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STM32 BASED MPPT CONTROLLED SOLAR PANEL LIGHTING SYSTEM DESIGN

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Abstract:

In this study, the design of a modular solar panel lighting system using STM32 systems, which is the most popular microcontroller unit of today, has been examined. In the study, Maximum Power Point Tracking (MPPT) algorithm will be used in order to make effective use of the lighting system. The system to be installed includes open source software, providing users with an infrastructure suitable for development. The system will be developed as a prototype but will serve as a basis for larger and integrated systems.

Keywords: Solar panel lighting system, STM32 microcontroller unit, Maximum Power Point Tracking (MPPT), photovoltaic (PV) systems, 32-bit Arm Cortex-M0 microprocessor

INTRODUCTION

Human beings need energy in every aspect of daily life. In order to meet this energy, electricity is produced, primarily oil, coal, wood and hydroelectric power plants. In some developed countries, electricity is produced with atomic energy in nuclear power plants, although it poses great environmental hazards. However, the limited amount of coal, oil and natural gas reserves on earth and the acceleration of depletion have made it necessary to research and use new energy sources. It is another important issue discussed by experts that the emission resulting from the consumption of these energy sources has a very negative return to the environment.

Today, alternative and new energy sources are called "renewable energy sources". The most important type of energy among renewable energy sources is solar energy. The solar heating energy is the main energy source that affects the physical formations in the earth and atmosphere system. It has no fuel problem, ease of operation, no mechanical wear, being modular, being commissioned in a very short time, working without any problems for many years, being a clean energy source, etc. The use of photovoltaic (PV) systems that convert solar energy into electrical energy is increasing due to such a reasons.

In this context, the use of solar energy generation systems, which has an important place among renewable energy sources in terms of both its potential and production technologies, has been examined. In the application phase of the study, a system design will be made for the control of a solar lighting system that can be used in different areas such as home, workplace and street with STM32 microcontroller unit and Power Point Tracking (MPPT) algorithm. The design of the system will first be simulated in the MATLAB program and then the electronic circuit design will be carried out. STM32Cube IDE application with C programming language will be used for coding of STM32 based microcontroller. In the system, an inverter system will be designed to provide 12 V DC LED lighting and 220 V AC bulb lighting. In the prototype system, switching on and off the lamp according to the light and dark conditions of the air, the charge status of the battery, the selection of LED or bulb lighting according to the battery power, and the protection of the system in case of a possible malfunction in the system will be controlled by the STM32 MCU.

It is evaluated that the system, the prototype of which will be developed with the study, can be used for home, workplace and street lighting in regions with medium and high solar utilization rate of our country, thus contributing to the country's economy by establishing a cheap and maintenance-free lighting unit.

I. GENERAL FEATURES OF SOLAR PANEL LIGHTING SYSTEM

Solar powered lighting systems appear as the area where solar panels are first applied. Especially as of the early 1990s, as a result of the development of technology, the increase in cell efficiency and the decrease in panel prices, solar lighting systems have become quite common throughout the world. The general principle of the system is based on the principle that the electricity obtained from the solar panels is stored in the batteries during the day and the energy turns on the special light bulbs at night (https://www.tekniksolar.com, 13.10.2020).

a. General Structure of the System

The general structure of the STM32 MCU controlled solar panel lighting system is shown in Figure 1.

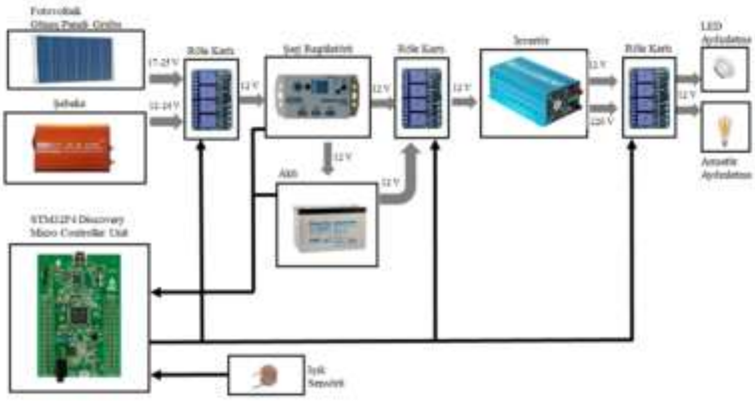


Figure 1. General structure of STM32 MCU controlled solar panel lighting system

In this design study, a polycrystalline solar panel with 10W peak power and a 10 Ah 12V battery or battery group will be used. STM32 Discovery MCU board will be used for the control application. STM32Cube IDE software will be used for programming the STM32.

