Simulation and realization of a controlled solar water heating system

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Abstract: - This paper describes a design and a realization of an example of solar energy exploitation systems; it is a simulation and a realization of solar water heating system with a control board based on the microcontroller PIC 16F877. The project is foremost simulated by ISIS-Proteus software and then realized in real time. The practical results of this application were carried out using a digital LCD which displays the hot water temperature. This temperature varies between the minimal value 20^{o}C and its maximal value 70^{o}C. The results prove the competitiveness of the solar hot water system with its controlling board. The economized coast of the realized project can help and encourages the use and may be the commercialization of this system.

Key-Words: - Control, Solar energy, Thermal, Solar water heater, PIC 16F877, Renewable energy, NTC.

1 Introduction

A huge quantity of electricity can be accounted for by water heating needs, such as taking showers, washing clothes, doing dishes, and more. The fact that requires other techniques to reduce the cost of heating water such as using solar energy [11]. In addition to that, solar water heating seems to be better for the environment, such it causes no harmful emissions to be released into the air and it does not contribute to the depletion of the planet's natural resources [11].

Solar Water Heating is a reasonable technique of water heating, which uses the received energy from the sun to heat water in a panel often sited on the roof which can transfer this heat as hot water to be exploited directly at home or to be moved to a central heating system. Solar Water Heating is the renewable technology of choice for all developed countries, because it can provide at least 40-60% of all people hot water requirements throughout the year [10].

Solar panels should be placed on a south-facing inclined roof, at an angle of between 20 and 50 degrees, or may be attached onto an inclined frame on the ground or on a horizontal roof. The typical heating water installations require 2-5 m^2 of area and it may also need space to locate a water tank that stores the hot water if required [7].

Now Algeria, aware that its oil and gas riches will one day run dry, is gearing up to tap its sunshine on an industrial scale for itself and even Europe. Algeria potential in solar power is four times the world's energy consumption so citizens of this country can have all the ambitions they want with that. The solar potential of Algeria is huge, enormous, because solar radiation is high and there is plenty of land for solar plants. Table 1 presents the sunshine time and the received energy in deferent areas from which we can conclude that the Great Desert of Algeria (Sahara) is the most important pole of collecting the solar energy [11].

AREAS	COASTLINE	HIGHSLANDS	SAHARA
Surface %	4	10	86
Sunshine time (h/year)	2650	3000	3500
Received energy (Kw/year)	1700	1900	2650

Table 1. Solar energy potentiality in Algeria

2 Solar water heater principle

Solar heater is water heated by the use of solar energy. Its system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage and subsequent use. A solar heater system can form part of a solar thermal cooling system, promoting efficient temperature control of buildings or parts thereof [10].

Solar Thermal systems capture heat from the sun and use it to pre-heat cold water before it goes into a hot water tank, saving a family of four up to 50% on their hot water costs. The Solar Water Heating System will become a primary source of hot water, while an existing electric, natural gas, propane, or oil hot water heater functions as an auxiliary heating source.

Solar water heating is done in an active or passive manner as shown in figure 1. A passive solar water heater needs neither circulating pumps nor controlling board. It is a simple water heater which consists of a storage tank and collector. This last is placed facing the sun. Water is then pumped through it by the process of natural convection; the produced hot water is stored in the tank [9].

On the other hand, an active solar water heater does use some additional devices as pumps and controls. Water is heated by using a non-freezing heat-transfer liquid heated by the sun; this liquid can heat the stored water in the panel. When the water is heated it will be transferred to a storage tank automatically by using the control board.

In an active solar water heater as in our study case, the ball can be located outside or inside the house. This type of solar water heater as shown in figure 1 is suitable for all different configurations. It is usually consists of three parts as follows:

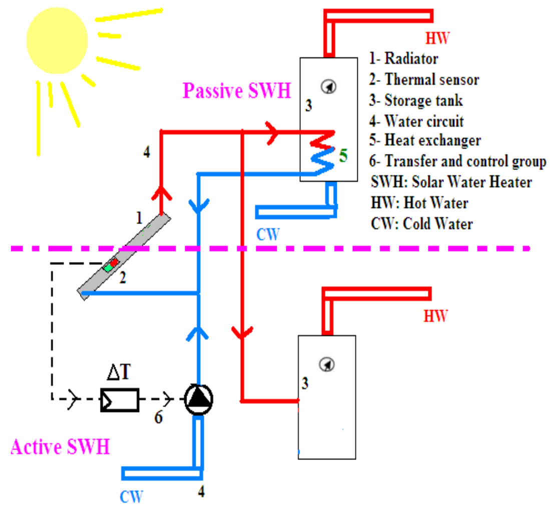


Fig.1. Block diagram of passive and active solar water heating system

2.1 The solar flat plate collector

It is a solar collector designed to collect heat by absorbing sunlight. A collector is a device for converting the energy in solar radiation into a more usable or storable form. The solar energy striking the earth's surface depends on weather conditions, as well as location and orientation of the surface [10].

