A microcontroller based system to maximize Extraction of solar energy

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Abstract:
This paper presents the design of a microchip PIC 18F452 micro controller based tracking solar energy system, where the panels could be located so that maximum solar energy could be extracted.
The system is based on a small light detecting resistor mounted on a small miniature motor known as PILOT. Its role is to search for a position where maximum energy extraction could be obtained without consuming high energy. A second set represents the solar cells panels system. The panels are mounted on a bigger motor. If the energy, where the PILOT is located, is bigger than that produced by the panels, then the panels are rotated to align themselves with the PILOT position otherwise they are maintained at the current one.
The main advantage of the system is that it uses a search procedure based on the PILOT scheme. The PILOT is rotated at a pre-programmed angle and at pre-determined periods using short pulses produced by the microcontroller's timers. This is done by delivering programmed pulses which drive the rotating motor carrying the PILOT through the same programmed angle. When the PILOT comes to standstill on the falling edge of the driving pulse, the voltages picked up by the two sensors mounted on the PILOT and the panels are compared. If the difference between the voltages picked by the PILOT sensor and the panel's sensor is less than the threshold, then the panels maintain their current position and the PILOT continues tracking the sun. If the difference is bigger than the threshold, then the microcontroller activates the panel's motor drive so that they align themselves with the PILOT. This is done by using a proximity switch mounted on the panels and a switch reflector mounted on the PILOT. When the proximity switch comes into the proximity of the reflector (about 3mm), it triggers the microcontroller to deactivate the panels drive, so that the panels come to a standstill after aligning themselves with the PILOT. The PILOT then waits for the next search; and it continues tracking the sun.
When the system hits the end of run proximity switch, it stops and waits for sun set. When this is the case, then the system rolls forward through 180 degrees angle where the sunrise proximity switch is activated so it stops back and waits for the following morning.
The choice of the PIC flash micro controller is because it could be reprogrammed on-line using the technique known as In-Circuit Serial Programming as well as its competitive price and size. It has also all the required interfaces and timers, and is very easy to program using either C language or assembly language.

Keywords:
Panels, PILOT, PIC micro controller, LDR, sunrise, sunset, motor drive

1- Introduction:

For the last few decades, researchers have been concentrating on developing clean, renewable energy resources, and certainly will be in the near future, to replace carbon based energy resources such as oil, gas and coal. This is due two main reasons. One is that most of carbon based energy will dry up within the next fifty years at most, and secondly, carbon based energy is responsible for the green house emission decade (This has become known as gas emission or global warming), from Americas, Europe and recently has reached Asia and will certainly reach Africa if nothing has been done to address the problem. One of the renewable energies of interest is solar energy, especially in region where sun shining is of abundance like ours. Lot of research has been carried out in improving solar cells efficiency. This has been encouraged by the improvement of the cells efficiency where it was merely 17% in the early 90's to pass the 33% mark lately. But, unfortunately, it is still suffering from few draw backs. The first one is the relatively high cost of the cells. The second one is that the efficiency is still low even at the current rate of 33%.The third one is the positioning of the solar cells, especially during the long summer days where the sun shines for more than 16 hours a day and fixed cells do not extract maximum energy.

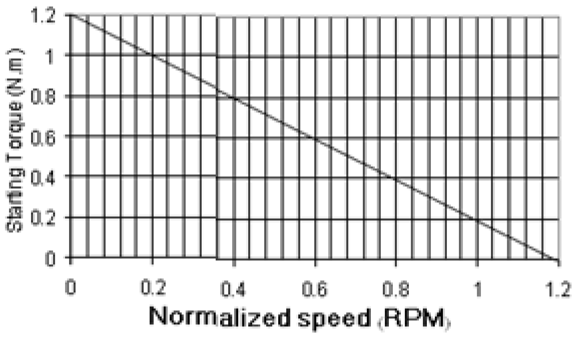
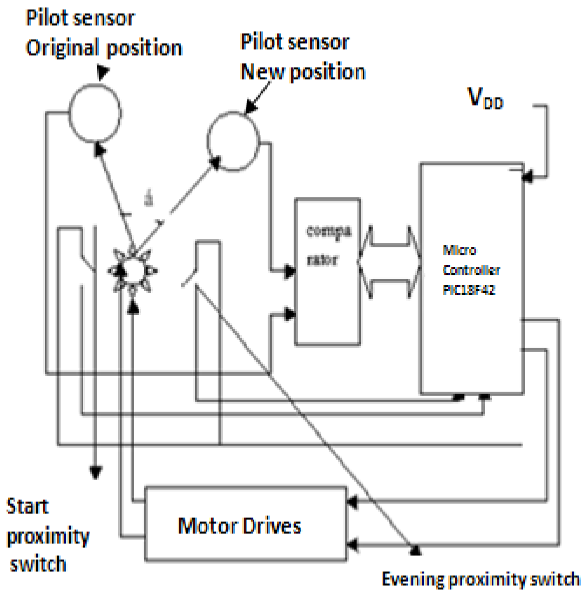


