AUGUST 2019 M.Sc. in Engineering of Physics CEYHAN KARAÇETİN

REPUBLIC OF TURKEY

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGN AND PRODUCTION OF A PORTABLE SOLAR TEST DEVICE TO TEST, THE CHARACTERISTIC VALUES AND THE CLASSIFICATION OF SOLAR PANELS

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CEYHAN KARAÇETİN

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M.Sc. Thesis in

Engineering of Physics

Gaziantep University

Supervisor

Assoc. Prof. Dr. Mustafa YILMAZ

By

Ceyhan KARAÇETİN

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Name of Student: Ceyhan Karaçetin

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Prof. Dr. A. Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Ramazan KOC
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Dr. Mustafa YILMAZ
Supervisor

Examining Committee Members	Signature
Prof. Dr. Celal KORASLI	…………………..
Assoc. Dr. Mustafa YILMAZ	…………………..
Assoc. Dr. Rabia Güler YILDIRIM	…………………..

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ceyhan KARAÇETİN

ABSTRACT

DESIGN AND PRODUCTION OF A PORTABLE SOLAR TEST DEVICE TO TEST, THE CHARACTERISTIC VALUES AND THE CLASSIFICATION OF SOLAR PANELS

KARAÇETİN, Ceyhan
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Supervisor: Assoc. Prof. Dr. Mustafa YILMAZ
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The electric output performance of crystalline silicon and thin film PV modules are generally measured under standard test conditions (STC), ensuring a relatively independent comparison and output evaluation of different solar PV modules. STC is an industry-wide standard to indicate the performance of PV modules and specifies a cell temperature of 25°C and an irradiance of 1000 watt/m^2 with an air mass 1.5 (AM 1.5). These correspond to the irradiance and spectrum of sunlight incident on a clear day upon a sun-facing 37 degrees tilted surface with the sun at an angle of 41.81 degrees above the horizon. This condition approximately represents solar noon near the spring and autumn equinoxes in the continental United States with surface of the cell aimed directly at the sun. However, these conditions are rarely encountered in the real-world.

In this study, DC voltmeter and DC ammeter has been used which has RS485 communication protocol. Open circuit voltage (V_{oc}) , short circuit current (I_{sc}), maximum voltage under load (V_{mp}) and maximum current under load (I_{mp}) of different power solar panels have been measured after that compared with label values. Additionally, Open circuit voltage (V_{oc}) , short circuit current (I_{sc}), maximum voltage under load (V_{mp}) and maximum current under load (I_{mp}) values have been transferred to touchable Liquid crystal display (LCD) with the aid of RS485 protocol for user benefit.

Key Words: PV Modules, Testing Measurement and Classification System for the PV Panels

ÖZET

GÜNEŞ PANELLERİNİN SINIFLANDIRMASINI YAPAN VE KARAKTERİSTİK DEĞERLERİNİ TEST EDEN, TAŞINABİLİR BİR TEST CİHAZININ TASARIM VE ÜRETİMİ

KARAÇETİN, Ceyhan

Yüksek Lisans Tezi, Fizik Mühendisliği
Danışman: Doç. Dr. Mustafa YILMAZ
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63 Sayfa

Kristalin silikon ve ince film Fotovoltaik Güneş Panellerinin elektriksel çıkış performansı genellikle standart test koşulları altında (STC) ölçülür. Bu sayede farklı güneş panellerinin elektriksel değerlerinin karşılaştırılması yapılabilir. STC, Fotovoltaik Güneş Panellerinin performansını belirtmek için endüstri çapında bir standarttır ve 25 ° C'lik bir hücre sıcaklığını ve bir hava kütlesi 1.5 (AM1.5) ile 1000 watt/m^2 ışınımını belirtir. Bunlar, güneşin ufkun üzerinde 41.81 derece açıyla güneşe maruz bıraktığı 37 derece eğimli yüzeyde net bir günde meydana gelen güneş ışığının ışınımına ve spektrumuna karşılık gelir. Bu durum yaklaşık olarak kıta Amerika Birleşik Devletleri'ndeki ilkbahar ve sonbahar ekinokslarına yakın güneş öğlenini temsil eder ve gün ığışının Fotovoltaik Güneş Panellerinin yüzeyine doğrudan geldiği varsayılır. Ancak gerçek dünyada, bu durum nadiren yaşanmaktadır. Bu çalışmada, RS485 haberleşme protokolü olan DC voltmetre ve DC ampermetre kullanılmıştır. Açık devre voltajı (V_{oc}), kısa devre akımı (I_{sc}), yük altındaki maksimum voltaj (V_{mp}) ve farklı güneş panellerinin yük altındaki maksimum akım (I_{mp}) etiket değerleri ile karşılaştırıldıktan sonra ölçülmüştür. Ek olarak; kullanıcı kolaylığı için, Açık devre voltajı (V_{oc}), kısa devre akımı (I_{sc}), yük altındaki maksimum voltaj (V_{mp}) ve yük altındaki maksimum akım (Imp) değerleri, RS485 protokolü ile dokunulabilir ekrana (LCD) aktarılmıştır.

Anahtar Kelimeler: Güneş panelleri, Güneş panellerinin test, ölçüm ve sınıflandırmasının yapılması.

''Dedicated to my family''

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I would like to thank my supervisor, Assoc. Prof. Dr. Mustafa YILMAZ for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to express my love and gratitude to my family for their support, always best wishes.

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LIST OF SYMBOLS

P	Power
V	Voltage
I	Current
W	Watt
°C	Degrees Celsius
mm	Millimeter
µm	Micrometre
eV	Electronvolt

LIST OF ABBREVIATIONS

PV	Photovoltaic
MPPT	Maximum Power Point Tracking
$\mathbf{V_{oc}}$	Open Circuit Voltage
$\mathbf{P_{max}}$	Maximum Power
$\mathbf{V_{mp}}$	Maximum Voltage
$\mathbf{I_{sc}}$	Short Circuit Current
LCD	Liquid Crystal Display
EVA	Ethanol Vinyl Acetate
AM	Air Mass

CHAPTER I
INTRODUCTION

Renewable energy sources emerge in forms such as wind energy, solar energy, water power, bio fuel energy, sea wave power, geothermal energy and so on. The easiest of these to convert into electricity is wind and solar energy.

The idea of using photovoltaic panels in non-mains areas has emerged in the early 1970s. After this development, the researches in this field have increased and the use of photovoltaic solar cells has been widespread in various fields. [9]

As the use of photovoltaic solar cells becomes more important, studies on simulation models are increasing rapidly. Having different characteristics from direct current and alternating current sources and affected by their environment and working conditions are the main reasons for compromising the simulation models of photovoltaic solar cells. The operation temperature, environment temperature and sunlight intensity characteristic are changing dynamically. The model to be developed should be able to respond to these changes. [9]

Photovoltaic solar panels, current, voltage, power and so on. Electrical parametric values are presented to the user through the use of solar sun simulators power during the production phase of the panels. Solar panel customers that are installer or investors can see only after the systems are switched on the accuracy of efficiency of the solar panels in the real environment and the accuracy of electrical parametric values under electrical load. After the system is switched on, it is both waste of power and time to examine each panel separately from the arrays.

In this study, it is given information about the design of a device which makes electrical parametric values measurements of under natural daylight and load before commissioning photovoltaic solar panels.

