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DESIGNING AND IMPLEMENTATION OF A PV POLYCRYSTALLINE PANEL-BASED, TWO-AXIS SOLAR TRACKING SYSTEM

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Abstract: A Solar Tracking System (STS) is developed to minimize the angle of incidence between the sunlight and a photovoltaic (PV) panel surface. The paper presents the designing and implementation aspects in order to obtain a system capable to automatically direct a solar panel to the point of maximum light intensity, considering two axes: North-South (for differences in angle during winter vs. summer) and East-West (over a day). By using the tracking system we developed, the total power generated by the panel is higher than the one obtained by a fixed configuration, the panel efficiency being estimated to increase with 42%.

Keywords: *photo-voltaic polycrystalline panel, solar energy, two-axis tracker, photodiode, motors, PCB design, Arduino.*

I. INTRODUCTION

The present work aims to provide a solution regarding the increased efficiency of solar power systems. The function of a photovoltaic system is to generate electricity from sunlight, either as DC (direct current) or as AC (alternative current), in order to meet the need of electricity. Generally, it is composed of multiple interconnected solar panels, a control system and energy storage elements. Depending on the year period but also of the day, the angle of the photovoltaic (PV) panel should be adjusted on vertical and horizontal such that to maximize the generated energy. The sun position is different according to the geographical coordinates, season and daytime. The solar panels used by the PV systems from the Northern hemisphere are always oriented to South direction.

The PV cell, also called solar cell is a semiconductor piece that converts light energy into electrical energy. The solar energy causes a current that flows through the load when the cell is illuminated. When several PN junctions are connected in series, they produce higher voltage values, solar panels appearing based on these considerations. The PV systems are of two types: the off-grid ones that are not connected to the local power, and the grid-connected ones. The off-grid ones are reliable especially in areas where there is no electricity grid. As concerns the total cumulative capacity generated by solar systems, Germany lead, followed by China, Japan and Italy, according to [1].

A Solar Tracking System (STS) is used to guide the panel so that the sun rays to fall perpendicular to the panel and thus the system efficiency to be increased. The fixed solar systems have a small number of hours in which sunlight is perpendicular to the panel surface. In contrast, by using a STS, panels are exposed to sunlight for several hours throughout the day: the number of hours is maximum, bringing thus a maximum power converted at the end of a day. Solar panel output parameters are the elements that indicate if the panel is in the optimum point. To prove that the practical implementation achieved the purpose, some measurement were performed. These results were compared with the results obtained by a fixed configuration. In our case, the same pannel was used in two different situations: in a fixed position and mounted on the STS. The measurements were realised from 6:00 a.m. to 8:00 p.m. during an ordinary summer period. Adding the values measured in the fixed panel case, the total power generated by the panel was 64.87W, while the total power generated using the Solar Tracker was 93.39W. In this way, the power generated using the STS was 42% higher than in the case of mounting the panel in a fixed position, as suggested in Figure 1.

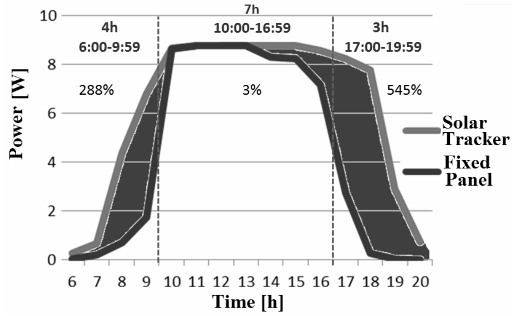

Figure 1. The power measured in the two situations: fixed panel and on solar tracker

Many articles report that using one-axis solar tracker system, the energy gain is with at least 10%-25% increased, and for a two-axis solar tracker the gain is even higher, i.e. between 30% and 40% [2].

Section II presents the functioning principle; we show which is the algorithm we inspired from and how we decided to implement it in our STS. Section III introduces and describes the main aspects of the components forming the STS. Which is the main purpose these components were needed in the system and how they relate to each other in the entire STS is also presented in this part. Section IV mainly relates to the designing aspects, as it will also show the pins of each component, the connection diagrams and some mathematical relations on which the project development was based on. Section V presents some preliminary tests required in order to decide the exact type and the

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connections of each component from the final structure of the system. It also presents some of the final results we obtained. Section VI concludes the main aspects of our system.

II. THE STS OPERATION PRINCIPLE

The system intended to be designed and implemented aim to support and guide a PV panel towards the sunlight of maximum intensity. In order to capture the maximum solar energy and thus to assure an efficient functioning of the system, the panel should be correctly positioned in relation to the sun (i.e. sun rays to fall perpendicular to the panel).

Thus, to obtain the maximum intake of solar energy, the panel has to be correctly positioned as reported to the sun. This means that during a day, as the sun moves from East (sunrise) to West (sunset), the panel should be able to track the sun, so that in any moment, the sun rays to be perpendicular to the panel plane.