2.2 Tank heat storage

Two tanks can be used to store the water, one can be used to store the cold water that must be heated, then the second can be thermal to store the hot water, the sizes of those two tanks depend on the collector capacity and its dimensions.

2.3 Group of transfer and control

It contains the water pipes to carry the cold water from the tank cold storage to the collector, and the hot water from the collector to the tank heat storage. These channels can be metallic or isolating [7].

3 Project overview

This project is a simple and economical public service. Generally the whole system is shown in figure 2, it is a good description of all the blocks that construct the system approach. To increase the effectiveness of the implemented solar water heater and its control board, we optimize this work by adding some components such as (pump, test tank ...) [11].

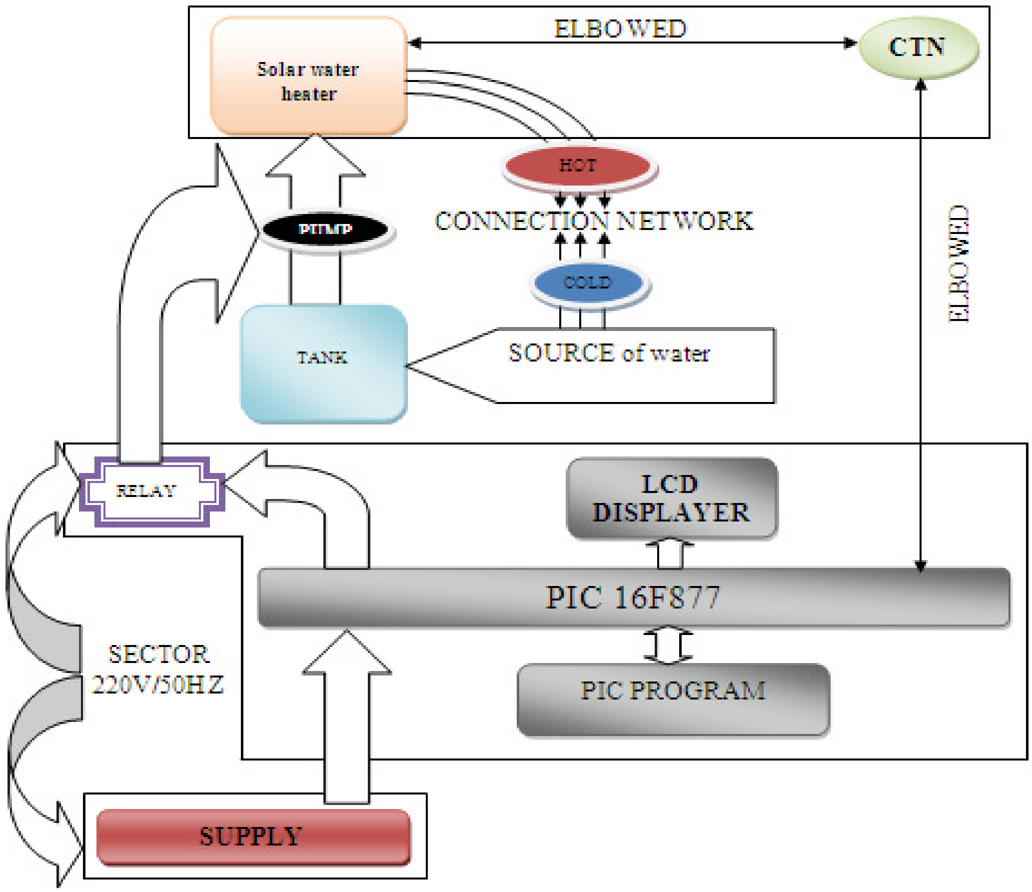


Fig.2. Block diagram of the proposed solar water heater with its control board

4 Simulation and routing

Figure 3 illustrates the program pathway starting by the construction of its algorithm, and its redaction by using a specialized PIC programming language; in our case one uses the PROTON programming language. In this practical case, the program must be loaded into the PIC with Hexadecimal format; by using special software that helps to flash the program into the PIC [9].

The followed steps to obtain a functional system must meet the needs of the user. To study our practice, we conducted our work divided into eight steps:

Step 1: To design the program, it is necessary to construct the initial idea on which the program will be created that is called an “organizational chart”.