CHAPTER II
LITERATURE SURVEY

During the last decades, the developing in electricity rapidly has taken place and has evolved in the latest technology. The electricity has occupied significant place in the nowadays life of humanity. After the using the fossil fuels for the generation of electricity which has been produced by harming the environment. People thought that the electricity should minimize damage to the environment. To meet the necessity by returning to renewable energy sources. The simplest system that production of electricity from solar (photovoltaic systems) when the payment of wages to the raw energy sources is not expensive especially when renewable energy sources are the most prefer red because of personal expenses are not high during operation. Also more advantages are obtained because of the low main tenancy cost due to the less devices. In this study, the world photovoltaic system integrated in to the existing structure has been investigated. Review the systems as a result of the inclined roof, flat roof and wall applications collected were analysed under three headings of efficiency. Afyonkarahisar modelled inclined roofs has been chosen as
Sample to use and utilizing these applications. To get the most efficient of the three different roofs technologies which has been chosen as good sample (mono crystalline, polycrystalline and thin film) was place das a solar panels. The power of solar panels is provided by mounting the same side as selected and affected by the same sun lighter source. Developing the microcontroller control board and the C # software with production data of solar panels (voltage and power) was followed instantly Access the database from the computer and was recorded at 10-sec intervals. According to these data which are calculated using the efficiency of the solar panels were compared with same applications in most of places of the World. [1]

Usage of renewable energy sources has been rapidly increased recently and solar Energy being plenty of amount in the nature with easy access is one step ahead in respect to the other renewable energy sources. Especially, rapidly growing technological infrastructure to generate electricity from solar energy via photovoltaic (PV) method also has been increased the process of integration PV systems into daily life. In this study, basic definitions about Photovoltaic Systems were made and, the I-V Curve of Photovoltaic cell (PV) was plotted at Matlab. Later, its modelling was made using the catalogue figures of "BP SX 170B PV module. " The impact of serial resistance on the operating power of PV system was observed. In PV module, the impact of ambient temperature and radiation on the I-V curve was drawn by using Matlab m-files. It was observed that PV modules were negatively affected by the temperature, and as the temperature rose, output potential and power of PV modules decreased. It has been understood that the most suitable environment for the PVs is cold and sunny conditions. The operating and nominal output power of PV module was calculated using Matlab, and was made to operate at maximum output power. Three different model simulations were prepared, and a comparison was made among these. The figures acquired in PV Module Battery System were considered, and the stability of the system was studied carefully. Efforts were shown to make the batteries work steadily using the values acquired in simulations. After the simulations and the acquired values, it was shown that PV systems should run at the maximum possible efficiency. Therefore, for the changing ambient temperature and solar radiation levels, it was also shown necessary to determine the maximum power point that the module could provide. [3]

This paper takes a look at the simulation model of photovoltaic cell in order to study the electrical behaviour of the photovoltaic cell with respect to the changes of environmental parameters such as temperature and solar irradiation level Maximum power point tracking is the most important issue for the better performance of a photovoltaic system. Taking this in account, this paper also proposes the maximum power point tracking (MPPT) control system for photovoltaic (PV) module using the Perturb and Observe algorithm and the system design of single phase grid connected photovoltaic system. For MATLAB simulation model BP SX 150S photovoltaic module is chosen. Module is made of 72 multi-crystalline silicon solar cells in series and 150W of maximum nominal power. Maximum power point tracking control is implemented over this selected type of module and the effect of variable solar resistance over module performance is also taken into account. Since photovoltaic (PV) energy utilization has increased interest in electrical power applications, it is very much essential to develop a simulation model of the PV system for simulation studies. It is crucial to operate the PV energy conversion system near the maximum power point to increase the efficiency of the PV system. Because of nonlinear nature of PV system, the current and power of the PV array depends on the array terminal operating voltage. In addition, the maximum power operating point varies with solar irradiance level and temperature. Therefore the tracking control of the maximum power point is most important issue for a successful PV system. [2]

Searches for Renewable energy sources are increasingly continue in the last century we are living in. After 1970 energy crisis, Works on associated with get rid of dependence of non-renewable energy sources are speed gained by the countries and the scientists who want to get rid of the OPEC pressure and take into consideration of environmental factors. Solar Energy which is powerful and unlimited energy resource has taken place in these works. Although works on efficiency about continuous and uninterrupted use of solar energy is not successful enough, it has large potential which is already actively used with other renewable energy systems in many countries. In this thesis, application is focused on resolving lightening problem in the area experienced network problems. In this application, three different types of solar panels are used as Mono crystalline, polycrystalline and amorphous-silicon. Efficiencies of panels are examined on January and July in Ankara. Designs are made with three different types of solar panels for lightening system which works network independent. After efficiency examinations are accomplished experimentally, recommendations are given about increase of efficiency. [4]

In this work a general literature review, especially for solar and wind energies, has been done on the topic of Renewable Energy sources which includes how these energies occur in nature and how electrical energy derived from these kind of energies. After doing so, an efficiency phenomenon for solar cells positioning according to wind turbines in solar-wind hybrid electrical energy production units tried to be understood via empirical observations. The thought that solar cells positioning may have an impact on their efficiency arouses from two different known subject; the first is that the wind which flows through the wind mill has different speed and pressure characteristics and the second is that, which is proven by previous works, solar cells work more efficiently at low temperatures; combining these two known truths the question which air characteristics is more able to keep the solar cells at low temperatures by means of heat convection has been investigated.[5]

CHAPTER III
SOLAR CELLS AND PHOTOVOLTAIC SYSTEMS

Photovoltaic is the name given to technology that can produce electricity directly from special semiconductor devices illuminated by photons. Devices designed to produce direct electricity from solar energy with photovoltaic technology are called solar cells. Today, solar cells are widely used. Especially in remote areas to the main grid; telephone receivers, lighting, lighted warning plates can be met by photovoltaic panels. In addition, domestic or industrial energy needs are also met. Nowadays, the installation of solar power plants, which are constructed from photovoltaic panels, is getting widespread. [9]

3.1 Solar Cells

Solar panel is the name given to the device that converts solar energy directly to electricity with photovoltaic effect. It consists of a standart solar panel, one or more thin semiconductor layers. Generally, silicon is used as a semiconductor. The amount of electric energy obtained from a single solar panel is low. Therefore, solar panel systems or solar field are created by combining more than one solar panel and adding other components.

The photovoltaic effect was first discovered by the French physicist A. Edmond Becquerel in 1837. Becquerel discovered that when light comes into an electrolyte-immersed electrode, there is voltage. Then in 1873 Willoughby Smith discovered the photovoltaic effect of selenium (Se). William G Adams and a student discovered that a joint formed by selenium (Se) and platinum (Pt) was photovoltaic, in 1876. As a result of these two inventions, the first selenium solar cell was produced in 1877. In 1918, Jan Czochralski discovered the method of monocrystalline silicon production, which is the basis for the production of monocrystalline solar cells currently in use.

The first silicon monocrystalline solar cell was produced in 1941. In 1951, the first germanium solar cell was produced. In 1955, solar cells began to work to energize satellites. In 1961, the United Nations organized a solar energy conference.

A photovoltaic panel with a power of 14 W was installed on Telstar, the first commercial telecommunications satellite produced in 1962. In 1963, Sharp produced the first usable photovoltaic panel from Silicon Solar batteries. Between 1970 and 1979, the number of PV panel manufacturers increased. In the following years, there has been a significant increase in both photovoltaic panel production and solar field use in many European countries, especially in Germany and Spain. As of 2010 in Turkey, Photovoltaic panels has started to produce and export by Anel Elektrik Enerji Üretim Sanayi ve Ticaret A.Ş.

In order to understand the photovoltaic effect and photovoltaic systems, it will be useful to examine the structure of the semiconductor materials and the p-n junction first. [9]

3.2 Semiconductors

A semiconductor material is a material that is not electrically conductive but can be converted into a conductive state by some external influences that means they cannot be accepted as insulators. These materials, which are insulator under normal conditions, enter a conducting state to release some electrons under external influences such as magnetic effect, heat, electrical potential or light.

Atoms are made up of nuclei and orbital electrons around them. The electrons of an isolated atom may consist only of packet energy levels (quantization) or certain parts. In atoms with more than one electron orbit, the electrons closest to the nucleus so that they need the highest amount of energy to beat the pull of the nucleus and become free. When the atoms come together, each atom's electronic energy is excited and energy levels are accumulated in the energy generations. In some energy generations ejecting an electron does not possible in some cases where ejecting an electron is possible. However, the outermost electrons may interact with other atoms.

An atom's electrons are called generational valence band that electrons normally interact with other atoms. The electrons in this band are tied to the atom by weak bonds and they can easily migrate and interact with neighbour atoms. Thus, they leave a negative charge on the atoms they join and leave positive ions as they leave. Thus, they leave a negative charge on the atoms they join and leave positive ions as they leave. Thus, they leave a negative charge on the atoms they join and leave positive ions as they leave some electrons in this generation carry a lot of energy, this energy can provide a jump to the higher generation. These electrons are the electrons that transmit heat and electricity, this generation is called the transmission generation.