One simple method to check if the sun rays are perpendicular to the panel consists in using two light sensors, disposed on the panel plane as Figure 2 shows. This type of sensors will convert the incident light in electrical energy (current or voltage) and this can be measured. The method we relied on, to detect the shadow with light sensors, was previously used in literature [3]. For our STS system, in order to determine the point of maximum light intensity, a pair of sensors will be used on a single axis and another pair on a second axis. As noticed in Figure 2, for a single axis, the sensors are mounted on a plane, separated by a barrier placed perpendicular to the plane.

The PV panel position would be parallel to the plane, so that, in the ideal situation, as illustrated in Figure 2.a), the sun rays will be perpendicular to the panel. In this situation, the two light sensors would measure the same or almost the same value. Thus, the panel will receive the maximum quantity of solar energy and will function optimally.

If the sun changes its position relative to the sensors, as illustrated in Figure 2.b) for example, one of the sensors will be shadowed and it will receive a smaller amount of light. How much will be the difference between the values measured by the two sensors will show how far is the panel from the ideal position. In order to align the panel to the sun's new position, the panel should be inclined to the sun direction, or to the sensor having the greater amount of energy registered.

There are several types of light sensors. The most popular ones are: photoresistors, phototransistors and photodiodes. These are capable to generate output voltage or current when the light falls on their surface.

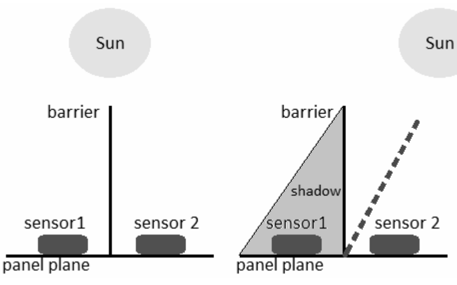

Figure 2. The panel movement according to the sun's position; a) ideal position; b) missed sun.

For stability and accuracy reasons, in the present application, the photodiodes were chosen to be used as light sensors. Our choice is motivated because generally, a photodiode characteristic is similar to that of the solar cell.

The panel will be considered aligned on an axis if the value of the difference between the sensor 1 and the sensor 2 on that axis is approximately zero or as small as possible; this value could be considered adjustable by using a threshold value. If the difference is greater than a predetermined threshold, then a motor would be needed to adjust the position of the panel until the panel reaches the desired state, i.e. being in the ideal situation. Thus, the motor will command the panel to incline in the direction of the sensor which register greater amount of light. Because the panel will be tracked on 2 axes, for the implementation of our STS, will therefore be required 4 sensors and two motors. In this way, the panel could be oriented in the optimum position, and will collect the maximum solar energy possible. This energy will further have to be deposited or stored in a battery.

Given that the entire ensemble should be sharply controlled and the operations must be executed in a certain order and quite accurate, we thought the ideal solution is to use a microcontroller system. Thus, we chose to manage all situations that may occur by using the Arduino Micro board.

The present application will function based on an algorithm which searches the maximum light point, and this is described below. It aims to identify the optimum position of the panel, so that to bring in the maximum energy at a time. At first, the functioning mode of the panel should be chosen, two possibilities being available: demo or solar. The difference between them is only in the value of the interval time elapsing between one complete cycle and the next.

The demo mode is intended for use in a room, just to demonstrate the panel operation, so where the light beam position is often changed (simulation of the real case). In the solar mode, corresponding to a real case of operation, this does not happen: the movement of the sun as related to the panel will not be so consistent as in the demo mode.

After choosing the functioning mode of the ensemble, demo or solar, one cycle of the panel begins with reading the values provided by the light sensors. The algorithm continues by computing their differences, to see which of the 2 axis has more priority. This calculation also helps to set up a level of system sensitivity as concerns the sensors.

In this application, we choose not to activate any motor unless the sensors difference is somewhat significant, so the system will not consume energy if this is not cost effective (saves energy consumed by the motor). If the difference is below a certain threshold, it is considered that the panel is aligned well enough and it is not justified to turn on a motor to adjust even more than that. The difference of the sensors values will be compared in the following steps with a threshold value. When this threshold is not exceeded, the corresponding motor will be turned off. The actual movement of the panel toward a peak of light is also conditioned by the voltage generated by the panel. A predefined threshold value is chosen and if the voltage measured from the panel is below this panel threshold, the motors will be stopped (not enough energy produced to ensure the consumption of the motors). To summarise, to activate the motors is necessary to meet two conditions, one as concerns the light registered by the sensors and another one as concerns the voltage generated by the panel.

Further, if the condition that the voltage generated by the panel to exceed the panel threshold is met, the algorithm proceed to compare the values from the sensors. If also the other condition is accomplished, on both directions, East-West and North-South, the motor will be operated to start performing in the direction indicating a higher difference value. For example, if the value read by the sensor positioned to the East is less than the West counterpart, the motor will guide the panel to move towards the West direction. Similarly, is the case on the North-South direction. After making these comparisons, the system waits a number of x milliseconds, prior to start again a new operation cycle. The two operating modes of the system are identical, the only difference being in the value of the waiting time (5 times lower in the demo case than in the solar one). For the demo mode this time was fixed at the value of 400 milliseconds.

Thus, the main elements needed to develop the STS are: panel, battery, light sensors, motors and Arduino board. These are designed to work together as Figure 3 shows.

