REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

# EXPERIMENTAL INVESTIGATION OF A NOVEL HYBRID ROTARY ENERGY SYSTEM

ABDURRAHMAN YAVUZDEĞER

MASTER OF SCIENCE

ADANA 2020

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SUPERVISOR

Asst. Prof. Dr. FIRAT EKINCI

ADANA 2020

I hereby declare that all information in this thesis 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 information that is not original to this work.

[Signature]

Abdurrahman YAVUZDEĞER

# ABSTRACT


## EXPERIMENTAL INVESTIGATION OF A NOVEL HYBRID ROTARY ENERGY SYSTEM



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August 2020, 100 pages



Energy demand has increased with the rapid growth in technological developments in recent years. A number of applications in renewable energy has increased significantly today instead of non-renewable energy. The main purpose of present study is to increase efficiency of energy in renewable energy. In the thesis, a novel rotary energy system is presented. In the proposed system, a hybrid system whose energy is derived from solar and wind energy is envisaged. A prototype for novel rotary energy system has been designed and manufactured. The designing, manufacturing, installation and output power prediction for the prototype are explained in detail. Some parts of the prototype are manufactured by a 3D printer. Energy has been produced in solar panels for the prototype. The prototype has been tested at different rotation speeds to evaluate effect of wind energy. The dimensions of solar panel are 140x60x2.5 mm. Ten solar panels are mounted on the prototype. The electrical properties for panel are 6V and 100 mA. The output power prediction based on Feedforward Neural Network (FFNN) and Particle Swarm Optimization trained Feedforward Neural Network (PSO-FFNN) are performed for the FFNN architecture, the RMSE, MAPE and TIC values are calculated as 0.0690, 0.0455 and 0.0278, respectively. For the PSO-FFNN architecture, RMSE, MAPE and TIC values are 0.0530, 0.0383, and 0.0213, respectively. The proposed novel rotary system is intended to be installed in place high solar and wind energy potential. According to the results, it has been proved that it will be produced energy more effectively with a hybrid rotary system consisting of photovoltaic and wind turbines in meeting the energy needs in place high energy potential.



**Keywords:** Renewable energy, hybrid energy system, rotary energy system, output power prediction, building integrated energy systems, artificial intelligence

# ÖZET

## YENİ BİR HİBRİT DÖNER ENERJİ SİSTEMİNİN DENEYSEL İNCELENMESİ

Abdurrahman YAVUZDEĞER
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Ağustos 2020, 100 sayfa

Son yıllarda teknolojik gelişmelerdeki hızlı büyüme ile enerji talebi artmış durumdadır. Günümüzde yenilenemeyen enerjinin yerine yenilenebilir enerjideki uygulamaların sayısı önemli ölçüde çoğalmıştır. Bu çalışmanın temel amacı yenilenebilir enerjide enerji verimliliğini artırmaktır. Tezde yeni bir döner enerji sistemi sunulmuştur. Önerilen sistemde güneş ve rüzgar enerjisinden enerji elde eden hibrit bir sistem öngörülmektedir. Yeni döner enerji sistemi için bir prototip tasarlanmıştır ve imalatı gerçekleştirilmiştir. Prototipin tasarımı, imalatı, montajı ve çıkış gücü tahmini detaylı olarak açıklanmıştır. Prototipin bazı parçalarının imalatı 3D yazıcı tarafından yapılmıştır. Prototip için enerji güneş panellerinden üretilmiştir. Prototip, rüzgar enerjisinin etkisini değerlendirmek için farklı dönüş hızlarında test edilmiştir. Güneş panelinin ölçüleri 140x60x2.5 mm'dir. On adet güneş paneli prototipe monte edilmiştir. Panelin elektriksel özellikleri 6V ve 100 mA'dir. İleri Beslemeli Sinir Ağı (IBSA) ve Parçacık Sürüsü Optimizasyonu eğitimli İleri Beslemeli Sinir Ağı'na (PSO-IBSA) dayanan çıktı gücü tahmini gerçekleştirilmiştir. IBSA mimarisi için RMSE, MAPE ve TIC değerleri sırasıyla 0,0690, 0,0455 ve 0,0278 olarak hesaplanmıştır. PSO-IBSA mimarisi için RMSE, MAPE ve TIC değerleri sırasıyla 0,0530, 0,0383 ve 0,0213'tür. Önerilen yeni döner sistemin güneş ve rüzgar enerji potansiyeli yüksek yerlere kurulması amaçlanmıştır. Elde edilen sonuçlara göre, yüksek enerji potansiyeli olan yerlerde enerji ihtiyacının karşılanmasında fotovoltaik ve rüzgar türbinlerinden oluşan hibrit döner sistem ile enerjinin daha verimli üretileceği kanıtlanmıştır.

**Anahtar Kelimeler:** Yenilenebilir enerji, hibrit enerji sistemi, döner enerji sistemi, güç tahmini, güneş enerjisi, binaya entegre enerji sistemleri, yapay zeka

*Dedication*

*I would like to dedicate my thesis to my family.*

# ACKNOWLEDGEMENTS

In the preparation of this thesis, I would like to thank my esteemed adviser Asst. Prof. Dr. Fırat EKİNCİ who has always been exemplary of her knowledge, business approach, skills and a broad perspective.