The difference in energy between the valence band and the electrons at the innermost level of the transmission band is called the band gap. The energy generation diagram of the three different materials is shown schematically in figure 3.1

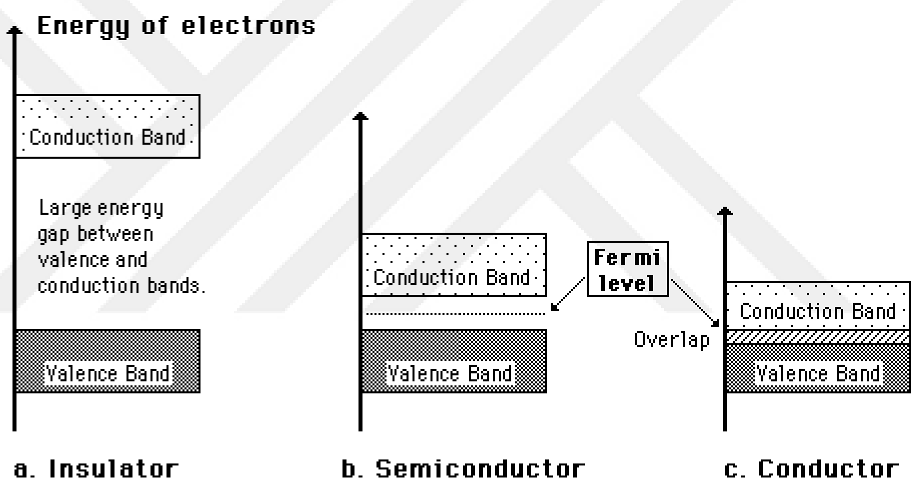

Figure 3.2.1 Valence and conduction band in conductor, semiconductor and Insulators [13]

The materials that are relatively empty valence belts and have a certain number of electrons in the conduction band are called conductors. In this case, the level of value and transmission is struck. The valence electrons can take energy from the outside and the energy level on the same band can come to a slightly higher position. Metals are in this category. The electrons of valence in metals can easily spread out of the atomic structure and transmit electrons. Materials with partially filled valence ranges have intermediate band gap and are called semiconductors. The band gap in these materials is less than 3eV. Semiconductors have the same band structure as the insulators, but the energy ranges are narrower.

The semiconductors are divided into two parts as fully doped semiconductors and as doped semiconductors with a small amount of foreign particles added. In self-semiconductors, valence electrons can be stimulated by light and radiation. Thus, in the transmission generation, they can jump into a narrower range of energy in which electrons do not form atomic bonds and thus can move freely. [9]

3.2.1 P-N Junction

N type and P type semiconductor materials together they behave in a very different way merging together and producing what is generally known as a "PN Junction". When the N-type semiconductor and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the PN junction. The result is that some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions.

However, because the electrons have moved across the PN junction from the N-type silicon to the P-type silicon, they leave behind positively charged donor ions (ND) on the negative side and now the holes from the acceptor impurity migrate across the junction in the opposite direction into the region where there are large numbers of free electrons.

As a result, the charge density of the P-type along the junction is filled with negatively charged acceptor ions and the charge density of the N-type along the junction becomes positive. This charge transfer of electrons and holes across the PN junction is known as diffusion. The width of these P and N layers depends on how heavily each side is doped with acceptor density NA, and donor density ND, respectively. This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more charge carriers from crossing over the junction. Eventually a state of equilibrium (electrically neutral situation) will occur producing a "potential barrier" zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons.

Since no free charge carriers can rest in a position where there is a potential barrier, the regions on either sides of the junction now become completely depleted of any more free carriers in comparison to the N and P type materials further away from the junction. [10]

N-type, P-type semiconductors and P-N junction is shown below Figure 3.2 and Figure 3.3

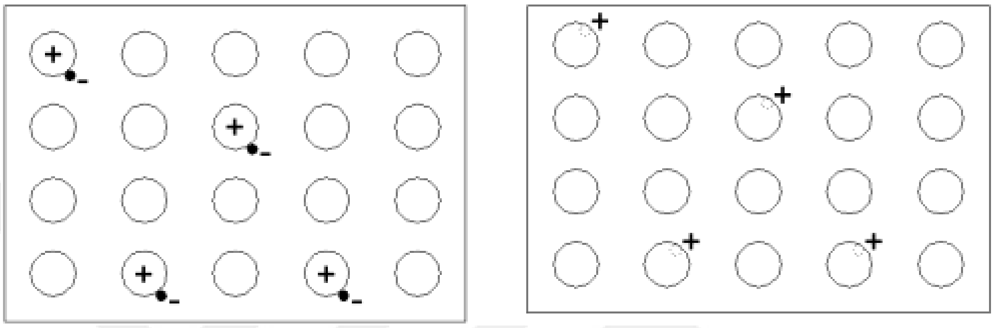

Figure 3.2.2 n-type and p-type semiconductors [9]

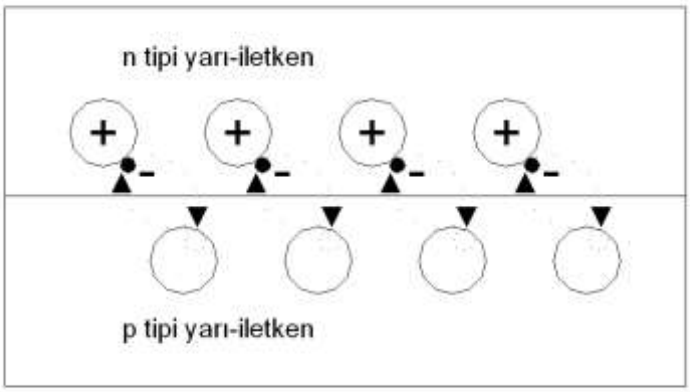

Figure 3.2.3 Schematic representation of P-N junction [9]

3.2.2 Photovoltaic Effect

The photovoltaic effect is the photoelectric effect characterized by the production of an electric current between two pieces of different material that are in contact and exposed to light or, in general, to electromagnetic radiation. This photovoltaic effect constitutes the principle of photovoltaic cells and is, therefore, fundamental for the production of solar electricity.

The photovoltaic effect starts at the moment a photon hits an electron from the last orbit of a silicon atom. This last electron is called Valencia electron and receives the energy with which the photon travelled. The photon is nothing but a particle of radiant light.

If the energy that acquires the electron exceeds the attraction force of the nucleus (valence energy), it leaves its orbit and is free of the atom and therefore can travel through the material. At this point, we would say that silicon has become conductive (conduction band) and, in order to do this, the impact force of a photon must be at least 1.2 eV. Each released electron leaves behind a hole, or free space, until it is occupied by an electron that has jumped from another atom. These movements of the released electrons or the spaces left behind are what are called electrical charges.

This charging current can reach the contacts and exit the material in order to perform useful work. For this to happen consistently and regularly, it is necessary that there is the presence of an electric field of constant polarity. This field polarizes the particles and acts as a real bomb that drives the electrons in one direction and the holes in the opposite.

In conventional solar cells, the electric field (0.5 V) is formed by a PN junction, in one area of the material has excess electrons (negative charge), while the other has a lack of them Positive), so that when an electron is released it is driven through the material to the low-resistivity silver conduits.

If the energy that acquires the electron exceeds the attraction force of the nucleus (valence energy), it leaves its orbit and is free of the atom and therefore can travel through the material. At this point, we would say that silicon has become conductive (conduction band) and, in order to do this, the impact force of a photon must be at least 1.2 eV. [9]

Solar panel and solar cell structure is shown in below figure 3.4

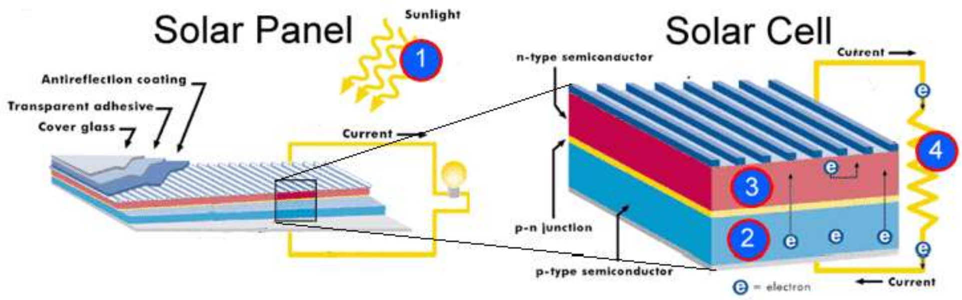

Figure 3.2.4 Schematic diagram demonstrating the operation of p-n junction Photovoltaic cell. [14]

3.3 Photovoltaic Cell Types

Solar cells are made up of semiconducting materials, often chosen as silicones that combine to provide special conditions. It can be named Photovoltaic Cell or Solar Cell. The thickness of the N-type semiconductor is generally about 0.5 µm and the thickness of the P-type semiconductor is usually about 0.25 mm.