Figure (1) Torque speed relationship

In the past, people using solar energy fix the panels mid way between the geographical east and west with approximately 30 degrees towards the south, depending on the region of course. Studies have shown that this is not ideal positioning in order to maximize energy extraction.

A better way is to continuously orient the panels towards the sun. This necessitates the continuous rotation of the latter at a very low speed so that they lock towards the sun all the time . As it is known, at very low speed, the electric motors driving the panels, draw a very high current due to the high torque required, so an important part of the problem which has hit the world in the last extracted solar energy will be fed back to the motors and this not only results in the loss of most of the energy but heats up the motors as well (figure(1)). This renders the scheme inefficient.



Figure(2) Tracking system to determine The maximum sun inclining angle

An improved scheme(1) was implemented around a PIC18F452 microchip microcontroller by continuously running a timer, delivering constant short bursts at predetermined periods distributed over the length of the day. These pulses drive the motor through pre determined angles, at constant intervals of time. Although this scheme has improved the efficiency considerably, it still suffers from a major drawback. It is not intelligent enough so that it could only rotate the panels to the new position if they deliver higher energy. In fact, sometimes the driving motors consume more energy than the cells produce.

To improve the system, a better scheme was designed (3 and 4). The scheme is designed around two sub-systems (Figure(2)). The first sub-system is for detecting the position where maximum energy could be extracted and is known as the PILOT, and a second sub-system is made up of the solar panels with the control strategy and is known as panels. This scheme presents an optimal positioning mechanism of the panels so that maximum energy is extracted regardless of the weather conditions and the length of the day. The position is determined by using a search technique, based on a PILOT scheme. The PILOT is built around a small sensor mounted on a miniature electric motor, which only consumes a very tiny amount of energy. The aim of the PILOT is to move to the new angle, and picks up the voltage induced. That voltage is compared with that sensed by the sensor mounted on the panels. If the PILOT voltage is bigger than that of the panels by a predetermined offset, then the panels move and align themselves with the PILOT, otherwise they stay in their current position. This scheme suffers from a major drawback; that is the alignment procedure used(5). The procedure was based on counting the number of missed pulses then generating a pulse equivalent to the missed pulses to drive the panels. Due to natural phenomena such as friction, and load variation, the panels could slightly vary and this results in the miss-alignment between the PILOT and the panels. On top of that the creation of this total driving pulse has lead to the introduction of extra software which has resulted in sometimes missing of some the pulses due to the fact that the loading of time constant into the low and high timer registers of the microcontroller results into missing about fifteen pulses which would not be counted. Adding to that the two extra timers resulted in continuous configuration of the latter, one time configured in producing the pulses which drive the PILOT and another time, configured to drive the panels. This has lead to a time lag which is not easy to compensate depending on the variation of the missed unpredictable pulses due to the variation of the weather. Adding to this, when the sky gets unpredictably cloudy especially in winter, the sensor tends to sense lower energy than expected.

This has led to a better solution (6).The solution is based on placing a proximity switch on the panel support, and a reflector on the PILOT . When the new position produces higher energy, the panels move forward until the proximity switch comes into the proximity of the reflector, they come to a standstill. Though the system has improved considerably, it is still suffers from two drawbacks. The first one, the two systems have been mounted separately; when they come close to each other, the proximity switch does not sometimes face exactly the reflector. This has sometimes lead the system out of synchronism. The second one is that when the system goes back to its original position, this is done by reversing the currents through the motors. In turn, this requires extra electronic circuitry either by using an H bridge or two normally open, normally closed relays and extra microcontroller programming.

