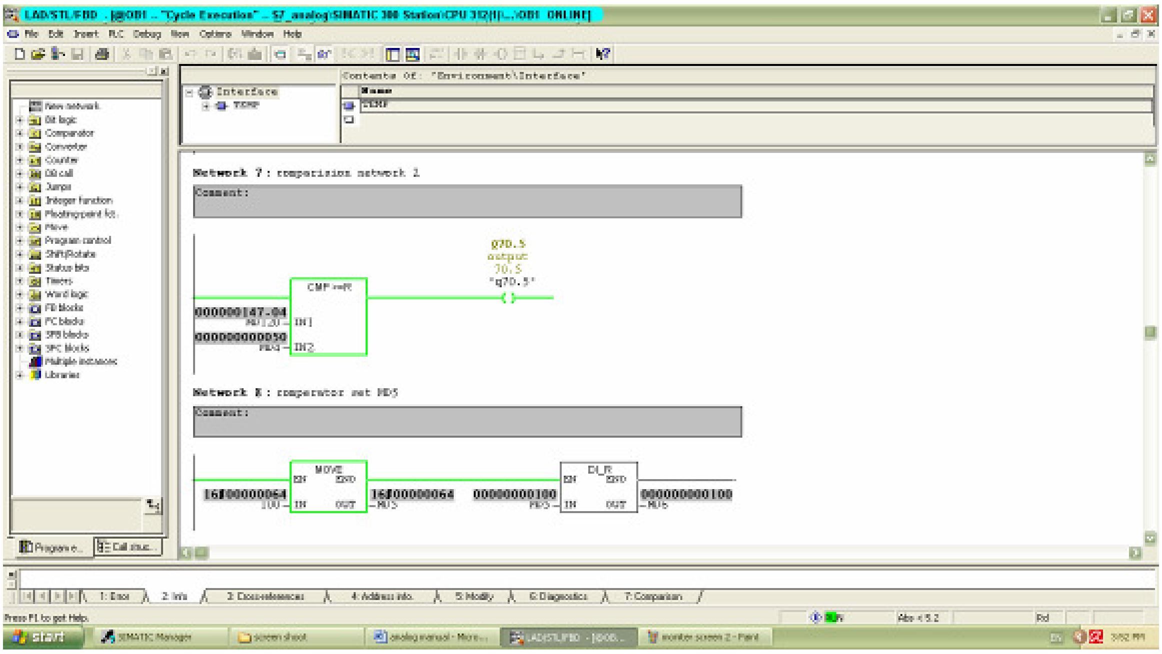
كما يمكنك إجراء محاكاة لما يجري على الـ PLC من برنامج الـ SIMATIC و ذلك من خلال الضغط على زر Monitor من برنامج مبرمج الـ OB1, في ما يلي صور لمحاكاة تجربة حقيقية على الـ PLC:

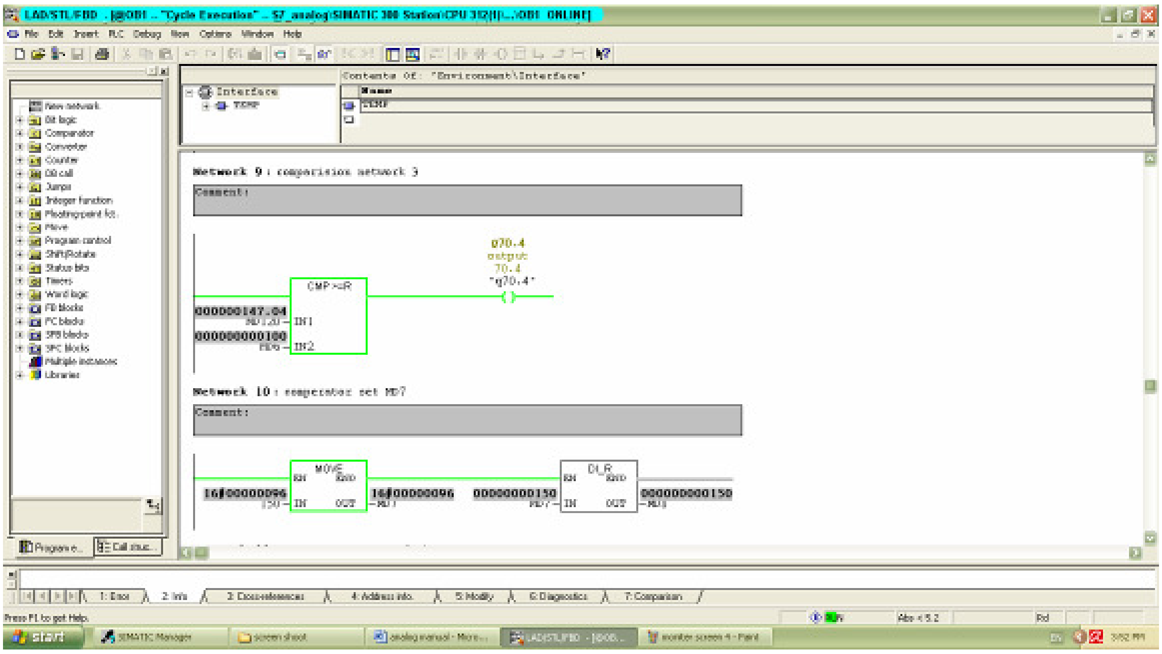
(جميع اللقطات التالية أخذة للحظة إدخال قيمة كهربائية تساوي 5.3 فولت عند مدخل الـ Analog)

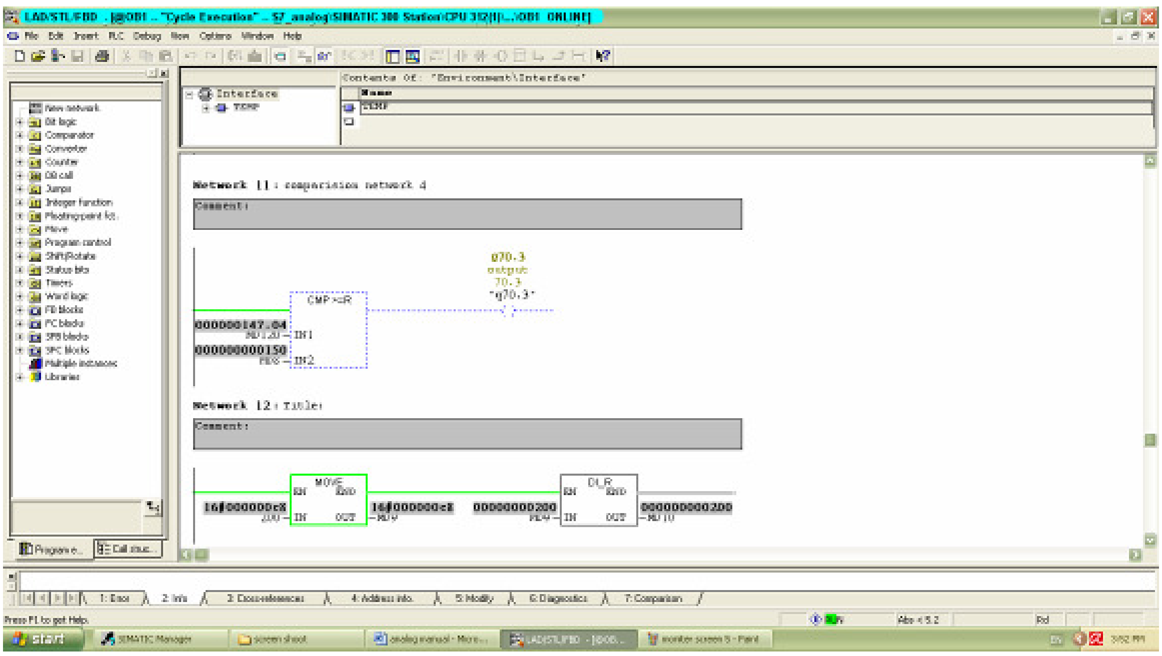


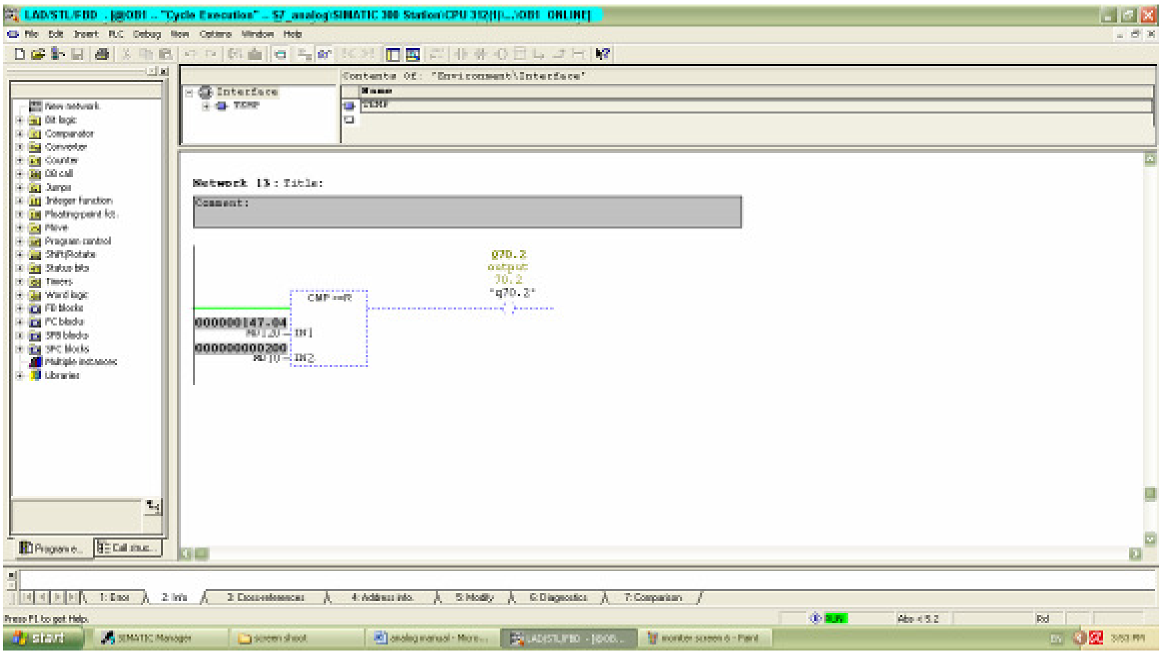





Network 7 : comparision network 2
Network 8 : comparator set MD5


Network 9 : comparision network 3
Network 10 : comparator set MD7

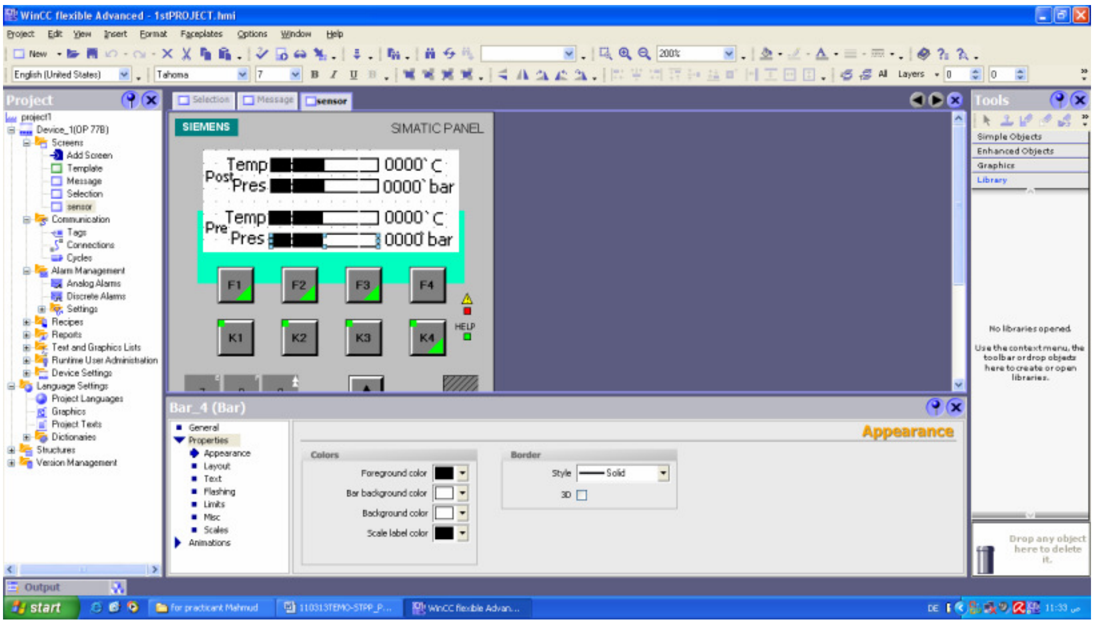

Network 11 : comparision network 4
Network 12 : Title:



4.5 WinCC WorkFlow:

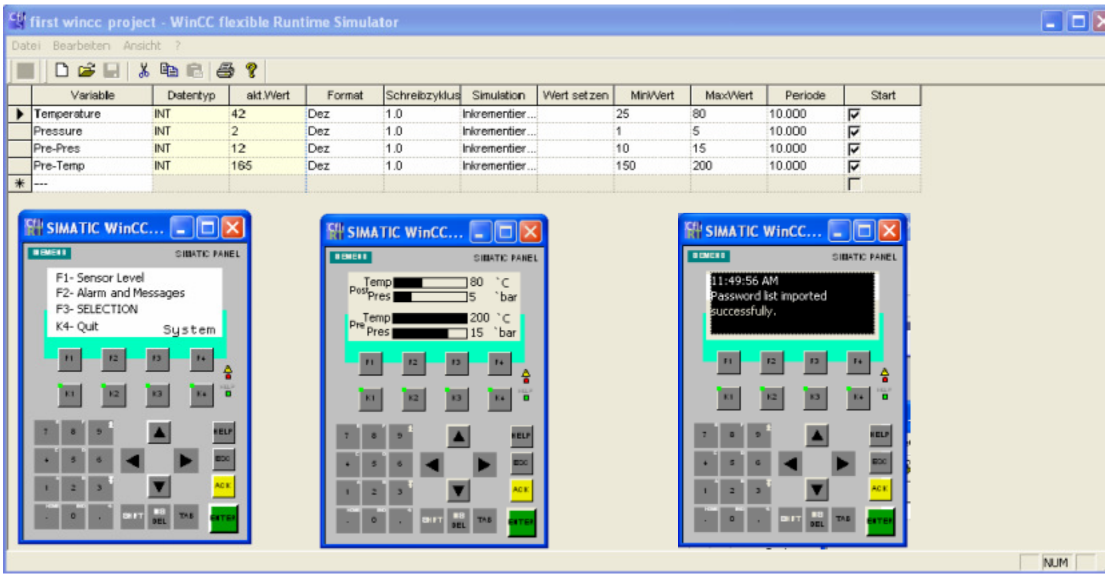
4.5.1 المشروع الأول (التطبيق) على الـ WinCC

بداية للتدرب على برنامج الـ WinCC قمنا بتطبيق الـ Tutorial الموجود في الملف WinCCflexible-GettingStarted-FirstTimeUser مع بعض التعديلات ليتناسب مع مشروع TEMO-STPP



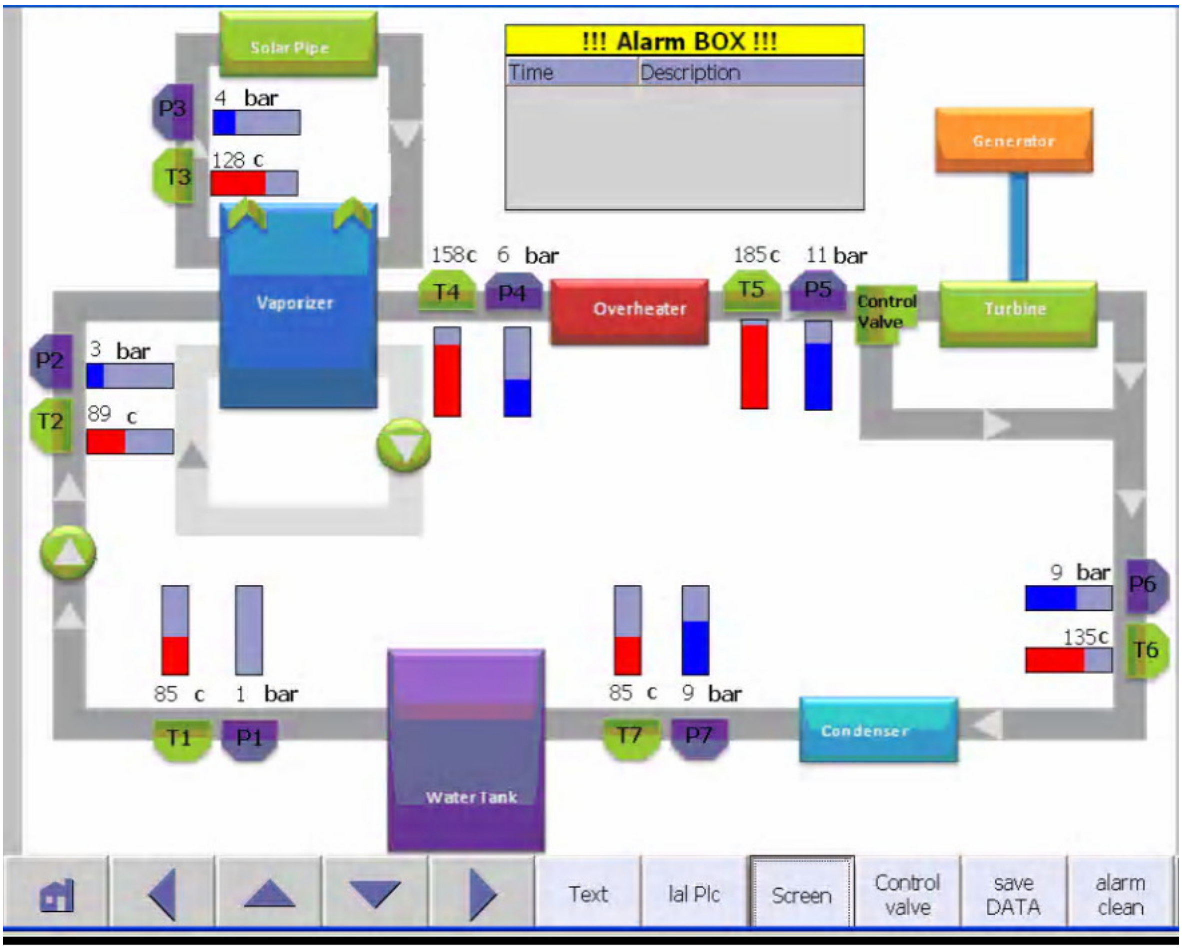
و قمنا بعد ذلك بتشغيل وهمي للبرنامج من خلال برنامج (flexible Runtime Simulator) و ذلك من خلال الضغط على المفتاح الظاهر في اللوحة التالية:

و ستظهر اللوحة التالية مع لوحة البداية (start screen) التي قمنا بتحديدها لتكون الشاشة (selection) لوحة البداية هي اللوحة الأولى من اليسار و من ثم (sensor) في المنطصف و لوحة (alarm) التي على اليمين



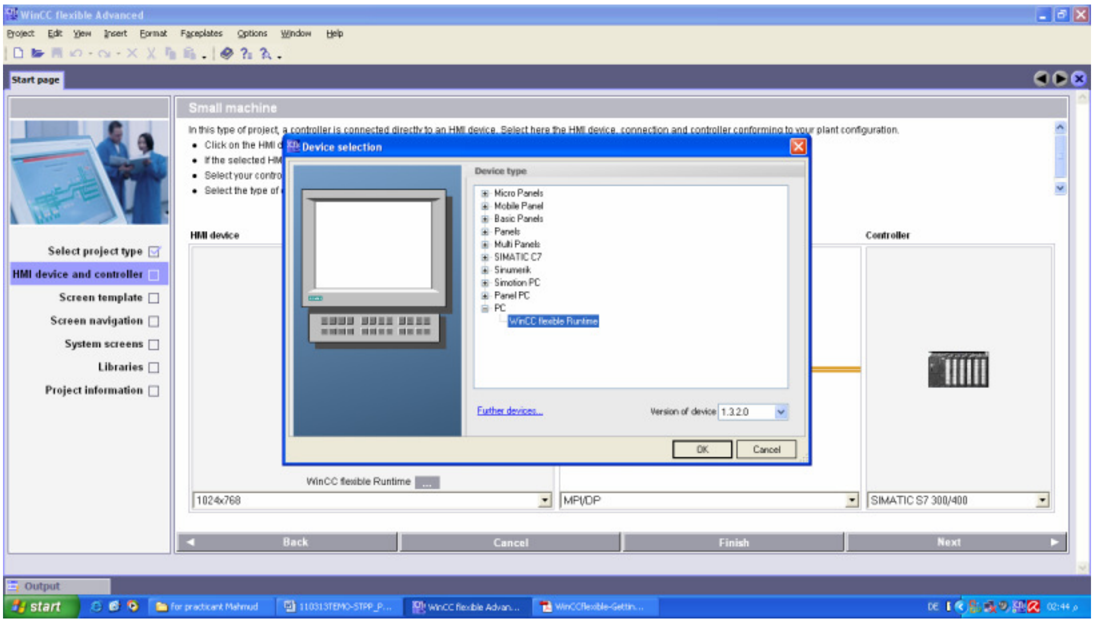
4.5.2 بداية تنفيذ المشروع على الـ WinCC

و بعد هذا التمرين الأولي قمنا بتطوير العمل إلى لوحة أكثر ملائمة لمشروع (TEMO-STPP) لتكون بهذا الشكل:



و تم تنفيذ ذلك من خلال و ضع المؤشرات القياسية على صورة المشروع الرئيسية مع إضافة شاشة عرض المنبهات (Alarm BOX) مع بعض أزرار المساعدة التي في الاسفل

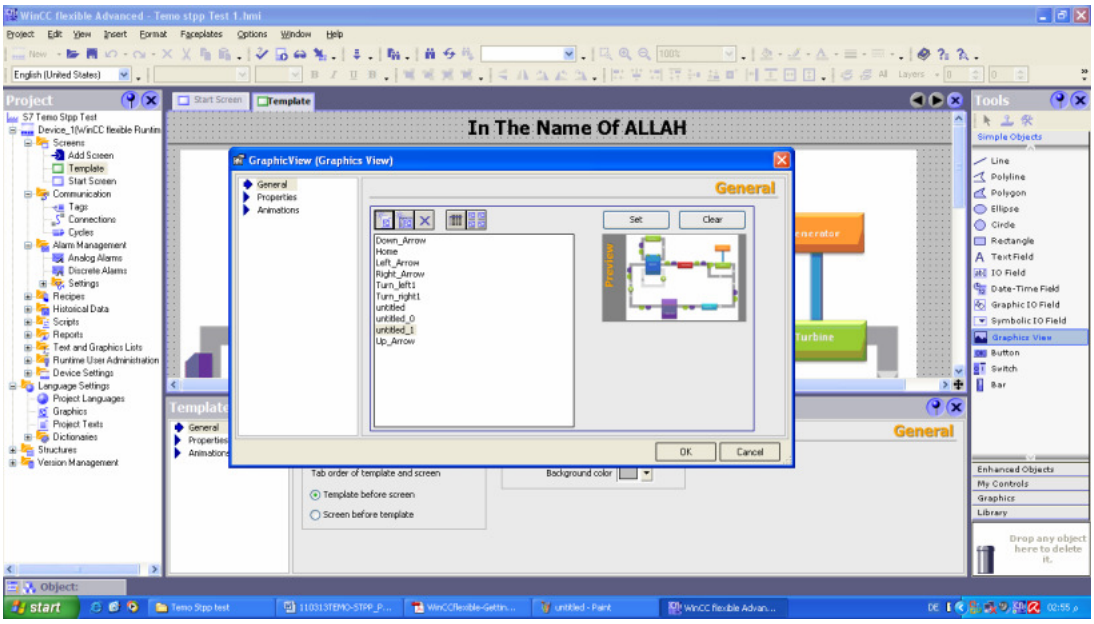
تختلف الشاشة التي هنا عن التي في الكتاب التعليمي (المشروع الأول) كون هذه الشاشة هي كاملة التحكم لا تلتزم بحدود جهاز التحكم (MobileControl) في المشروع الأول و معدة للكمبيوتر و ليس لجهاز الـ HMI كما في الملف التعليمي الاول. يتم تحديد هذا الخيار أثناء بداية مشروع جديد في الخطوة التي تختار بها أنظمة التحكم () و تختار حينها الـ PC و WinCC flexible Runtime على الشكل التالي:



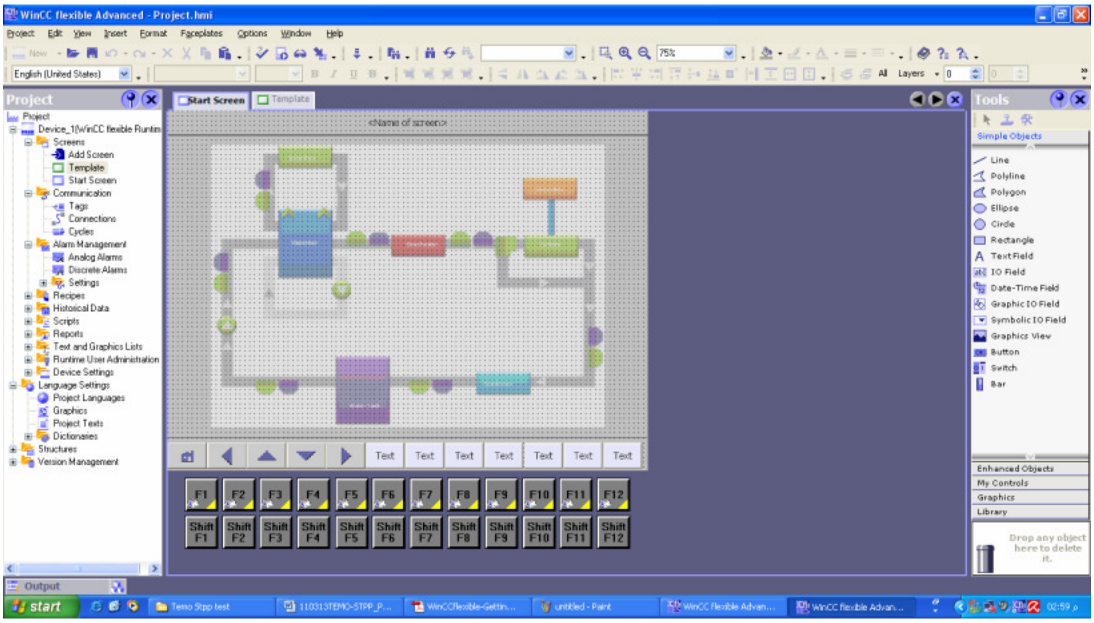
و تستطيع التحكم بباقي الخيارات حسب الحاجة كما يمكنك في حال عدم وجود خيار محدد, الإبقاء على الخيارات الأساسية للوحة.

لوضع صورة الخلفية أو أي شيئ أساسي في برنامج التحكم تقوم بوضعه في اللوحة الأساسية (Template Screen) و سيظهر في جميع لوحات البرنامج و أي تخصيص يكون باللوحة الخاصة فقط و ليس في اللوحة الأساسية (Template Screen).

صورة لكيفية وضع صورة خلفية:

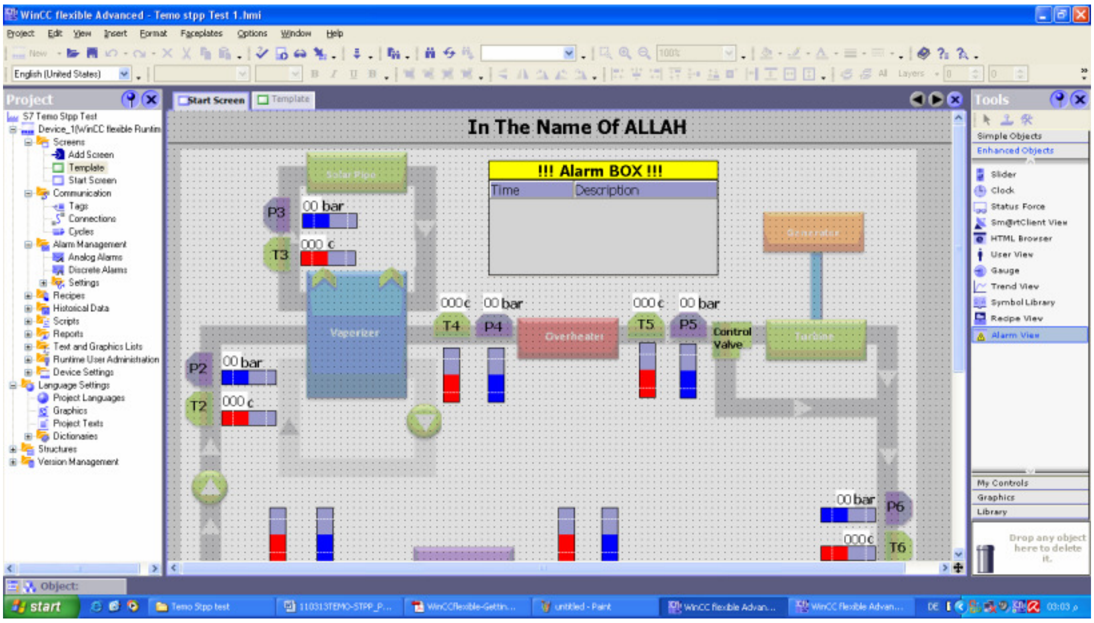


صورة توضح كيفية ظهورها في اللوحات الأخرى مثلا (Start Screen):



و بعد إضافة التخصيصات عليها حسب حاجتك و بنفس الطريقة التي تم بها تنفيذ المشروع الأول

صورة للوحة البداية بعد إضافة التعديلات عليها:



بعد ذلك يتم حفظ المشروع و أقلاعه كما في المشروع الأول ليتم الأنتقال إلى العمل على برمجة الـ PLC S7-300 من خلال برنامج SIMATIC Manager ليتم توصيل برنامج الـ WinCC المنفذ به.

لكن ما زال علي أن أعرف كيفية توصيل برنامج الـ SIMATIC manager Step 7 ببرنامج الـ WinCC لأستطيع التحكم و مراقبة الـ PLC من خلال أي كمبيوتر يحتوي برنامج الـ WinCC الذي أقوم بإعداده.

4.6 WinCC/step7 Integration

4.6.1 أساسيات التوصيل:

سيتم التوصيل عبر وصلة MPI . . .

تم إقاف العمل على هذا القسم بسبب انتهاء الترخيص الخاص بـــ WinCC

4.7 Monitoring software

في مشروعنا TEMO-STPP قمنا بأستخدام Velleman P8061 board لنقوم من خلال وصلها على جهاز كمبيوتر بمراقبة و التحكم بالمشروع كطريقة ثانية تعمل بالتوازي مع الـ PCL لتستمر واحدة في حال تعطل الأخرى أو إيقافها للصيانة.

تبرمج الـ Velleman VK8061 CPU بطرق متعددة, إخترنا منها طريقة Python. و Python هي لغة برمجة سهلة و قريبة جدا من لغات البرمجة السائدة و المعروفة بين المبرجين و المهندسين.

4.7.1 Velleman P8061 board

Velleman Board هي لوحة تحكم بمداخل و مخارج متعددة مع ودخل USB يتيح لك أمكانية توصيلها بالكمبيوتر لأجراء محاكاة و تحكم و مراقبة مداخلها و مخارجها المتعددة

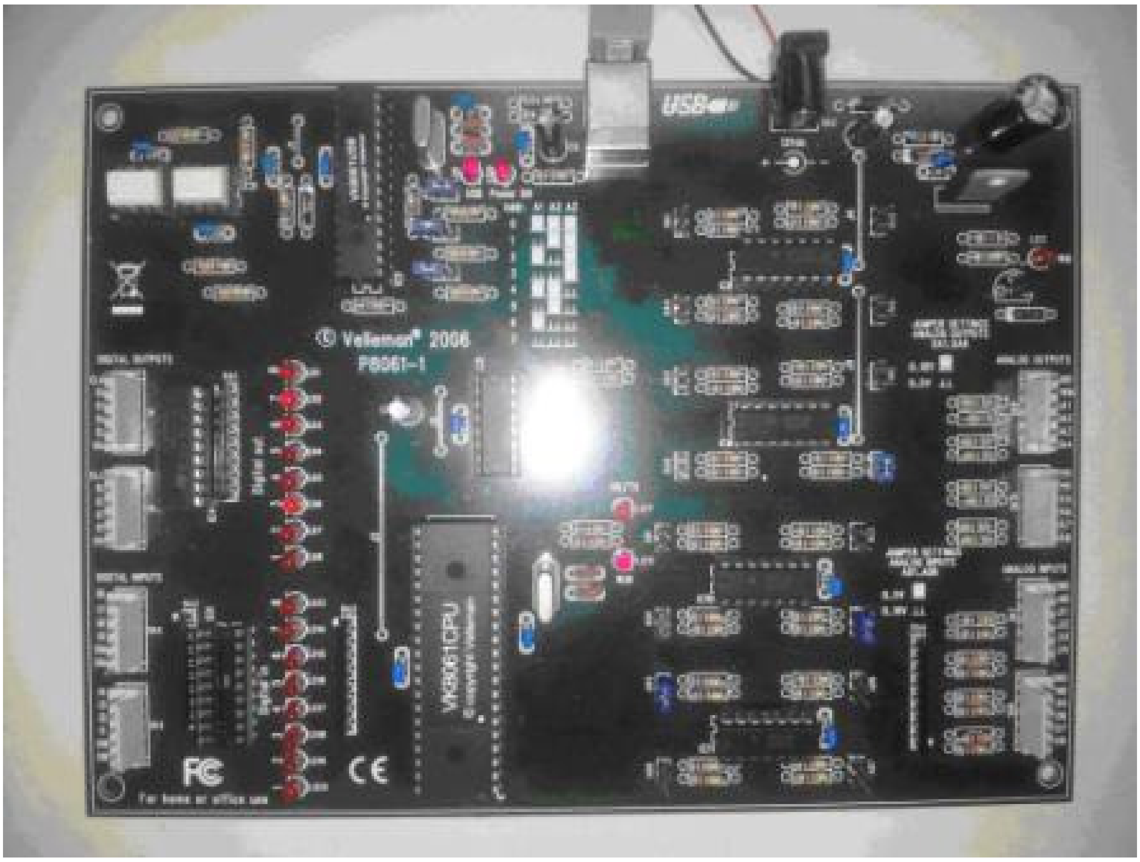


Figure 4.7.1: Velleman Board

يمكنك توصيل من 1 إلى 8 لوحات Velleman board إلى جهاز الكمبيوتر, ذلك كون الـ Velleman board لديها عنوان Board address يحدد من خلال الـ A1, A2 and A3 Jumpers (انظر الصورة 2) و يكون من 0 لـ 7 بما مجموعه ثمانية عناوين أي ثمانية لوحات.