Photovoltaic panels are formed by assembling photovoltaic cells. It was mainly composed of 36 photovoltaic cells with a solar panel because the voltage needed for 14V to 18V range is required for normal 12V acupressure charge and the voltage provided by a photovoltaic cell is usually around 0.5V.After that, panels with 54-80 photovoltaic cells were produced with the increase of the usage area which is directly connected to the load and does not require a battery charge. When solar panels are considered to be operated in open areas and considering the structures of photovoltaic cells, photovoltaic cells must be brought together to form a solar panel, which should minimize the effect of conditions on photovoltaic cells and their connections. Another key consideration when creating a solar panel is that the transparent front cover to be used to protect the cells is selected from those that reflect the sun's rays at the lowest level. Figure 3.6 shows the structure and operation of the crystalline silicon semiconducting photovoltaic panel.

"Photovoltaic Solar Cells" or "Photovoltaic Cells" are divided into two groups: crystalline silicon and thin film. [9]

3.3.1 Crystal Silicon Cells

The most important raw material of crystal silicon-built batteries is silicon. The optical, structural and electrical properties of the atom of the silicon do not change long periods of time and developments in silicon production technology are the factors that increase the usability of this material in the production of solar cells. However, pure crystal production is very demanding and expensive. Silicon is the most found element in the Earth after oxygen, although it is not pure in nature due to the absence of solar cells to be used in the production of the first needs to be purified. For this, it is necessary to be separated from the silicon dioxide (quartz) ($SiO2$) compound by applying heat treatment requiring high temperature and increasing the purity with some other methods. Crystal solar cells are divided into monocrystalline and polycrystalline cells. [9]

3.3.1.1 Monocrystalline Solar Cells

Although the oldest and most expensive technique among solar cell manufacturing techniques, solar cells with the highest efficiency value still are mono crystal built solar cells. In the market, the current mono-crystalline solar cells are examined with efficiency between 15% and 18%.

Mono Crystal Silicon production method known as "Czochralsi method" is used. Developed in 1971, in this method, Czochralsi, a small vaccine crystal, dipped into crystal material and gradually attracted a long single crystalline cylinder by pulling it into a cold zone. With this method requiring processing at very high temperatures, it is sliced in a circular, rectangular or polygonal shape by forming silicon rollers of 0, 3m diameter and a few meters tall, and slices in thickness of 0.2 -0, 3mm. As a result, the resulting layers make the P-type layer of the solar cell ready. The N-type layer is also obtained by way of lower thicknesses and phosphorus propagation. P-type and N-type layers are made in combination with the rear connections, special adhesives with anti-glare glass layer is pasted and the battery is created. The structures of Mono crystal cells are homogenous and their colours are characteristic in the dark blue-black range. This solar cell type is shown in below figure 3.5 [9]

Figure 3.3.1 A solar cell made of Mono crystal silicon [12]

3.3.1.2 Polycrystalline Solar Cells

The most commonly used method in the production of polycrystalline silicon is the casting method, which is similar to the starting point mono crystalline silicon. Polycrystalline structure silicon is obtained by cooling the silicon of the semi-conductive quality (purity) of the solution in the moulds. This solar cell type is shown in below figure 3.6. The formation of the crystalline structure is composed of a polycrystalline structure because it is not monitored and controlled as mono crystal production. Although the efficiency values of the semiconductor solar cells manufactured from polycrystalline silicon are lower, the cost of production is lower. Since the structures of polycrystalline batteries are very crystalline, this situation can be observed with the naked eye because of the refracting of light. The battery is displayed as blue due to the anti-glare glass, but the battery does not have a non-reflective glass coating.

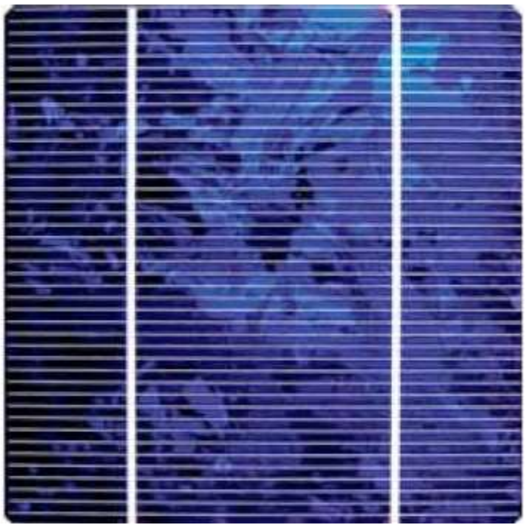

Figure 3.3.2 A solar cell manufactured from polycrystalline silicon [12]

3.3.1.3. Thin Film Solar Cells

Based on the logic of the coating of semiconductor materials on large surfaces, this method allows the production of cells with different characteristic properties. This cell type is shown in below Figure 3.7. According to research conducted in this area, many semiconductor materials that can be used in the production of solar cells have shown to be coated on large surfaces such as glass or plastic foil with low costs.

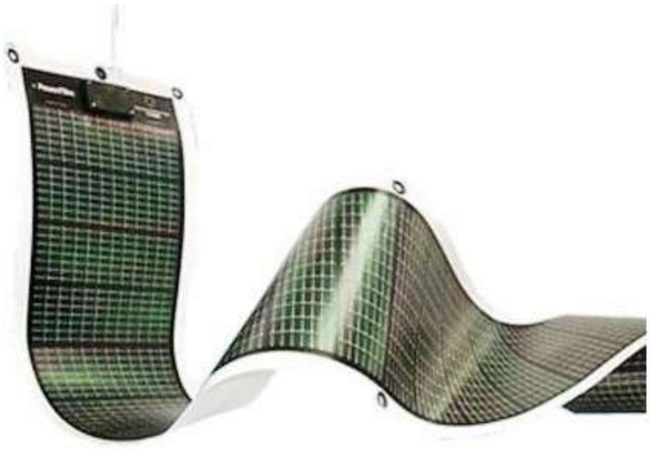

Figure 3.3.3 Thin-film solar cell

3.3.1.4. Amorphous Silicone Solar cells

Amorphous silicon has no predictable crystalline structure, so there are many potential covalent bonds in silicon. This structure creates irregularities in the belt range and allows for very low amounts of electron and gap propagation. However, it has been observed that the formation of these negative covalent bonds can be neutralized by hydrogen aid and thus the development of electron and gap propagation can be caused. With this method, amorphous silicon batteries can be said to generate the potential in the production of solar cells in thin film layer form.

3.3.2 Gallium Arsenic

Relatively high absorption and 1.43 eV direct belt range leads to gallium arsenic (GaAs) to be seen as a potential photovoltaic material. The high production costs limit the use of gallium arsenic (GaAs) based solar cells to some special applications for now.

3.3.3. Optical Concentrator Mechanisms

The current solar cells are concentrated on 10-500 times the solar rays coming onto the solar cell by adding some optical reflector or concentrator. In this way, the efficiency of the solar cell and module can be increased, but some problems such as high temperatures are encountered.

3.3.4. Other

Although there is not yet widespread use for various reasons, there are also types of batteries such as gallium dieseline, cadmium telluride, medium belt, Super tandem, hot carrier, organic photovoltaic cells.

3.4 Structure of Photovoltaic Panels

The efficiency of solar batteries or systems depends on the efficiency of many other equipment or utensils, such as absorption efficiency, corridor glass permeability, atmospheric effects, joint yield, yield of connection assemblies and sunlight angle. The joint yield of a solar cells depends on the joint geometry parameters and joint material. It is of great importance that the energy from the solar cell of the connection devices can be taken to the highest level. The extent to which the sun's surface can absorb sunlight directly affects the end result.

However, the permeability of the protective glass to be used on the cell also directly affects the total yield, and the glass to be used must be of low reflection quality. The raw materials and panel structure used in the production of photovoltaic modules can be explained as in figure.

3.5 Classification of Photovoltaic Panel

As you can see, there are many different types and structures of solar cells / panels in the market. Whether it is a building or a power generation plant, it is necessary to evaluate special conditions of the project and projected expectations as well as the cells characteristics in order to be able to select the panel to be used for any project. The bestselling and used type cells in the market are crystal silicon cells, which have higher productivity values than thin film batteries. For this reason they are especially preferred where there is limited space, such as building roofs. Mon crystalline cells have higher efficiency than polycrystalline cells, and the production costs of polycrystalline panels are lower.