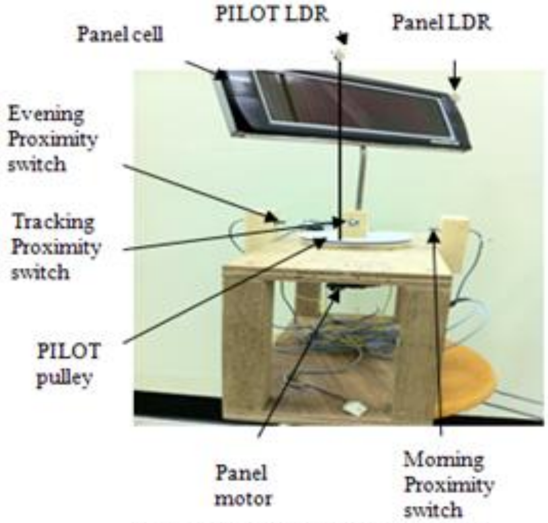


Figure 3.a tracking system

The solution to this problem is the subject of the current paper. That is by redesigning the rotation mechanism. This is based on a140 mm pulley. Mounted on a bearing. Within the bearing a hole is drilled through which passes the panel stand. The stand is mounted on a motor known as panel motor fixed just underneath the system stand below the support wooden plate. On either side of the pulley are fixed two proximity switches at 180 degrees apart which synchronize the sun rise and sun set. A third proximity switch is mounted on the panel support. At the pulley edge is fixed the PILOT holder on which is mounted the PILOT LDR. At the same time, the reflector is mounted on the same holder at the same height as the proximity switch. So on synchronization, they will exactly face each other. The pulley is driven by a belt, which in turn is driven by a small motor fixed at the corner of the system stand. (3.b) shows the dispositive. The system works as follows. When the PILOT moves to the new position, the voltage difference between the voltage detected by the PILOT sensor and that detected by the panel sensor are compared. If the difference is greater than the threshold then the panels rotate forward to align themselves with the PILOT. That happens when the reflector comes close to the proximity of the reflector mounted on the PILOT (about 3 mm), the proximity switch closes. This latter activates the input of the microcontroller; and as a result, the controller drives the panels to standstill. In this way, the panels always follow the PILOT regardless of the load , weather conditions, friction as well as the software problem where duration adaptation was needed all the time with the old design. The system waits for the next pulse, and the procedure repeats itself for the whole trajectory. When the end run proximity switch is activated, the system comes to a standstill and waits for the sun to set for the system to roll forward another 180 degrees until it comes to the proximity switch of sun rise, the system stops; and the procedure repeats itself the following day. The tracking system is designed around a PIC 18F452 microcontroller. The choice of this type of controller is due to the fact that it is cost effective, easily programmable, and has many features such as the analogue to digital conversion, comparison as well as timers and counters required for the operation. It could also be erased and reprogrammed online using the In-Circuit Serial Programming technique (ICSP).

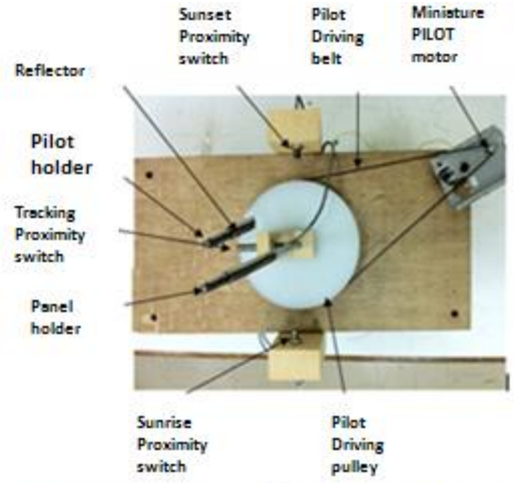


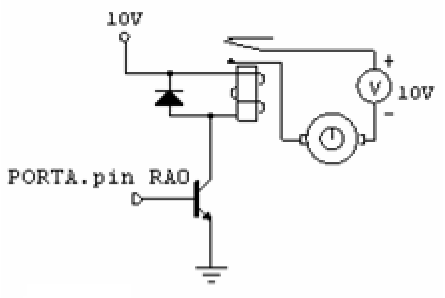
Figure (3.b) Top view of the tracking system