Step 2: The programming is a construction game in which, it is essential to use some basic instructions towards solving the proposed problem. In our case we used the compilation software "Proton".

Step 3: In the third phase, once the source file is compiled, we have to move it to the PIC memory. This requires a programmer and transfer software, in our case one used "IC_PROG”.

Step 4: To test our program in the PIC 16F877, and the connection of electronic components of the system we use the "electronics test board".

Step 5: To draw the printed circuit supply and control boards, we need the "EAGLE" software.

Step 6: electronic components pinout.

Step 7: Connection between the solar water heater system and the control board.

Step 8: Verification and testing.

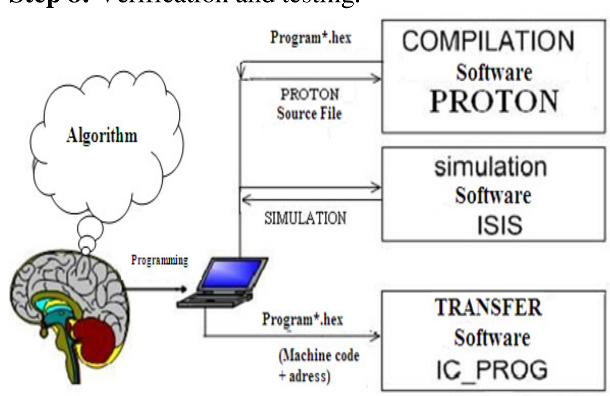


Fig.3. Program pathway

4.1 Chart

The chart in figure 4 represents the idea of the project we want to do, the water temperature is limited between two values 20°C and 70°C and the pump must run or stop in function of the water temperature.

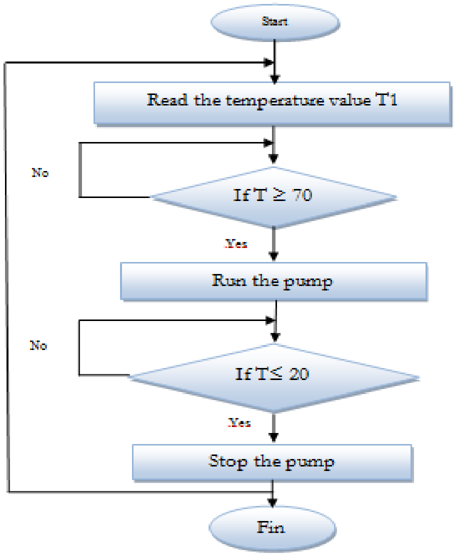


Fig.4. Chart of the project

4.2 PROTON program

The program of this project can be written in many programming languages and so introduced to the microcontroller by different methods, in our case the program was been written in PROTON programming language which is the one of the most popular language for microcontrollers programming. This program is shown in figure 5 [11].

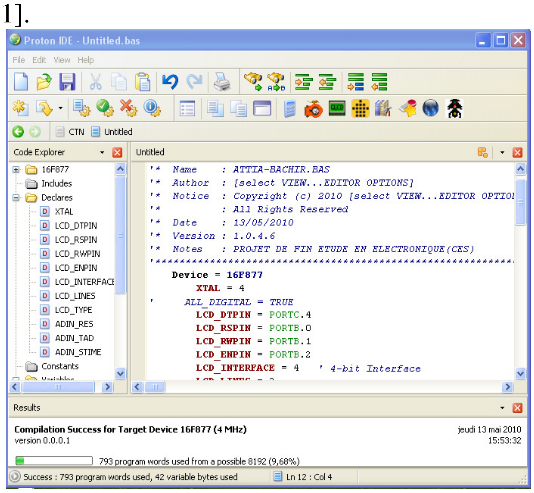


Fig.5. Program configuration

The constructed PROTON program can be uploaded to the PIC as a hexadecimal file by using special software as IC-Prog. Some other configurations must been adjusted in function of the chosen microcontroller. Figure 6 demonstrates the IC-Prog interface when loading the program [10].