CHAPTER IV
PRODUCTION AND QUALITY CONTROL PROCESSES OF PHOTOVOLTAIC PANELS

Solar cells are often formed by combining selected semiconductor materials as silicon to provide special conditions. These cells are passed through the appropriate production stages and electrically connected to produce a solar panel with greater strength and multiplex.

4.1 Overview of Photovoltaic Panel Production Line

The module line consists of a large number of machines (stations). Each of them has a working principle. The photovoltaic module production line is also referred to as the interconnected production lines. The most important purpose in photovoltaic module production lines is to obtain the maximum number of module production by giving minimum amount of waste from the used raw materials. The cells entering the production line have yield values of 15% -20%. Depending on the quality of the raw materials used in the production line, the module obtained is produced with the lowest yield loss. These yield losses, which depend on the workmanship and raw materials of the production lines, are an indication of both the quality control process of the production line and the quality of the raw materials. The stations and tasks on the production line are as follows. [12]

4.1.1 Photovoltaic Module Production Steps

The module line is used to produce ready-framed solar modules for connection. The manufacturing proses of photovoltaic panels is shown in below Figure 4.1. The photovoltaic modules are manufactured in a number of functional steps applied by the machines in the production line.

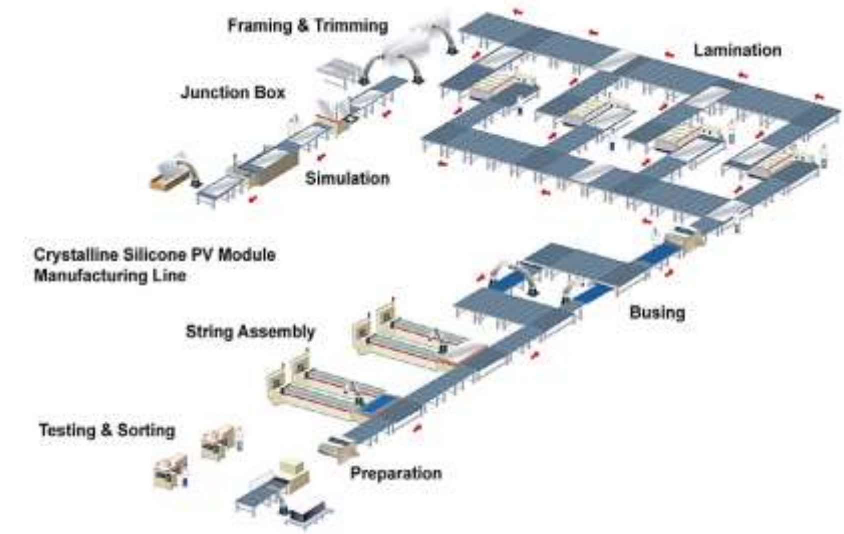

Figure 4.1.1 The manufacturing proses of photovoltaic panels [12]

- Installation of solar glass plates and EVA foil in the module line.
- Installation of finished cells in the module line.
- Soldering of cells in String.
- Positioning and soldering the strings in the form of a matrix.
- Completing and laminating glass plates, matrices and foils as a solar module.
- Mounting the Solar Module in the frame, mounting the junction box.
- Solar modules are classified and labelled according to their power class.

We can list the machines and stations in the photovoltaic module production plant as follows. Production plants also have different operating structures such as manual, semi-automatic and fully automatic. Therefore, different machines and stations can be used. The machines and stations we mentioned here are the machines used in every production facility. [12]

- ✓ Glass Loading Machine
- ✓ Glass Washing Machine
- ✓ Solar Cell Line Station
- ✓ Soldering Department
- ✓ Pre-lamination Electroluminescence Test
- ✓ Laminating Station

- ✓ Framing phase and connection box assembly
- ✓ Power Measurement with Solar Simulator

4.1.2 Glass Loading Machine

The glass loading machine is used to bring the solar glass plates to a module line for the production of solar modules and place them in the production line. Glass Loading Machine is shown in below figure 4.2. Each glass plate is taken from a stack of glass plates with the aid of a rotary crane, which is vacuum-tight and placed on a reeled conveyor. The rolled conveyor glass plate first carries to the first station of the module line, and then to the windscreen washer unit. [12]

Figure 4.1.2 Glass Loading Machine [12]

4.1.3 Glass Washing Unit

The glass washing machine is a cleaning unit that horizontally passes through the plates, allowing the glass plates to be cleaned. This Glass Washing Unit is shown in below Figure 4.3. The entrance consists of sections such as a brush station, module washer and dryer. The glass plate is transported between rotating rolls. Machine Units are automation controlled. The workflow can be managed and supervised.

However, today's production lines do not operate this station because of damage to the Anti-Reflective coating surface of new technology-produced lenses. [12]

Figure 4.1.3 Glass Washing Unit [12]

4.1.4 Solar Cell Distribution Station

EVA (Ethanol Vinyl Acetate) is placed on the glass placed in the glass loading station and sent to the stringer machine. Solar Cell Distribution Station is shown in below Figure 4.4. The operator in this station is first placed in the entrance of the string machine. Stringer machine all the cells used in production are passed through the physical data control before the soldering process and the properties such as finger, bus bar, diagonal, asymmetry, and colour are controlled. Thus, the cell usage standard is maintained. Loss of yield is prevented. The operator working in this station should always wear protective gloves and should not touch the solar cells with bare hands. The robotic arm with pneumatic absorbers in the stringer section takes the cells from which the cells are placed and divides the images of each individual

In this section, the cells are separated as intact or defective. Sturdy cells pass to the infrared soldering stage and are turned into arrays after this step. For example, to make 250 W panels, 6 pieces are prepared in 10 series. Robot arm is placed on the glass coming from the glass washing unit perfectly. EVA is laid on the glass from the production line. The cells placed on this EVA are sent to the soldering station. [12]

Figure 4.1.4 Solar Cell Distribution Station [12]

4.1.5 Soldering Station

The EVA material and cells were aligned on the glass that came into the production line at the soldering station. This station is shown in below Figure 4.5. At this stage, it is ensured that the alignment of the operators and the visual control of the solders yield the best type image.

Figure 4.1.5 Soldering Station [12]

These stations are available in manual, semi-automatic and fully automatic. However, in all three cases the presence of an operator is preferred in terms of production control. Sequence placed on the glass is the part where soldering is performed serially to each other and is called soldering station. [12]

4.1.6 Pre-Lamination Electroluminescence Test Station

The EL Tester is used to control the micro fracture formations and solder qualities of the pre-lamination modules. In this way, minimum defective product formation, maximum productivity is ensured. A Broken Solar Cell Detected by EL Tester is shown in below Figure 13. This station is shown in below Figure 4.6. Electroluminescence (EL) is an optical and electrical phenomenon and emits light in response to electrical current passing through the material or in response to very strong electrical fields. Similar to this situation, the EL test process before the lamination process of the solar panels produced in the production line determines the production defective cells that the operator can not recognize or the micro fractures on the cell that are not visible at the time of production, thus preventing material losses in operation.

Figure 4.1.6 EL tester [12]

The EL tester applies an electric current to the solar panel for a short period of time to determine the quality of the panel by displaying the light emitted from each zone of the panel. If this process is noticed after the lamination process, the panel does not have a chance of being corrected again and falls down to the state of the panel of B quality. A broken Solar panel is shown in below Figure 4.7. This is a loss for the enterprise. Therefore, EL test equipment before lamination must be used. [12]

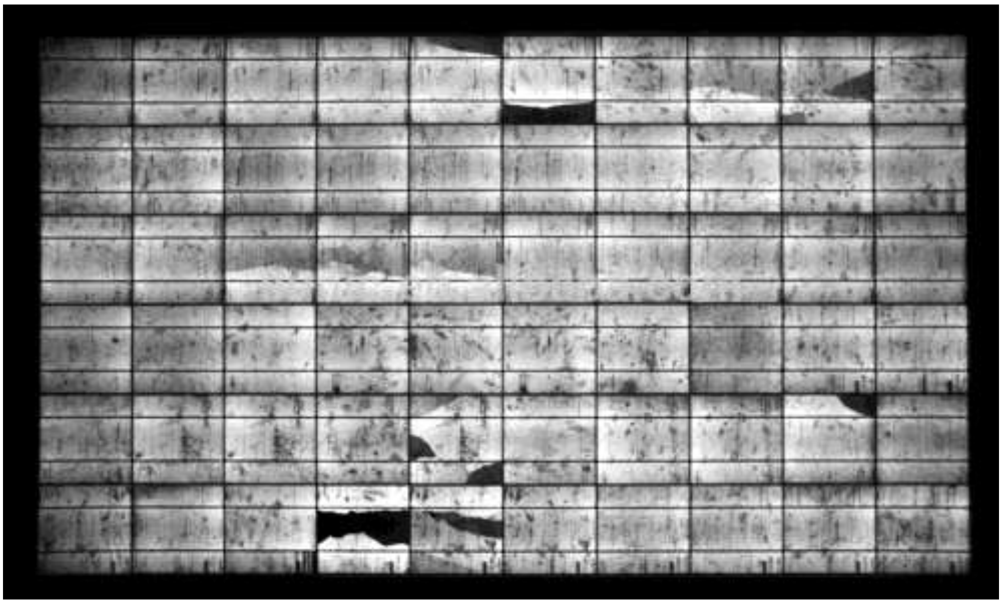

Figure 4.1.7 A Broken Solar Cell Detected by EL Tester [12]