2- System design:

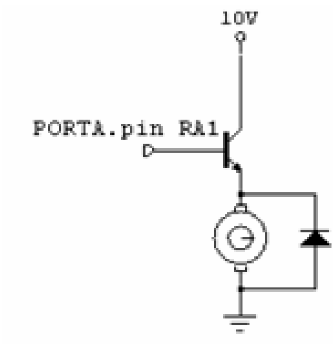
The design depends on two light dependent resistor sensors. One mounted on the solar panel and the second on the miniature motor (PILOT). The miniature motor only draws a very small current, and is used to search for the position where maximum possible energy could be extracted. Before sunrise in the morning, both panels and PILOT are oriented towards the geographical east (known as start run) and wait for sun rise. For synchronization purpose, this position is detected by two sensors. A light dependent resistor (LDR) detects the sun rise and a proximity switch detects the east position. A block diagram of the tracking system is shown in figure (1). On sun rise, the pilot starts rotating through a fixed angle determined by the micro controller internal timer0. Timer0 is programmed with its pre-scalar dividing the system clock (500KHz obtained from the 4 MHz crystal oscillator) by 1:256, and is used to count the clocks produced by the pre-scalar. When the time elapses, the timer delivers a programmed pulse proportional to the angle which the PILOT has to be driven through to the new position, so that it keeps facing the sun. On the trailing edge of the pulse, ie when the PILOT comes to a standstill, the panels and PILOT voltages are compared (this could be done either by software or hardware. In the case of software, both voltages are read by the micro controller through two of its analogue to digital converter channels then compared using the ordinary logic operations. In the case of hardware, which is the case here, the two voltages are compared through a hardware comparator, and the output is used to trigger the controller accordingly). If the panel voltage is less than that of the PILOT by the predetermined threshold(this is set through a variable resistor), then the panels start moving to align themselves with the PILOT until the proximity switch is activated when it comes close to the reflector mounted on the PILOT. If this condition is not met, then the system moves to the next scan (Figure (3) shows the design of the new system).

This procedure repeats itself with each PILOT movement until one of the following conditions is met. Either the end proximity switch is activated or the sun sets, activating the PILOT LDR. In the first case, the proximity switch(known as evening proximity switch) is activated where the PILOT is oriented towards the west (sunset). During longer days of the year, it makes sure that the panels do not over run their trajectory and a misalignment takes place, so that the PILOT and the panels will no longer be facing the sun. If this is the case both panels and PILOT stop and wait for the sun to set which is detected by the LDR. On sun set, the system rotates all the way back to the starting position. When the start proximity switch is activated, the system comes to a halt (facing geographical east) and waits for the sun rise for next day to repeat the procedure (This is basically triggered through a software RS flip flop with reset priority, where the flip flop is set when end run proximity switch is activated and sun sets, and is reset when the start proximity switch is activated).

3- Motor drive:

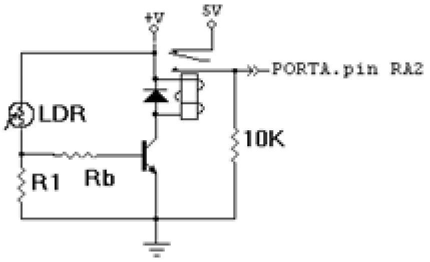


Fig(4.a) Panels motor drive



Fig(4.b) PILOT motor drive

The control drives for PILOT and panels motors are shown in figure (4.a) and (4.b). For the panels, the motor requires high current. This current is delivered through an isolation relay. When the microcontroller drives its output PORTA.pin RA0 high, it only produces a small current which is not enough to drive the relay. To overcome this problem, a common emitter power transistor is used to produce a collector current about 100 times the base current. So the transistor is turn on. So the collector is almost grounded. This will connect the power supply to ground through the relay. So current flows into the transistor collector. This creates a magnetic field into the relay winding which closes the normally open contact of the relay; so current flows into the motor, which rotates the panels. As it is well known, and at the end of the run pulse, the microcontroller pulls RA0 low. The transistor is driven into cut off and a very high di/dt is produced. This could damage the transistor. To prevent this, a flywheel diode is connected across the relay to bypass the transistor and makes an alternative path through which the magnetic energy is discharged. For the PILOT motor, only small current is required. So the transistor is connected as an emitter follower to produce sufficient current to drive the motor. So when the microcontroller pulls its output pin RA1 high, it drives the transistor into saturation (switching transistor) ; and a current of about (β+1) times the base current, where β is about 100, flows out of the emitter to drive the PILOT motor. This current is more than enough to drive this tiny motor. The flywheel diode is used to play the same role as mentioned in panels drive. This procedure repeats itself until the sun set proximity switch is activated when the PILOT reflector comes into its proximity. If that is the case the PILOT comes into a halt waiting for sunset if it has not done so yet. On sunset, both PILOT and panels restart again and rotate forward through an angle of 180 degrees until the sunrise proximity switch is activated when the system comes into its proximity, they stop and wait for the following day sunrise, then the procedure is repeated. By going forward to align itself with the sunrise, two advantages have been achieved. One the saving of two digital outputs from the microcontroller which could be used for other purpose and the non utility of the output H bridge to control the two motors.



Figure(5) Sun rise and sun set capture

4- Sun rise and sun set detector:

The sun rise and sun set detection is straightforward. It is done through a light dependent resistor as shown in figure (5). When sun rises, the LDR resistance decreases and the current through it increases. The voltage at the transistor base builds up until the transistor is forced into saturation. The collector current in turn increases and the coil is energized, and in turn it forces the relay to close connecting the supply to the micro controller input PORTA pin RA2. When darkness falls, the LDR resistor increases and the transistor base current decreases cutting the collector current, and in turn disconnecting the relay (The flywheel diode is connected to protect the transistor against the di/dt effect). An identical circuit is used for the sun set, with small difference where the input is connected to the micro controller through pin RA3. The 10K resistor is included to make sure that when the relay is off, PORTA.pin RA2 is forced to ground. This prevents any pick up of unwanted jitters which could drive RA2 high. This leads the microcontroller to produce a complete misalignment of the system.

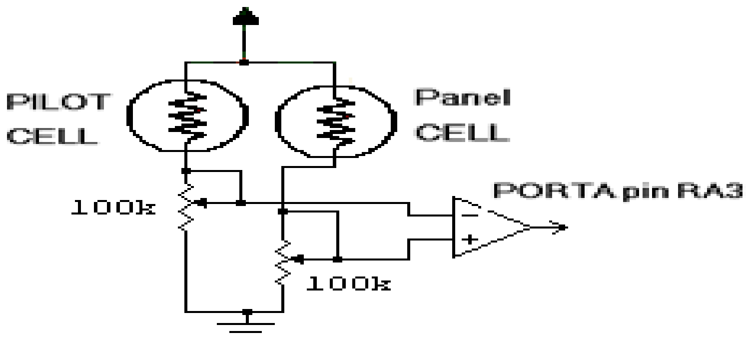


Figure (6) Detection of voltage difference Between PILOT LDR and Panel LDR cells

5- Voltage level detection:

The voltage difference between that of the panels and that of the PILOT is detected using the circuit shown in figure (6). The LDR on the right is connected to the panel and the LDR on the left is connected to the PILOT. The two variable resistors are used so that the voltage threshold could be adjusted. When the light intensity on the PILOT's cell is bigger than that on the panel's cell, the induced current is bigger in the PILOT's branch than that in the panel branch; and the voltage at the positive input of the comparator is bigger than the voltage at the negative input; as a result the output of the comparator goes high. This triggers the microcontroller through its PORTA pin RA3 to activate the panel to follow the PILOT as mentioned earlier. If the difference between the two voltages is less than the threshold, then the panels stay in the current position, and the PILOT searches for new position.