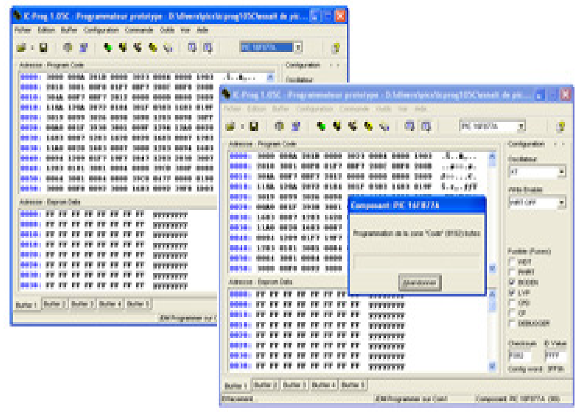


Fig. 6. Transfer of the Hexadecimal file by using IC-Prog

4.3 ISIS-Proteus simulation

4.3.1 Connecting the LCD to the PIC

In our application, we used an LCD alphanumeric display with 2 lines and 16 characters. This screen must be connected to the microcontroller as shown in figure 7 by using the pins of the B port, we have retained all the pins of port D to bind the data (D4 to D7). A set of specialized instructions that can easily drive this LCD is available in the PROTON software. It is also possible to drive the LCD directly by using control instructions in binary form [11].

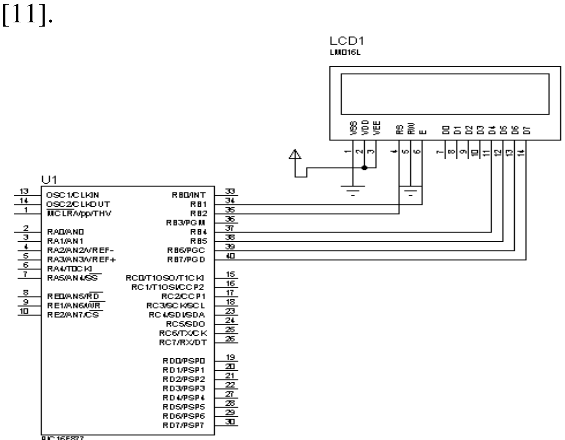


Fig. 7. Connection between the LCD and the PIC

4.3.2 Control board simulation

In the simulation one has used the ISIS software and through it we load the Hexadecimal version of the built program into the PIC. One can use four displayers or LCD display screen to display the two values of the temperature limits with the hot water temperature. The NTC (Negative Temperature Coefficient) thermistor, TMAX and TMIN can be symbolized by three voltages dividing. The DC motor represents in the real case the pump which is connected to the PIC by a relay [7]. Figure 8 illustrates the ISIS simulation of the controlling board.

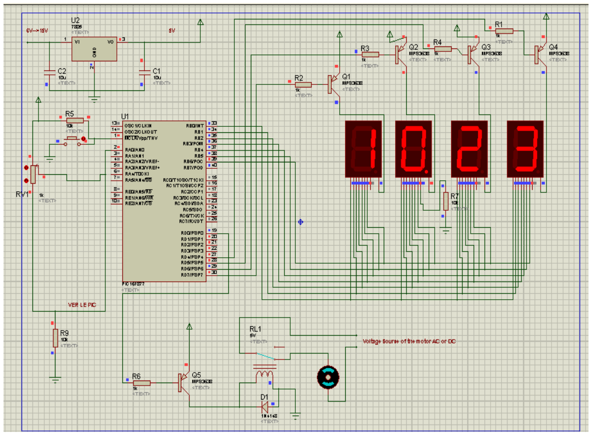


Fig.8. ISIS simulation scheme

5 Practical realization

5.1 Microcontroller PIC 16F877

5.1.1 Choice

A microcontroller is a unit of information processing of microprocessor type, to which an internal devices are added to make arrangements without the need to attach additional external components. Choosing a microcontroller is important because on it depend the performances, the size, the facility of use and the price of the assembly. The PIC 16F877 is a cheap circuit, it has an integrated ANC (Analog Digital Converter), also it has more ports than the 16F876 and 16F84, which correspondingly increases the numbers of I/O available, it has 33 I/O lines divided into five ports (Port A has six bits, port B has eight bits, port C has eight bits, port D has eight bits, and port E has three bits) [11].

5.1.2 Characteristics

The 16F877 is part of the subfamily 16F87x. This branch is part of the family of PIC ® Mid-Range, Table 2 represents the characteristics of a PIC 16F877.

PIC	FLASH	RAM	EEPROM	I/O	A/D	Parallel PORT	Serial PORT
16F877	8K	368	256	33	8	PSP	USART/MSSP

Table 2. Characteristics of a PIC 16F877

5.2 Solar energy collector (Radiator)

It is the fundamental unit of the solar water heater; it converts the solar energy to a thermal energy. In our case we have used a radiator in copper, because it absorbs well the heat, which the dimensions are: length: 61.2 cm, width: 37.5 cm, height: 3.5 cm, as shown in figure 9. Painting the radiator in black helps in optimizing the sunshine absorption [7].