4.1.7 Lamination Station

Products passing through the EL test on the production band reach the lamination station. The product arrives at the lamination station on the tempered glass as two EVA (ethanol Vinyl Acetate) cells. This situation is shown in below Figure 4.8. One of the important points in the production of solar panels is to prevent the cells from touching the outside world and to make the insulation perfect. In this case, solar cells arranged between Eva materials are insulated from the outside world by being laminated under high temperature and pressure. The laminators used in today's conditions are being used in 2 states as preheating and heating.

However, manufacturers with a serious market share in the industry add a third level, which performs cooling down to 25 ° C, in order to make the test results more accurate. In this case, it is tested at a value close to the Standard Test Condition (STC) temperature (25 ° C), which gives values very close to the real value. [12]

Figure 4.1.8 Lamination Station [12]

4.1.8 Frame And Junction Box Assembly

Panels that have completed the lamination process and the necessary cooling process reach this station for framing. The produced panel is framed with aluminium frames cut to the required dimensions according to the power. The framed solar panels are transferred to the other station for mounting the junction box. Frame machine and junction box picture is shown in below Figure 4.9, Figure 4.10.

Figure 4.1.9 Frame Machine [12]

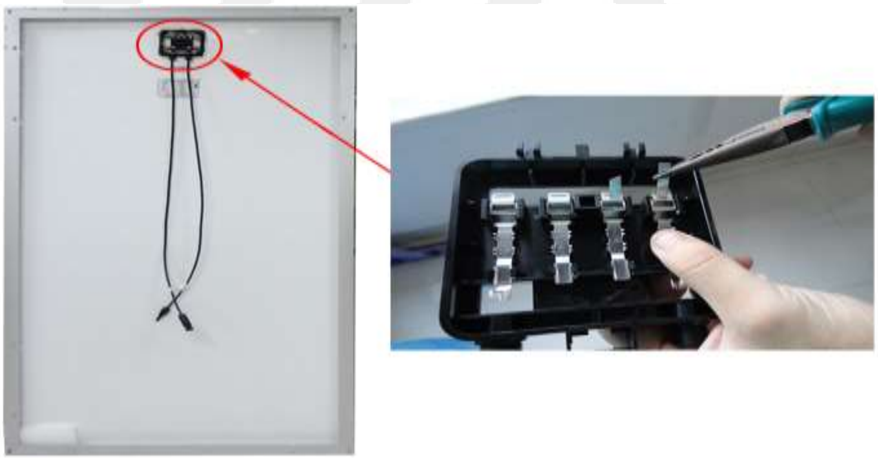

Figure 4.1.10 Junction box [12]

The photovoltaic panel was obtained after the connection box was assembled. The next step is to test and record the solar panels before reaching the customers. [12]

4.1.9 Power Measurement with Solar Simulator

The output values of the panels produced on the production line are tested. The panels tested under standard test conditions (25 °C, 1000 w/m2 and A. M: 1.5) are also subjected to high voltage testing. This machine is shown in below Figure 18.

In this situation, the output power of the panel, voltage, short circuit current properties such as the products are classified according to different power classes. [12]

Figure 4.2.1 Power Measurement with Solar Simulator [12]

4.2 Quality Control Processes of Solar Panels

Photovoltaic solar panels must pass through quality control processes before reaching the end user. We should evaluate the quality control processes not only in the production line but also in a wider perspective. These Control processes is shown in below Figure 19-28. The first stage is control of the raw material before the product is formed, the control of the second stage production and the third stage is the last control stage before delivery to the user. The first stage, raw material control; is the physical control of raw materials such as photovoltaic cells which are obtained from suppliers, EVA (ethanol Vinyl Acetate), soldering materials (ribbon), back sheet, tempered and antireflective glass, connection box, etc.. This control is made by the purchasing manager and the operating supervisor and sent to the production line. [12]

4.2.1 Controlling Cells with Victronic Camera

In Stringer device; all the cells used in production are passed through the physical data control before the soldering process and the properties such as finger, bus bar, diagonal, asymmetry, and colour are checked. Thus, the cell usage standard is maintained. Loss of yield is prevented. [12] Cell control with Victronic camera is shown in below Figure 19.

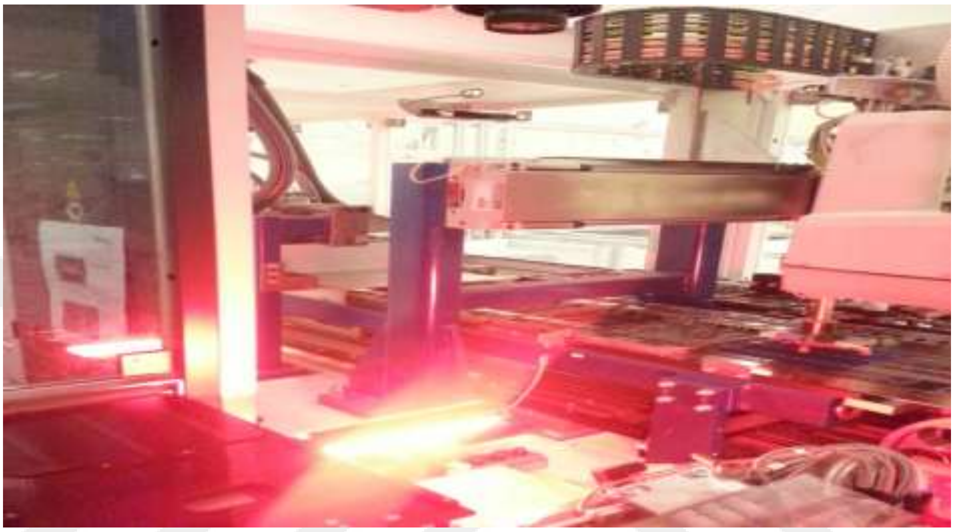

Figure 4.2.2 Cell control with Victronic Camera [12]

4.2.2 Cell Temperature Control

For all generated strings in Stringer device; cell soldering, control of temperature and temperature application times are done with precision measuring devices and contactless infrared soldering is done. Thus, the efficiency of the cell is preserved. [12] Cell temperature control machine is shown in below Figure 20.

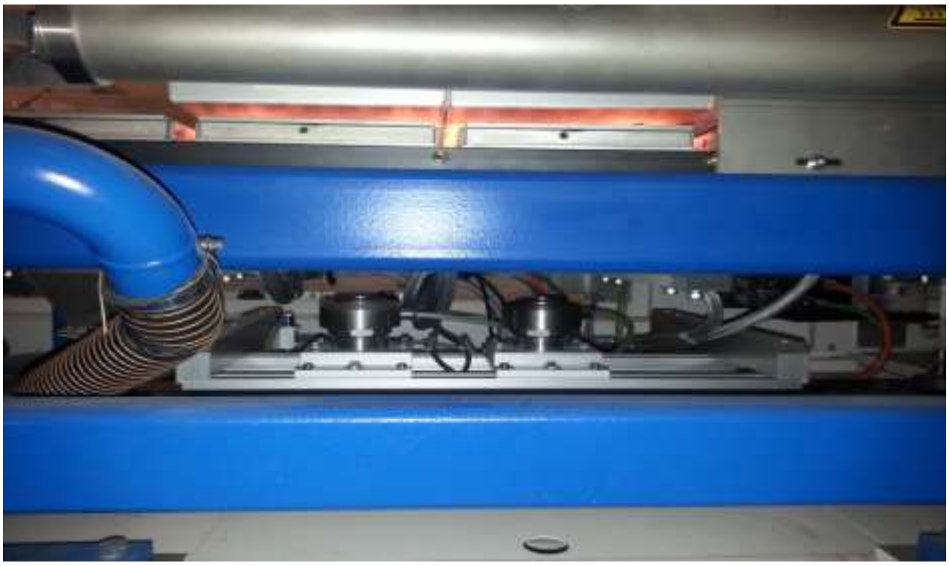

Figure 4.2.3 Cell Temperature Control [12]

4.2.3 Electrical Control of the Strings

All strings produced in Stringer are also subjected to electrical yield testing before laying-up and the use of strings in modules with low electrical power is prevented. Thus, the electrical effiency inthe generated modules is kept at maximum. [12] Electrical control of string process is shown in below

Figure 4.2.4 Electrical Control of Strings [12]

4.2.4 Eye Control of the Strings and Brazing

Visual control of alignments and brazing made by the operators during the sequencing phase. This ensures that the best string image is obtained. Eye control station is shown in below Figure 22.