I would also like to thank my committee members, Asst. Prof. Dr. Tuğçe DEMİRDELEN, Prof. Dr. Mehmet BİLGİLİ for letting my defense be an enjoyable moment, and for their brilliant comments and suggestions.

I would like to thank Res. Asst. İnayet Özge AKSU, Res. Asst. Burak ESENBOĞA, Res. Asst. Hüseyin NAZLIGÜL and Res. Asst. Kemal AYGÜL for their valuable discussion and technical help.

Finally, I owe a debt of gratitude to my father Süleyman YAVUZDEĞER for his all manner of support, to my mother Sevinç YAVUZDEĞER for her prayers and spiritual support and to my brother Ahmet YAVUZDEĞER who always providing me with unfailing support throughout my years of study. I would like to thank my dear wife Mrs. Harika YANADUR YAVUZDEĞER who has motivated me with patience, understanding and support.

This thesis was financially supported by Adana Alparslan Türkeş Science and Technology University Scientific Research Projects with project number of 19103006.

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# NOMENCLATURE

| | |
|---|---|
| FFNN | : Feedforward Neural Network |
| PSO | : Particle Swarm Optimization |
| PSO-FFNN | : Particle Swarm Optimization trained Feedforward Neural Network |
| RMSE | : Root Mean Square Error |
| MAPE | : Mean Absolute Percentage Error |
| TIC | : Theil’s Inequality Coefficient |
| MAE | : Mean Absolute Error |
| MPPT | : Maximum Power Point Tracking |
| PV | : Photovoltaic |
| P&O | : Perturb and Observe |
| IC | : Incremental Conductance |
| BOA | : Butterfly Optimization Algorithm |
| GWO | : Gray Wolf Optimization |
| GSA | : Gravitational Search Algorithm |
| HOMER | : Hypergeometric Optimization of Motif Enrichment |
| Rpm | : Revolutions Per Minute |
| FFA | : Firefly Algorithm |
| SVMs | : Support Vector Machines |
| ANN | : Artificial Neural Network |
| AI | : Artificial Intelligence |
| GP | : Genetic Programming |
| GA | : Genetic Algorithm |
| WNN | : Wavelet Neural Network |
| ENN | : Elman Neural Network |
| PCA | : Principal Component Analysis |
| ARMA | : Auto Regressive Moving Average |
| DNN-MRT | : Deep Neural Network based Meta Regression and Transfer |

| | |
|---|---|
| ANFIS | : Adaptive Neuro Fuzzy Inference System |
| EELM | : Extreme Learning Machine Expanded |
| SVR | : Support Vector Regression |
| CFD | : Computational Fluid Dynamics |
| LSTM | : Long Short Term Memory |
| DNN | : Deep Neural Network |
| AC | : Alternative Current |
| DC | : Direct Current |
| LMPP | : Local Maximum Power Point |
| GMPP | : Global Maximum Power Point |
| BRANN | : Bayesian Regularized Neural Network |
| SOM | : Self Organizing Maps |
| GaAs | : Gallium Arsenide |
| CdTe | : Cadmium Telluride |

# 1. INTRODUCTION

Energy is an indispensable phenomenon to sustain human life safely and comfortably. The dependency and need of people for energy are clearly observed in every aspect of our lives. Besides, the dependency increases day by day with the developments in technology. Energy means almost the same as oxygen to survive for human. The more energy supply is evaluated as an advanced indicator for the countries. Today, there are many different ways to meet energy needs with new technological developments. While the use of fossil resources has started to decrease, the use of renewable energy resources has increased. The energy source can be categorized into two groups as renewable energy sources and non-renewable energy sources. Fossil fuels are known as non-renewable energy sources. Examples of non-renewable energy sources are Coal, Oil, Natural Gas, Uranium and Thorium. The energy sources used today are as shown in Figure 1.1 (Panwar, Kaushik and Kothari, 2011).