The collector connection must be made so as to circulate the water easily; the collector must be joined in a wooden frame whose dimensions are given before. This framework allows the fixation and isolation of the collector using polystyrene.

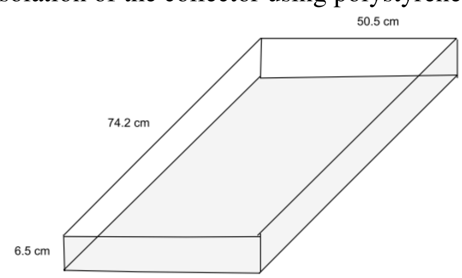


Fig.9. Radiator dimensions

The frame has two holes that allow the connection of the sensor by the cold and hot water pipes. A transparent mirror must be placed on the collector attached to the wood frame so that the collector can receive light; the final stages of preparation of the solar collector are shown in figure 10.

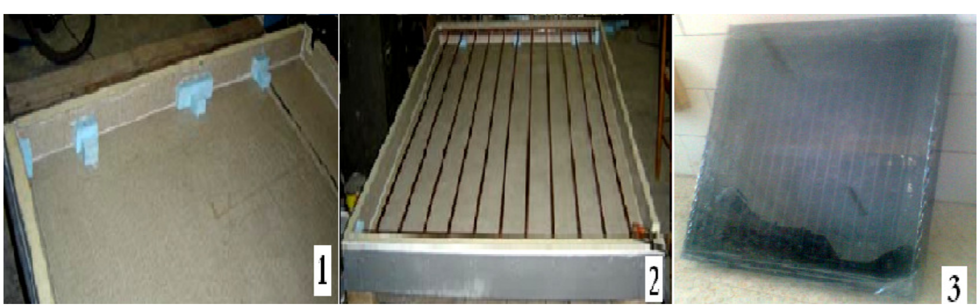


Fig. 10. Steps of collector realization

5.3 Water pump

Generally, centrifugal pumps are most common in solar plants. They are reliable and they have a reasonable cost, even more, they are too powerful for many solar water heaters.

The pump we used is of type DRAIN PUMP B20-6, its operating voltage is between 220V-240V/50Hz, and its power is 30W with 0.2A. This pump has a speed of 300 rev / min and a compression capacity of water 20L/min [15].

5.4 NTC (Negative Temperature Coefficient Thermistor)

The extent of a given temperature induces a specific resistance to the thermistor. Various thermistors are made of small grains of semiconductor and metal oxide (iron, titanium, etc. ...) which are called ceramic oxides; these thermistors are used to measure temperatures between -10 °C and 100 °C. These oxides are sintered (heated and compressed) to a limit melting temperature. Their properties depend on the choice of the semiconductor and the dosage of the oxides.

In this test each time you vary the values of temperature which can extract new values of RCTN. The results are stored in a table, and the calibration graph defined by the equation:
RCTN = f (temp) is shown in figure 11. Hence we can notice that the value of this resistance that has the corresponding temperature of 25° C is:
RCTN ≈ 10K.

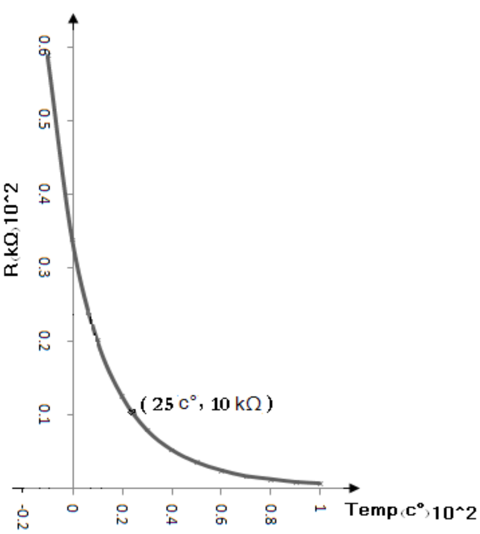


Fig. 11. Calibration graph of the NTC in function of temperature

5.5 Test Board

This step is very important before beginning the practical work, to verify the success of the printed board. All electronic components are connected in the test board; Figure 12 shows the pinout of the components in the card test.