6- Chronology of the system:

Figure (7) shows the itinerary of the system trajectory during the course of the day. The first pulse shows the correct orientation of the pilot and panels towards the east waiting for sun rise. When the sun rises (sun rise), the PILOT sensor is activated and it starts rotating at a pulsating rate(say 2seconds on and half an hour off. This is software programmable) as explained earlier. On each falling edge, the comparison process takes place. When the PILOT voltage is smaller than or equal to that of the panels, the required pulses to drive the panels motor are not generated (panels do not follow the PILOT). And when the PILOT voltage is bigger than that of the panels by the programmed offset, the solar panels follow the PILOT until it hits the end proximity switch, the system stops and waits for sun set. When this happens, the system rotates forward until the sunrise proximity switch is activated, it stops and waits for the following morning.

7- Microcontroller programming:

As mentioned earlier, PIC18F452 has four timers, timer0 (TMR0), timer1 (TMR1), timer2 (TMR2) and timer3 (TMR(3). In this project, only timer0 and timer3 are used, because they could be programmed either as 8 or 16 bit timers/counters as well as having a flexible programmable pre scaler to scale down the clock. Timer0 is used to determine the wait duration. That is the time for which the PILOT is standstill, and timer3 is used to determine the time of the rotation. This helps avoiding save timer to be reprogrammed for more one function continuously. Each timer is associated with a number of special registers. Those registers have to be configured before use. First let's see how Timer0 control register is set

TMR0 ON	T08 BIT	T0CS	TOSE	PSA	TOP S2	TOP S1	TOPS0
1	0	0	0	0	1	1	1

TOPS2-TOPS0 set to 111 to choose 1:256 prescaler
PSA set to 0 to assign a pre scaler to the timer.
TOSE set to don't care because external clock is not selected.
TOCS set to 0 where internal clock is selected.
T08BIT set to 0 to configure timer0 as a 16 bit timer

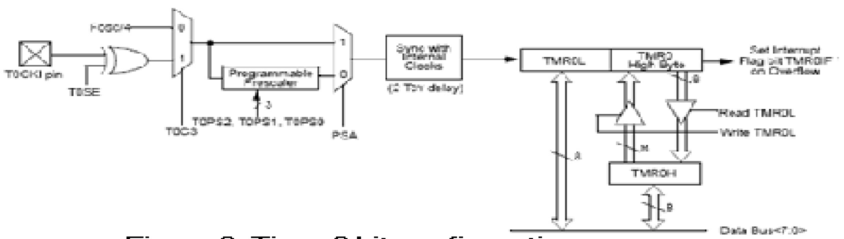
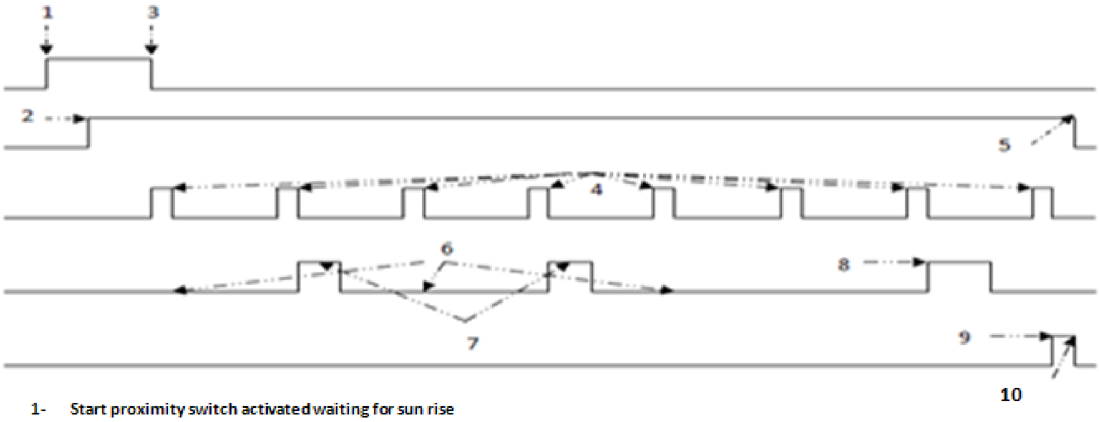