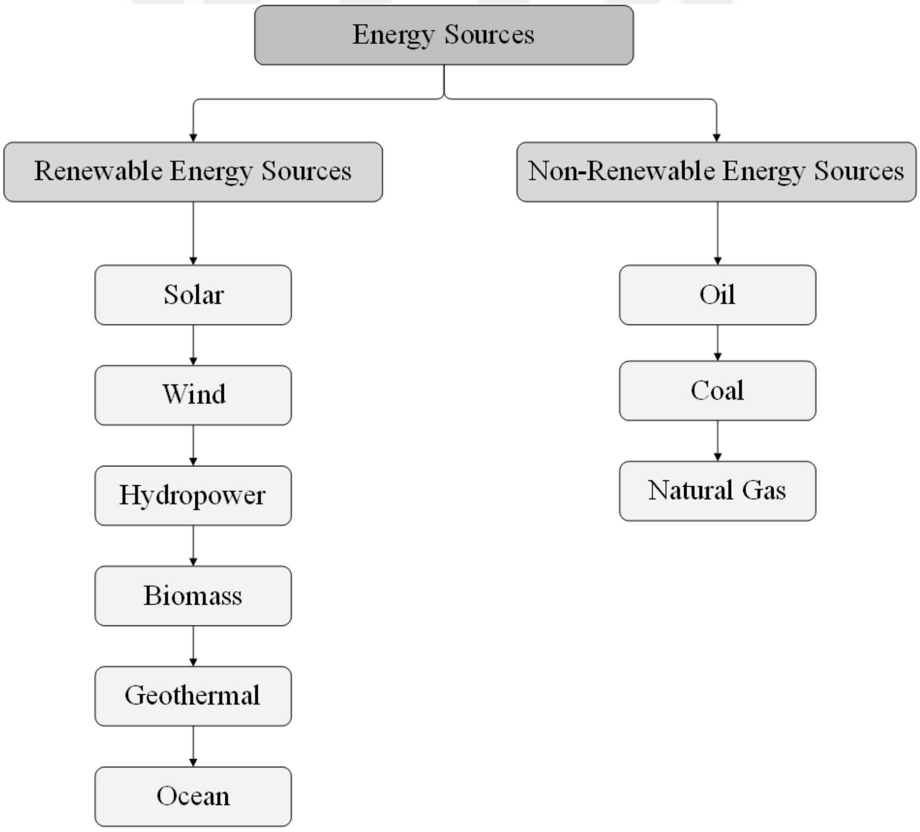


**Figure 1.1.** Renewable and non-renewable energy sources.

The coal is a product that occurs as a result of degradation of plant and animal residues under the influence of temperature and under high pressure. It has been observed that microorganisms in environment are effective for Coal. Today, Coal is used in electrical power generation, thermal power plants, iron and steel industry and cement manufacturing, steam production, chemical production and heating. In the application areas of Coal, it is observed that it is mostly used in the production of electrical energy.

One of the non-renewable energy sources is Natural gas. The formation of Natural gas is similar to Coal. Natural gas is formed when the organisms that died millions of years ago sink into the bottom of the ocean and are covered with other layers, and the residues turn into gas as a result of exposure to high pressure and heat. Natural gas is located under the rocks. Considering the content of natural gas, it consists of approximately 90% methane ($CH_4$) and a small amount of other hydrocarbon gases. Today, it is used for Natural gas heating purposes, in factories in different applications, as fuel for different types of engines and for electricity production.

One of the non-renewable energy sources is Oil source. The formation process in petroleum is similar to Natural gas and Coal. Only the physical state of resulting product is different from the others. When looking at the content of Oil, it consists of a mixture of various hydrocarbons. These components include paraffins, naphthenes and aromatic hydrocarbons. Generally, Oil consists of approximately 30% Paraffins, 40% Naphthenes, 25% Aromatic hydrocarbons. The remaining small from 5% are Oxygen, Nitrogen and Sulfur compounds. The usable of Crude oil is limited today. Today, as a result of the processing of Petroleum, products such as gasoline, fuel oil, diesel oil, lipid petroleum gas, jet fuel and asphalt are emerging. However, as a result of processing Oil, nearly 80 thousand processed products are obtained. The products are used in transportation and energy sector in most.

Non-renewable energy sources have advantages and disadvantages. Considering Coal as an energy source, it can be extracted and used from wherever there is a reserve. When Coal is used in power plants, energy can be produced without fluctuation in energy production. And also, it is a reliable energy source. It generates high income for the producer financially after the crude oil is processed. Processed oil is one of the most valuable resources in the world. Natural Gas stands out as a cleaner energy source for the environment compared to fossil fuels. After the combustion of Natural Gas, only products such as carbon dioxide and water vapor emerge. On the other hand, non-renewable energy sources also have some disadvantages. Considering that Coal is extracted from the mine, mining is one of the riskiest and dangerous sectors in terms of occupational safety. Moreover, miners are constantly exposed to toxic dust due to their environment. As burning coal occurs, many toxic gases are released into the atmosphere. Thus, air pollution increases. Likewise, burning oil causes air pollution. During oil drilling works carried out in the seas, oil can leak into the water. As increase pollution on the sea, pollution threatens the life of sea creatures emerges. Large rocks need to be broken to obtain Natural Gas. So, it can cause mini earthquakes.

Non-renewable energy resources have a limited reserve in the world and use of these energy resources has been increasing. This will pose serious problems in future regarding energy production and use. As a result of this situation, these resources are rapidly depleting. As the tendency towards fossil fuels increases, situations arise that negatively affect the life of all living things. Pollutions in soil, air, sound and water can be shown as examples. In addition, global warming has become inevitable with increasing carbon dioxide emissions.

The Carbon Dioxide concentration in the atmosphere has increased considerably. Climate changes, acid rains, change of seasons are clear indications for pollution. To overcome such negative situations, studies on alternative energy sources should be intensified. The interest in energy resources needs to be increased. Environmentally energy systems should be installed by expanding use of renewable energy sources. Examples of renewable energy sources are solar energy, wind energy, geothermal energy, wave energy, hydroelectric energy and biomass energy, ocean energy. As increasing in usage of renewable energy, the minimum environmental damage occurs. Renewable energy has many following advantages:

- It allows the use of electricity for rural areas where electricity cannot reach.
- It decreases the foreign dependency of the countries.
- Damage to the environment is reduced by decreasing fossil fuel use.
- It provides new employment opportunities.
- It provides sustainable energy since there is no limited reserve amount.