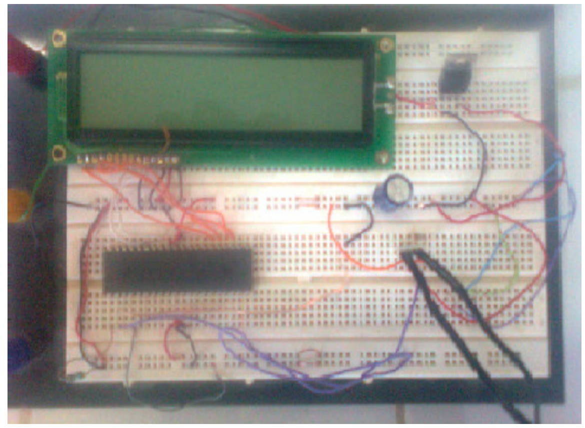


Fig.12. Test board

5.6 Supply board

In the supply board of figure 13, a transformer generates a voltage of 5V, which is rectified by the diode bridge and filtered by capacitors C1 and C2. This voltage is then adjusted to 5V by U1 and U2, The capacitors C2 and C3 are used to filter noise, their values must been specified. One obtains at the regulator output a voltage of 5V stable enough to not disturb the control circuit [11].

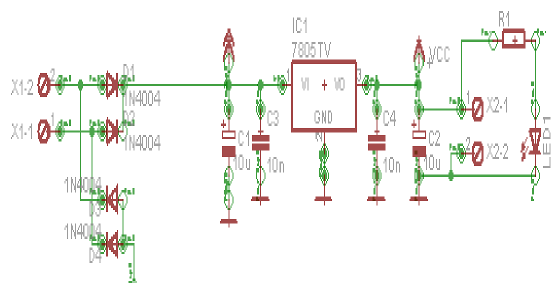


Fig. 13. Complete assembly stabilized supply

5.7 Control board realization

Figure 14 represents an EAGLE simulation of an electronic board to control the water circulation pump. It will be filled by a set of electronic components such as resistances, transistors, diodes and relays that can trigger or activate the pump when needed by using signals sent by the NTC [11].