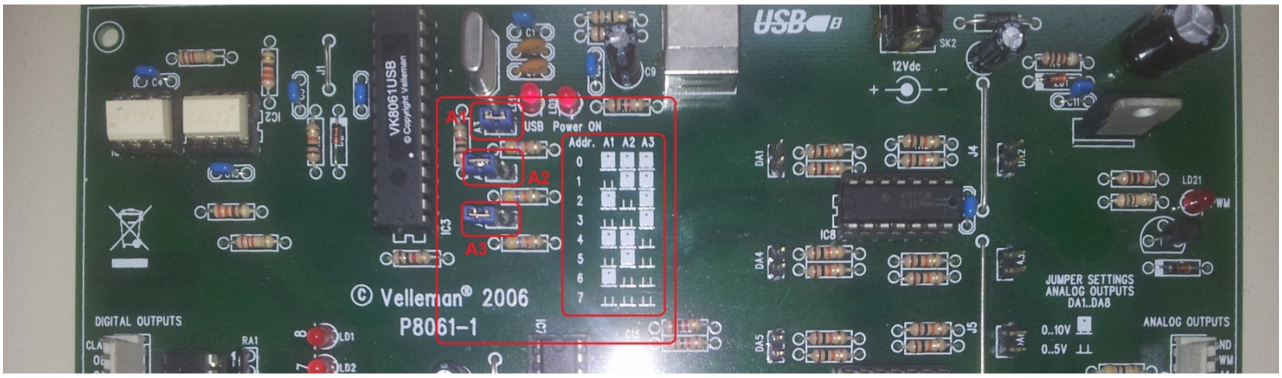


Figure 4.7.2: Velleman Board address setting

4.7.1.1 مواصفات و خصائص الـ Board

إن k8061 board تحتوي على ما مجموعه 33 مدخل و مخرج: ضمنه متغير و ثابت و مخرج إشارة PWM :

- 8 مدخل متغيرة Analog 10 bit: من 0 لـ 5V أو من 0 لـ 10V
- 8 مخارج متغيرة Analog 8 bit: من 0 لـ 5V أو من 0 لـ 10V
- 8 مداخل ثابتة Digital بحالة open collector
- 8 مخارج ثابتة Digital بحالة open collector و يتحمل تغدية خارجية 50V كحد أقصى
- مخرج PWM 10 bit بحالة open collector و يتحمل تغدية خارجية 40V كحد أقصى
- سرعة التنفيذ: 4 مل-ثانية للأمر الواحد 4ms per command
- تغذية خارجية = 12 V DC بقوة 300 mA

4.7.1.2 توصيل الـ board بجهاز الكمبيوتر

كما سبق و ذكرنا تتيح Velleman board إمكانية التوصيل بالكمبيوتر من خلال وصلة USB بطريقة آمنه من تأثير خارجي مضر.

كأي وصلة كمبيوتر خارجية يجب توفر ملف التعرفة Driver الخاص بهذه القطعة ليستطيع الكمبيوتر التفاعل معها, الملف الذي نحتاجه الـ Velleman board هو (mchpusb.sys) المتوفر على الأنترنت أو في القرص الصلب المرفق مع الـ Board. تقوم بإضافته من قسم Add new hardware من جهاز كمبيوترك.

كذلك يحتاج الكمبيوتر ملفات الوصلات الديناميكية (DLL (Dynamic Link Library للـ Board ليستطيع التفاعل معها و تضاف إلى نفس الملف الذي يحتوي البرنامج, و هي متوفرة أيضاً إما على الانترنت أو في القرص الصلب المرفق مع الـ board. جميع برامج و صيغ التوصيل متوفرة على DLL files عليك أن توفر هذه الملفات لتقوم بتفعيل التواصل و التفاعل بين الكمبيوتر و الـ Board. الملف الذي ستحتاجه لهذه الـ Board هو (K8061.dll) و ملف (mpusbapi.dll) يوجد أيضا على القرص المرفق أو يمكنك تحميله من الانترنت برنامجين لتجربة (Demo) و لتشخيص (Diagnosis) الـ board مع الكمبيوتر, و هذه بعد التجارب المنجزة:

برنامج الـ Demo :

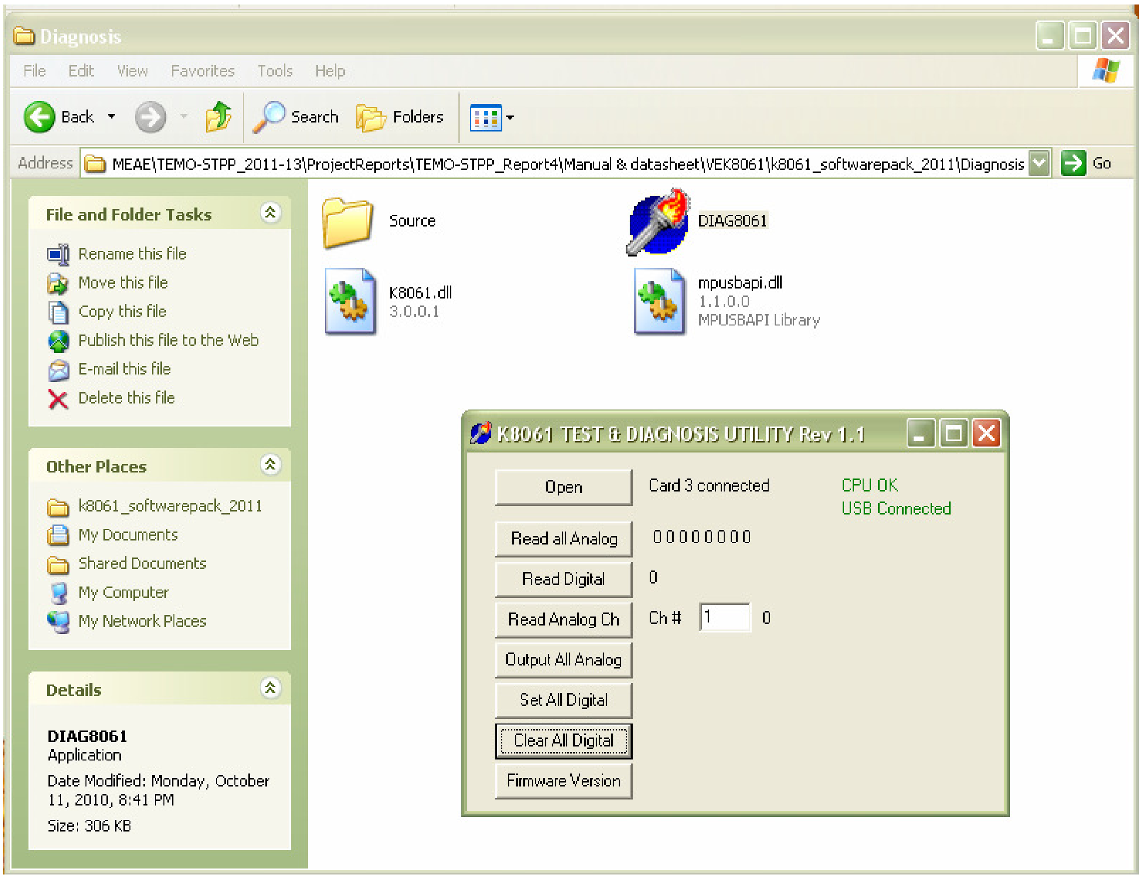


Figure 4.7.3: Demo screen shot on PC

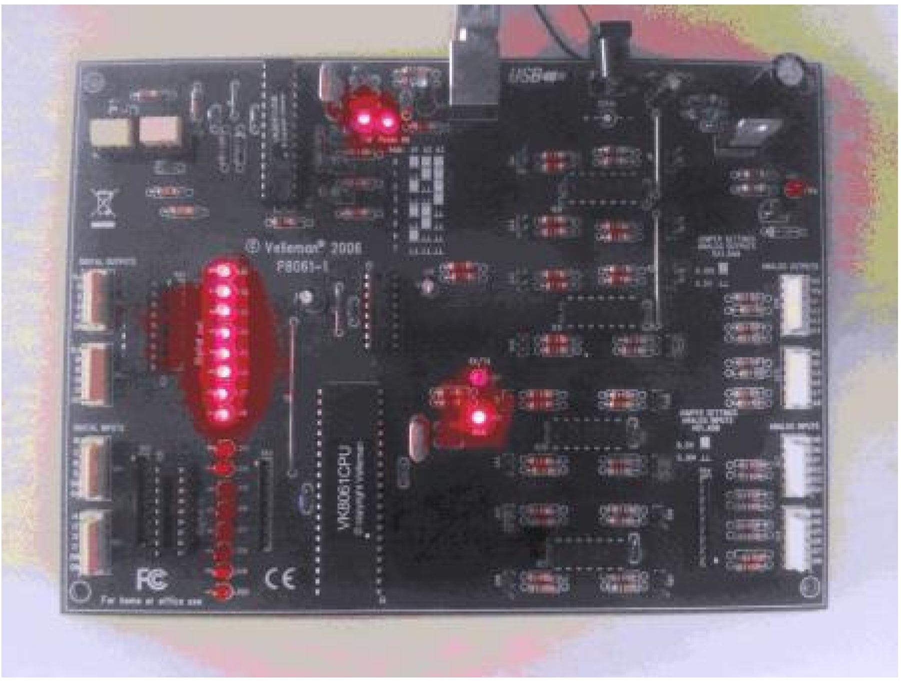


Figure 4.7.4: Velleman board interaction with Demo

برنامج الـ Diagnosis تجربة أولى:

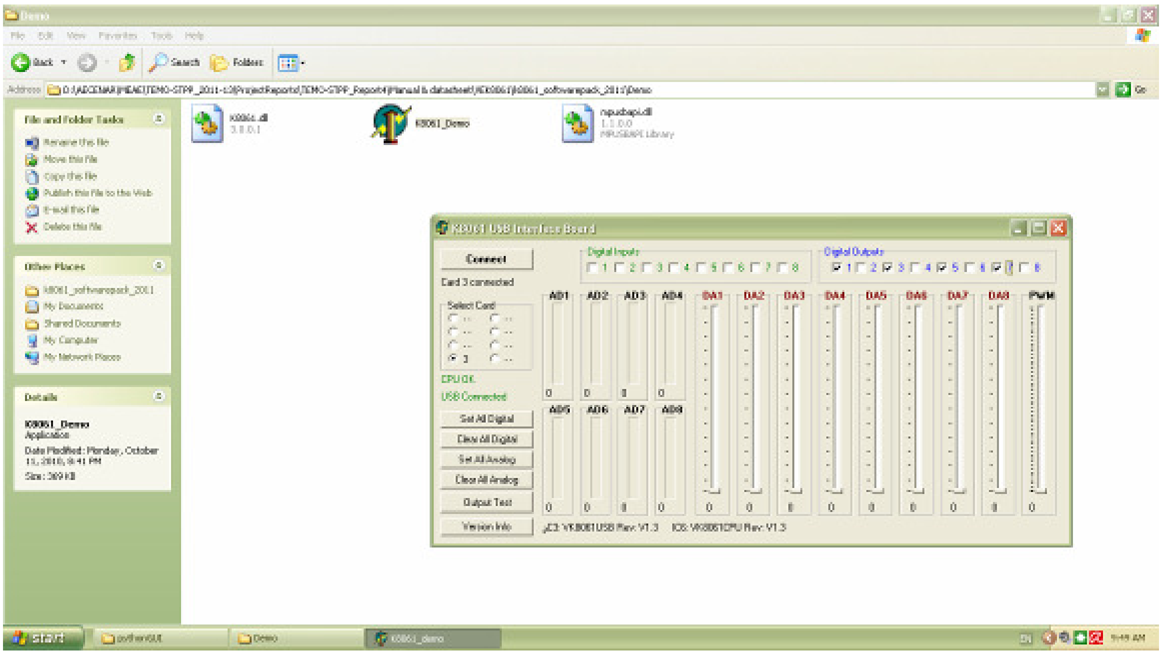


Figure 4.7.5: Diagnosis screen shot on PC

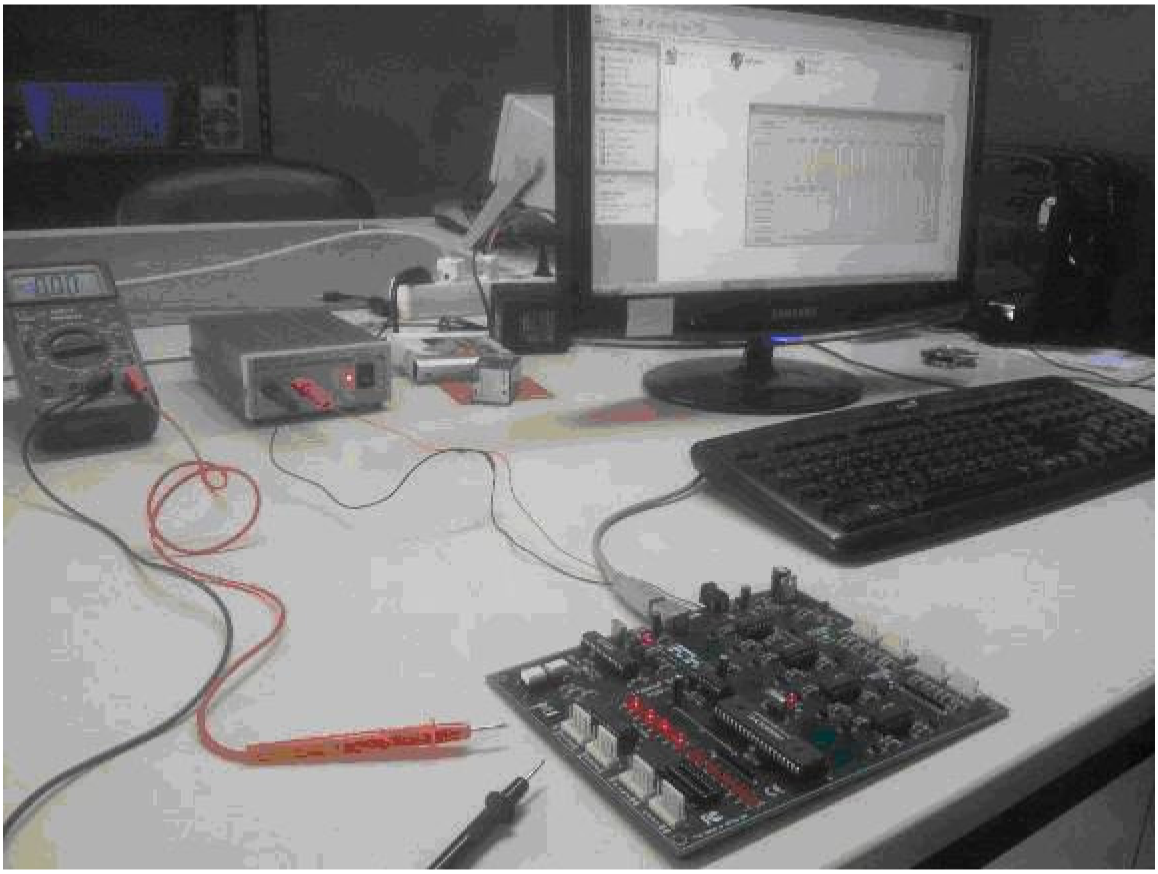


Figure 4.7.6: Velleman board interaction with Diagnosis

برنامج الـ Diagnosis تجربة ثانية:

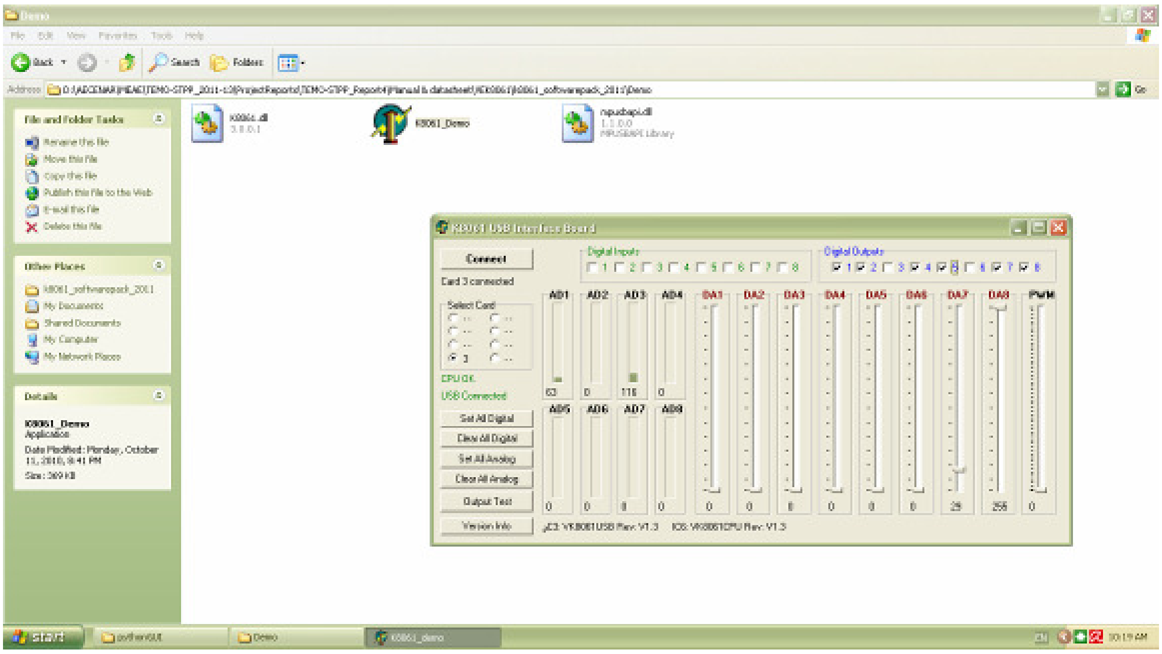


Figure 4.7.7: Diagnosis screen shot on PC

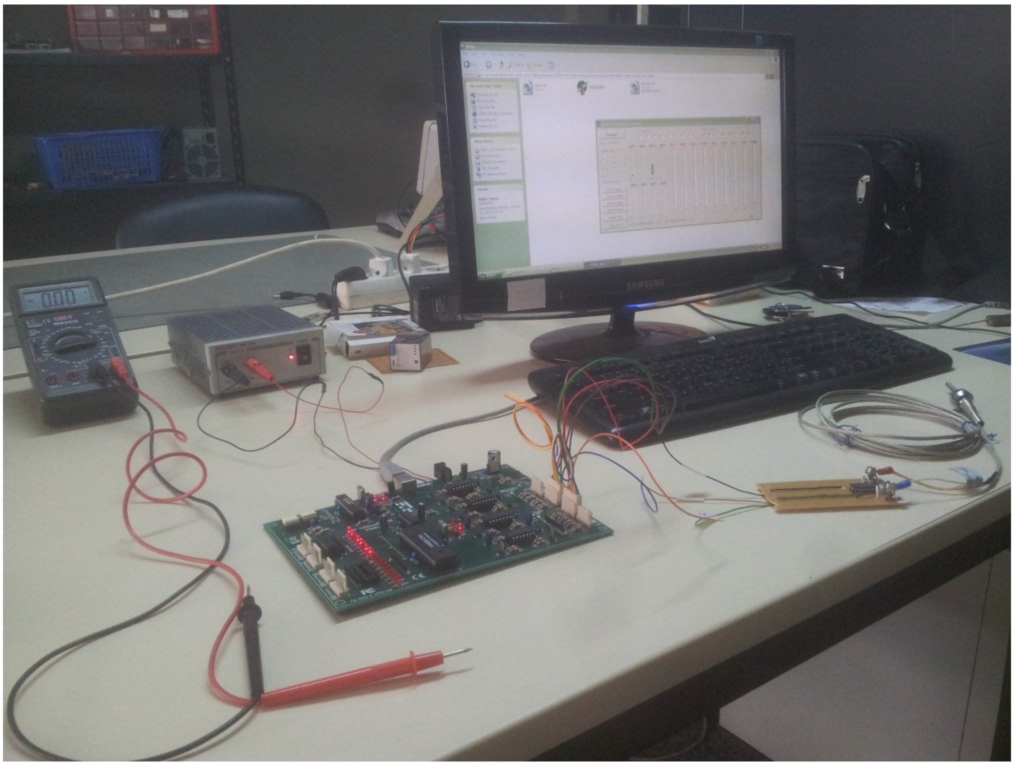
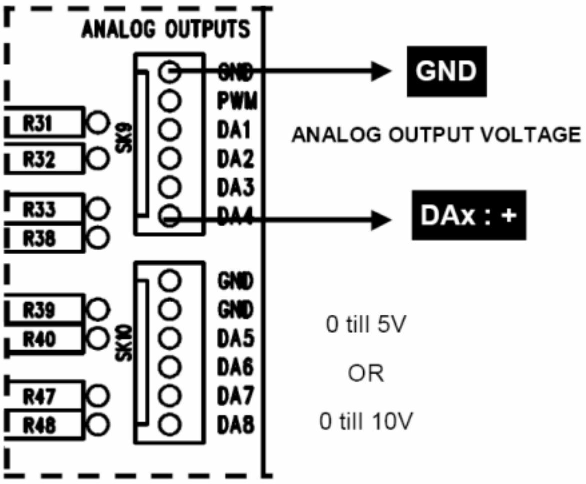


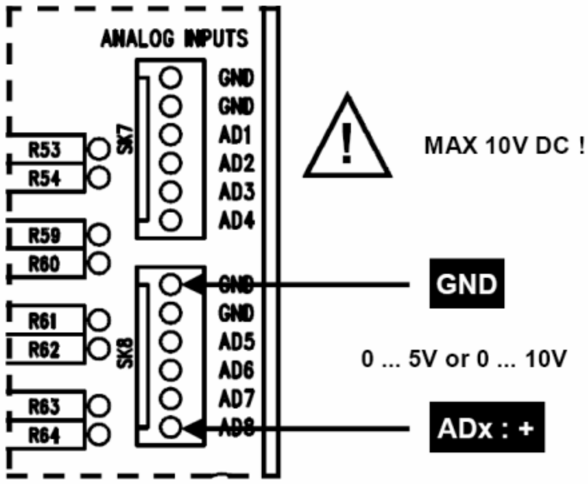
Figure 4.7.8: Velleman board interaction with Diagnosis

4.7.1.3 توصيل مداخل و مخارج الـ Board

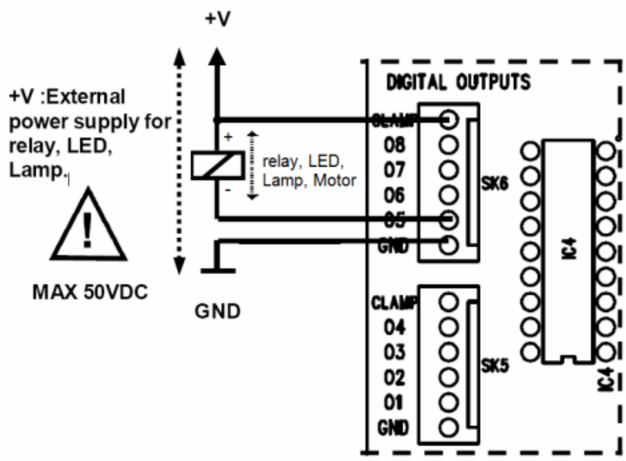
1. Analog output :



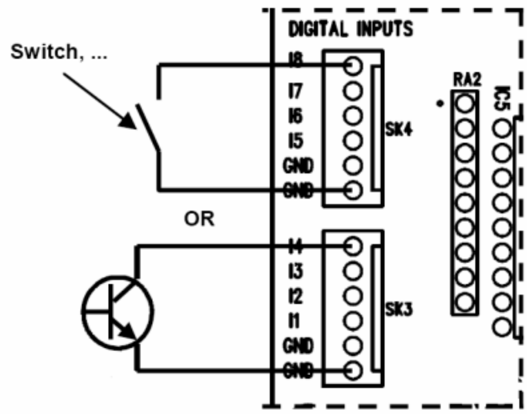
2. Analog input :



3. Digital output :



4. Digital input :



4.7.2 Python Software:

Python هى لغة برمجة عامة لمعظم المجالت ان لم تكن جميعها، وهى High Level Programming اى انها قريبة جدا من لغة الإنسان "الإنجليزية" بدأت فى عام 1989 على يد Guido Van Rossum Language وهو عالم هولندى

تتميز Python بـ:

- سهولة التعلم
- وضوح الكود وسهولة صيانته
- Open source: فيقوم على تطويرها ألاف المطورين

.pyo او .pyc او .py بيكون امتداها Python ملفات:

.py => ملف بايثون

.pyc => ملف بايثون مترجم

.pyo => ملف كائن لبايثون

لمعرفة المزيد عن لغة البرمجة Python يمكنك الإطلاع على عدة كتب و مصادر تحدثت بتفصيل عن Python. ولكن سنكتفي هنا بهذا القدر من الحديث عنه لنبدأ فورا ببرنامجنا الخاص.

هدف البرنامج الذي ننوي كتابته هو التحكم و محاكاة محطة الطاقة لمشروع TEMO-STPP من خلال برنامج User interface (GUI) على هذا الشكل كبرنامج أولي:

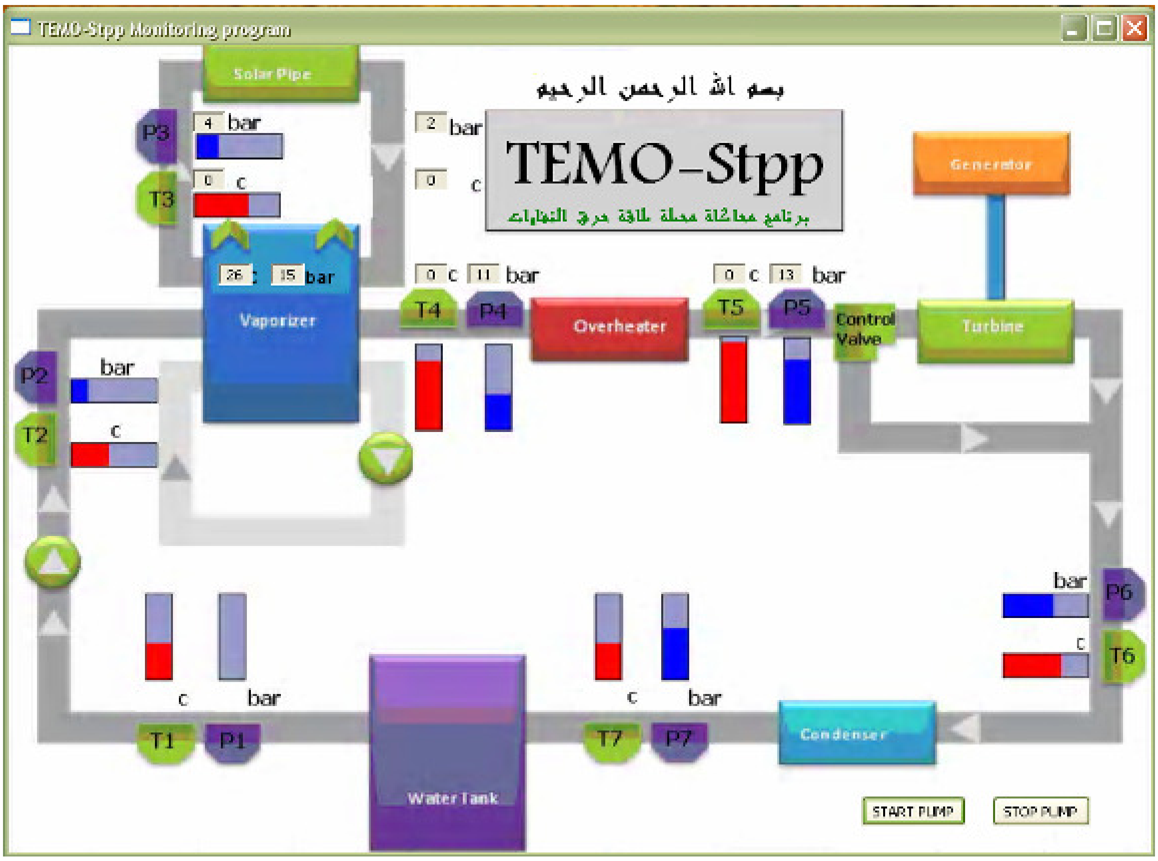


Figure 4.7.9: python monitoring software

نحتاج لتنفيذ و تشغيل هذا العمل إلى Python compiler و إلى مكتبة إضافية لا يحتويها الـ compiler العادي و هي wxPython,تجدها في القرص المرفق أو يمكنك لحصول عليها عبر الانترنت.

بعدها سيصبح بإمكاننا بدء كتابة البرنامج. و هو كما يلي مع توضيحات :

```
#*************************************************************************************************************
import wx
import random
import sys

import time

from ctypes import *
import thread

#********************panel frame **********************************************************************************
wx.SetDefaultPyEncoding("iso-8859-15")
BACKGROUND_IMAGENAME = "TEMO-STPPscreenshot.bmp"

class MyBackgroundPanel(wx.Panel):
    def __init__(self, parent):
        wx.Panel.__init__(self, parent)
        self.bmp = wx.Bitmap(BACKGROUND_IMAGENAME)
        self.SetSize(self.bmp.GetSize())
        self.Bind(wx.EVT_PAINT, self.on_paint)

    def on_paint(self, event = None):
        dc = wx.BufferedPaintDC(self, self.bmp)

class MyFrame(wx.Frame):
    def __init__(self, parent = None, title = "TEMO-Stpp Monitoring program"):
        self.testUSB = True
        self.dll = None
        self.USBAdr0 = 0
        self.USBAdr1 = 1
        self.USBAdr2 = 2
        self.USBOpened = False
        self.counterUSBBoards = 3
        wx.Frame.__init__(self, parent, -1, title)
        panel = MyBackgroundPanel(self)
        LABELSTYLE = wx.BORDER_SUNKEN | wx.ST_NO_AUTORESIZE |
        wx.ALIGN_CENTER_HORIZONTAL

        #Start of pump
        self.button_Start_Flow_Read = wx.Button(panel, -1, "START PUMP",
        pos=(650,570))
        self.Bind(wx.EVT_BUTTON, self.OpenPumpANDStartRead,
        self.button_Start_Flow_Read)
        #Stop of pump
        self.button_Stop_Read_pump = wx.Button(panel, -1, "STOP PUMP",
        pos=(750,570))
        self.Bind(wx.EVT_BUTTON, self.StopReadButton, self.button_Stop_Read_pump)
```

```
        # Vaporizer out
        self.temp_Vaporizer_out = wx.StaticText(
        panel, size = (26, -1), pos = (160, 165), style = LABELSTYLE
        )
        self.pressure_Vaporizer_out = wx.StaticText(
        panel, size = (26, -1), pos = (200, 165), style = LABELSTYLE
        )
```

بنفس الطريقة يتم كتابة الـ LabelStyle الخاص بـ:

```
        # Overheater in
        # Overheater out
        # SolarPipe in
        # SolarPipe out

        # Layout
        self.Fit()

    def on_timer(self, event = None):
        division = 2

    # Vaporizer out
        answer = (self.dll.ReadAnalogChannel(3,1))/division
        new_value = str(answer)
        self.temp_Vaporizer_out.SetLabel(new_value)
        self.temp_Vaporizer_out.Refresh()
        new_value = str(random.randint(12, 16))
        self.pressure_Vaporizer_out.SetLabel(new_value)
        self.pressure_Vaporizer_out.Refresh()
```

بنفس الطريقة يتم ضبط الـ Label الخاص بكل من:

```
    # Overheater in
    # Overheater out
    # SolarPipe in
    # SolarPipe out
```

مع تغيير الـ Analog PIN Channel number

```
#******************** Run USB System ************************************************************************
    def OpenUSBBoardThread(self):
        self.dll = windll.K8061
        i = self.counterUSBBoards
        for doit in range(0,i+1):
            try:
                self.dll.OpenDevice()
                self.USBOpened = True
# debug info
                print 'USB Board is now connected!'
#end debug info
            except:
                txt = 'Please Check USB Board connection'
                print txt
                return

        self.dll.OutputAnalogChannel(3,8,255)

#******************** STOP Button ****************************************************************************
```

```
        def StopReadButton(self, event):
                self.dll.ClearDigitalChannel(3,1)
                print 'Digital Channel Cleared, pump turn off'

#******************** START Button ****************************************************************************************
        def OpenPumpANDStartRead(self, event):
                wx.MessageBox("Do you want to open pump and start monitoring?", "start
                monitoring", wx.OK|wx.ICON_INFORMATION)

        # open the USB board
                self.OpenUSBBoardThread()
                time.sleep(0.5)
                self.dll.SetDigitalChannel(3,1)
                self.timer = wx.Timer()
                self.timer.Bind(wx.EVT_TIMER, self.on_timer)
                self.timer.Start(1000)

#******************** main definition and loop ****************************************************************************
        def main():
                """Testing"""
                app = wx.PySimpleApp()
                f = MyFrame()
                f.Center()
                f.Show()
                app.MainLoop()
        if __name__ == "__main__":
                main()

#*******************************************************************************************************************************
```

بعد إتمام كتابة البرنامج يمكن تشغيله من خلال الضغط على Run و ستظهر لك الشاشة التفاعلية المنفذة.

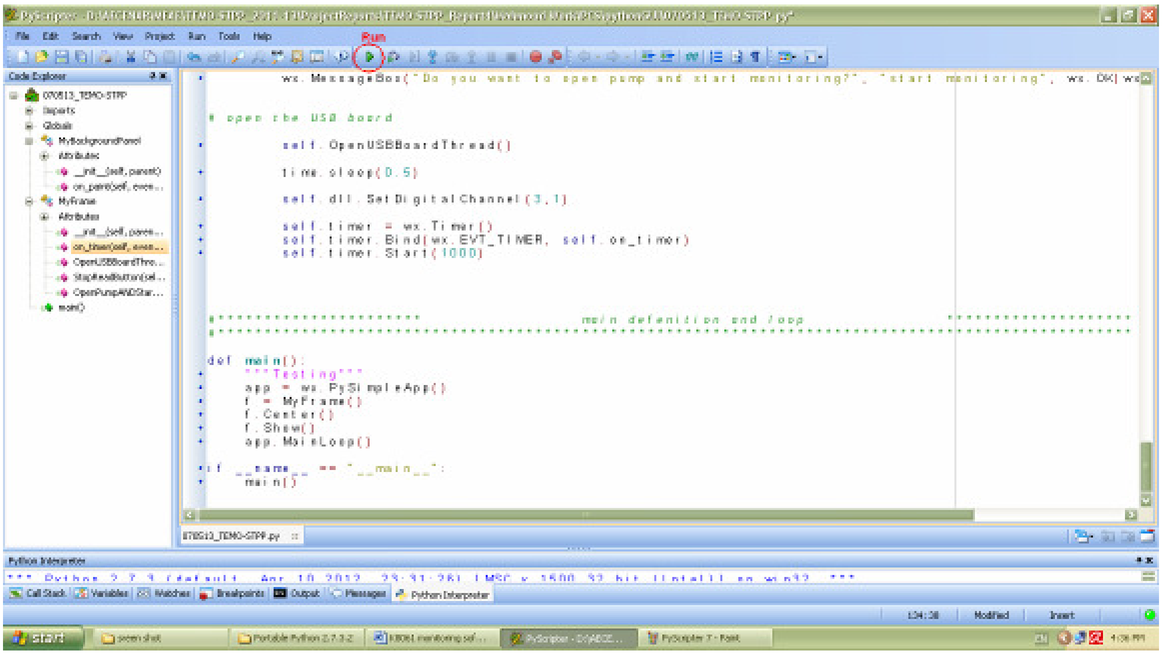


Figure 4.7.10: PyScripter software

أما أن كنت لا تملك برنامج PyScripter فيمكن كتابة البرنامج كـ text file عادي من خلال الـ NotePad و لكن عند الحفظ يحفظ بصيغة .py مثال (TEMO-STPP.py) بعدها يمكن تشغيلها من خلال الـ **Python (command line)** .