Solar energy is formed by converting the sunlight coming to the world into electrical energy by using semiconductor technology in solar panels. Thus, solar energy technology a high-cost technology is being installed at affordable costs with the increase of investors and manufacturers. Solar energy is widely used in rural areas, electric vehicle technology and hybrid energy systems.

Wind energy is the conversion of the wind, which arises from pressure difference between the lands and the seas and the rotational movement of the world into an energy form. Thanks to technological advances in wind energy, wind power can be predicted with high accuracy and maximum efficiency is obtained from wind energy. The technological developments also help determine the installation locations of wind fields. In addition, hybrid energy systems are created by integrating wind energy systems into solar energy systems.

Hydroelectric energy is a form of energy obtained by using the flow power of water. As a result of the turbine rotating in hydroelectric power plants with the rapid flow of water, electrical energy is obtained. Global warming is prevented by not emitting greenhouse gases during this energy conversion. Hydroelectric power plants, especially regions where the slope is high, are suitable for electricity production with high flow rate. Because the flow power determines the amount of energy to can be obtained. Moreover, this system benefits many regions where power plants are established thanks to its advantages such as providing water to settlements or irrigation of agricultural lands.

Geothermal energy is the conversion of hot water, vapors and gases that contain chemicals, formed by the heat accumulated in various depths of the earth's crust, into an energy form. Geothermal energy is used directly or indirectly. Geothermal energy is used as a renewable energy source in different application fields such as heating, cooling, electricity generation and mineral production. In addition, this type of energy is integrated into the tourism sector with hot springs. In our country, geothermal energy is generally used for tourism purposes as well as electrical energy production. Turbines are rotated by hot water steam generated by hot water from geothermal springs. And so mechanical energy is converted into electrical energy.

Biomass energy is the form of energy obtained by passing the substances of vegetable and animal origin through various processes. Today, fuels such as biogas, biodiesel and bioethanol are obtained using biomass energy sources. Although biomass energy potential is very much in Turkey is underutilized from this energy source. However, recently, public and private investments have started to increase in this technology area using waste garbage. In addition, biomass energy has been experimentally observed that it can be obtained from all kinds of organic waste, plants, herbs, algae and algae. Apart from biomass energy production, building materials are used for recycled paper and plastic production.

The Ocean energy applications among renewable energy sources is observed more widely in recently. The oceans can be a promising renewable energy source for the future. Energy is produced by making use of physical events such as waves and tides in the oceans. It is not a widely used technology in the world. Before the ocean energy systems are installed, how the coastal ecology will be affected by the shipping industry and fisheries should be examined seriously. But in the future, Ocean energy will become popular, such as wind power and solar power, and maybe an alternative source of energy.

For energy to be sustainable, it is necessary to utilize its existing resources with maximum efficiency and to develop new energy systems. By using more than one energy source in the same system, hybrid energy systems are used for different applications. Also, for a cleaner environment and safer future, renewable energy systems need to be integrated more into our lives.

### 1.1. The objective of the thesis

The main aim of this study is to present an effective hybrid rotary energy system in places high solar and wind energy potential. To demonstrate applicability of the proposed system, an integrated system for high-rise buildings was designed and manufactured. For this purpose, a novel rotary hybrid energy system that can be integrated into high buildings due to high solar and wind energy potential has been examined in this study. A prototype has been manufactured and the applicability of novel rotary system has been proved thanks to obtained data. The experimental studies have been carried out under different climatic conditions. Output energy prediction was performed after the experimental studies were completed. For the prediction, Feedforward neural network (FFNN) and PSO trained feedforward neural network (PSO-FFNN) are used. Output power prediction accuracy is increased with PSO-FFNN architecture. The efficiency of proposed system was revealed with power curves. The industrial use of proposed new type hybrid system has been paved and the necessary information has been obtained to transform it into a product with the obtained data.

## 1.2. The outline of the thesis

In parts of the thesis, an overview of the sections and content of the thesis has been realized. The solar energy and its applications have been more popular in renewable energy sources. Firstly, studies on solar energy have been investigated in the literature section. Working principles and setups of different types of solar energy systems have been evaluated. Comprehensive information about photovoltaic applications is given in the materials and methods. Important topics such as the structure and history of photovoltaic panels, photovoltaic cell types and its problems encountered in solar energy are presented in detail. In addition, information was given in development process of artificial intelligence (AI) technology, AI applications in edible energy systems and artificial neural network types. The design of the prototype in the last part of the materials and methods section is presented. An experimental procedure is described in the results and discussions section. Then, the power prediction based on FFNN and PSO-FFNN for the proposed rotary system was performed.

# 2. LITERATURE REVIEW

Energy demand has become an important criterion for measuring the level of development of countries. Because producing energy will significantly reduce the foreign dependency of countries. Alternative energy sources have emerged to obtain energy. In addition, various studies have been carried out to improve the performances of these energy sources. Among the renewable energy sources, solar energy and wind energy have become the most used. In general, wind energy systems are installed in regions with high wind energy potential, and solar energy systems are installed in regions with high solar energy potential. In regions with high wind and solar energy potential, energy is obtained from hybrid energy systems. Many research and development studies have been carried out on solar and wind energy systems. The fluctuations of energy production in renewable energy can be mostly occurred in one day. In order to eliminate this problem studies focusing on subjects such as Maximum Power Point Tracking (MPPT), solar and wind power prediction are seen in literature. Furthermore, solar radiation estimation, cost analysis and optimization algorithms has been working on among the most studied topics. The main purpose of these studies is to increase the energy efficiency from solar and wind energy systems. In recent years, studies on solar and wind energy in the literature are presented in detail below.