In the developed control card design, firstly, a control will be carried out to turn the lamp on and off (On/Off) according to the light and dark weather. In my card design, necessary resistors and capacitors will be used for the STM32 MCU controller to work properly with other output units. In addition, where necessary to provide digital data to the STM32 MCU unit, analog data will be digitized and processed with the ADC card.

By monitoring the output voltage of the battery, the full-empty status will be determined and if the battery is 30% empty, charging commands will be generated, and if 125% full, charging cut-off commands will be generated. In the developed system, 12 V DC LED and 220 V AC fluorescent bulb will be used for lighting. Since it is an AC voltage lamp, a DC/AC inverter will be connected to the battery output, the inverter output will be controlled by the STM32 MCU, and the system will be protected and shut down in case of any malfunction.

When necessary (such as, when the battery is dead and energy is not taken from the solar panel), it will be possible to receive energy from the grid. The decision whether the network will be activated or not will be followed by the designed STM32 control card. In addition, current, voltage, power and temperature values of the system will be monitored and recorded with the STM32 MCU.

b. Power Management Algorithm Used in the System

Many algorithms have been developed to obtain maximum power from photovoltaic panels. The most commonly used algorithms are the open circuit voltage algorithm, the short circuit current algorithm, the change-and-observe algorithm, and the incremental conductivity algorithm. Thanks to these algorithms, the highest level of power is obtained from the panels and the converter works at this operating point. In the study, the Maximum Power Point Tracking (MPPT) algorithm, which is widely used in solar panel electricity generation systems, will be used. MPPT systems enable the power obtained from the solar panels to be sent to the load unit by following the peak values (peak value) in certain periods.

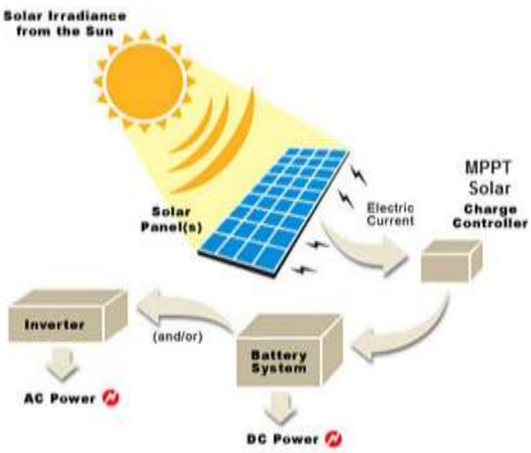


Figure 2. Working principle of maximum power tracking system

MPPTs provide a healthier charging process in the system. Thanks to this method, the life of the batteries is longer than other methods. In this way, the maintenance and operating costs of the system are more economical. In addition to an effective and efficient charging system, it offers fast charging of MPPTs as it technically charges with the maximum power point. This feature stands out as an advantage over other systems.

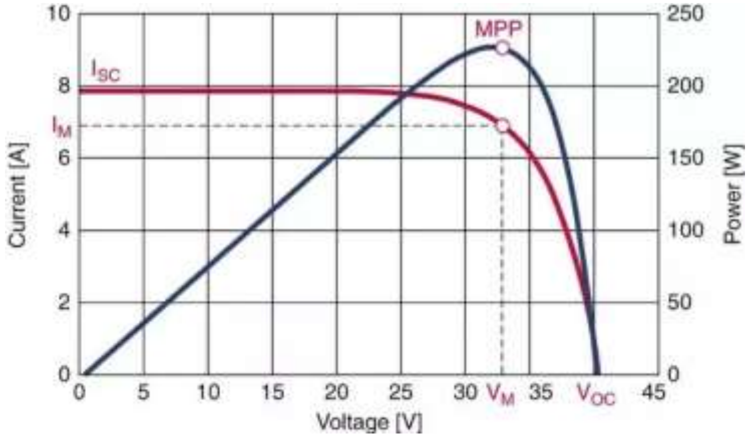


Figure 3. I-V curve of MPPT System

c. Advantages and Disadvantages of the System

1) Advantages

PV technology is the most powerful electricity generation technology that provides a solution to global warming. Almost every region of our country is suitable for using this technology. PV energy is used worldwide with different conversion technologies as autonomous power packages and grid-integrated systems. The converter type and load are determined by the application. The study presents a practical analysis of solar powered home lighting systems. In this respect, it is an energy generation system that is reliable and provides optimum performance.

The designed photovoltaic lighting system has important advantages. First of all, the system will be controlled with an STM32 MCU-based microcontroller, giving the system an effective and stable operating performance. In addition, the production of the system software with national means makes it possible to intervene in the system and develop the system in the future. For example, the system has a suitable infrastructure for the development to be made in the form of sending information about working performance to its users over mobile networks or the internet.