The entire Solar Tracking System mainly comprises four parts, organized as concerns the function each of them accomplishes: to interact with the user, to control the main functions of the system, to collect and then deposit the energy or to guide the PV panel such that to maximize the solar energy intake. In the following, these will be denoted:

A. The user ***interaction*** subensemble – comprising the control panel and the charge level indicator;

B. The ***control*** unit of the system, Arduino-based;

C. The ***intake*** and ***storage*** subensemble, containing the PV panel and the battery;

D. The ***orientation*** subensemble, comprising the sensors and the motors.

The PV panel is connected directly with the battery charger system and with the module monitoring the panel voltage. Arduino is the central element of the entire scheme, as it controls every component of the STS. Thus, Arduino will receive signals from panel, battery and sensors. Each of the 4 sensors signal is not provided directly, as it is, but passed through an amplifier circuit. Also, the voltage signal from the battery is modified, being a stabilized one. After analyzing the signals received for the current situation, Arduino emits signals to one or to both of the driver motors, so it controls the motors to be on or off, depending on the activation conditions. Figure 3 shows the diagram of the entire ensemble. The wiring diagram of it will be given, due to space constraints, in section IV, one component at a time.

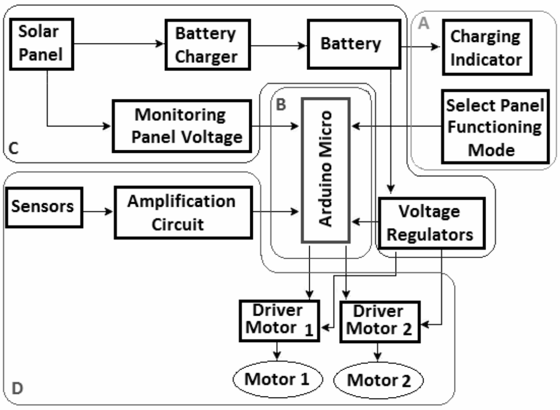

Figure 3. STS bloc diagram

III. THE MAIN COMPONENTS AND HOW THEY RELATE IN THE STS

In this section, only a few concepts, i.e. the most basic information about each of the components we used, as they appear in the composition of each sub-ensemble are specified. More details will appear in section IV, where the operation of each circuit is revealed.

For a proper functioning and to physically connect these components, especially as concerns the connection between Arduino and the other circuits, a PCB (Printed Circuit Board) was realized. This was designed for mechanically support but also to electrically connect the components in the system. The panel is supported and moved to the optimal position by using a metallic structure as shown in Figure 4. This has an important role in the mechanic support but also in the panel guidance process. The 3D model structure of the present system is shown, and here one can easily observe most of the constructive components. In the figure, the PCB is located at the base of the STS.

The structure of each of the 4 parts of the STS, as appeared in Figure 3, is next presented: which are the internal components and how these interact to eachother.

III A. The user interaction subensemble

This subensemble is denoted by the letter A in Figure 3 and comprises 2 modules, one for choosing the mode, which acts like an entry in the system and the other for displaying the battery level, which acts as an output.

Control panel

When the switch to select the functioning mode is closed, a logic "1" is sent to the corresponding pin at Arduino, so that the selected functioning mode will be the solar one. Otherwise, if this switch is not actioned, a value of 0 will be transmitted to Arduino and the demo mode will be chosen. Arduino will know (by programming) to choose the right value for the time between two cycles of the STS.

In order to control the application, e.g. to activate actions like motors on/off, to allow the selection of the functioning mode, a second circuit board was realized. This supports switches and the bar-graph that indicates the battery charge level. Thus, it serves as a control panel for the whole application.

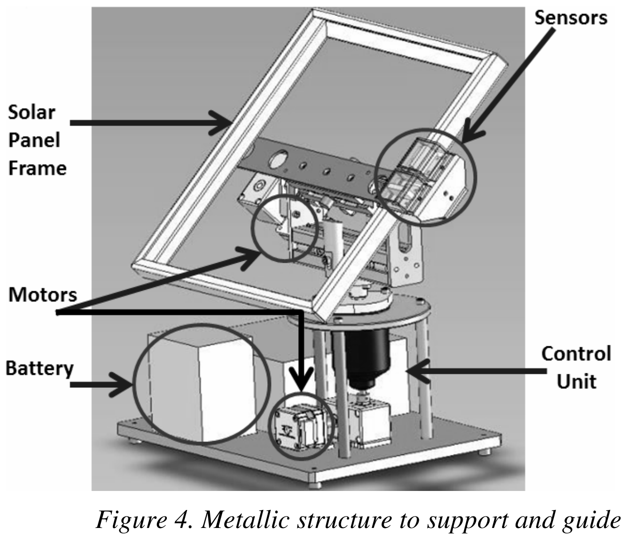

Figure 4. Metallic structure to support and guide the panel as part of the STS.