An experimental study on energy production with maximum efficiency under moving partial shading conditions of a 250 W photovoltaic (PV) system installed on a train was carried out. Step Up Gain Converter structure is proposed for this photovoltaic system. The effect of the proposed control algorithm and the traditional Perturb and Observe (P&O) algorithm on the output power of the PV panel is presented comparatively. The results obtained provide high gain with the proposed transducer and quickly track maximum power point in moving partial shading conditions (Raizada and Verma, 2018).

The maximum power point monitoring techniques used to maximize the energy obtained from the PV panels are presented comparatively from different criteria. The performances of different algorithms were observed under different solar radiation using MATLAB/SIMULINK. It was also carried out in cost analysis for MPPT applications. Two algorithms have been proposed, the best performing P&O methods the Incremental Conductance (IC) Faranda and Leva (2008).

Four different algorithms that Butterfly Optimization Algorithm (BOA), Particle Swarm Optimization (PSO), Gray Wolf Optimization (GWO) and Gravitational Search Algorithm (GSA) based on MPPT have been proposed for the photovoltaic energy system under partial shading. simulations studies of these algorithms carried out comparative by using MATLAB/SIMULINK. It is observed that BOA is obtained better-tracking speed than other algorithms (Aygul et al., 2019).

A hybrid energy system was created by using solar energy and wind energy, one of the renewable energy sources. For the hybrid energy system at maximum efficiency, an MPPT controller has been designed. Thus, the power quality problem caused by ambient conditions and loading conditions is minimized. Simulation results obtained from MATLAB software and the effects of the designed controller on the hybrid energy system are presented in detail (Sharma, Singh and Sinha, 2018).

The need for electrical energy is quite high in urban rail systems. Providing the energy required for these systems from renewable energy sources can be minimized the dependence on fossil fuels. It is proposed to supply the necessary energy from solar energy in interior lighting in the urban metro in Istanbul. Simulation studies were carried out for this system using Hypergeometric Optimization of Motif Enrichment (HOMER) software. Its contribution to energy efficiency is explained by using LED lighting systems instead of fluorescent lamps (Kılıc and Dursun, 2017).

In order to utilize solar energy with maximum efficiency, performance results of ten different maximum power point monitoring algorithms are compared and presented in detail. In addition, it is explained that solar energy is an indispensable energy source for our future. The optimized P&O and IC algorithms are clearly observed in terms of their cost and performance. Also, MPPT systems are compared in terms of cost (Faranda, Leva and Maugeri, 2008).

In China, use of a photovoltaic energy system and an energy storage method are provided as an auxiliary power source to meet the energy needs of a passenger train. The installation of solar panels on the train and the control of this auxiliary power system are examined in detail. Energy-saving and emission reduction are clearly observed with the proposed system (Wei et al., 2016).

Successful integration of the photovoltaic energy system and the swirling wind turbine energy system has been achieved. The vertical axis wind turbine used in this new energy system has a helical three-blade. Performance results of helical blade models with six different twist angle angles were observed. According to the analysis results obtained, the proposed system has 69% efficiency and the optimum rotational speed range has 67 kW output power at 30-34 revolutions per minute (rpm). In addition, the proposed system is presented to be more economical than the single PV energy system. (He et al., 2019).

The efficiency of the turbine's output power has been increased by integrating the design called Omni-direction-guide-vane into a vertical axis wind turbine. Thanks to the designed structure, it is observed that it works more during the day by producing energy even at low wind speed. Using the Omni-direction-guide-vane design, the torque output of the NACA 0015 airfoil used in the vertical axis wind turbine has been observed to increase approximately by 58% and 39% respectively at TSR = 2.5 and TSR = 5.1 (Chong et al., 2013).

Using the Angstroms linear approach and artificial neural network model, solar radiation estimation has been made in the solar energy system. These two estimation models are presented comparatively with graphics. Three different analyzes were carried out for the Angstroms linear approach model. Seven different analyzes were carried out for the artificial neural network model. The solar radiation estimation results obtained from artificial neural network models in times of low solar radiation are more accurate than the angstroms linear approach. The RMSE of the artificial neural network model with the best performance among the proposed prediction models is 5.67% (Tymvios et al., 2005).

Using the sun's duration (sunhine duration), maximum temperature and minimum temperature data as input data, solar radiation prediction based on Firefly Algorithm (FFA) was performed. With this algorithm, a new method has been developed by integrating Support Vector Machines (SVMs). Performance analysis results of the proposed method are presented in comparison with Artificial Neural Network (ANN) and Genetic Programming (GP) models. The proposed system has been observed to give more accurate estimates than other models (Olatomiwa et al., 2015).

An artificial neural network model has been developed to use daily diffuse solar radiation with the data obtained from nine different locations in China. Thanks to the proposed ANN model, it will be possible to estimate solar radiation in places where there are no monitoring stations. It has been observed that the solar radiation prediction results are estimated with 98.81% accuracy compared to the actual data (Jiang, 2008).