نتيجة العمل برنامج تفاعلي بين المستخدم و المحطة كما تظهر الصورة التالية (انظر الصورة 11) في المثال هذا كما نلاحظ تم تفعيل حساس حراري واحد و هو الموجود على الـ Vaporizer.

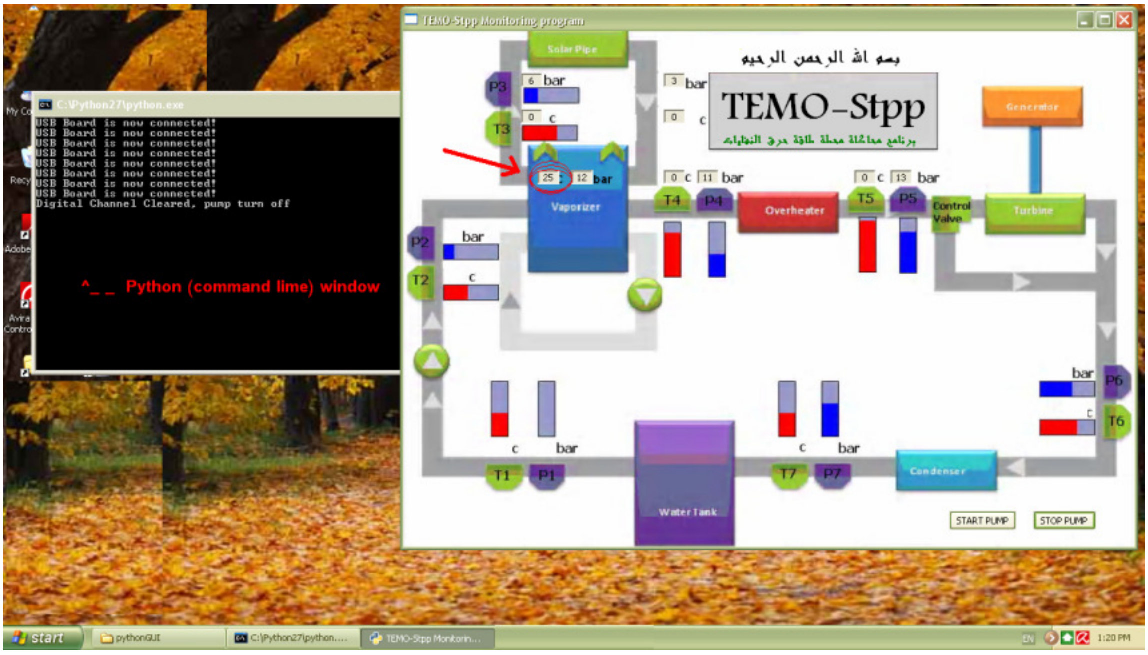


Figure 4.7.11: GUI software

يمكنك أيجاد برنامج الـPython كاملاً في الـ Appendix D

5 Sensors implementation and design

5.1 Temperature sensor:

In TEMO-STPP project We use 8 thermocouple sensors distribute as shown in **figure 1**. The thermocouple sensor we use it, is the PTFE Exposed Welded Tip Thermocouples ' type K ' which conform the project's need. The 'K' PTFE thermocouple have a temperature range between 0°C and 200°C with cable length 3 or 5 meter (the datasheet of this sensor can find it in Appendix A).

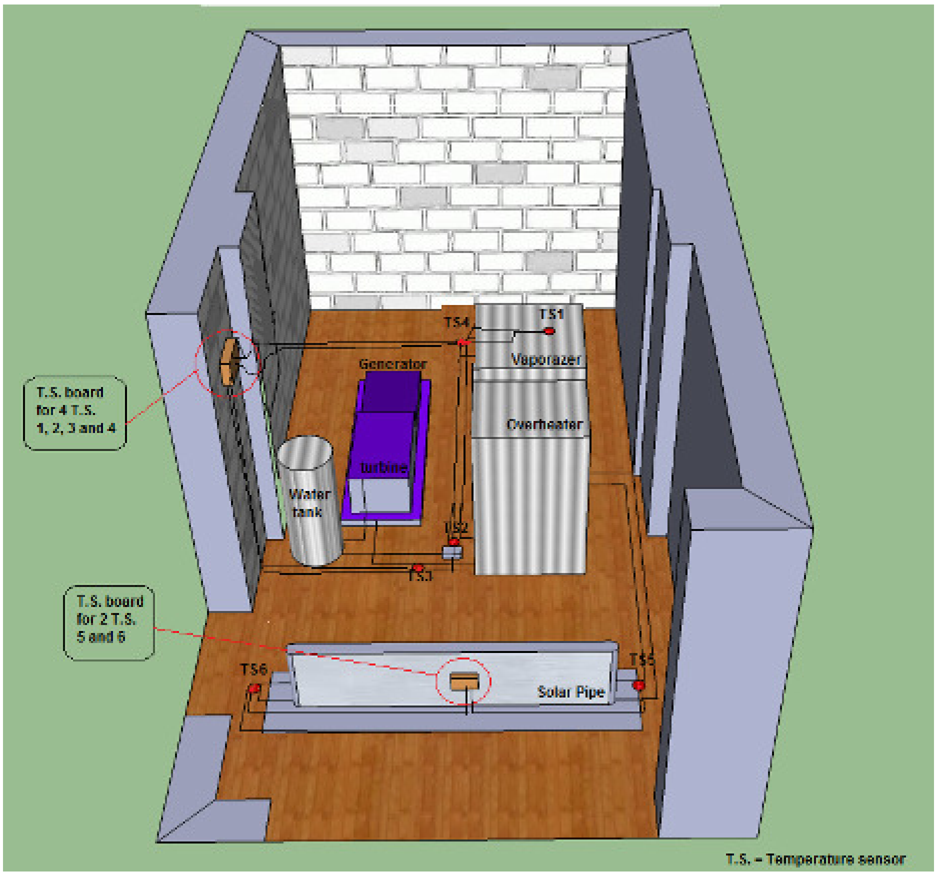


Figure 5.1.1: Temperature sensors distribution for TEMO-Stpp project

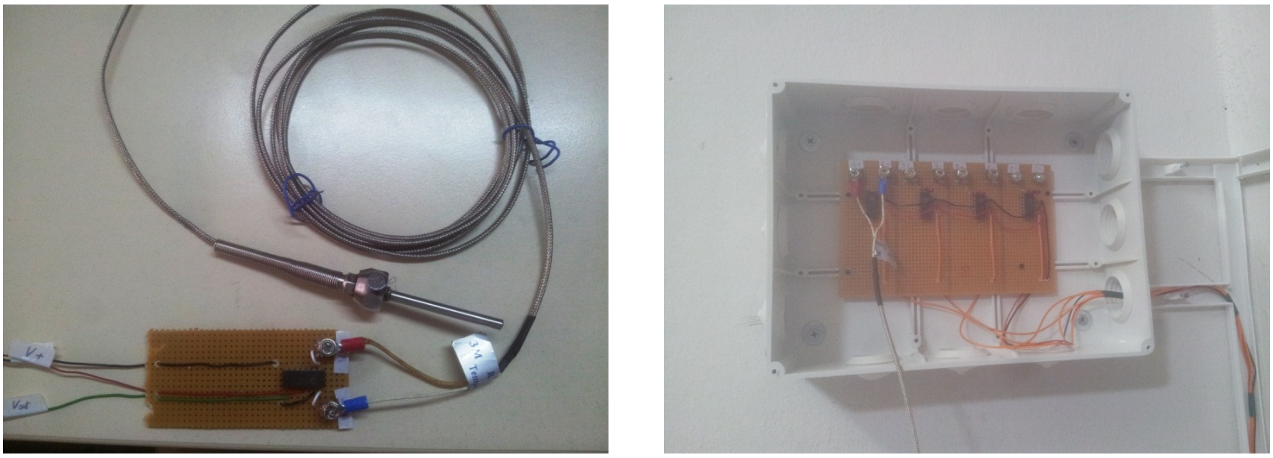


Figure 5.1.2: Temperature sensor boards

The thermocouple output voltage is nonlinear with respect to temperature, for this reason we use a Monolithic Thermocouple Amplifiers **AD595** (the datasheet of this sensor you can find it in **Appendix B**) which linearly amplifies the compensated signal.

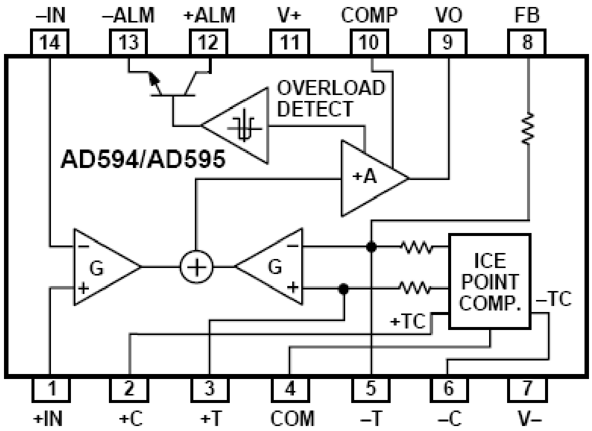


Figure 5.1.3: AD595 design

To achieve a temperature proportional output of 10 mV/°C and accurately compensate for the reference junction over the rated operating range of the circuit, the AD595 is gain trimmed to match the transfer characteristic of K type thermocouples at 25°C. For a type K output in this temperature range the TC is 40.44 mV/°C. The resulting gain for the AD595 is 247.3 (10 mV/°C divided by 40.44 mV/°C). In addition, an absolute accuracy trim induces an input offset to the output amplifier characteristic of 11 mV. This offset arises because the AD595 is trimmed for a 250 mV output while applying a 25°C thermocouple input.

The thermocouple sensor should be connecting to the AD595 amplifier as figure 3.

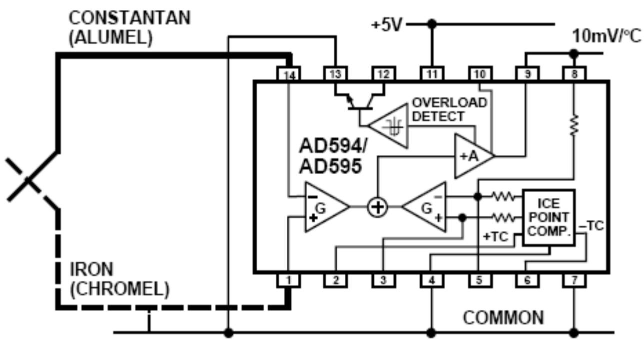


Figure 5.1.4: sensor-Amplifier connection

The output pin give you a linear voltage (AD595 output) with respect to the input voltage (Type K voltage) is shown by the following equition:

$$AD595\ output = (Type\ K\ Voltage + 11\ \mu V) \times 247.3$$

$$Type\ K\ voltage = (AD595\ output/247.3) - 11\ \mu V$$

When the connection is done well you can do a testing for the sensor. For example, If you use an input voltage V_{in}=5V in a 25°C the output voltage should be as the table bellow:

Table 1: V_{out} with respect to the temperature for 25°C

Thermocouple Temperature °C	Type K Voltage mV	AD595 Output mV	Thermocouple Temperature °C	Type K Voltage mV	AD595 Output mV
–200	–5.891	–1454	100	4.095	1015
–180	–5.550	–1370	120	4.919	1219
–160	–5.141	–1269	140	5.733	1420
–140	–4.669	–1152	160	6.539	1620
–120	–4.138	–1021	180	7.338	1817
–100	–3.553	–876	200	8.137	2015
–80	–2.920	–719	220	8.938	2213
–60	–2.243	–552	240	9.745	2413
–40	–1.527	–375	260	10.560	2614
–20	–.777	–189	280	11.381	2817
–10	–.392	–94	300	12.207	3022
0	0	2.7	320	13.039	3227
10	.397	101	340	13.874	3434
20	.798	200	360	14.712	3641
25	1.000	250	380	15.552	3849
30	1.203	300	400	16.395	4057
40	1.611	401	420	17.241	4266
50	2.022	503	440	18.088	4476
60	2.436	605	460	18.938	4686
80	3.266	810	480	19.788	4896

Temperature sensor board design:

The amplifier board may design manually or may be print on PCB. The layout design of the PCB circuit is designed using ARES Proteus PCB Layout Design. The figure bellow show the layout design.

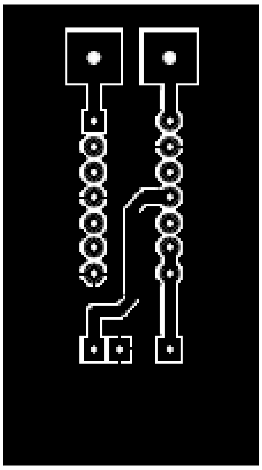


Figure 5.1.5: Layout

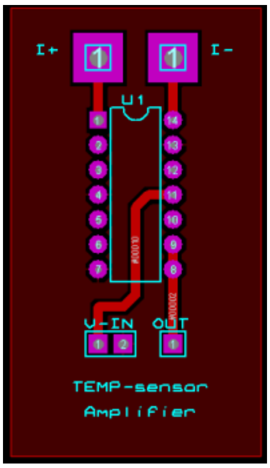


Figure 5.1.6: ARES Design

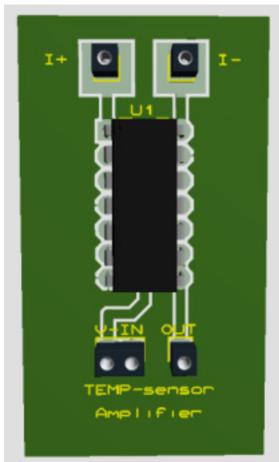
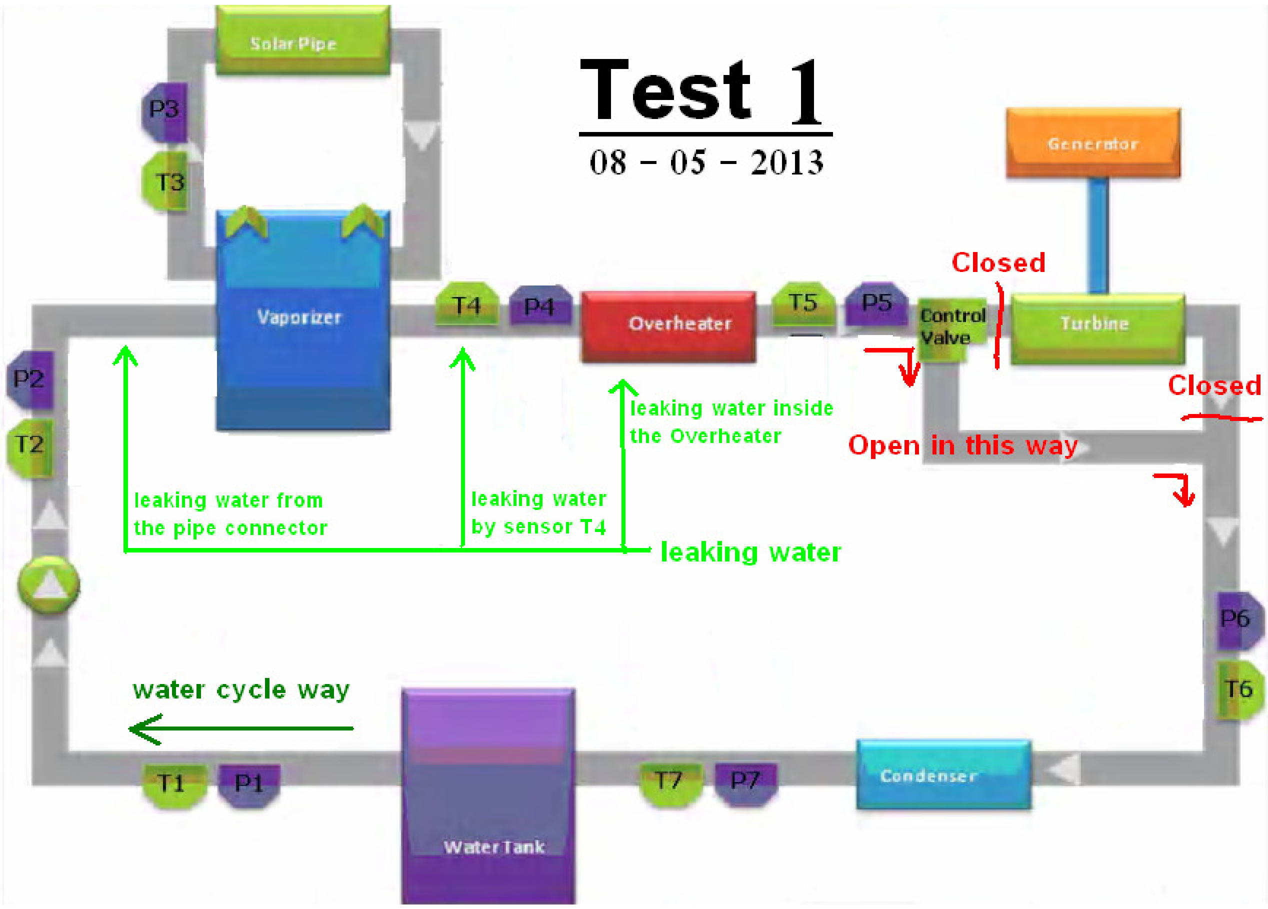