Charging indicator

To actually see that battery charging takes place, we chose to indicate the value of the voltage applied to the battery on a scale of 0 to 10. The range of values for the voltage required to charge the battery is 12.9 V - 14.1V, and the charging nominal voltage is 13.5V. Thus, the domain 12.9V-13.8V is the field that best describes the charge level of the battery, the value 13.8V being the floating maximum one. For the implementation, the LM3914 integrated circuit (IC) was chosen. According to the datasheet, it is a circuit to which if at the input an analog voltage is applied then at the output it is able to translate the analog voltage level on 10 levels. These are actually drivers for 10 leds, thereby obtaining a linear analogue display. The schematic of this circuit is shown in Figure 5, but due to time constraints, its final implemented form was not presented.

III B. The control subensemble

Micro Arduino is a development board that meet the needs of the current application, due to the fact that it provides both digital and analog ports. Therefore, the sensors will be read by the analog pins as inputs; in the same way, the voltage generated by the panel (converted in 0-5V) will be read on an analog pin. The digital pins are those which will command the motors drivers. Also, a digital pin will take the state of the switch which chooses the functioning mode of the system; all these and the specific meaning of the signals can be tracked in Figure 6.

For an accurate and ordered functioning of the whole system, the microcontroller must execute certain instructions in a specified order. These instructions are described by the code written in the microcontroller memory (on the Arduino board) via USB connection.

III C. The intake and storage subensemble

The subensemble denoted by the letter C on Figure 3 consists of most components, especially those related to the panel and battery.

Solar Panel

The type of the solar panel chosen for the present application is polycrystalline. Some of the critical characteristics of the PV panel, like size and weight, were strongly considered in order to achieve the mechanical structure. From the datasheet of the panel, the following information is known: maximum power 10Wh, maximum power voltage 17V, open circuit voltage 21.5V, maximum power current 0.59A, short circuit current 0.63A, temperature range: -40°C to +85°C, size (LxWxH) in mm: 327x357x18, weight 1.68kg, aluminum as frame material.

Monitoring panel voltage module

To permanently know which is the point to maximize the captured energy and to possibly keep the panel in that optimal position, monitoring certain parameters of the panel is absolutely necessary. As mentioned above, the current and the voltage generated by the panel are maximized when it is oriented to a peak of light. Because of the simplicity of the circuits necessary for the implementation, the voltage generated by the panel was chosen to be monitored. To be used in the ensemble of the circuit system, the voltage generated by the panel must be brought within 0-5V and thus be compatible with the voltage that can be read by a microcontroller analog input. For this, an AD8032 IC used as voltage divider circuit was chosen.

Battery

Taking into account also the specifications of the solar panel, a battery with the following specifications was chosen: type Lead Acid Battery with 6 cells, 12V nominal voltage, float charging voltage at 20°C: 13.65V (2.27V per cell), cyclic charge voltage at 20°C: 14.5V (2.42V per cell), capacity: 4 Ah, float charge current limit: no limit, cyclic charge current 1A, the maximum discharge current: 40A per 1 minute, dimensions (LxWxH): 90mm x 70mm x 101mm, weight: 1.6Kg, capacity loss per month at 20°C approx. 3%, life: up to 5 years to 20°C.

Battery charger module

Given the specifications of the battery and of the solar panel, it is necessary to adapt the panel generated voltage to the voltage required to charge the battery. To accomplish this, a linear voltage regulator was chosen. At the input, a voltage Vin would be applied and at the output the voltage can be adjusted to the desired value using a resistive report. The LM317 IC fulfills this function. More details will be given in the corresponding section IV.

Voltage regulators at 5V and 12V

To power supply various components from the system, it is required the existence of different voltages: 5V supply voltage for logic circuits, while the motors drivers and Micro Arduino development board uses 12V voltage. Considering that the current value extracted by these components is not large, we have opted for a linear stabilizing circuit with fixed output voltage (5V or 12V). They offer good performance and are low price. These circuits are integrated ones with three terminals and belong to the LM78XX series (where XX is the stabilized voltage).

III D. The orientation subensemble

The orientation ensemble is the one denoted with letter D on Figure 3 and it is composed of the motor control system and the light sensors.

Motor driver

The motors chosen for the current application have the following specifications: bipolar motor, 2-phases, 1.2A per phase, 2.4Ohm wiring resistance, 2.3mH per phase winding inductance, holding torque 0.2 N*m. Given the fact that our system needs motors with as much torque as possible and the chosen motors are bipolar type, for the driver, a chopper one was chosen.

Being a high performance driver circuit, the TB6560 chip is designed for bipolar stepper motors, PWM chopper type, and meets the requirements previously listed. It can be used in applications using excitation modes: 2-phases, 1-2 phase, 2W 1-2 phases and 4 phases. It can control the motor direction of rotation (forward and backward) of a two-phase bipolar motor using only a logic signal called CW/ CCW signal and a clock signal.

Light Sensors

The selected photodiode is BPW21R type and from the datasheet we mention the following operating parameters: 10V reverse voltage, 300mW power dissipation, operating temperature from -40 to +125 °C, 1V typical forward voltage, reverse light current of 9μA, range of wavelengths 420-675 nm. To use the output measure of this sensor, it must be converted to voltage and brought to values between 0 and 5V, these being values admitted to the analog input of the microcontroller.

IV. PCB DESIGNING ASPECTS

The details required to implement the scheme, such as the circuits pins role can be noticed in figures given below. These details are essential in the design of the entire system, in the final system operation analysis, but also in the ensemble maintenance.