Figure 8: Timer0 bit configuration



1- Start proximity switch activated waiting for sun rise
2- Light Detection Resistor activated indicating sun rise
3- After the preprogrammed delay, the PILOT starts rotating through the programmed. As soon as the motor starts, the morning start proximity switch is deactivated
4- Pulses by which the PILOT rotates during the day
5- Sun set detected by the Light Detecting Resistor
6- Missed pulses by the panels because of the voltage difference between the PILOT's voltage and the Panel's voltage is less than the threshold
7- Panel motor is activated and starts rotating until its proximity switch is activated when it comes close to the PILOT, it stops
8- The microcontroller does not need to count the missed pulses
9- End of run detected when the PILOT hits the end proximity switch, so it comes to a halt and waits for sun set
10- When sun set LDR is activated, the system rolls back to the start position

Figure (7) Chronology of PILOT and Panel course

TMR0ON set to 1 whenever the timer is turned on. (see figure below extracted from PIC18F452 data sheet). To derive a 15 second clock from the system clock, a 256 pre-scaler is selected; then the timer is programmed to roll off by 6966 counts. So instead of rolling off from 65536 counts to 00, it is programmed to roll off from (65536-58594 + M + 2 = 6942 +M +2 = 6966) to 00, where M=12 counts which represents the number of cycles between the reading of TMR0L and the writing back to TMR0L. Because the timer register is loaded indirectly,(figure(8)) and it requires 12 clocks, during which the timer counter stops; and the added 2 cycles when writing to TMR0L, resets the synchronizer causing the loss of 2 extra cycles. To obtain a 30 minutes delay for instance, the timer is looped 4 times to obtain a full minute, then looped 30 extra times to obtain a full half an hour. After the thirty minutes has elapsed, the PILOT motor is controlled through PORTB, just by setting pin RB3 of PIC18F452, and to bring it to standstill at the end of the step the pin is reset (known as soft latch). The angle by which the PILOT rotates is set through timer3. To obtain a one second pulse, timer3 is used. It rolls off from (65536-59300+12+2 = 6250) to zero to produce half a second pulse and by looping it twice, a full second pulse is obtained. It is worth mentioning here that it would have much better to use two timers in cascade. But unfortunately the PIC18F452 timers could not be cascaded because there is no hardware output pins currently available. As for the panel rotation, when the condition is met, the panel‘s motor is activated by setting pin RB6, until its proximity switch comes into proximity of the reflector where it is reset and the panel stops. The procedure then repeats itself.

8- Proximity switches

The proximity switches are monitored through PORTB, pin RB0, RB1 and RB2 and are represented as LS1, LS2 and LS3(figure(10)). The switches are connected to ground through a 10K resistors to make sure when the switches are open the pins are properly grounded. This ensures no pick up of noise which trigger wrongly the controller.

9- Software

The program was written using the microchip assembly language and was tested using the MPLAB utility interfaced to the In Circuit Debugger (ICD2).

10- Test

The prototype is tested in the laboratory using a mobile lamp as a light source, a PILOT and a single panel delivering 24 volts. At the beginning, the prototype is oriented towards the east where the proximity switch (start proximity switch of Omron M8 eight millimeter spacing type mounted on the panel pivot refer to figure (3)) is closed forcing the pin RB0 of micro controller input PORTB to the high state, forcing in its turn the motors (panel and PILOT) to the stand still state. The graph in figure(9) shows the response of the system.

When the lamp is turned on, the RA2 goes high; and this in turn activates timer0 to start and delivers pulses of one millisecond every five minutes interval. The pilot sensor rotates through an angle of approximately twenty degrees for each pulse. Its voltage rises up to approximately 24V. This is shown as black on the graph, so does the panels voltage which is shown as red.