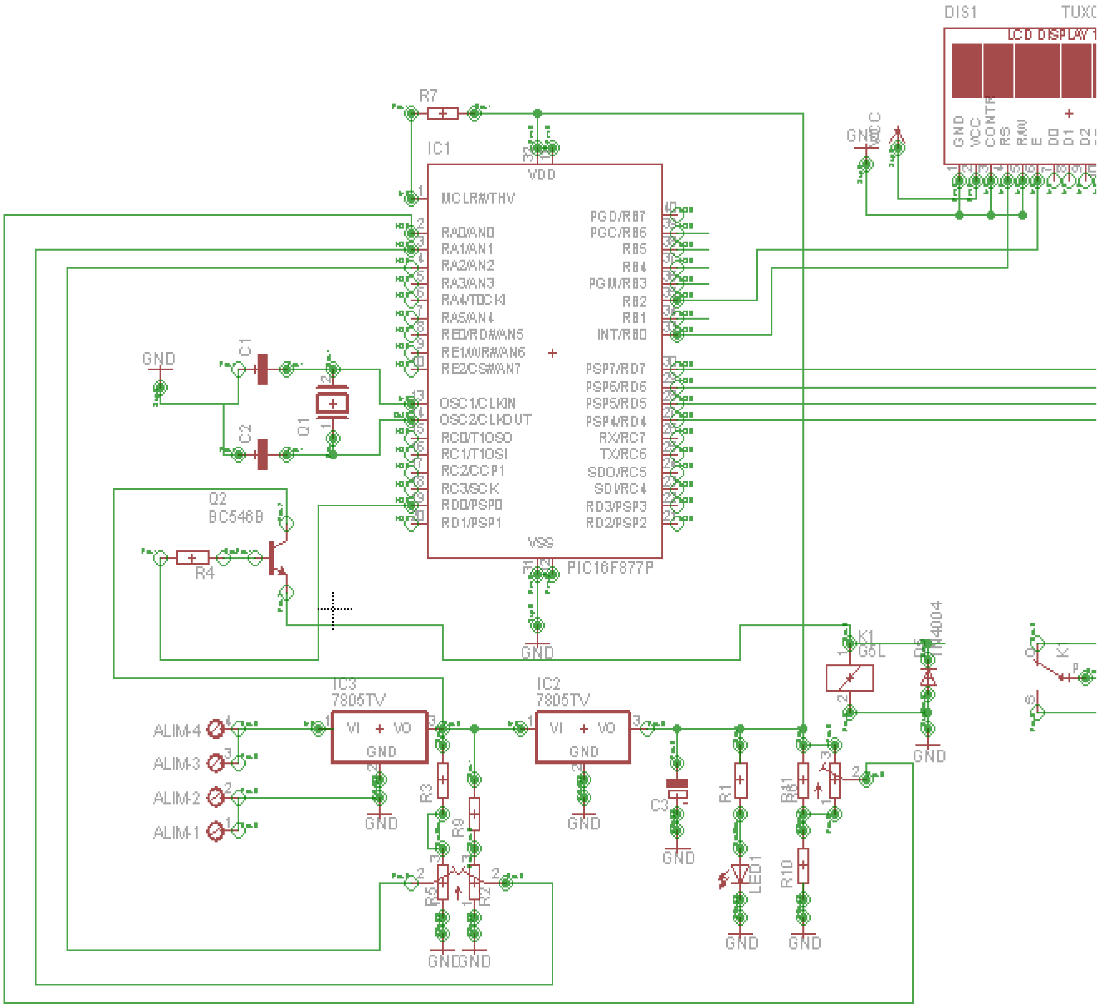


Fig.14. EAGLE simulation of the PCB

6 Mechanical-Electronical assembly

This programmer can program a wide range of recent PIC (12C508, 12C509, 16F877 ...), and also serial EEPROMs of protocol 12C, type 24Cxx or 24LCxx. It can be simply connected to the parallel interface of a PC. In addition, it works with the excellent freeware IC_Prog, while the voltage is raised to the input of RESET / MCLR to 13 V and the positive supply voltage VDD of the circuit adopts the value of the programming which is equal to 5V [11].

RB6 becomes the programming clock and therefore it operates as an input, while RB7 becomes the serial input/output of data. It operates as input during all the programming phase and as output in the verification phase. RB6 and RB7 are Schmitt Trigger inputs in this mode. For the duration of programming, the watchdog timer is automatically disabled to prevent that it generates a reset that would be undesirable [17].

After the realization of the PCB, it is imperative to check the continuity of all tracks and the absence of short circuits between tracks using an Ohmmeter or another tester, Figure 15 shows the final image of the printed board.

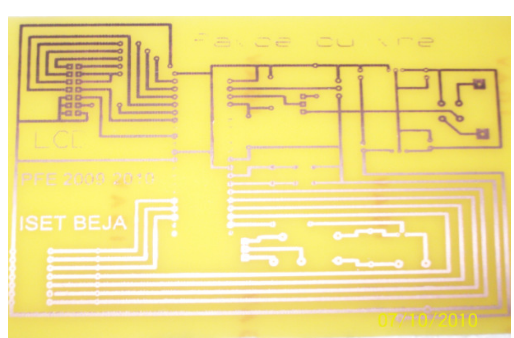


Fig.15. Printed Circuit Board

All the electronic components must be welded in the printed circuit in an ascending order of size by using a soldering iron and tin.

The final scheme of solar water heater connected to the control board is shown in figure 16, the pump is connected to the control board on one side and the other is connected by pipes to the hot water heater [10].

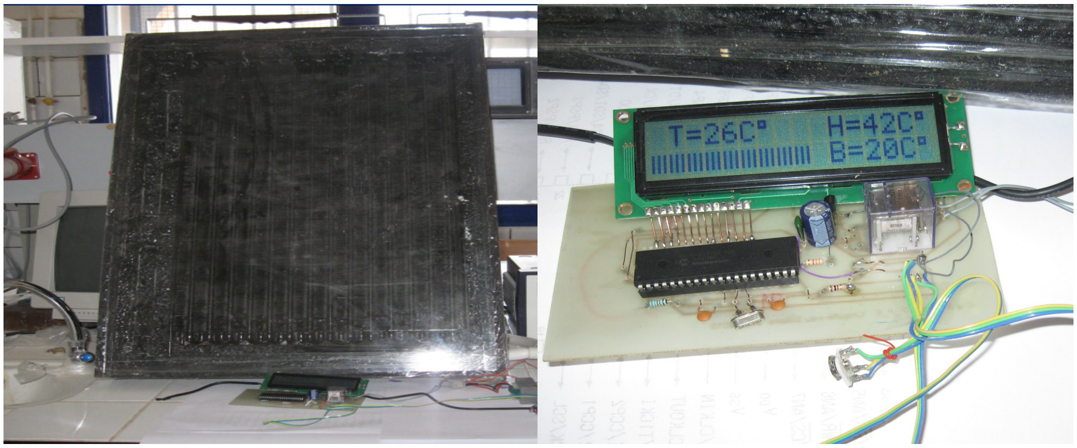
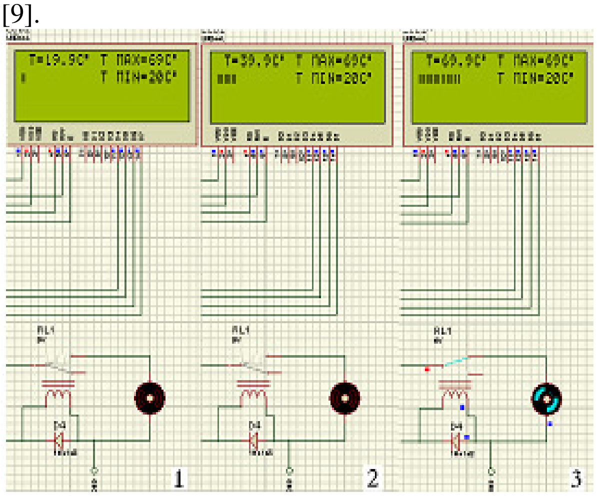