Another important advantage of the system is that it does not require any maintenance and operation. Since the system works in closed loop, the system is intervened only in case of malfunction. In addition, the current, voltage, power and temperature values of the system will be monitored and recorded with the STM32 MCU. In this way, the changes in the performance of the system over time will be evaluated more effectively in the computer environment.

Other prominent advantages of the system are that both PV panel and mains energy can be used to charge the battery used in the system, and that both LED lighting and normal luminaire lighting can be used. With this way of working, the system can be used both as a lighting system and as an uninterrupted power supply.

With the light energy obtained by the system for three to five hours a day, 12 V direct current (DC) power can be supplied to low-power DC devices such as radios and small TVs. Also, using an inverter, 12V power is converted to 240VAC power for larger appliances. In addition, the system will be developed as a small and mobile system. In this way, it will be possible to provide fast and easy assembly at the desired location. No expertise is required for the installation of the system. As such, the system appeals to a wide range of users.

2) Disadvantages

The system to be installed has some disadvantages. First of all, the supply power of the system is limited to 800W. For this reason, it can be used in small-scale applications. Another important disadvantage of the system is the autonomy time of the battery used in the system. This time is anticipated to be approximately 10 hours at full power. To extend the time, the number of batteries should be increased to 3. However, this process will both increase the cost of the project and reduce its portability.

Another important disadvantage of the system is that, due to the use of fixed PV panels, the worst insolation value will be obtained in the year where the system will be installed. Therefore, it is inevitable that there will be variations in the energy and power performance of the system throughout the year. In order to eliminate this problem, it is considered to use 3 PV panels placed at different angles in the system. In this way, energy loss will be minimized and the effect of the angular position disadvantage to the sun will be eliminated.

II. CONTROLLING SOLAR PANEL LIGHTING SYSTEM WITH STM32 MICROCONTROLLER

a. Basic Components to be Used in the System

Components of the system to be installed; will be selected according to personal needs, climatic conditions, settlements, weather conditions and power needs. The most important factor that determines the basic system elements is the functional needs. Generally a photovoltaic system;

- Photovoltaic (PV) panels or arrays of panels,
- Charge regulator,
- Battery (battery),
- Inverter (DA - AC inverter),
- STM32 controller card,
- Load (lighting) and
- It consists of seven sections, including the network.

The block diagram showing the use of the system as a lighting unit is shown in Figure 4.

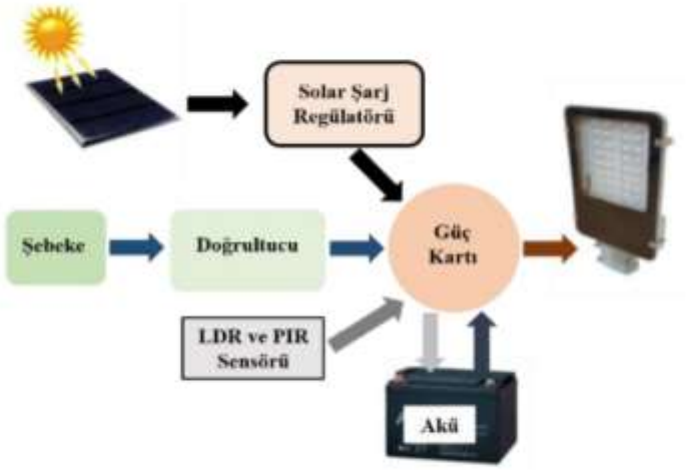


Figure 4. Block Diagram of Using the System as a Lighting Unit

1) Photovoltaic (PV) panel

Today, solar energy is used as an alternative solution in order to alleviate the environmental problems caused by solid fuels, mostly in developed countries. It is not possible to meet the energy need for industry, residences or individual uses directly from the sun, as is the case with plants. For this reason, solar energy can be used by converting it by various means. Many technologies have been developed to take advantage of the sun's rays. Although solar energy technologies vary widely in terms of method, material and technological level, some of them directly use solar energy as light or heat energy, while other technologies are used to obtain electricity from solar energy. Among the usage areas of solar energy, direct or indirect electricity generation, hot water generation, space heating and cooling, process heat energy for industrial establishments and greenhouse heating can be counted (Pandey vd., 2015).