Figure 4.2.5 Eye Control [12]

4.2.5 Short Circuit Test with Voltmeter

After mounting the back sheet, error formation is minimized before isolation control lamination. [12] Short circuit test process is shown in below Figure 23.

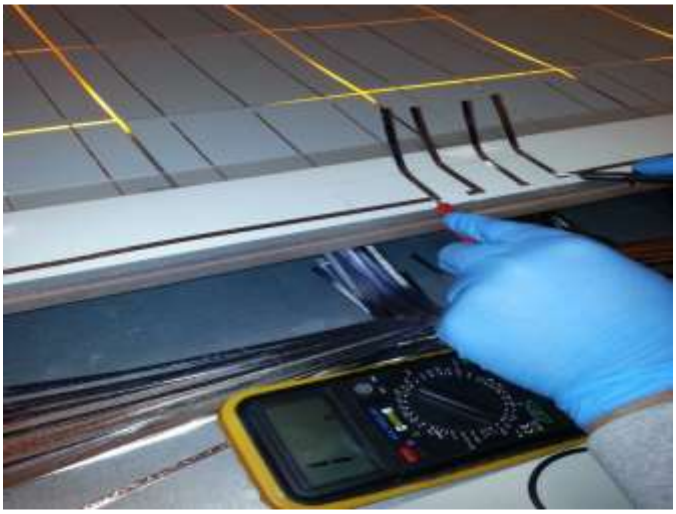

Figure 4.2.6 Short Circuit Test

4.2.6 Electro luminance Test Before Lamination

EL Test device provides control of micro fracture formations and soldering qualities of pre-lamination modules. Thus, minimum faulty product formation, maximum efficiency is ensured. [12] Electro luminance test station is shown in below Figure 24.

Figure 4.2.7 Electro luminance Test before Lamination [12]

4.2.7 Eye Control in Module Control Unit

In the module control unit, the standard measurements and visual controls of the modules are performed. The operator working on this unit also controls the errors that will occur after lamination of the solar panel from the production line. Thus, the protection of production standards is ensured. Module Control Station is shown in below Figure 25.

Figure 4.2.8 Eye Control in Module Control Station [12]

4.2.8 High Voltage (HI-POT) Test

Each module produced is subjected to a high voltage test with a duration of 5ms under 3600 volts, 50 micro amps, and insulation testing is performed. In this way, a module that will create an isolation problem in the field is separated by pre-determination. [12] High voltage test station is shown in below Figure 26.

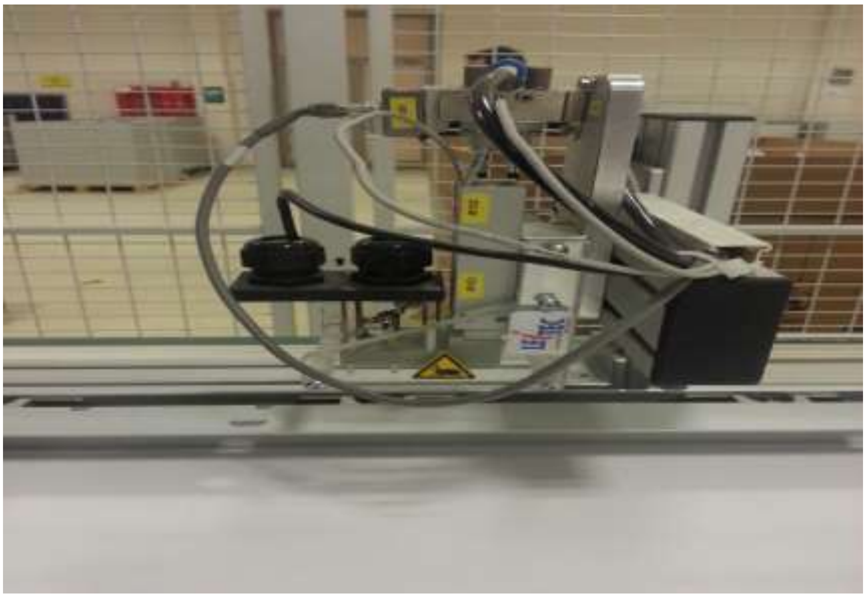

Figure 4.2.9 High Voltage Test [12]

4.2.9 Sun Simulator Test

The Power measurement standard is maintained by machine calibration every two hours. By measuring the electrical power of the module with the Sun Simulator tester, the modules (+ 5 w) are provided with a classification of tolerance. The Sun simulator is also mentioned in the test section. [12] Sun simulator Test station is shown in below Figure 27.

Figure 4.2.10 Sun Simulator Test [12]

4.2.10 Electro luminance Test of the Produced Panel

It is documented to comply with the quality standards of the panel manufactured with the Electroluminescence tester and is stored to be given to the end user with serial number. The operating principle of the Electroluminescence tester is based on the principle of giving the current from the + and – connection terminals of the photovoltaic solar panel. It creates more brightness at the points where the current is flowing correctly, the problem is that the zones are darker and the defective panel is detected. [12] Electro luminance Test of The Produced Panel is shown Figure 28.

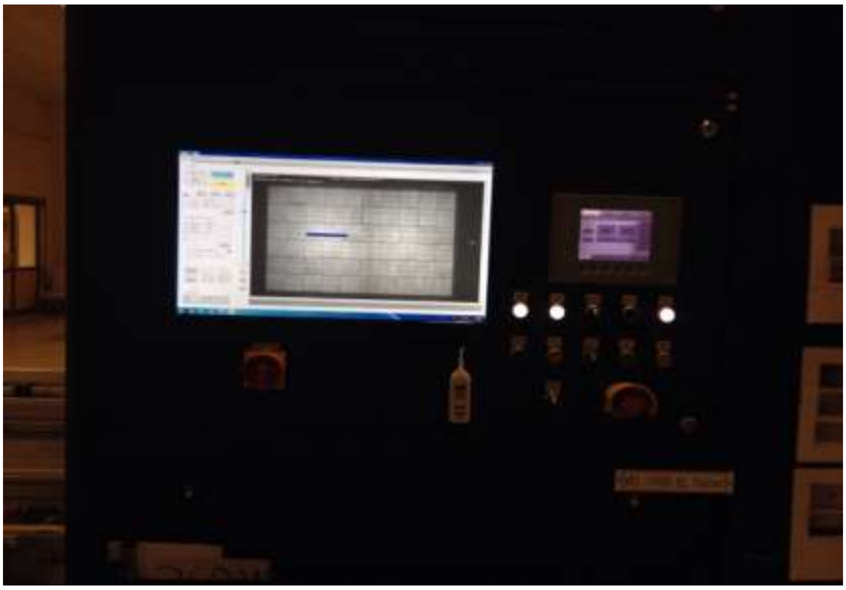

Figure 4.2.11 Electro luminance Test of The Produced Panel [12]

CHAPTER V
DESIGN AND APPLICATION OF A PROTOTYPE SOLAR TESTER WITH MEASUREMENT AND CLASSIFICATION OF SOLAR PANELS

Given today's usage, solar panels have several different application areas. These applications can be examined in two parts, mainly land type and roof type. In 2012, unlicensed electricity generation capacity in our country has been increased to 1000 kW. [15] After this unlicensed power generation regulation, the number of executions with solar panels is expected to increase rapidly and reach 2 GW value at the end of 2017.

A large part of solar energy power executions in our country are executions that sell electricity to the state and are on-grid systems integrated into the network. The input voltages of the on-grid inverters used in these systems are max. Models with 1000 VDC are widely used in practice. In system designs made with such a high input voltage, 20-23 panel arrays are out of series.