In recent years, when different input parameters such as temperature, relative humidity, wind speed and solar time are used, studies on solar radiation prediction have been presented in detail. The important role of solar radiation prediction in solar energy system designs has been emphasized. According to traditional approaches, it has been observed that more accurate results are obtained with ANN based solar radiation estimates (Meenal and Selvakumar, 2017).

Solar radiation estimation based on Wavelet Neural Networks and Artificial Neural Networks has been performed to obtain maximum efficiency from solar energy systems. A detailed and comparative analysis was made for these two prediction models. Different combinations have been tried to increase the accuracy of the proposed prediction model. According to the data obtained from the simulation results, the solar radiation prediction model consisting of Wavelet Neural Network (WNN) and ANN combination has been proposed (Alluhaidah, Aly and El-Hawary, 2019).

Comprehensive information about solar energy and its application areas is described in detail. The importance of solar radiation prediction and solar tracking systems are clearly stated to provide maximum efficiency from solar energy. Different application areas of solar energy are presented using these systems. It was discussed how to follow these practices. Microprocessor-based and electro-optic sensor-based prediction systems are recommended to provide optimum energy production in photovoltaic application areas (Loschi et al., 2015).

Wind energy power prediction is widely used in wind energy applications. Prediction models are using different topologies for use in wind energy applications. With the data obtained from onshore and offshore wind farms, comparative performance analysis results of different estimation models are presented (Madsen et al., 2005).

In short term estimation for wind energy, Elman neural network (ENN) model has been created for wind speed. Also, it is used together to increase the accuracy of ENN and principal component analysis (PCA) estimation. The accuracy of this prediction model is demonstrated by experimental results. Three different prediction models have been applied to provide high accuracy in short term prediction. It has been observed that the proposed PCA-Elman prediction model has the best performance among the three models in predicting wind power (Yin et al., 2015).

With the data obtained from the wind power plant in Crete, Greece, Kalman filtering method is used to estimate in wind speed. This filtering system provides more useful input data to the prediction model. Thus, it is observed that it significantly improved the accuracy rate in wind speed prediction. The advantages, application areas and reliability of the proposed method are presented comprehensively (Louka et al., 2008).

Solar radiation estimation is made with solar energy data obtained from different locations and eleven statistical models. In order to increase the reliability of the results to be obtained, regions with high meteorological variability, medium and low regions were selected. According to the results of the performance analysis, Auto regressive moving average (ARMA) gives good results when the cloudiness rate is low. However, in cases where the cloudiness rate is high, the regression tree based on the bagging mode is the most reliable (Fouilloy et al., 2018).

To integrate wind energy systems into the electricity network, a highly reliable estimation method is required. While estimating the proposed estimation method, it is requested to estimate in a short time and with reasonable error rate. An estimation method based on the combination of decision trees and SVMs algorithms has been proposed for a high accuracy wind energy estimate. With the proposed estimation method, 37% estimation improvement has been achieved (Heinermann and Kramer, 2016).

In order to realize a high accuracy wind energy estimate, a data estimation method based on Deep Neural Network-based Meta-Regression and Transfer learning (DNN-MRT) has been proposed. The performance analysis results of this proposed method are carried out for five different wind farms. Also, the superiority of DNN-MRT based wind energy estimation technique is presented (Qureshi et al., 2017).

A study is conducted to improve the accuracy of solar radiation prediction based on the adaptive neuro-fuzzy inference system (ANFIS). The data required for solar radiation prediction are obtained from a meteorological station established in Nigeria. The performance of the estimation method studied is observed with simulation results. RMSE in the training phase and the testing phase are 1.0854 and 1.7585 respectively (Olatomiwa et al., 2015).

MPPT control techniques are used to improve the efficiency of photovoltaic energy systems. A comprehensive study is carried out on these control techniques, which are widely used today. The performances of different MPPT techniques are presented comparatively. To obtain the highest energy from the photovoltaic energy system, nine methods have been applied and Beta method with the highest overall performance has been proposed. The tracking factor ratio of the beta method is 98.8 percent (Eltawil and Zhao, 2013).

Solar radiation prediction and MPPT algorithm techniques are performed on photovoltaic energy systems in microgrid applications under different meteorological weather conditions. The effects of dustiness and solar radiation arrival angle on the performance of photovoltaic energy systems are investigated. Under these conditions, it is observed that the system performance is improved by the improved P&O MPPT algorithm (Abo-Al-Ez et al., 2020).

The high accuracy rate of the solar power forecast topology based on the proposed Expanded Extreme Learning Machine (EELM) is presented in detail in a short time. The proposed EELM estimation method has been evaluated based on parameters such as Mean Absolute Error (MAE), symmetric mean absolute percentage error and RMSE. Effective use and management of energy has been provided with this proposed estimation method (Mishra et al., 2020).

MPPT technique based on P&O was used to charge the battery with maximum efficiency from a photovoltaic panel. Since the ambient temperature and solar radiation values are not very variable, the P&O algorithm has been proposed. The proposed solar system design and the experimental data obtained are presented in detail. According to the data obtained from the experimental analysis, it is observed that the photovoltaic panel charged the battery faster by using the proposed MPPT technique (Hiwale, Patil and Vinchurkar, 2014).