The system formed by photovoltaic cells by arranging them side by side for the desired power is called photovoltaic panel. The amount of cells increases in proportion to the amount of power needed. In large powers, it is possible to connect too many cells in series as panels, but they have disadvantages as they take up a lot of space at large powers. For energy conversion, the PV element, which is a semiconductor diode, directly converts the energy carried by sunlight into electrical energy by utilizing the internal photoelectric effect. The features of the photovoltaic panel to be used in the study are as follows:

- Maximum power: 10W ±3%
- Maximum voltage: 17 - 30V
- Maximum current: 0.67 A
- Short circuit current: 0.82 A
- Operating temperature range: -45°C to +80°C
- Maximum system voltage: 600V
- Module dimensions: 381x350x35 mm

2) Charge Controller (DC-DC Convertor)

Charge regulators are used to store the energy obtained from solar modules in batteries. Since the voltage generated in the solar panels changes according to the situation of the sun during the day, it is not possible to charge the batteries without charge regulators. Charge regulators are used to regulate energy and control battery charge status. Thanks to the microcontroller and software on them, they automatically select the most ideal operating mode for the system by looking at the sun, batteries and load status. Charge controllers with digital or led indicators are available in the market. This unit performs voltage-current control on solar panels and batteries, and selects the appropriate one from 3 charging modes according to the current status of the batteries and enables the batteries to be charged. In other words, they protect the battery by detecting low or high voltage of solar energy panels that give high power and voltage. They also help batteries last longer.

A DC-DC buck converter will be used as a charge regulator in the system to be developed.

3) Battery

In photovoltaic systems, batteries store electricity for use at night or during the day when the modules are not producing enough power to meet the load needs. Correct operation of the battery in the system is the most important aspect of the reliable operation of the lighting system. The capacities of the battery cells are given in ampere hours. This; It is the amount of electricity that can be drawn from a fully charged battery to a certain voltage under a certain discharge rate and electrolyte temperature. The electrical current produced by the PV systems is stored for use when needed. The characteristics of the battery to be used in the study are as follows.

The main parameters used to determine the efficiency of the battery are as follows: Battery types, capacities, maximum charging currents, gaseous state voltage values, temperature, manufacturer tolerances, dynamic time constant of the battery, age of the battery and other parameters affecting the gaseous state. It is also possible that these parameters are interdependent. Gel type battery will be used in the system.

4) DC-AC Inverter

The inverter is the device that converts the DC voltage in the battery to the alternating voltage we use at home. In other words, they convert 12VDC battery voltage to 220VAC 50Hz voltage. Thus, televisions, lighting lamps, computers or power tools that we use at home can be operated in mobile environments such as cars, boats, solar energy, camping, by means of the inverter. In general, inverters are divided into two in terms of output wave figures. Modified sine inverters and Full sine inverters. The subtle difference between the two waveforms is difficult to discern, but their performance should be looked at in terms of the devices they run.

Where there is no AC 220 volt electrical energy, 220VAC energy is provided by the inverter from the 12 volt battery. Designed as smart systems, the inverter automatically protects itself by warning the user with a sound in overload, output short circuit, over temperature, low and high voltage of the battery. Inverter designs can work 90-95% efficient with the Switch mode system. It is extremely ideal with its small dimensions, vibration-free structure and maintenance-free technology.

The output of the inverter used in the system is in the form of a modified sine wave. A modified sine wave is an imitation of a full sine wave. With square wavelets, a sine wave is obtained. Their advantage is that they are cheap, they can be used for TV, computer, small appliances, lamps, etc. it runs smoothly. Clean, smooth and high quality output power is obtained with the modified sine wave. Therefore, it can be used in applications without any problems. In addition, the devices heat up less. A full sine inverter is definitely recommended in case of operating motor, air conditioner, refrigerator as a load or for industrial devices and applications.

5) STM32 Microcontroller Board

The STM32 controller board is an integrated board unit that contains a 32-bit Arm Cortex-M0 microprocessor and its connected units. The microcontroller is the element that combines all the units that should be in a computer system in a single integrated circuit. It is very useful for automation and control systems. General features of microcontroller control units are as follows;

- Programmable parallel input/outputs
- Programmable analog input/outputs
- Serial in/outs
- Pulse Width Modulation (PWM)
- Interrupts
- RAM, ROM type memory units
- External memory interface
- Timers

The image of the STM32 Discovery MCU card is shown in Figure 5.