In the designed systems, it is not possible to see the electrical parametric values on the solar panels before entering the inverter by connecting 20 to 23 solar panels. In other words, it can be understood that the panels from the production plant to the project site are damaged during transport, but only when they are connected to the inverters, that is, when the plant is switched on. The idea of the emergence of a portable solar panel tester is due to the need for quality control in power plants.

5.1 Working Principle of the Solar Tester

Solar panels emerging from the production line are separated into groups by power classification in the "Solar Simulator" station on the production line and electrical parametric values on the solar panels are determined. The electrical parameters on the solar panels contains information such as maximum power, maximum current and maximum voltage that the panel will generate.

Designers or installers operate by looking at this information. In this study, we will explain the solar panel tester to test whether the label value of the produced panel is correct. In fact, with the aid of a very simple multimeter, the open circuit voltage and short circuit current of solar panels can be measured. However, it is important to measure the production value under natural conditions by measuring the solar panel under load for a longer period of time.

Our solar tester is designed according to the principle of measuring the solar panel under load and is designed to be resistant to the measurement of panels between 10W and 400W. At the ease of use, the DC voltmeter and DC ammeter test the panels by transferring them to a sufficiently large digital display. DC voltmeter, DC ammeter, LCD display is shown in below figures 30-33.

Figure 5.1.1 Solar Tester

Figure 5.1.2 DC Ammeter [16]

Figure 5.1.3 DC Voltmeter [16]

Figure 5.1.4 LCD Touch Panel [16]

5.2 Solar Testers Used in Industry

The using of solar panels have become widespread in our country, has brought together requirements such as system maintenance and fault detection. Solar panel testers sold in our country market can measure values such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum voltage under load, and maximum current (I_{mp}) of a panel or series of panels. When we examine the solar tester used nowadays, we see that such a product is not manufactured as a domestic product. The products on the market can measure current voltage such as multimeter, but they do not have a resistance to load duty. They can measure the current, voltage and power of the panel groups to which they will be measured.

5.3 Portable Solar Tester Design and Products

According to the working principle of the portable domestic solar tester, each panel must be able to accommodate a resistance that can be applied and load duty. Products used in our portable domestic solar tester consist of DC voltmeter, DC ammeter, shunt resistor series connected with DC ammeter, 4 Ohm resistor as load, a load switch connected to this resistance and a touch digital screen that is open to programming. Current and voltage information from voltmeter and amper meter provide to calculate power value the with the software applied to the back panel. Touch digital screen yazılım includes general electrical below power equation,

The panel testing process is thought to be understood by the end user. Before starting to measure the panel, it will give a more accurate test result with 22-30 degree inclination without sunshine angle. The solar panel cables are connected to the connection sockets and the open circuit voltage (V_{oc}) is measured without depending on the load of the panel. We can read this information both on the DC voltmeter and on the digital touch screen. In the second stage, the load switch is turned on and the generated electricity is allowed to flow through the resistor so that the panel can measure the maximum voltage (V_{mp}) under load and the maximum current (I_{mp}) under load. The current information obtained from the DC voltmeter and DC ammeter is transferred to the digital touch screen via the communication system. With this data transferred, the power information is calculated by the program written in the background of the digital touch screen. User interface of this is shown Chapter VI.

CHAPTER VI
PRESENTATION OF RESULTS AND DISCUSSIONS

In this section, 6 different brand panels were stationary at a 25 degree angle to the south because of Turkey is on North Pole. It was about 12 o'clock and the weather was about 25 °C. There was a steady wind and there was no negative weather condition. When performing the test, each panel was left under load for 10-15 seconds and the connections were meticulously done. Using the device's screenshot feature, the results are taken on screen and saved in the flash memory.

Figure 6.1 six pieces different brand solar panels

6.1 Results and Discussions

This test stage consists of 2 sections. In the first stage, open circuit voltage measurements were made without load. In the second section, measurements were made under load. According to this test method, 260 w solar panel were tested six different brands. The test results of these solar panels tested under same conditions are shown in the Table 6.2. However, the highest and lowest test result are shown in this section. Panel 1 has the highest test results which is shown Figure 34. Panel 6 has the lowest test results which is shown Figure 35.

Figure 6.1.1 Panel 1 Results of Measurements

Figure 6.1.2 Panel 6 results of measurements

Table 6.1 shows that the electrical values of six pieces 260 w different brands on the solar panels used for testing. Table 6.2 shows that field measurement results of different brand 260 w solar panels.

Table 6.1 Electrical parametric values on the 6 pieces different brand solar panels

PRODUCT NAME	Vmp (V)	Imp (A)	Voc(V)	Pmax (W)
PANEL 1	30.03	8.58	37.70	260.00
PANEL 2	30.51	8.53	37.65	260.00
PANEL 3	31.10	8.38	38.10	260.00
PANEL 4	30.06	8.50	38.20	260.00
PANEL 5	29.08	8.39	37.06	250.00
PANEL 6	30.06	8.17	36.30	250.00

Table 6.2 Field measurement results of different Brand 260 W Solar Panels

PRODUCT NAME	Vmp (V)	Imp (A)	Voc(V)	Pmax (W)	Deviation of Given Standart Value by Producer (%)
PANEL 1	27.5± 0,13V	8.51± 0,04 A	34.48± 0,17 V	235.4± 0,17 W	**9.44**
PANEL 2	27.51± 0,13V	8.47± 0,04 A	34.52± 0,17V	231.00± 0,17 W	**11.15**
PANEL 3	27.40± 0,13V	8.42± 0,04 A	34.27± 0,17V	230.16± 0,17 W	**11.48**
PANEL 4	27.28± 0,13V	8.37± 0,04 A	34.39± 0,17V	225.76± 0,17 W	**13.17**
PANEL 5	26.63± 0,13V	8.17± 0,04 A	34.27± 0,17V	215.46± 0,17 W	**13.82**
PANEL 6	25.54± 0,12V	7.51± 0,03 A	33.15± 0,17V	198.90± 0,15 W	**20.44**

6.3 Calculation of Measurement Tolerance

As it is a physical measurement, the devices used in the measurement stage necessarily have a margin of error.

In this section, we calculated the error margin of the measurements we made using solar tester.

The universal electrical power formula is as follows,

$P = V \ x \ I$ (1)

Where, P is power, V is voltage and, I is current.

The Uncertainty Test Formula for the measurements of the panels, one can obtain the Uncertainty of Power Measurements,

$$\Delta P = \sqrt{\left(\frac{dP}{dV} \ x \ \Delta\right)^2 \ x \ + \left(\frac{dP}{dI} \ (\Delta V)\right)^2} \quad . \quad [11]$$

with the help of the formulation (1),

$$(\frac{dP}{dV}) = I$$

$$(\frac{dP}{dI}) = V$$

Then,

$$\Delta P = \sqrt{(I)^2 \ x \ (\Delta V)^2 \ + (V)^2 \ x \ (\Delta I)^2}.$$

For the current and the voltage values from any experimental measurement, say;

$I = 8{,}51 \ A$

$V = 27{,}54 \ V$

P =234,365 watt

If the measurement uncertainties of the devices are

$\Delta I = \%0.5$ A

$\Delta V = \%0.5$ V

Then the uncertainty in the power could be found as,

$\Delta P = 0{,}1775\ Watt$

Then the percentage error in the power measurements is

$\left(\frac{\Delta P}{P}\right) = \pm\%\ 0{,}0757$

CHAPTER VII
CONCLUSION AND RECOMMENDATIONS

The solar tester developed, in the present used allowed to test six different brand 260 w solar panels under the same conditions were tested under load via tester device. Whether or not the resulting values are the same as the electrical parametric values on the solar panels were compared and presented in tabular form. Then, the difference between each of panel and the output values under load was determined. All of these data are tabulated and calculated as to how much power difference they have. Loss of 9.44% for Panel 1 can have many causes. A significant loss was observed from the air temperature. At the time of measurement, if the air temperature is 35 degrees, it exceeds 25 degrees by 10 degrees and a power loss of approximately 4% is considered. [18] The remaining 4.4% loss can be thought to be caused by electrical conversion losses and pollution negativity. According to the seasonal and environmental conditions on March 21, this solar panel normally produces electricity. The other 5 pieces solar panel are up % 20, more than % 10. Losses up to approx. 10% may be caused by environmental conditions such as temperature, humidity, pollution. However, higher losses can be caused by defects in raw material quality and production.

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