IV A. The user interaction subensemble design

Control panel

The control panel wiring diagram is not shown here, but four switches corresponds to the following components: panel (SW2), battery (SW3), charging indicator (SW4), Arduino (SW9). Each of these components will be active only after actuating the respective switch to close the corresponding circuit. The effective starting of the system is given by the closing of the switches SW2 and SW3: SW2 starts the battery charging circuit and SW3 establishes a connection between the battery and the other circuits.

Charging indicator

As it could be noticed from Figure 5, the LM3914 circuit has pin 1 and pins 10-18 as led drivers, pin number 2 to GND, pin 3 is V+ (scalled voltage), pin 4 is driver low, pin 5 input, pin 6 is driver high, pin 7 is reference, pin 8 adjusts reference and pin 9 selects mode.

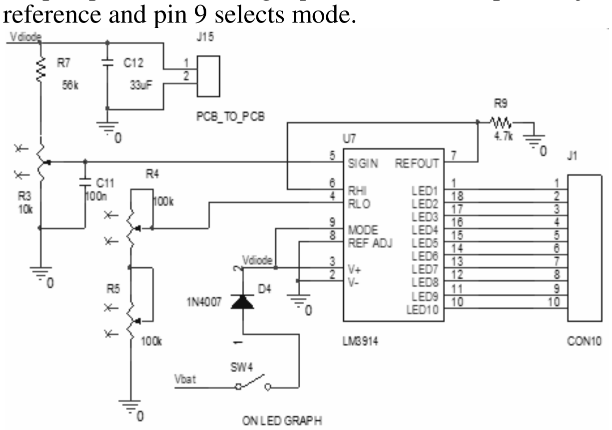

Figure 5. Charging indicator module schematic

IV B. The control subensemble – Arduino Micro

In the following, each connection with the control circuit, i.e. the Arduino Micro pins will be described and explained.

Like it can be noticed in Figure 6, the pins GND will be connected to the ground. The Vin pin is the external power supply pin for the Arduino Micro board and it will be connected to the fixed voltage stabilizer LM7812. The pin +5V is an output pin generating +5V voltage to supply the peripherals connected to Arduino.

The A4 pin receives the divided voltage from the one generated by the PV panel, as we shall see in section IV C.

The pin 8 and pin 9 will be connected to pins selecting the direction of the motors drivers. The pins 10 and 11 will be connected to the pins of the motors drivers to start or to stop the motors rotation. The pins A0 and A3 are analog inputs that take the signals amplified by the light sensors on the 4-directions, as presented in section IV D.

On the figure, it can be noticed the earlier mentioned switch SW9 which connects Arduino to the control panel.

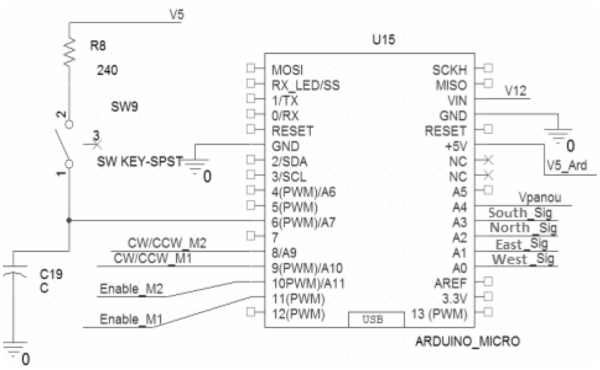

Figure 6. Arduino Micro connections schematic

IV C. The intake and storage subensemble design

Solar Panel

The voltage from the solar panel, after passing through the panel monitoring circuit module, where it is brought from 0-17V range in the 0-5V range, comes to the Arduino pin A4, as it can be tracked in Figure 6.

Monitoring panel voltage module

The maximum output voltage of the panel is 17V and the Arduino board should receive values between 0 and 5V. For this, the circuit illustrated in Figure 7 was chosen. It uses an operational amplifier in a repeater configuration for impedance adaptation. Like it can be noticed, the resistance at the bottom of the schematic is composed of two 15KOhm resistors in parallel, calculated using the equation (1):

$$5V = \frac{R_{21} + R_6}{R_{10} + R_{21} + R_6} * 17V \qquad (1)$$

in which R_{10} was chosen of value 18kOhm. On the figure, the notation V17 can be noticed, this being the voltage from the PV panel, between 0 and 17V; also, V5 is the fixed voltage of +5V and Vpanou will go to Arduino on pin A4, being between 0 and 5V, as shown in Figure 7.

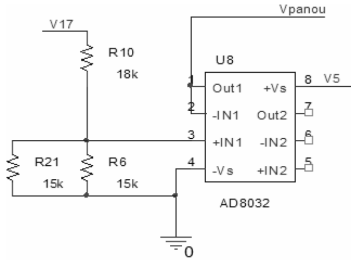

Figure 7. Monitoring panel voltage with AD8032

Battery

In choosing the battery, compatible with the solar panel specifications, also the following were considered: the maximum current given by the panel is Iomax = 0.59A and a battery charging current represents 10% of the current battery capacity, according to [4]; thus, from the total maximum current of 0.59A, a maximum value of 0.4A for the charging current (Ic) was chosen, the remaining being used for the rest of the ensemble. In this way, the battery capacity will be 4Ah, and the maximum charging current Ic is 0.4A. Figure 8 and Figure 9 present which is the relation between the panel and the battery, but also how these are connected with other circuits in the system.