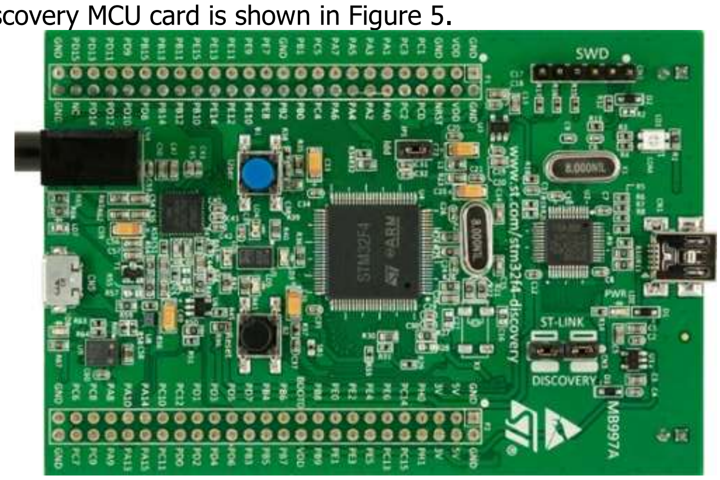


Figure 5. STM32 Discovery Microcontroller Board Used in the System

b) Steps of System Software

The steps for the use of the system as a lighting unit are as follows;

1) The voltage of 17-30 volts coming from the solar panel is converted to 12 volts by the charge regulator and stored in the battery.
2) The charge controller sends 12 volts to the inverter via the load output.
3) The inverter converts 12 volts to 220 volts and sends it to the STM32 controller.
4) 220 volts from the mains are sent to the controller.
5) STM32 controller continuously controls the DC 12 V coming from the charge controller.
6) With the STM32 controller, the current, voltage, power and temperature values of the system will be monitored and recorded.
7) STM32 controller transfers 220 volts, which is the inverter output, to the output (load) if the voltage at the charge controller is at 12 volts.
8) The STM32 controller cuts off the 220V inverter output when the voltage in the battery drops below 10 volts and activates the 12V LED lighting.

9) STM32 controller gives 220 volts from the mains to the output (load) when the voltage value in the battery drops below 6 volts, thus preventing the battery from being short circuited.
10) The voltages coming from the solar panel (inverter) and the grid are combined in a 220 volt AC load.
11) The power of the prepared system is 600 wh.
12) The prepared system is portable.
13) It will be mounted on a 150cm x 40cm plantain/sea table.

III. EXPERIMENTAL FINDINGS

In this section, the experimental findings of the STM32 MCU controlled solar panel lighting system and the comments made in this context are included.

a. Simulation Results

The simulation/simulation experiments of the system developed within the scope of the study were carried out in MATLAB/Simulink environment. The image of the simulation application is given in Figure 3.1.

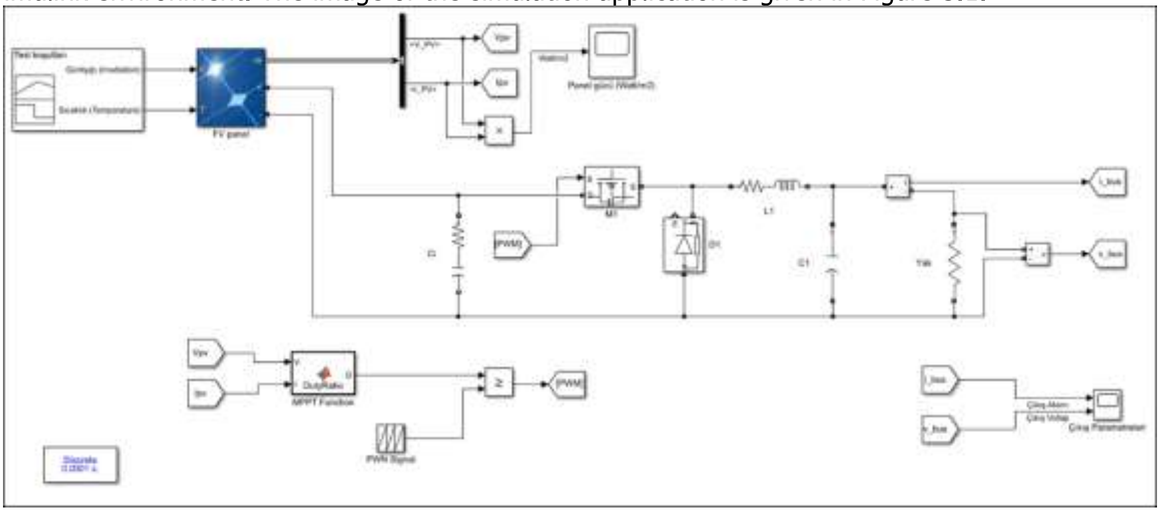


Figure 3.1. MATLAB/Simulink implementation of the design

The current, voltage and power parameters of the solar panel used in the simulation application under standard conditions (daylight emission: 1000 Watt/m2; temperature: 250C) are given below.