Figure 5.1.7: 3D view

6 Test reportsتجارب

6.1 Test 1 (8 May 2013)

Precondition	Test activity	Expected postcondition	Postcondition	Test ok/Test failed
Pipes without water	Filling all pipes with water	P7: 4 bar No leaking water	P7: 1,5 bar Pipes and overheater were leaking water	Failed failed

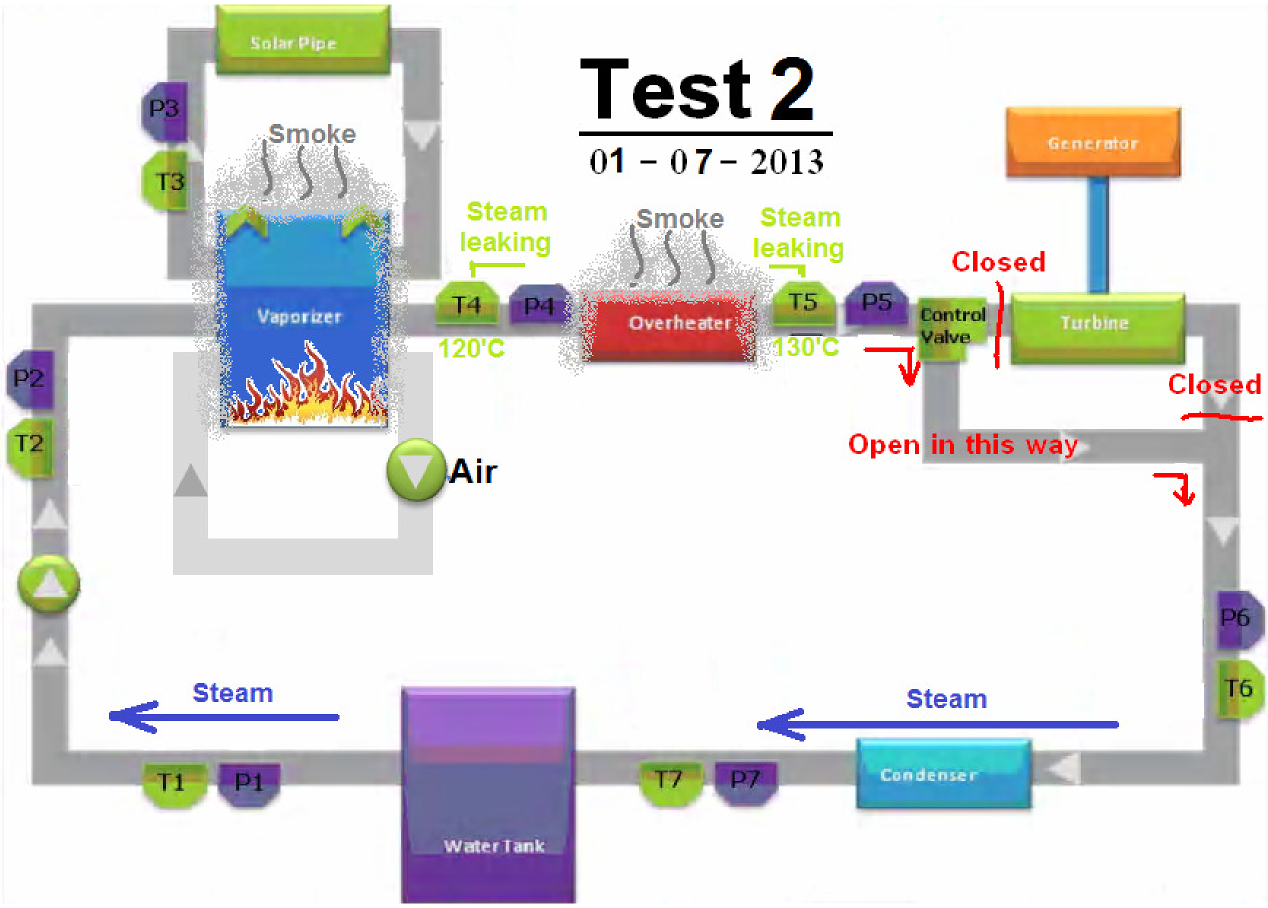


As we see, a new action should be taken after this failed test to solve the problem occured

Action	delay time	Penalty cost	situation
Solving leaking water problem on the pipe	3 hours	No penalty cost	Done with success
Solving leaking water problem on the overheater system	3 days	50$	On pregress

6.2 Test 2 (1 July 2013)

Test activity	Expected postcondition	Postcondition	Test ok / Test failed
Ignite fire on the vaporizer for a heaf of hours	No leaking water	No leaking water	Success
	No leaking Steam	Leaking steam by temp. sensors	Failed
	No leaking smoke	Leaking smoke from vaporizer and overheater	Failed
	Valve open and producing steam	Valve open but is crashing because of high temperature	Success with problem



As we see, a new action should be taken after this failed test to solve the problem occured

Action	delay time	Penalty cost	situation
Solving leaking steam problem on sensors	3 hours	20$	On progress
Solving leaking smoke problem on the vaporizer and overheater	2 weeks	500$	Done with success

7 Literature / المراجع

[Mourad et. al. 2010] 2nd TEMO-STPP report, 2nd edition, April 2010, http://aecenar.com/download/doc_download/13-temo-stpp-report-2

Gourche et. al., Siemens S7-300 مدخل الى , Karlsruhe/Ras Nhache, July 2010 (http://www.aecenar.com/download/doc_download/25-siemens-s7-300–)

Karl Strauss, "Kraftwerkstechnik"

Zahornsky, "Energietechnik"

8 ملحق Appendix

8.1 البرمجة بـSTEP7 / Appendix A: Programming with STEP7[1]

بالتفصيل بالغة العربية انظر

Gourche et. al., Siemens S7-300 مدخل الى , Karlsruhe/Ras Nhache, July 2010 (http://www.aecenar.com/download/doc_download/25-siemens-s7-300--)

8.1.1 The communication interface

MPI-USB - interface for S7-300

The multipoint interface (MPI) is a proprietary interface of SIMATIC S7 controller from Siemens and is used for the connection of programming devices (PGs) to the automation device. The PC-MPI adapter converts the data from the RS232 or USB Schnittstelledes PC to the MPI bus (RS485 level). The transmission speed of seriellenSchnittstelle is 19.6 kbaud. The MPI interface operates with 187.5 Kbit / s The MPI adapter has a connection cable that is plugged directly into the CPU connector of the PLC. The power supply receives the MPI adapter from the CPU via the MPI cable. The configuration of the MPI interface of the program supplied with STEP 7.

Setting the PG-PC interface. This is the COM port (USB) set the serial port, registered transfer speeds and defines the MPI address of the PC. The PC is assigned the MPI address 0.

See appendix of 3rd project report	MPI-USB BUS for S7-300/400

With "real" PLC (no simulator): Setting the PG / PC interface

A started simulator makes working with a real PLC impossible. He has to be stopped in communication priority and must if you want to work with a PLC. An AG is always addressed over that interface, which has been so well set for a project in the Simatic Manager globally for the entire program package, globally. - If the status bar is displayed in the SIMATIC Manager, the interface is displayed permanently.

Is selected on the interface:

- **Simatic Manager --> Extras --> PG/PC-Schnittstelle einstellen... (Step1)**

1 From Mohamed Gourche, Development environment and elements of the Process Control System for the TEMO-STPP test rig Development of a Process Control System for a STPP Test Stand, www.aecenar.com

بالتفصيل بالغة العربية انظر

Gourche et. al., Siemens S7-300 مدخل الى , Karlsruhe/Ras Nhache, July 2010 (http://www.aecenar.com/download/doc_download/25-siemens-s7-300--)

See appendix of 3rd project report

Step1

The mark in this dialog is only very weakly visible. If the desired interface is not found in the list, the button must be "Interfaces -> Add / Remove -> Select ..." be pressed to open a dialog that can be installed in the interfaces (Step2).

Here is chosen as an example of the "PC Adapter" in the variant "MPI". This is when one does not have a PG, which has built an RS-485 interface, be the first path that one chooses for a communication with a PLC.

See appendix of 3rd project report

Step2 Step3

A PC adapter has two sides, so to speak, the PC side and the PLC side. On the PC side, it is possible the RS-232C interface to use (in this case must be taken on the data rate!) Or to use the more modern adapter's USB port, as shown here.

On the PLC side is through the pre-selection in the first dialog the MPI interface has been defined (there are also "auto" for communication via Profibus). This generally works at a data rate of 187.5 kbit / s This setting should be checked for safety's sake, just because modern CPUs support a higher data rate. - And especially do not let them impress the serial adapter that also has a data rate must be set on the PC side! These have nothing to do with each other and each refer to only one side of communcation. Between these pages (Step4) provides the adapter, both in terms of level adaptation as well as in terms of data rate.

See appendix of 3rd project report

Step4

8.2 Appendix B: thermocouples sensor datasheet:

Farnell
element14

temperature and process technology

LABFACILITY
TEMPERATURE & PROCESS TECHNOLOGY

About Labfacility

Formed in 1971, Labfacility specialize in the field of Temperature and Process Measurement.

We are the largest UK manufacturer of both temperature sensors and thermocouple connectors.

Quality & Service

Quality and Service are key elements in the continued growth of Labfacility.

Technical support is always freely available from our experienced technical sales teams and the company has ISO9001 accreditation.

Contact Details

Email
sales@labfacility.com

Website
www.labfacility.com

PTFE Exposed Welded Tip Thermocouples

Available in type K & T

- Thermocouple types K & T
- Fast response, welded exposed junction
- 1, 2 , 3 & 5 metre long PTFE twin twisted cable
- 1/0.2mm conductors
- Temperature range –75°C to +250°C
- Tolerance to IEC 584 Class 1
- Colour code to IEC 584-3
- Good mechanical strength and flexibility, resistant to oils, acids and other adverse fluids
- Ideal for test & development applications

T/C Type	Length	Manufacturing Part Number	+Positive tail wire	-Negative tail wire	Farnell Order Code
‘K’	1 metres	Z2-K-PTFE-TT-1/0.2-1.0-T	Green	White	707-6150
‘K’	2 metres	Z2-K-PTFE-TT-1/0.2-2.0-T	Green	White	707-6162
‘K’	3 metres	Z2-K-PTFE-TT-1/0.2-3.0-T	Green	White	163-3481
‘K’	5 metres	Z2-K-PTFE-TT-1/0.2-5.0-T	Green	White	163-3482
‘T’	1 metres	Z2-T-PTFE-TT-1/0.2-1.0-T	Brown	White	707-6174
‘T’	2 metres	Z2-T-PTFE-TT-1/0.2-2.0-T	Brown	White	707-6186
‘T’	3 metres	Z2-T-PTFE-TT-1/0.2-3.0-T	Brown	White	163-3483
‘T’	5 metres	Z2-T-PTFE-TT-1/0.2-5.0-T	Brown	White	163-3484
‘K’	1 metres	Z2-K-PTFE-TT-1/0.2-1.0-Tx5	Green	White	859-8223 (pack of 5)
‘K’	2 metres	Z2-K-PTFE-TT-1/0.2-2.0-Tx5	Green	White	859-8150 (pack of 5)
‘T’	1 metres	Z2-T-PTFE-TT-1/0.2-1.0-Tx5	Brown	White	859-8231 (pack of 5)
‘T’	2 metres	Z2-T-PTFE-TT-1/0.2-2.0-Tx5	Brown	White	859-8169 (pack of 5)

FAR003/0313. PTFE Exposed Welded Tip Thermocouples

LABFACILITY

8.3 Appendix C: thermocouple Amplifier AD595 datasheet:

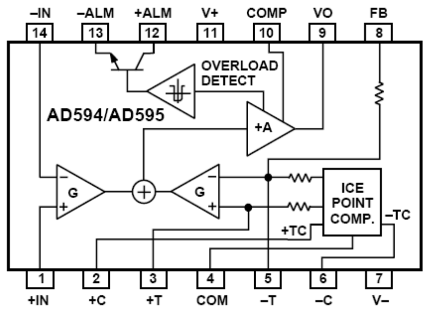
ANALOG DEVICES

Monolithic Thermocouple Amplifiers with Cold Junction Compensation

AD594/AD595

FEATURES
Pretrimmed for Type J (AD594) or Type K (AD595) Thermocouples
Can Be Used with Type T Thermocouple Inputs
Low Impedance Voltage Output: 10 mV/°C
Built-In Ice Point Compensation
Wide Power Supply Range: +5 V to ±15 V
Low Power: <1 mW typical
Thermocouple Failure Alarm
Laser Wafer Trimmed to 1°C Calibration Accuracy
Setpoint Mode Operation
Self-Contained Celsius Thermometer Operation
High Impedance Differential Input
Side-Brazed DIP or Low Cost Cerdip

FUNCTIONAL BLOCK DIAGRAM



PRODUCT DESCRIPTION

The AD594/AD595 is a complete instrumentation amplifier and thermocouple cold junction compensator on a monolithic chip. It combines an ice point reference with a precalibrated amplifier to produce a high level (10 mV/°C) output directly from a thermocouple signal. Pin-strapping options allow it to be used as a linear amplifier-compensator or as a switched output setpoint controller using either fixed or remote setpoint control. It can be used to amplify its compensation voltage directly, thereby converting it to a stand-alone Celsius transducer with a low impedance voltage output.

The AD594/AD595 includes a thermocouple failure alarm that indicates if one or both thermocouple leads become open. The alarm output has a flexible format which includes TTL drive capability.

The AD594/AD595 can be powered from a single ended supply (including +5 V) and by including a negative supply, temperatures below 0°C can be measured. To minimize self-heating, an unloaded AD594/AD595 will typically operate with a total supply current 160 μA, but is also capable of delivering in excess of ±5 mA to a load.

The AD594 is precalibrated by laser wafer trimming to match the characteristic of type J (iron-constantan) thermocouples and the AD595 is laser trimmed for type K (chromel-alumel) inputs. The temperature transducer voltages and gain control resistors are available at the package pins so that the circuit can be recalibrated for the thermocouple types by the addition of two or three resistors. These terminals also allow more precise calibration for both thermocouple and thermometer applications.

The AD594/AD595 is available in two performance grades. The C and the A versions have calibration accuracies of ±1°C and ±3°C, respectively. Both are designed to be used from 0°C to +50°C, and are available in 14-pin, hermetically sealed, side-brazed ceramic DIPs as well as low cost cerdip packages.

PRODUCT HIGHLIGHTS

1. The AD594/AD595 provides cold junction compensation, amplification, and an output buffer in a single IC package.
2. Compensation, zero, and scale factor are all precalibrated by laser wafer trimming (LWT) of each IC chip.
3. Flexible pinout provides for operation as a setpoint controller or a stand-alone temperature transducer calibrated in degrees Celsius.
4. Operation at remote application sites is facilitated by low quiescent current and a wide supply voltage range +5 V to dual supplies spanning 30 V.
5. Differential input rejects common-mode noise voltage on the thermocouple leads.