Battery charger module

The LM317 circuit has three terminals, like it can be tracked in Figure 8: Input, Output and Adjustable. We recall that battery charging voltage is 13.5V (Vout) and the panel maximum voltage is 17V. According to the catalog data, reference voltage of the LM317circuit is Vref of 1.25V, which must be kept constant between the output terminal and the control one [5]. Figure 8 shows the stabilizer used in the wiring schematic, where the following equation (2) stands:

$$V_{out} = \frac{V_{ref}}{R_{20}}(R_{20} + R_{19}) \tag{2}$$

By replacing the voltage values and replacing R_{20} with a chosen value of 240 Ohm it will result the value for R_{19} of 2.3kOhm as shown in Figure 8.

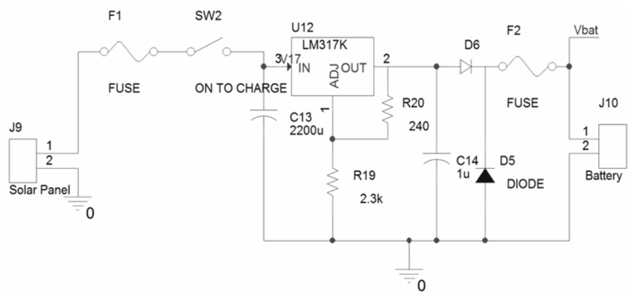

Figure 8. Charging regulator with LM317

The J9 connector is for the photovoltaic panel, the F1 and F2 fuses have a protective role, the C13 and C14 capacitors are provided for voltage filtering, the D5 diode serves as protection (connecting the battery in reverse sense), the D6 diode provides conduction only to the battery, and through the J10 connector the battery connects to the system.

Voltage regulators at 5V and 12V

In Figure 9 the electrical schematic for voltage stabilizers to 5V and respectively 12V is shown. On the figure, one can notice the Vbat and J10 from Figure 8; thus, Figure 9 is a sort of continuation of Figure 8. As stated earlier, V5 is necessary to Arduino, while V12 is required by motors.

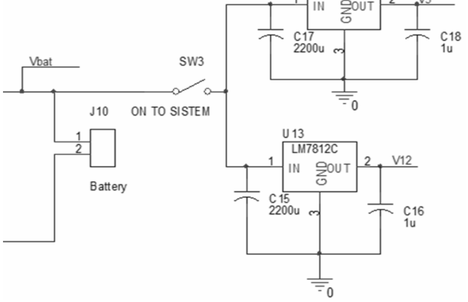

Figure 9. Voltage regulator with LM7805 and LM7812

IV D. The orientation subensemble design

Motor driver

The voltages for the motors to function are: supply voltage Vdd at 6V, the wiring one 40V, the maximum output current Io peak is 3.5A, the supported temperatures are between -30 and +85°C. Figure 10 shows in detail how the TB6560 chip is connected for motor 1. From space reduction reasons, the modifications for the motor 2 will only be mentioned in text, as compared to motor 1. The rezistors or capacitors placed on the pins numbered 7, 11, 14, 18, 22 will have another name, but the same value (resistence, respectively capacitance). Similarly, pins number 4, 9, 12,13, 16, 21 and the J7 connector will replace M1 with M2. The new connector for motor 2, instead of J7 will be J8. Also, in the case of pins 23 and 25 SW1 will be replaced with SW5.

According to the datasheet, the TB6560 chip need a clock signal of maximum frequency Fclk of 15kHz and supply voltage for the control part Vdd of 5V. In the same way, on the pins numbered 11 and 14 (NFA and NFB), the rezistors which will be connected, will have the values computed after the consideration that the maximum current value on wiring is 1.2A and the voltage is 0.5V.

The pin numbered 4 offers the possibility to stop the driver motor by a logical signal. This will be connected to a digital output of the microcontroller. The supply voltage for the motors will be connected to the 12V voltage stabilizer. Figure 10 shows the final schematic diagram of the driver for one motor, i.e. the motor number 1. The same schematic can be draw for the second driver, with the earlier specifications, so to command the motor number 2.