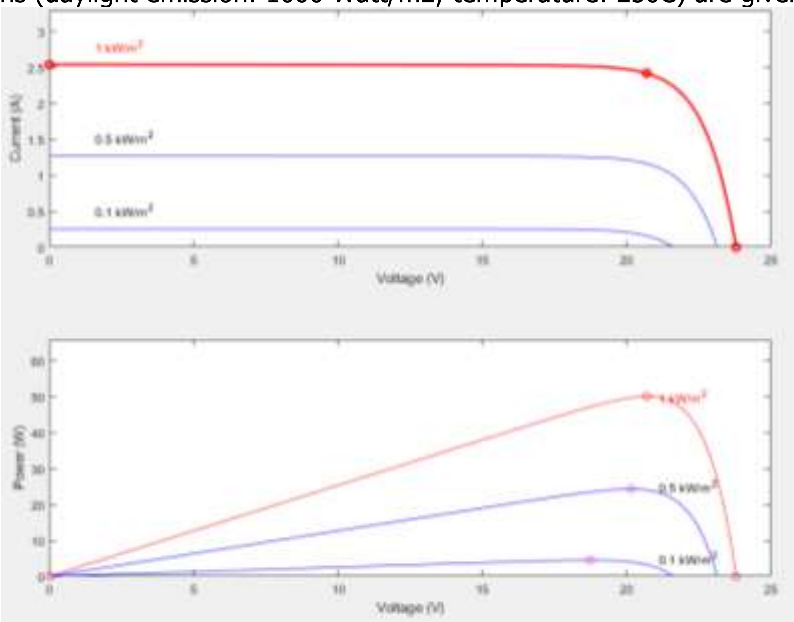


Figure 3.2. Current, voltage and power changes of the solar panel under standard conditions

In the simulation, one-day daylight spread and temperature variations shown below were used as test conditions.

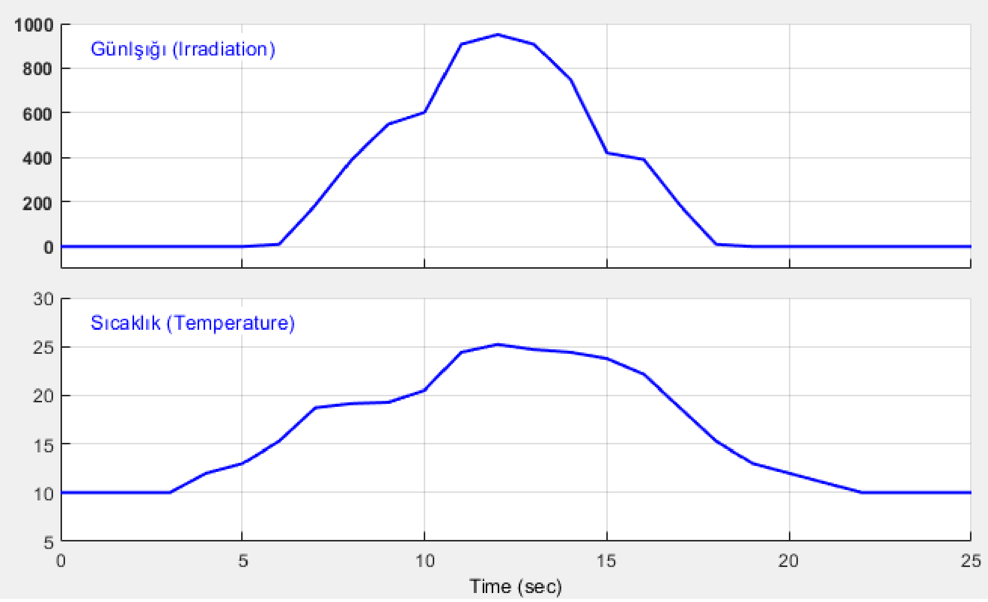
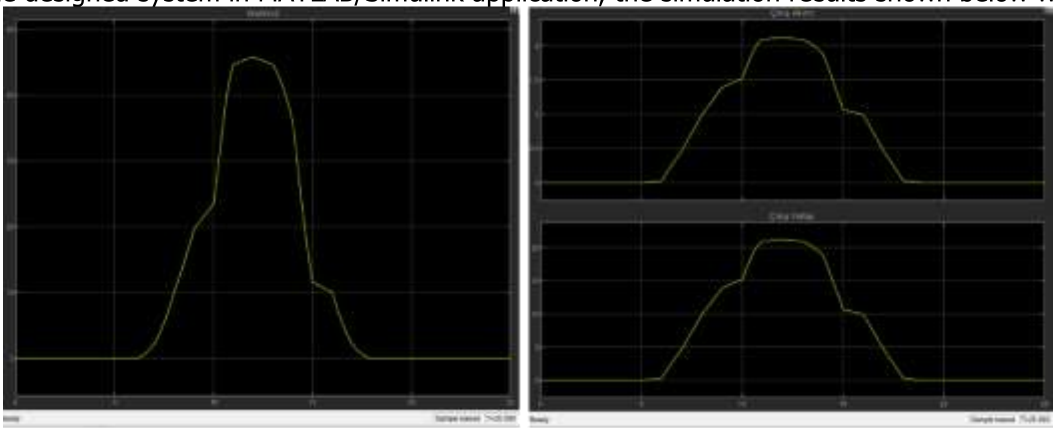