On the pulse trailing edge, the pilot and the panels voltages are compared. Because the two are still close to each other, their voltage difference is still less than the offset.(the offset is set using the two potentiometers to 2V shown in figures(6 & 7)). As a result, the panel maintains its current position. This procedure repeats itself for the next three pulses where the offset is still below 2V. On the fourth one, the voltage difference is more than the offset where the red voltage goes below the black voltage by the offset. In this case the panel rotates for approximately eighty degrees to align itself with PILOT. When it comes into proximity of the proximity switch mounted on the panel stand, it stops . This is repeated all along the trajectory, until the PILOT hits the END RUN proximity switch, the system comes to a halt, after rotating through a full 180 degrees. The lamp is then turned off, the output voltages slide down towards zero, as expected, and the system rotated forward until it hit the START proximity switch, it stopped.

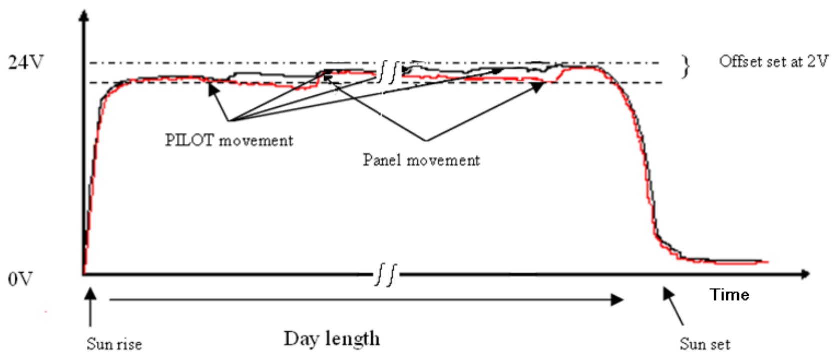
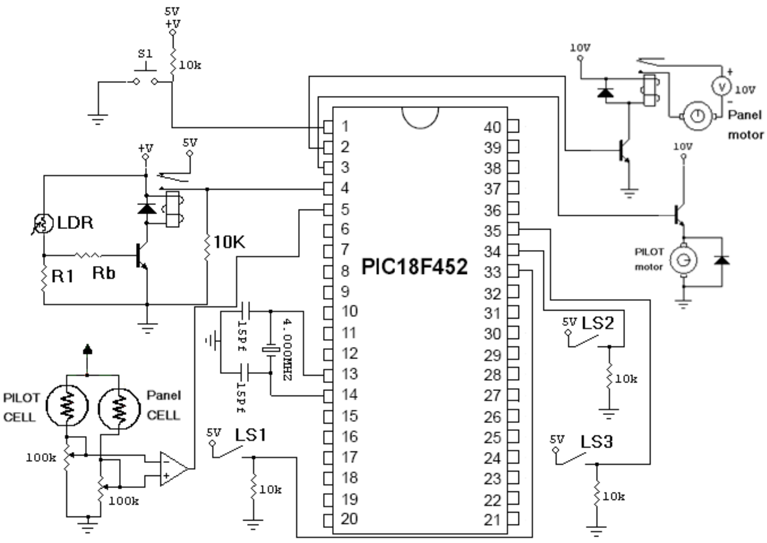


Figure 9 shows the trajectory of both PILOT and panel and the induced voltage

11- Conclusions

a cost effective intelligent sun tracking system to extract maximum solar energy possible was designed. Unlike what was reported in literature, the main advantage of the system is that it is intelligent enough so that the panels track the sun only if that contributes to extra energy extraction and at the same time, the energy consumed by panels driving motor is less than that extracted. The system can also align itself to perfection either on sunrise or sunset so no drift is could occur. Another main advantage is that it takes the days variation during the year into consideration so to make sure that the panels do not lead the sun during longer days nor lag it during shorter ones,

neither could it overrun its trajectory during summer longer days.
Figure (10) shows the design of the whole circuit. Needless to mention, that a full size crystal oscillator has to be connected to pin 13 of the microcontroller. On top of that, the circuit has to be energized by a 5 volt regulated voltage. It should be noticed that R_4 is added to ensure that the input to pin RA_2 is grounded when the proximity switch is open. It also should be noticed that the parasite capacitors connected the oscillator should not exceed 22 ρF. An extra reset switch (S1) is added and connected to ground through a pull up resistor of 10KΩ. This resistor is not critical. It could have any value between 1 and 10K



Fig(10) Full control circuitry

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