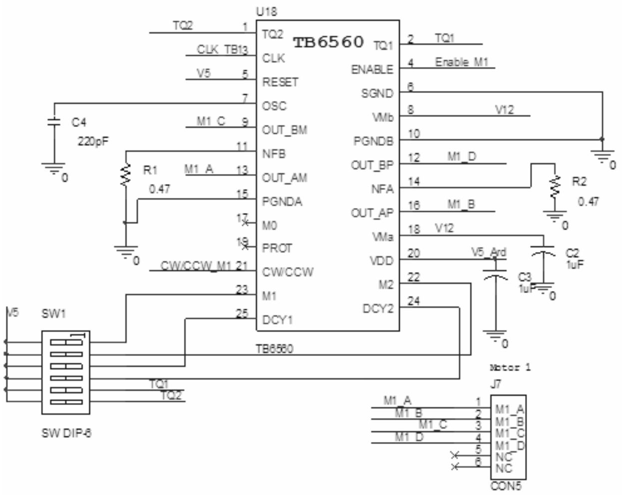

Figure 10. TB6560 stepper motor driver schematic

In Figure 10, the SW1 is the switch for the signals to configure the integrated circuit and the capacitor C4 is the one denoted Cosc. The capacitors C2 and C3 are for decoupling the power supply, the resistors R1 and R2 are for the current setting and the J7 connector make the physical connection between the motor and the system board.

The clock signal, called "ClK_TB" is generated by an astable circuit realized with the integrated circuit 555, as presented in Figure 11. The astable circuit generates at the output a rectangular signal. The frequency and the duty cycle of the generated signal are dependent on the values of the additional passive components.

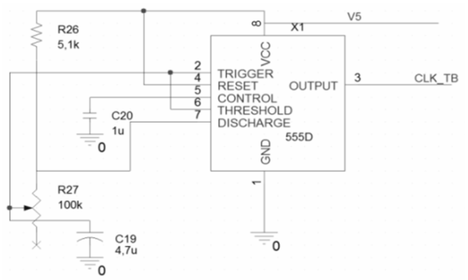

Figure 11. Astable circuit with 555 – Generating the Clock signal

Applying the value of 5V at the input of the circuit, the circuit will generate at the output a square wave signal, with 5V amplitude and the frequency set by the values of the passive components. For the present application, the value of the frequency of the clock signal determines the speed of rotation for the motors. This speed of the motor's rotation was determined by repeated experiments.

In order to have at the output a signa with variable frequency, a potentiometer is used for the resistance between terminals 7 and 6 of the 555 chip. In order to have a wider frequency range, the standard value of 100KOhm was chosen for the potentiometer, 5.1kOhm for R26 and 4.7μF for the discharge capacitor C19. Figure 12 presents the clock signal in the time domain.

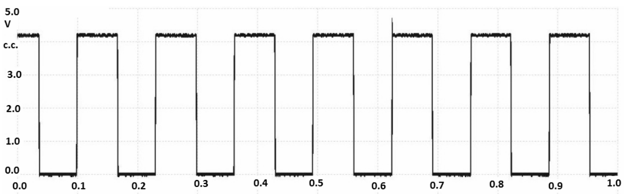

Figure 12. Waveform of the Clock signal – in time domain

Light Sensors

Given the fact that the system will seek the maximum point on two axes, i.e. both horizontally and vertically, it needs a pair of sensors for both directions. Therefore, a total of four sensors will be required, and to these, the amplification circuit add. The output of this circuit amplifying the current generated by the photodiode has to be converted from current to voltage and brought to values between 0 and 5V. The resistors value from Figure 13 were computed with the equation (3).

$$R_f = \frac{V_{out}}{I_{ra}} = \frac{5V}{9\mu A} \cong 560kOhm \tag{3}$$

For accuracy and simplicity, the amplification of the 4 signals is intended to be made simultaneously. One possible solution is to use an integrated circuit which encapsulates four operational amplifiers. The integrated circuit LM324AN was chosen for this purpose in the present application. The electrical schematic diagram of the sensors amplifier is shown in Figure 13.

Since the vertical axis refers to the North-South direction of a point on the Earth's surface and the East - West is for horizontal axis, the sensor signals were denoted with suggestive names.

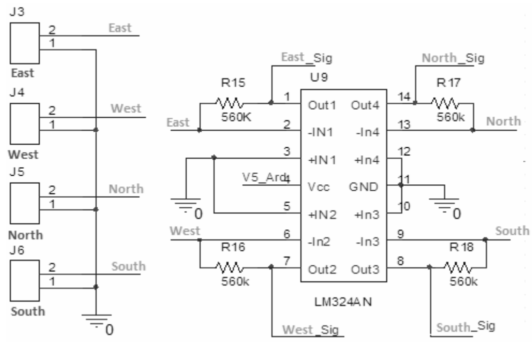

Figure 13. Sensors signals amplification with LM324

The J3- J6 connectors are designed to connect the sensors to the system board. Then the sensor signals are connected to the input (-) of the operational amplifiers. The resistors R15 to R18 are the amplifier resistances and have the value calculated by equation (1). The output voltage has suggestive name (West_Sig, etc.). These outputs will be connected to the analog inputs of the microcontroller to be processed, as shown in Figure 6.

For the experimental stage, the first tests were carried out on the breadboard and only after, they were conducted on the PCB and the other components were also inserted.