Figure 3.3. Daylight and temperature changes in a day

By running the designed system in MATLAB/Simulink application, the simulation results shown below were obtained.



a) b)

Figure 3.4. Simulation results a) panel power, b) current and voltage output values

When the MATLAB/Simulink simulation results in Figure 3.4 are examined, it is seen that the output power obtained from the PV panel is utilized at the maximum level according to one-day daylight and temperature values, and the step-down converter DC-DC output current and output voltage values reflect this ideally. Therefore, it has been determined that the designed system and the developed MPPT algorithm are successful in monitoring the PV panel power at the maximum level.

b. Real Time Experimental Results

The real-time application results of the developed system are given in Table 3.1 and the graphical representation of the data is given in Figure 3.5.

Table 3.1. Real-time experimental results of the system

NU.	TIME	MODE	PANEL V (Volt)	PANEL I (mA)	BATTERY V (Volt)
1	08:00	FLOAT	12,52	85	11,80
2	09:00	BULK	13,00	110	12,45
3	10:00	BULK	13,22	450	12,45
4	11:00	BULK	13,35	712	12,50
5	12:00	BULK	13,56	1100	12,72
6	13:00	BULK	13,66	1323	12,79
7	14:00	BULK	13,69	1556	12,75
8	15:00	BULK	13,70	1689	12,80
9	16:00	ABSORBTION	13,44	617	12,79
10	17:00	ABSORBTION	13,30	285	12,72
11	18:00	ABSORBTION	13,26	114	12,45

12	19:00	FLOAT	14,25	15	11,75
13	20:00	OFF	0,00	0	12,79
14	21:00	OFF	0,00	0	12,70
15	22:00	OFF	0,00	0	12,56
16	23:00	OFF	0,00	0	12,24
17	00:00	OFF	0,00	0	12,10
18	01:00	OFF	0,00	0	12,03
19	02:00	OFF	0,00	0	12,00
20	03:00	OFF	0,00	0	11,95
21	04:00	OFF	0,00	0	11,92
22	05:00	OFF	0,00	0	11,90
23	06:00	OFF	0,00	0	11,85
24	07:00	FLOAT	12,00	11	11,82

* Table values, 5 min. Includes hourly display of measurements made in the time interval.