REV. C

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

AD594/AD595–SPECIFICATIONS (@ +25°C and V_S = 5 V, Type J (AD594), Type K (AD595) Thermocouple, unless otherwise noted)

Model	AD594A Min	AD594A Typ	AD594A Max	AD594C Min	AD594C Typ	AD594C Max	Units
ABSOLUTE MAXIMUM RATING							
$+V_S$ to $-V_S$			36			36	Volts
Common-Mode Input Voltage	$-V_S - 0.15$		$+V_S$	$-V_S - 0.15$		$+V_S$	Volts
Differential Input Voltage	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Alarm Voltages							
+ALM	$-V_S$		$-V_S + 36$	$-V_S$		$-V_S + 36$	Volts
–ALM	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Operating Temperature Range	–55		+125	–55		+125	°C
Output Short Circuit to Common	Indefinite			Indefinite			
TEMPERATURE MEASUREMENT (Specified Temperature Range 0°C to +50°C)							
Calibration Error at +25°C[1]			±3			±1	°C
Stability vs. Temperature[2]			**±0.05**			**±0.025**	°C/°C
Gain Error			**±1.5**			**±0.75**	%
Nominal Transfer Function			10			10	mV/°C
AMPLIFIER CHARACTERISTICS							
Closed Loop Gain[3]		193.4				193.4	
Input Offset Voltage		(Temperature in °C) × 51.70 μV/°C			(Temperature in °C) × 51.70 μV/°C		μV
Input Bias Current		0.1			0.1		μA
Differential Input Range	–10		+50				mV
Common-Mode Range	**$-V_S - 0.15$**		**$-V_S - 4$**	**$-V_S - 0.15$**		**$-V_S - 4$**	Volts
Common-Mode Sensitivity – RTO			**10**			**10**	mV/V
Power Supply Sensitivity – RTO			**10**			**10**	mV/V
Output Voltage Range							
Dual Supply	**$-V_S + 2.5$**		**$+V_S - 2$**	**$-V_S + 2.5$**		**$+V_S - 2$**	Volts
Single Supply	0		$+V_S - 2$	0		$-V_S - 2$	Volts
Usable Output Current[4]		±5			±5		mA
3 dB Bandwidth		15			15		kHz
ALARM CHARACTERISTICS							
$V_{CE(SAT)}$ at 2 mA		0.3			0.3		Volts
Leakage Current			**±1**			**±1**	μA max
Operating Voltage at – ALM			**$+V_S - 4$**			**$+V_S - 4$**	Volts
Short Circuit Current		20			20		mA
POWER REQUIREMENTS							
Specified Performance		$+V_S = 5, -V_S = 0$			$+V_S = 5, -V_S = 0$		Volts
Operating[5]		$+V_S$ to $-V_S \le 30$			$+V_S$ to $-V_S \le 30$		Volts
Quiescent Current (No Load)							
$+V_S$		160	300		160	300	μA
$-V_S$		100			100		μA
PACKAGE OPTION							
TO-116 (D-14)		AD594AD			AD594CD		
Cerdip (Q-14)		AD594AQ			AD594CQ		

Model	AD595A Min	AD595A Typ	AD595A Max	AD595C Min	AD595C Typ	AD595C Max	Units
ABSOLUTE MAXIMUM RATING							
$+V_S$ to $-V_S$			36			36	Volts
Common-Mode Input Voltage	$-V_S - 0.15$		$+V_S$	$-V_S - 0.15$		$+V_S$	Volts
Differential Input Voltage	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Alarm Voltages							
+ALM	$-V_S$		$-V_S + 36$	$-V_S$		$-V_S + 36$	Volts
–ALM	$-V_S$		$+V_S$	$-V_S$		$+V_S$	Volts
Operating Temperature Range	–55		+125	–55		+125	°C
Output Short Circuit to Common	Indefinite			Indefinite			
TEMPERATURE MEASUREMENT (Specified Temperature Range 0°C to +50°C)							
Calibration Error at +25°C[1]			±3			±1	°C
Stability vs. Temperature[2]			**±0.05**			**±0.025**	°C/°C
Gain Error			**±1.5**			**±0.75**	%
Nominal Transfer Function			10			10	mV/°C
AMPLIFIER CHARACTERISTICS							
Closed Loop Gain[3]			247.3			247.3	
Input Offset Voltage		(Temperature in °C) × 40.44 μV/°C			(Temperature in °C) × 40.44 μV/°C		μV
Input Bias Current		0.1			0.1		μA
Differential Input Range	–10		+50	–10		+50	mV
Common-Mode Range	**$-V_S - 0.15$**		**$-V_S - 4$**	**$-V_S - 0.15$**		**$-V_S - 4$**	Volts
Common-Mode Sensitivity – RTO			**10**			**10**	mV/V
Power Supply Sensitivity – RTO			**10**			**10**	mV/V
Output Voltage Range							
Dual Supply	**$-V_S + 2.5$**		**$+V_S - 2$**	**$-V_S + 2.5$**		**$+V_S - 2$**	Volts
Single Supply	0		$+V_S + 2$	0		$+V_S - 2$	Volts
Usable Output Current[4]		±5			±5		mA
3 dB Bandwidth		15			15		kHz
ALARM CHARACTERISTICS							
$V_{CE(SAT)}$ at 2 mA		0.3			0.3		Volts
Leakage Current			**±1**			**±1**	μA max
Operating Voltage at – ALM			**$+V_S - 4$**			**$+V_S - 4$**	Volts
Short Circuit Current		20			20		mA
POWER REQUIREMENTS							
Specified Performance		$+V_S = 5, -V_S = 0$			$+V_S = 5, -V_S = 0$		Volts
Operating[5]		$+V_S$ to $-V_S \le 30$			$+V_S$ to $-V_S \le 30$		Volts
Quiescent Current (No Load)							
$+V_S$		160	300		160	300	μA
$-V_S$		100			100		μA
PACKAGE OPTION							
TO-116 (D-14)		AD595AD			AD595CD		
Cerdip (Q-14)		AD595AQ			AD595CQ		

NOTES

[1]Calibrated for minimum error at +25°C using a thermocouple sensitivity of 51.7 μV/°C. Since a J type thermocouple deviates from this straight line approximation, the AD594 will normally read 3.1 mV when the measuring junction is at 0°C. The AD595 will similarly read 2.7 mV at 0°C.

[2]Defined as the slope of the line connecting the AD594/AD595 errors measured at 0°C and 50°C ambient temperature.

[3]Pin 8 shorted to Pin 9.

[4]Current Sink Capability in single supply configuration is limited to current drawn to ground through a 50 kΩ resistor at output voltages below 2.5 V.

[5]$-V_S$ must not exceed –16.5 V.

Specifications shown in **boldface** are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in **boldface** are tested on all production units.

Specifications subject to change without notice.

INTERPRETING AD594/AD595 OUTPUT VOLTAGES

To achieve a temperature proportional output of 10 mV/°C and accurately compensate for the reference junction over the rated operating range of the circuit, the AD594/AD595 is gain trimmed to match the transfer characteristic of J and K type thermocouples at 25°C. For a type J output in this temperature range the TC is 51.70 μV/°C, while for a type K it is 40.44 μV/°C. The resulting gain for the AD594 is 193.4 (10 mV/°C divided by 51.7 μV/°C) and for the AD595 is 247.3 (10 mV/°C divided by 40.44 μV/°C). In addition, an absolute accuracy trim induces an input offset to the output amplifier characteristic of 16 μV for the AD594 and 11 μV for the AD595. This offset arises because the AD594/AD595 is trimmed for a 250 mV output while applying a 25°C thermocouple input.

Because a thermocouple output voltage is nonlinear with respect to temperature, and the AD594/AD595 linearly amplifies the compensated signal, the following transfer functions should be used to determine the actual output voltages:

AD594 output = (Type J Voltage + 16 μV) × 193.4

AD595 output = (Type K Voltage + 11 μV) × 247.3 or conversely:

Type J voltage = (AD594 output/193.4) – 16 μV

Type K voltage = (AD595 output/247.3) – 11 μV

Table I lists the ideal AD594/AD595 output voltages as a function of Celsius temperature for type J and K ANSI standard thermocouples, with the package and reference junction at 25°C. As is normally the case, these outputs are subject to calibration, gain and temperature sensitivity errors. Output values for intermediate temperatures can be interpolated, or calculated using the output equations and ANSI thermocouple voltage tables referred to zero degrees Celsius. Due to a slight variation in alloy content between ANSI type J and DIN FE-CUNI

Table I. Output Voltage vs. Thermocouple Temperature (Ambient +25°C, V_S = –5 V, +15 V)

Thermocouple Temperature °C	Type J Voltage mV	AD594 Output mV	Type K Voltage mV	AD595 Output mV
–200	–7.890	–1523	–5.891	–1454
–180	–7.402	–1428	–5.550	–1370
–160	–6.821	–1316	–5.141	–1269
–140	–6.159	–1188	–4.669	–1152
–120	–5.426	–1046	–4.138	–1021
–100	–4.632	–893	–3.553	–876
–80	–3.785	–729	–2.920	–719
–60	–2.892	–556	–2.243	–552
–40	–1.960	–376	–1.527	–375
–20	–.995	–189	–.777	–189
–10	–.501	–94	–.392	–94
0	0	3.1	0	2.7
10	.507	101	.397	101
20	1.019	200	.798	200
25	1.277	250	1.000	250
30	1.536	300	1.203	300
40	2.058	401	1.611	401
50	2.585	503	2.022	503
60	3.115	606	2.436	605
80	4.186	813	3.266	810
100	5.268	1022	4.095	1015
120	6.359	1233	4.919	1219
140	7.457	1445	5.733	1420
160	8.560	1659	6.539	1620
180	9.667	1873	7.338	1817
200	10.777	2087	8.137	2015
220	11.887	2302	8.938	2213
240	12.998	2517	9.745	2413
260	14.108	2732	10.560	2614
280	15.217	2946	11.381	2817
300	16.325	3160	12.207	3022
320	17.432	3374	13.039	3227
340	18.537	3588	13.874	3434
360	19.640	3801	14.712	3641
380	20.743	4015	15.552	3849
400	21.846	4228	16.395	4057
420	22.949	4441	17.241	4266
440	24.054	4655	18.088	4476
460	25.161	4869	18.938	4686
480	26.272	5084	19.788	4896

Thermocouple Temperature °C	Type J Voltage mV	AD594 Output mV	Type K Voltage mV	AD595 Output mV
500	27.388	5300	20.640	5107
520	28.511	5517	21.493	5318
540	29.642	5736	22.346	5529
560	30.782	5956	23.198	5740
580	31.933	6179	24.050	5950
600	33.096	6404	24.902	6161
620	34.273	6632	25.751	6371
640	35.464	6862	26.599	6581
660	36.671	7095	27.445	6790
680	37.893	7332	28.288	6998
700	39.130	7571	29.128	7206
720	40.382	7813	29.965	7413
740	41.647	8058	30.799	7619
750	42.283	8181	31.214	7722
760	–	–	31.629	7825
780	–	–	32.455	8029
800	–	–	33.277	8232
820	–	–	34.095	8434
840	–	–	34.909	8636
860	–	–	35.718	8836
880	–	–	36.524	9035
900	–	–	37.325	9233
920	–	–	38.122	9430
940	–	–	38.915	9626
960	–	–	39.703	9821
980	–	–	40.488	10015
1000	–	–	41.269	10209
1020	–	–	42.045	10400
1040	–	–	42.817	10591
1060	–	–	43.585	10781
1080	–	–	44.439	10970
1100	–	–	45.108	11158
1120	–	–	45.863	11345
1140	–	–	46.612	11530
1160	–	–	47.356	11714
1180	–	–	48.095	11897
1200	–	–	48.828	12078
1220	–	–	49.555	12258
1240	–	–	50.276	12436
1250	–	–	50.633	12524

thermocouples Table I should not be used in conjunction with European standard thermocouples. Instead the transfer function given previously and a DIN thermocouple table should be used. ANSI type K and DIN NiCr-Ni thermocouples are composed

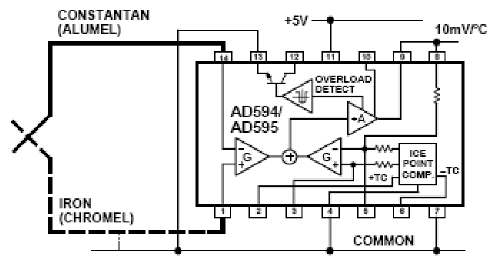


Figure 1. Basic Connection, Single Supply Operation

of identical alloys and exhibit similar behavior. The upper temperature limits in Table I are those recommended for type J and type K thermocouples by the majority of vendors.

SINGLE AND DUAL SUPPLY CONNECTIONS

The AD594/AD595 is a completely self-contained thermocouple conditioner. Using a single +5 V supply the interconnections shown in Figure 1 will provide a direct output from a type J thermocouple (AD594) or type K thermocouple (AD595) measuring from 0°C to +300°C.

Any convenient supply voltage from +5 V to +30 V may be used, with self-heating errors being minimized at lower supply levels. In the single supply configuration the +5 V supply connects to Pin 11 with the V– connection at Pin 7 strapped to power and signal common at Pin 4. The thermocouple wire inputs connect to Pins 1 and 14 either directly from the measuring point or through intervening connections of similar thermocouple wire type. When the alarm output at Pin 13 is not used it should be connected to common or –V. The precalibrated feedback network at Pin 8 is tied to the output at Pin 9 to provide a 10 mV/°C nominal temperature transfer characteristic.

By using a wider ranging dual supply, as shown in Figure 2, the AD594/AD595 can be interfaced to thermocouples measuring both negative and extended positive temperatures.

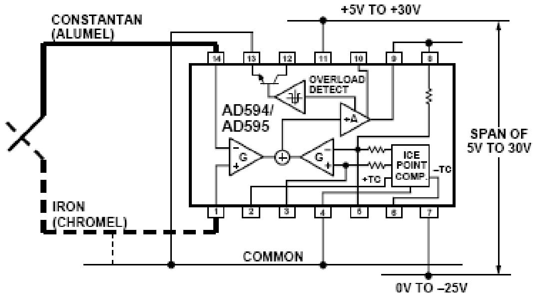


Figure 2. Dual Supply Operation

With a negative supply the output can indicate negative temperatures and drive grounded loads or loads returned to positive voltages. Increasing the positive supply from 5 V to 15 V extends the output voltage range well beyond the 750°C temperature limit recommended for type J thermocouples (AD594) and the 1250°C for type K thermocouples (AD595).

Common-mode voltages on the thermocouple inputs must remain within the common-mode range of the AD594/AD595, with a return path provided for the bias currents. If the thermocouple is not remotely grounded, then the dotted line connections in Figures 1 and 2 are recommended. A resistor may be needed in this connection to assure that common-mode voltages induced in the thermocouple loop are not converted to normal mode.

THERMOCOUPLE CONNECTIONS

The isothermal terminating connections of a pair of thermocouple wires forms an effective reference junction. This junction must be kept at the same temperature as the AD594/AD595 for the internal cold junction compensation to be effective.

A method that provides for thermal equilibrium is the printed circuit board connection layout illustrated in Figure 3.

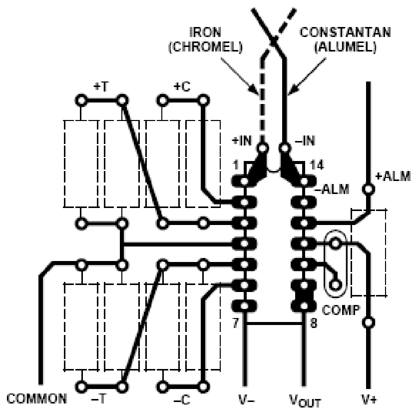


Figure 3. PCB Connections

Here the AD594/AD595 package temperature and circuit board are thermally contacted in the copper printed circuit board tracks under Pins 1 and 14. The reference junction is now composed of a copper-constantan (or copper-alumel) connection and copper-iron (or copper-chromel) connection, both of which are at the same temperature as the AD594/AD595.

The printed circuit board layout shown also provides for placement of optional alarm load resistors, recalibration resistors and a compensation capacitor to limit bandwidth.

To ensure secure bonding the thermocouple wire should be cleaned to remove oxidation prior to soldering. Noncorrosive rosin flux is effective with iron, constantan, chromel and alumel and the following solders: 95% tin-5% antimony, 95% tin-5% silver or 90% tin-10% lead.

FUNCTIONAL DESCRIPTION

The AD594 behaves like two differential amplifiers. The outputs are summed and used to control a high gain amplifier, as shown in Figure 4.

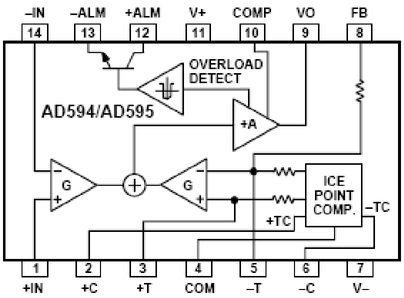


Figure 4. AD594/AD595 Block Diagram

In normal operation the main amplifier output, at Pin 9, is connected to the feedback network, at Pin 8. Thermocouple signals applied to the floating input stage, at Pins 1 and 14, are amplified by gain G of the differential amplifier and are then further amplified by gain A in the main amplifier. The output of the main amplifier is fed back to a second differential stage in an inverting connection. The feedback signal is amplified by this stage and is also applied to the main amplifier input through a summing circuit. Because of the inversion, the amplifier causes the feedback to be driven to reduce this difference signal to a small value. The two differential amplifiers are made to match and have identical gains, G. As a result, the feedback signal that must be applied to the right-hand differential amplifier will precisely match the thermocouple input signal when the difference signal has been reduced to zero. The feedback network is trimmed so that the effective gain to the output, at Pins 8 and 9, results in a voltage of 10 mV/°C of thermocouple excitation.

In addition to the feedback signal, a cold junction compensation voltage is applied to the right-hand differential amplifier. The compensation is a differential voltage proportional to the Celsius temperature of the AD594/AD595. This signal disturbs the differential input so that the amplifier output must adjust to restore the input to equal the applied thermocouple voltage.

The compensation is applied through the gain scaling resistors so that its effect on the main output is also 10 mV/°C. As a result, the compensation voltage adds to the effect of the thermocouple voltage a signal directly proportional to the difference between 0°C and the AD594/AD595 temperature. If the thermocouple reference junction is maintained at the AD594/AD595 temperature, the output of the AD594/AD595 will correspond to the reading that would have been obtained from amplification of a signal from a thermocouple referenced to an ice bath.

The AD594/AD595 also includes an input open circuit detector that switches on an alarm transistor. This transistor is actually a current-limited output buffer, but can be used up to the limit as a switch transistor for either pull-up or pull-down operation of external alarms.

The ice point compensation network has voltages available with positive and negative temperature coefficients. These voltages may be used with external resistors to modify the ice point compensation and recalibrate the AD594/AD595 as described in the next column.

The feedback resistor is separately pinned out so that its value can be padded with a series resistor, or replaced with an external resistor between Pins 5 and 9. External availability of the feedback resistor allows gain to be adjusted, and also permits the AD594/AD595 to operate in a switching mode for setpoint operation.

CAUTIONS:

The temperature compensation terminals (+C and –C) at Pins 2 and 6 are provided to supply small calibration currents only. The AD594/AD595 may be permanently damaged if they are grounded or connected to a low impedance.

The AD594/AD595 is internally frequency compensated for feedback ratios (corresponding to normal signal gain) of 75 or more. If a lower gain is desired, additional frequency compensation should be added in the form of a 300 pF capacitor from Pin 10 to the output at Pin 9. As shown in Figure 5 an additional 0.01 µF capacitor between Pins 10 and 11 is recommended.

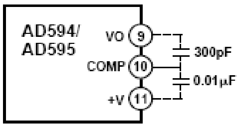


Figure 5. Low Gain Frequency Compensation

RECALIBRATION PRINCIPLES AND LIMITATIONS

The ice point compensation network of the AD594/AD595 produces a differential signal which is zero at 0°C and corresponds to the output of an ice referenced thermocouple at the temperature of the chip. The positive TC output of the circuit is proportional to Kelvin temperature and appears as a voltage at +T. It is possible to decrease this signal by loading it with a resistor from +T to COM, or increase it with a pull-up resistor from +T to the larger positive TC voltage at +C. Note that adjustments to +T should be made by measuring the voltage which tracks it at –T. To avoid destabilizing the feedback amplifier the measuring instrument should be isolated by a few thousand ohms in series with the lead connected to –T.