V. EXPERIMENTAL TESTS

Testing individual subcircuits: Before completing the final wiring diagram, the circuits mentioned in the previous section were tested individually. ***A first test*** was to start and verify the Arduino Micro board and this was accomplished with a simple example of switching on and off a led, Figure 14 a) showing the Arduino mounted on a breadboard. ***A second circuit*** we tested was the driver for the stepper motors: in Figure 14 b) is shown the breadboard when testing the motor driver using Arduino Micro and a test motor. The role of Arduino is to generate the signals required for the correct operation of the motor driver, i.e. a clock signal, a logic signal to start/ stop the motor and a signal CW/ CCW that can select the motor rotation direction. The generation of these signals is described by the code, the test code for the motor driver not being provided in this paper. ***The third tested circuit*** is the circuit for dividing the voltage generated by the solar panel: in Figures 14 c) and d), the panel was placed at various angles to the vertical. The measurement of the output voltage of the panel shows that different angles of the solar panel exposure to light produces different voltages. The multimeter displays the voltage from the operational amplifier output in a repeater configuration, this being the divided voltage of the solar panel output voltage. In this way, it was obtained 3.41V, and 2.39V respectively. ***Another tested circuit*** was the 555 chip-based astable circuit, for which the signal frequency has been experimentally determined. During operation, the potentiometer cursor (i.e., R27 in Figure 11) was varied so that motors execute steps of certain speeds.

Making the wiring: the PCB board comprises an insulating layer covered by a thin layer of copper. Figure 14 e) shows an intermediate process of achieving the PCB. Figure 15 shows the final PCB with all the components attached to it and electrically connected. We preferred to achieve it by using this method of PNP wiring, although outdated, for reasons of cost savings and speed of implementation.

Subsequently, if desired, this can be achieved by the current technology in order of miniaturization and multiplication. To do this, also Arduino should be replaced with its components (microcontroller, memory, etc). In Figure 15 one can see that there is also a second circuit board (supporting switches and the bar-graph indicating battery charging); this is numbered with 11 on the figure and it represents the control panel of the system.

Each circuit, as annotated in Figure 15, is denoted by a corresponding number, in no particular order: 1. Amplifier for sensors, 2. Sensors connector, 3. Arduino Micro, 4. Stepper motor driver, 5. Motor connector, 6. Motor connector, 7. Divisor and repeater, 8. Voltage regulators, 9. Charging indicator, 10. Solar Panel and Battery connectors, 11. Control panel, 12. Stepper motor driver.

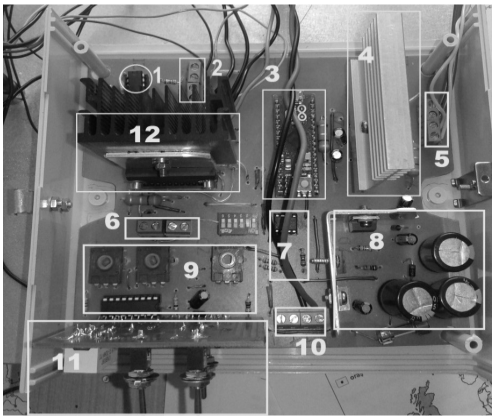

Figure 15. The final PCB with annotated components.

VI. CONCLUSION

When designing our solar tracking system, we take into account the weight of the panel, the support and guidance structure being thus made of steel. To implement the STS, stepper motors were selected, considering that the sun has a lazy movement, so the panel will move slowly following the sun's path, the power consumption should be as low as possible and the panel has to remain in the optimum position. In order to drive the stepper motor, a chopper driver was chosen, considering that it generates constant current in each winding. The movement synchronization and the order in operation required an intelligent system and for this, we opted for Arduino Micro. It is an open source board that uses an Atmega microcontroller and has software that allows users to write their own programs.

As further improvements, we propose to develop more extensive measurements, in different weather situations and to compute the efficiency as compared to the fixed position situation. In this attempt, we may consider the PV simulator designed in [6]. Being based on the mathematical model of the PV cell, the simulator is capable to generate arbitrary *I-V* characteristic for different weather conditions.

The experimental measurements we performed and the model results show that, our proposed system provides efficiency closed to those from the literature, so our purpose was accomplished. In a recent paper [7] is stated that the region for using STS should be carefuly chosen, due to the fact that „it is not economical to track the sun in hot and sunny regions" due to the overheating effect on the PV panel's performance. By contrary, their study demonstrated that „it is highly recommended to track the sun in cold and cloudy regions" in order to maximize the power output. Also, they recommend to access the ambient conditions before deciding to use a STS.

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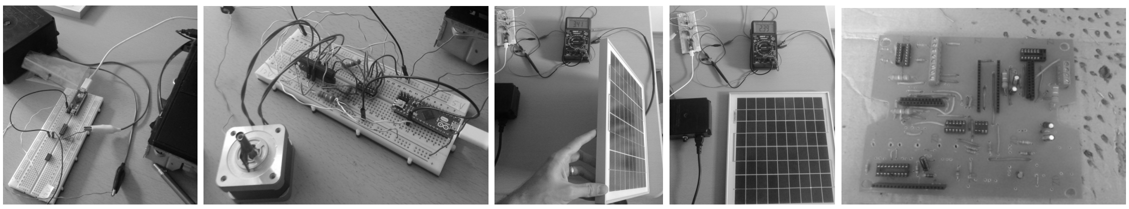

Figure 14. Experimental tests with: a) Arduino; b) motor driver; c) panel - vertically; d) panel - horizontally; e) the PCB realization in an intermediate stage.