A solar energy prediction method based on meteorological data obtained from 28 different regions in Malaysia and ANN is presented. For the proposed estimation method, data from 23 regions were used to train the network. Data from five regions were used to test the network. The MAPE has been observed to be reduced compared to the improved prediction method compared to traditional models (Khatib et al., 2012).

Today, it is very important to observe MPPT techniques commonly used in photovoltaic energy systems under very variable weather conditions. An experimental solar emulator is designed to observe the efficiency and performance efficiency of MPPT algorithms. Thanks to the designed solar emulator, the spectral distribution of sunlight is imitated very closely (Kuisis et al., 2020).

Maximum power point monitoring methods based on P&O, IC, Fractional Open Circuit Voltage algorithms for solar charge controller applications are examined in detail. Simulation studies using these algorithms are carried out with the buck converter using MATLAB software. According to simulation results, the Incremental conductance MPPT algorithm has 97% efficiency and overrides the other two methods (Atri, Modi and Gujar, 2020).

The design and performance analysis results of a new energy system consisting of rotational photovoltaic panels are performed. The availability of this system has been observed in supplying the energy need for buildings. The efficiency of the proposed new design photovoltaic system under different artificial light has been tested. (Artificial light type). Among the seven different artificial lights, Metal Halide Lamp has artificial light that increases the efficiency of the proposed system the most. High-pressure sodium lamp has the lowest artificial light performance in obtaining energy from the proposed system (Bagheritabar et al., 2018).

For solar energy system designed for electric vehicles, a modified IC MPPT topology is presented to achieve maximum efficiency under fast-changing meteorological conditions. The rapid change of solar radiation in photovoltaic panels integrated on the electric vehicle posed a challenge for the developed algorithm. However, with the developed IC algorithm, it is provided to charge the battery connected to the electric vehicle with maximum efficiency. In addition, the boost converter parameters used are presented such as switching frequency, input capacitance, load resistance, output capacitance, the series resistance of inductor and Inductance (Bhattacharya and Samanta, 2019).

In solar applications, the energy obtained in partial shading situations of photovoltaic panels is severely affected negatively. Various methods are offered to overcome this situation. An MPPT method based on the flower pollination optimization algorithm is performed for 100 kW photovoltaic panels under different shading conditions. The performance results of the proposed system are obtained using MATLAB/SIMULINK software. According to the results obtained, the fast response of the proposed method is observed (Elbehairy et al., 2019).

The advantages and disadvantages of solar energy compared to fossil fuels are discussed extensively. Problems encountered in solar energy applications and their solutions are presented. It is carried out experimentally and simulation in Proteus software on the use of energy obtained from photovoltaic panels with optimum efficiency and charging to the battery (Pathare et al., 2017).

As a disadvantage of solar and wind energy, it is observed that the output power is unbalanced and, in some applications, high installation and system cost. Using a Genetic Algorithm (GA) for a hybrid energy system consisting of solar and wind energy, the optimum numbers of panels, numbers of wind turbines and battery are determined. In addition, two different situations are observed with simulation results to perform a cost analysis with the proposed optimization method (Senjyu et al., 2006).

Scientific studies are carried out on many different parameters to improve the performance of renewable energy systems. In these systems, efficiency, size and cost analyzes are generally performed. In addition, many new generation optimization methods and genetic algorithms are widely used to realize these improvements. Thanks to the developments in (AI) technology, high accuracy estimation methods on many parameters are used in renewable energy systems. When the studies carried out in recent years are examined comprehensively, the forecasting methods used in renewable energy systems are presented in Table 1.1.

**Table 1.1.** A comprehensive literature review on prediction papers in renewable energy systems.

| **References** | **Type of renewable energy source** | **The method used** | **The parameters estimated** |
|---|---|---|---|
| Calcabrini et al., 2019 | Solar Energy | A simplified skyline-based method | The annual solar energy potential |
| Li and Liu, 2017 | Solar Energy | A pixel-based approach | Solar energy potentials |
| Bou-Rabee et al., 2017 | Solar Energy | Artificial neural networks | Solar radiation |
| Voyant et al., 2018 | Solar Energy | The regression trees methods | Solar radiation |
| Shuvho et al., 2019 | Solar Energy | The fuzzy logic and artificial neural networks | Solar radiation |
| Rosato et al., 2017 | Solar Energy | The neural and fuzzy neural networks, the adaptive neuro fuzzy inference system and the higher-order neuro-fuzzy inference system | Photovoltaic power |
| Bharadwaj and John, 2018 | Solar Energy | The proposed global maximum power point algorithm | Global maximum power |

| | | | |
|---|---|---|---|
| Premalatha and Valan Arasu, 2016 | Solar Energy | ANN models with different back propagation algorithms | Solar radiation |
| Asrari, Wu and Ramos, 2016 | Solar Energy | A Hybrid Algorithm for Short (feedforward artificial neural network and shuffled frog leaping algorithm | Short-term solar power |
| Abedinia, Raisz and Amjady, 2017 | Solar Energy | The modified Levenberg–Marquardt learning algorithm | The solar power |
| Schuss, Eichberger and Rahkonen, 2016 | Solar Energy | Higher sampling rates and improving the resolution of the data | The solar power and solar radiation |
| Li and Shi, 2010 | Wind Energy | Three artificial neural networks (adaptive linear element, back propagation, and radial basis function) | The wind speed |
| Kavasseri and Seetharaman, 2009 | Wind Energy | Fractional Autoregressive integrated moving average models | The wind speed |