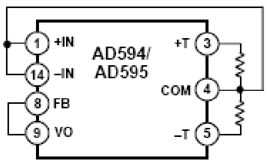


Figure 6. Decreased Sensitivity Adjustment

Changing the positive TC half of the differential output of the compensation scheme shifts the zero point away from 0°C. The zero can be restored by adjusting the current flow into the negative input of the feedback amplifier, the –T pin. A current into this terminal can be produced with a resistor between –C and –T to balance an increase in +T, or a resistor from –T to COM to offset a decrease in +T.

If the compensation is adjusted substantially to accommodate a different thermocouple type, its effect on the final output voltage will increase or decrease in proportion. To restore the nominal output to 10 mV/°C the gain may be adjusted to match the new compensation and thermocouple input characteristics. When reducing the compensation the resistance between –T and COM automatically increases the gain to within 0.5% of the correct value. If a smaller gain is required, however, the nominal 47 kΩ internal feedback resistor can be paralleled or replaced with an external resistor.

Fine calibration adjustments will require temperature response measurements of individual devices to assure accuracy. Major reconfigurations for other thermocouple types can be achieved without seriously compromising initial calibration accuracy, so long as the procedure is done at a fixed temperature using the factory calibration as a reference. It should be noted that intermediate recalibration conditions may require the use of a negative supply.

EXAMPLE: TYPE E RECALIBRATION—AD594/AD595

Both the AD594 and AD595 can be configured to condition the output of a type E (chromel-constantan) thermocouple. Temperature characteristics of type E thermocouples differ less from type J, than from type K, therefore the AD594 is preferred for recalibration.

While maintaining the device at a constant temperature follow the recalibration steps given here. First, measure the device temperature by tying both inputs to common (or a selected common-mode potential) and connecting FB to VO. The AD594 is now in the stand alone Celsius thermometer mode. For this example assume the ambient is 24°C and the initial output VO is 240 mV. Check the output at VO to verify that it corresponds to the temperature of the device.

Next, measure the voltage –T at Pin 5 with a high impedance DVM (capacitance should be isolated by a few thousand ohms of resistance at the measured terminals). At 24°C the –T voltage will be about 8.3 mV. To adjust the compensation of an AD594 to a type E thermocouple a resistor, R1, should be connected between +T and +C, Pins 2 and 3, to raise the voltage at –T by the ratio of thermocouple sensitivities. The ratio for converting a type J device to a type E characteristic is:

$$r\,(AD594) = (60.9\ \mu V/°C)/(51.7\ \mu V/°C) = 1.18$$

Thus, multiply the initial voltage measured at –T by r and experimentally determine the R1 value required to raise –T to that level. For the example the new –T voltage should be about 9.8 mV. The resistance value should be approximately 1.8 kΩ.

The zero differential point must now be shifted back to 0°C. This is accomplished by multiplying the original output voltage VO by r and adjusting the measured output voltage to this value by experimentally adding a resistor, R2, between –C and –T, Pins 5 and 6. The target output value in this case should be about 283 mV. The resistance value of R2 should be approximately 240 kΩ.

Finally, the gain must be recalibrated such that the output VO indicates the device's temperature once again. Do this by adding a third resistor, R3, between FB and –T, Pins 8 and 5. VO should now be back to the initial 240 mV reading. The resistance value

AD594/AD595

of R3 should be approximately 280 kΩ. The final connection diagram is shown in Figure 7. An approximate verification of the effectiveness of recalibration is to measure the differential gain to the output. For type E it should be 164.2.

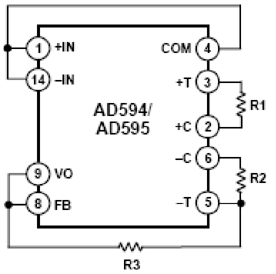


Figure 7. Type E Recalibration

When implementing a similar recalibration procedure for the AD595 the values for R1, R2, R3 and r will be approximately 650 Ω, 84 kΩ, 93 kΩ and 1.51, respectively. Power consumption will increase by about 50% when using the AD595 with type E inputs.

Note that during this procedure it is crucial to maintain the AD594/AD595 at a stable temperature because it is used as the temperature reference. Contact with fingers or any tools not at ambient temperature will quickly produce errors. Radiational heating from a change in lighting or approach of a soldering iron must also be guarded against.

USING TYPE T THERMOCOUPLES WITH THE AD595

Because of the similarity of thermal EMFs in the 0°C to +50°C range between type K and type T thermocouples, the AD595 can be directly used with both types of inputs. Within this ambient temperature range the AD595 should exhibit no more than an additional 0.2°C output calibration error when used with type T inputs. The error arises because the ice point compensator is trimmed to type K characteristics at 25°C. To calculate the AD595 output values over the recommended –200°C to +350°C range for type T thermocouples, simply use the ANSI thermocouple voltages referred to 0°C and the output equation given on page 2 for the AD595. Because of the relatively large nonlinearities associated with type T thermocouples the output will deviate widely from the nominal 10 mV/°C. However, cold junction compensation over the rated 0°C to +50°C ambient will remain accurate.

STABILITY OVER TEMPERATURE

Each AD594/AD595 is tested for error over temperature with the measuring thermocouple at 0°C. The combined effects of cold junction compensation error, amplifier offset drift and gain error determine the stability of the AD594/AD595 output over the rated ambient temperature range. Figure 8 shows an AD594/ AD595 drift error envelope. The slope of this figure has units of °C/°C.

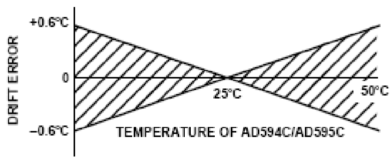


Figure 8. Drift Error vs. Temperature

THERMAL ENVIRONMENT EFFECTS

The inherent low power dissipation of the AD594/AD595 and the low thermal resistance of the package make self-heating errors almost negligible. For example, in still air the chip to ambient thermal resistance is about 80°C/watt (for the D package). At the nominal dissipation of 800 µW the self-heating in free air is less than 0.065°C. Submerged in fluorinert liquid (unstirred) the thermal resistance is about 40°C/watt, resulting in a self-heating error of about 0.032°C.

SETPOINT CONTROLLER

The AD594/AD595 can readily be connected as a setpoint controller as shown in Figure 9.

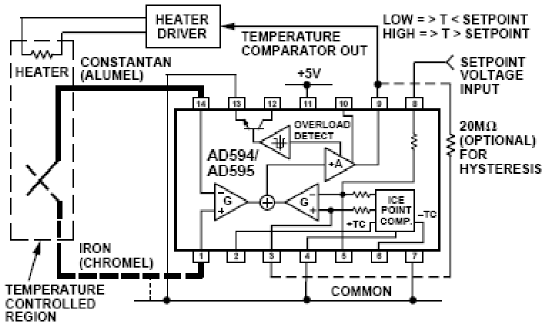


Figure 9. Setpoint Controller

The thermocouple is used to sense the unknown temperature and provide a thermal EMF to the input of the AD594/AD595. The signal is cold junction compensated, amplified to 10 mV/°C and compared to an external setpoint voltage applied by the user to the feedback at Pin 8. Table I lists the correspondence between setpoint voltage and temperature, accounting for the nonlinearity of the measurement thermocouple. If the setpoint temperature range is within the operating range (–55°C to +125°C) of the AD594/AD595, the chip can be used as the transducer for the circuit by shorting the inputs together and utilizing the nominal calibration of 10 mV/°C. This is the centigrade thermometer configuration as shown in Figure 13.

In operation if the setpoint voltage is above the voltage corresponding to the temperature being measured the output swings low to approximately zero volts. Conversely, when the temperature rises above the setpoint voltage the output switches to the positive limit of about 4 volts with a +5 V supply. Figure 9 shows the setpoint comparator configuration complete with a heater element driver circuit being controlled by the AD594/ AD595 toggled output. Hysteresis can be introduced by injecting a current into the positive input of the feedback amplifier when the output is toggled high. With an AD594 about 200 nA into the +T terminal provides 1°C of hysteresis. When using a single 5 V supply with an AD594, a 20 MΩ resistor from V_O to +T will supply the 200 nA of current when the output is forced high (about 4 V). To widen the hysteresis band decrease the resistance connected from VO to +T.

ALARM CIRCUIT

In all applications of the AD594/AD595 the –ALM connection, Pin 13, should be constrained so that it is not more positive than (V+) – 4 V. This can be most easily achieved by connecting Pin 13 to either common at Pin 4 or V– at Pin 7. For most applications that use the alarm signal, Pin 13 will be grounded and the signal will be taken from +ALM on Pin 12. A typical application is shown in Figure 10.

In this configuration the alarm transistor will be off in normal operation and the 20 k pull up will cause the +ALM output on Pin 12 to go high. If one or both of the thermocouple leads are interrupted, the +ALM pin will be driven low. As shown in Figure 10 this signal is compatible with the input of a TTL gate which can be used as a buffer and/or inverter.

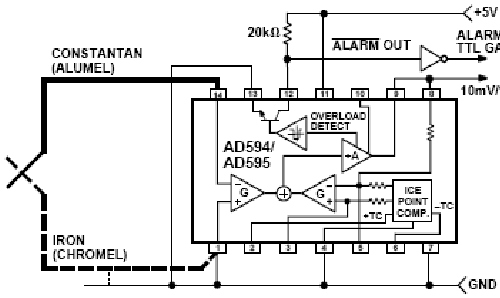


Figure 10. Using the Alarm to Drive a TTL Gate ("Grounded" Emitter Configuration)

Since the alarm is a high level output it may be used to directly drive an LED or other indicator as shown in Figure 11.

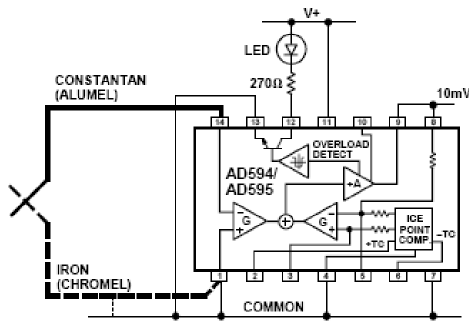


Figure 11. Alarm Directly Drives LED

A 270 Ω series resistor will limit current in the LED to 10 mA, but may be omitted since the alarm output transistor is current limited at about 20 mA. The transistor, however, will operate in a high dissipation mode and the temperature of the circuit will rise well above ambient. Note that the cold junction compensation will be affected whenever the alarm circuit is activated. The time required for the chip to return to ambient temperature will depend on the power dissipation of the alarm circuit, the nature of the thermal path to the environment and the alarm duration.

The alarm can be used with both single and dual supplies. It can be operated above or below ground. The collector and emitter of the output transistor can be used in any normal switch configuration. As an example a negative referenced load can be driven from –ALM as shown in Figure 12.

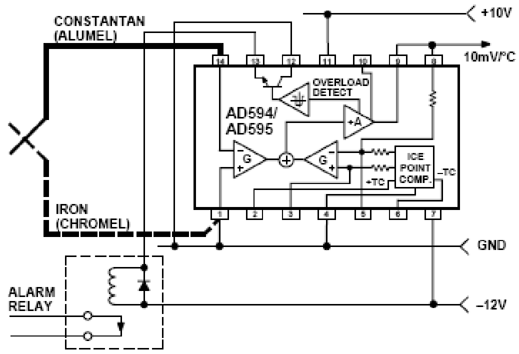


Figure 12. –ALM Driving A Negative Referenced Load

The collector (+ALM) should not be allowed to become more positive than (V–) +36 V, however, it may be permitted to be more positive than V+. The emitter voltage (–ALM) should be constrained so that it does not become more positive than 4 volts below the V+ applied to the circuit.

Additionally, the AD594/AD595 can be configured to produce an extreme upscale or downscale output in applications where an extra signal line for an alarm is inappropriate. By tying either of the thermocouple inputs to common most runaway control conditions can be automatically avoided. A +IN to common connection creates a downscale output if the thermocouple opens, while connecting –IN to common provides an upscale output.

CELSIUS THERMOMETER

The AD594/AD595 may be configured as a stand-alone Celsius thermometer as shown in Figure 13.

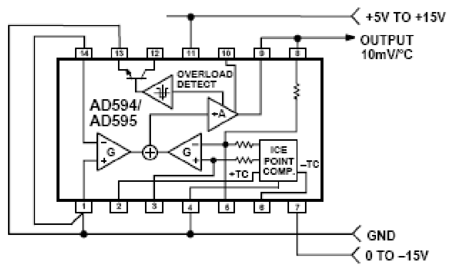


Figure 13. AD594/AD595 as a Stand-Alone Celsius Thermometer

Simply omit the thermocouple and connect the inputs (Pins 1 and 14) to common. The output now will reflect the compensation voltage and hence will indicate the AD594/AD595 temperature with a scale factor of 10 mV/°C. In this three terminal, voltage output, temperature sensing mode, the AD594/AD595 will operate over the full military –55°C to +125°C temperature range.

AD594/AD595

THERMOCOUPLE BASICS

Thermocouples are economical and rugged; they have reasonably good long-term stability. Because of their small size, they respond quickly and are good choices where fast response is important. They function over temperature ranges from cryogenics to jet-engine exhaust and have reasonable linearity and accuracy.

Because the number of free electrons in a piece of metal depends on both temperature and composition of the metal, two pieces of dissimilar metal in isothermal and contact will exhibit a potential difference that is a repeatable function of temperature, as shown in Figure 14. The resulting voltage depends on the temperatures, T1 and T2, in a repeatable way.

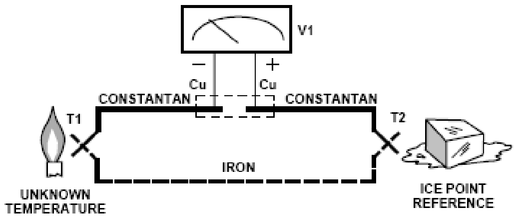


Figure 14. Thermocouple Voltage with 0°C Reference

Since the thermocouple is basically a differential rather than absolute measuring device, a know reference temperature is required for one of the junctions if the temperature of the other is to be inferred from the output voltage. Thermocouples made of specially selected materials have been exhaustively characterized in terms of voltage versus temperature compared to primary temperature standards. Most notably the water-ice point of 0°C is used for tables of standard thermocouple performance.

An alternative measurement technique, illustrated in Figure 15, is used in most practical applications where accuracy requirements do not warrant maintenance of primary standards. The reference junction temperature is allowed to change with the environment of the measurement system, but it is carefully measured by some type of absolute thermometer. A measurement of the thermocouple voltage combined with a knowledge of the reference temperature can be used to calculate the measurement junction temperature. Usual practice, however, is to use a convenient thermoelectric method to measure the reference temperature and to arrange its output voltage so that it corresponds to a thermocouple referred to 0°C. This voltage is simply added to the thermocouple voltage and the sum then corresponds to the standard voltage tabulated for an ice-point referenced thermocouple.

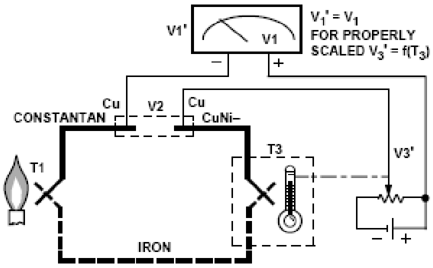


Figure 15. Substitution of Measured Reference Temperature for Ice Point Reference

The temperature sensitivity of silicon integrated circuit transistors is quite predictable and repeatable. This sensitivity is exploited in the AD594/AD595 to produce a temperature related voltage to compensate the reference of "cold" junction of a thermocouple as shown in Figure 16.

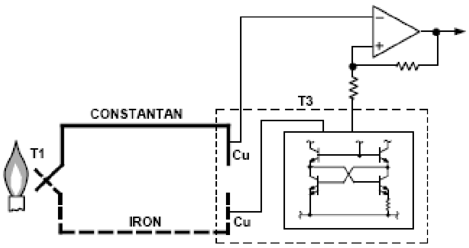


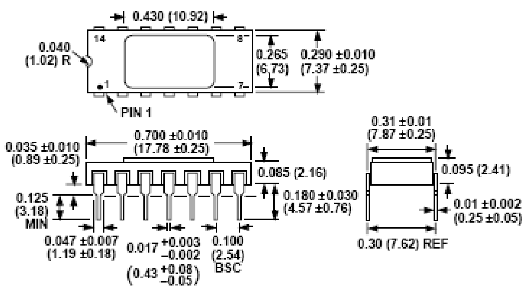
Figure 16. Connecting Isothermal Junctions

Since the compensation is at the reference junction temperature, it is often convenient to form the reference "junction" by connecting directly to the circuit wiring. So long as these connections and the compensation are at the same temperature no error will result.

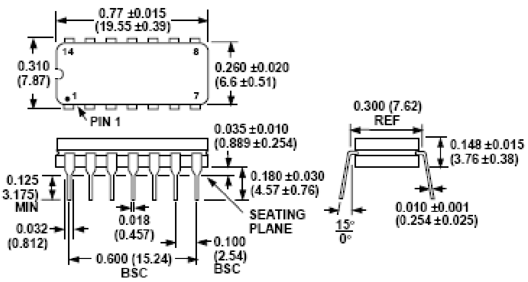
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

TO-116 (D) Package



Cerdip (Q) Package



C731g–0–11/99

PRINTED IN U.S.A.