Fig.16. Mechanical-Electronical assembly

7 Results

One changes the NTC value between two specified values T-MIN=20^{o}C, and T-MAX=70^{o}C. Certain values of the measured temperature of the water are displayed in the LCD screen as shown in the figure 17, from which one can remark that the DC motor, which symbolizes the pump in real time, doesn't operate ever if the temperature exceeds T-MAX≈70^{o}C, and then if one minimizes this temperature, the DC motor doesn't stop ever when the temperature is lower or equal to T-MIN≈20^{o}C [9].



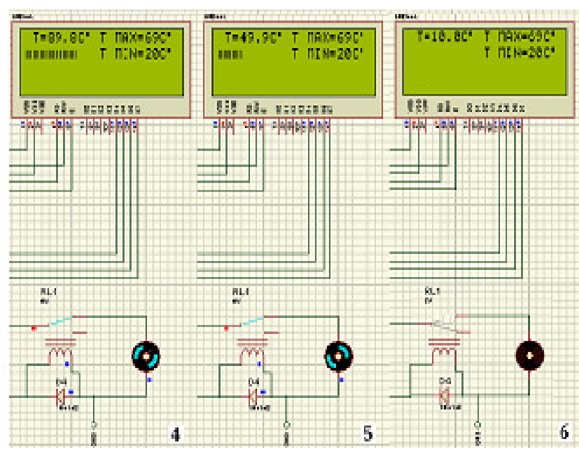


Fig.17. ISIS simulation results

Table 3 presents the results of the solar water heater control system. The minimum temperature is T-MIN = 20^{o}C, and the maximum temperature is set to a value of T-MAX = 70^{o}C. The external temperature is T-EXT=35^{o}C, and then we try to minimize the increasing temperature of the NTC. The pump can control the movement of water depending on water temperature in the radiator. From this table we can conclude that the pump is running when the temperature is higher than 70^{o}C, and when we minimize the value of the NTC temperature to become lower than 20^{o}C, the pump stops [10].

SOLAR WATER HEATING	TEMPERATURE					PUMP STATE	
WATER VOLUME IN THE SOLAR RADIATOR	T-MIN	T-MAX	T-CTN	T-EXT	T-LCD	RUN	STOP
2 litres	20 °C	70 °C	20 C°	35 °C	20 °C	X	✓
2 litres	20 °C	70 °C	30 C°	35 °C	29 °C	X	✓
2 litres	20 °C	70 °C	40 C°	35 °C	37 °C	X	✓
2 litres	20 °C	70 °C	50 C°	35 °C	48 °C	X	✓
2 litres	20 °C	70 °C	60 C°	35 °C	60 °C	X	✓
2 litres	20 °C	70 °C	69 C°	35 °C	69 °C	✓	X
2 litres	20 °C	70 °C	80 C°	35 °C	79 °C	✓	X
2 litres	20 °C	70 °C	75 C°	35 °C	75 °C	✓	X
2 litres	20 °C	70 °C	65 C°	35 °C	65 °C	✓	X
2 litres	20 °C	70 °C	55 C°	35 °C	54 °C	✓	X
2 litres	20 °C	70 °C	45 C°	35 °C	44 °C	✓	X
2 litres	20 °C	70 °C	35 C°	35 °C	32 °C	✓	X
2 litres	20 °C	70 °C	25 C°	35 °C	27 °C	✓	X
2 litres	20 °C	70 °C	15 C°	35 °C	15 °C	X	✓

Table 3. Practical results

8 Conclusion

The subject of our project is very relevant of using and controlling the solar power for heating water system. In that way we propose smart and suitable approach for saving the natural resources and reducing the cost of oil and gas. The obtained results by simulation as well as by practical realization prove that the water can be heated and its temperature can attains the desired temperature degree depending on the two specified values limits of temperature.

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