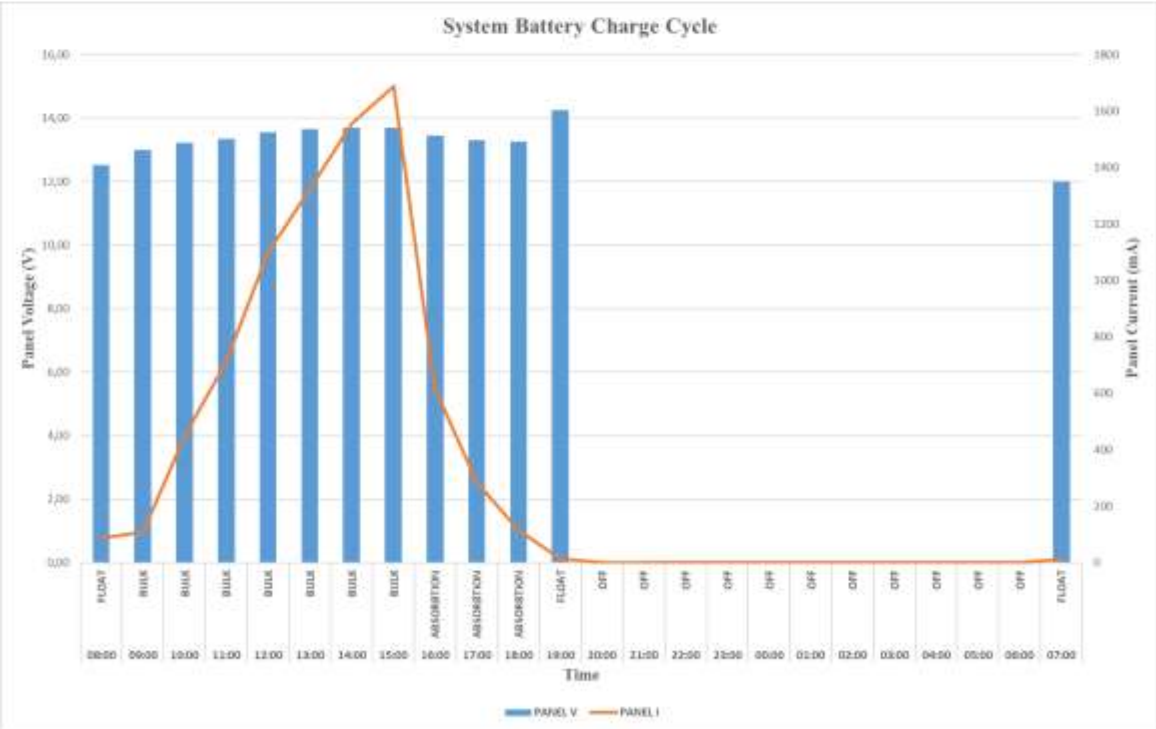


Figure 4.5. Graphical representation of the experimental results of the system

When the experimental results in Table 3.1. and Figure 3.5 were examined, it was determined that the developed system showed similar features with the simulation results produced by the MATLAB application. For example, the system is in accordance with the voltage produced by the panel and the current values drawn from the panel by the battery; followed the full charge (bulk), absorption and floating phase cycles.
When the real-time application results and simulation results were compared, it was seen that the maximum charging current of the battery, 2 ampere, could not be reached in the developed system. It is considered that this is due to the fact that the battery used in the system is very new and has a high output power (24A). It can be said that more than one solar panel should be used to obtain higher output power.

CONCLUSION

Although our country is in a good situation in terms of solar energy potential, unfortunately it cannot use this potential effectively and widely. However, studies on solar energy have been carried out for a long time in our country. Efforts are being made to effectively benefit from solar energy in public institutions and organizations, universities, foundations and associations established on the subject.
When the long-term financing opportunity is provided for the realization of environmentally compatible, solar-based energy generation systems with high initial investment costs but no operating costs due to the lack of fuel costs, these technologies will develop and the way to benefit from this resource at the highest level will be opened in our country. It is thought that there is a need for the state to introduce, certify and make the necessary legal

arrangements not only for solar cells but also for other methods of benefiting from solar energy. In addition, the existing solar potential in small consumption centers will be converted into electrical energy and used to feed the devices, and the surplus electricity generation will be transferred to the main grid, thus contributing to the country's economy.

In the application made in this thesis, a DC and AC voltage working lighting system will be developed by using a powerful solar panel and dry type battery together. In the prototype system, it is decided by the STM32 Discovery MCU whether the lamp is turned on or off according to the light and dark conditions of the air, and whether the battery will be charged according to the state of charge. The design of the system will first be simulated in the MATLAB program and then the electronic circuit design will be carried out. STM32Cube IDE application and C programming language will be used for coding of STM32 based microcontroller. In this way, it will be possible to improve many functions of the system.

The STM32 MCU controller is designed so that the solar panel will not charge the battery, that is, if the battery is below a certain voltage, the lighting device is fed by the normal mains voltage. In the system, 220V AC lighting will be made by the STM32 MCU first, and then it will be decided to switch to 12V LED lighting according to the battery power. In addition, the operation of the system will be regularly monitored by the STM32 MCU and in any system failure, the system will be protected and shut down. Regulator and inverter voltage values will be converted to digital data by ADC units, transmitted to STM32 unit and included in the calculations in the control software.

In the literature review, it is seen that automation and controls such as energy source selection were made with contactors in previous solar system lighting studies. The STM32 MCU controlled solar system will be a faster, more economical, smaller, lighter and more aesthetic system than the contactor controlled solar system. The most important feature of the system is that the STM32 control is faster than the contactor control. Thus, with STM32 control in solar systems, source switching is done so fast that it is not felt. In the STM32 controlled solar lighting system, when the solar panel and normal grid selection is made with the STM32 controller, it is predicted that problems such as the bulb not flashing during the source change will be eliminated and there will be no perceptible fluctuation in the system.

It is considered that the system whose prototype has been developed can be used as a cheap and maintenance-free solar system unit such as; in the operation of electrical devices in homes far from residential areas, in agricultural irrigation or water pump, in first aid, alarm and security systems, at meteorological surveillance or communication stations, in radio, wireless and telephone transmission systems, in the protection of oil pipelines or metal structures (bridges, towers, etc.) from corrosion, telemetric measurements in electricity and water distribution systems, in forest watchtowers and lighthouses, or drug or vaccine cooling units.

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