| | | | |
|---|---|---|---|
| Cadenas and Rivera, 2009 | Wind Energy | The artificial neural networks | The short-term wind speed |
| Singh and Mohapatra, 2019 | Wind Energy | Repeated wavelet transform based Autoregressive integrated moving average | The very short-term wind speed |
| Ding et al., 2019 | Wind Energy | A gated recurrent unit neural network | The short-term wind power |
| Wang et al., 2019 | Wind Energy | Sequence transfer correction algorithm | The wind speed |
| Zhang, Sun and Guo, 2019 | Wind Energy | PSO Support vector regression (SVR) and Grey Combination Model | The wind power and wind speed |
| Li et al., 2001 | Wind Energy | Neural Networks models | The power produced by each turbine |
| Kaiser and Snyder, 2010 | Wind Energy | Reference class approach | Offshore wind energy installation and decommissioning cost |
| Belabes et al., 2015 | Wind Energy | The present value cost method | The cost of wind energy system |

| | | | |
|---|---|---|---|
| Hammid, Sulaiman and Abdalla, 2018 | Hydroelectric Energy | Artificial neural network | The hydropower plant power production |
| Jain, Saini and Kumar, 2010 | Hydroelectric Energy | Computational Fluid Dynamics (CFD) approach | Efficiency of francis turbine |
| Bao et al., 2019 | Hydroelectric Energy | The finite volume type shallow-water model | The debris flow |
| Aleksandrovskii and Borshch, 2013 | Hydroelectric Energy | The proposed computational model (based on runoff-forming and atmospheric factors) | The hydropower plant power production |
| Dehghani et al., 2019 | Hydroelectric Energy | GWO-ANFIS | The hydropower plant power production |
| Pierini, Gómez and Telesca, 2012 | Hydroelectric Energy | ANN and an autoregressive model | The water flows |
| Wang, Li and Pei, 2017 | Hydroelectric Energy | Grey model | The hydropower plant power production |
| Mirzapour et al., 2019 | Wind and Solar Energy | The neural network and an intelligent evolutionary algorithm | The output power in the hybrid system |

| | | | |
|---|---|---|---|
| Xia et al., 2012 | Tidal Energy | 2D hydrodynamic numerical model | The annual energy output from a tidal barrage |
| Petley and Aggidis, 2016 | Tidal Energy | A zero dimension (0D) ‘back wards difference’ computational model | Tidal lagoon annual energy |
| Li, Lence and Calisal, 2011 | Tidal Energy | The model proposed which integrates a marine hydrodynamic model | The energy cost of a tidal current turbine farm |
| González-Gorbeña et al., 2018 | Tidal Energy | The multi-objective optimisation models | The optimum size of a tidal array |
| Walters, Tarbotton and Hiles, 2013 | Tidal Energy | A numerical flow model with form drag | The tidal power potential |
| Gangwani et al., 2020 | Geothermal Energy | LSTM (Long Short Term-Memory) Sequence to Sequence Encoder-Decoder Neural Network architecture | The geothermal energy production |
| Yener, Ozgener O. and Ozgener L., 2017 | Geothermal Energy | ANN | The soil temperatures |

| | | | |
|---|---|---|---|
| Luo et al., 2015 | Geothermal Energy | The mathematical model is composed | The conditions for effective development of shallow geothermal energy |
| Baruque et al., 2019 | Geothermal Energy | Time series and monitoring sensors optimization | Geothermal heat exchanger energy |
| Mudunuru et al., 2017 | Geothermal Energy | Regression-based reduced-order models | Thermal power output |
| Haklidir F. and Haklidir M., 2020 | Geothermal Energy | Deep neural network (DNN) algorithm | Reservoir temperatures |
| Douglas et al., 2013 | Geothermal Energy | The stochastic model | Ground motion in geothermal areas |
| Yousefi-Sahzabi et al., 2011 | Geothermal Energy | The dispersion model | $CO_2$ emission |
| Pérez-Zárate et al., 2019 | Geothermal Energy | ANN | Deep reservoir temperatures |
| Olatunji et al., 2019 | Biomass Energy | Hybrid Adaptive Neuro-Fuzzy Inference System | Elemental composition of biomass |
| Gonzalez-Salazar et al., 2014 | Biomass Energy | Monte Carlo algorithm | The biomass energy potential |
| Samadi, Ghobadian and Nosrati, 2020 | Biomass Energy | A stoichiometric equilibrium model | The biomass energy potential |

| | | | |
|---|---|---|---|
| Long et al., 2013 | Biomass Energy | Remote sensing and geographical information system | The biomass energy potential |
| Kumar et al., 2015 | Biomass Energy | Remote sensing | The biomass energy potential |

In this section of the thesis, a comprehensive overview of the studies on renewable energy systems has been made in the literature in recent years. When literature review was carried out, it was observed that (AI) technology was widely used in renewable energy systems. It is more common in solar and wind energy systems. However, work areas such as AI, machine learning and deep learning are integrated into tidal energy, biomass energy and geothermal energy systems.

A number of studies on hybrid energy systems has been increased in nowadays. Energy production can be provided with maximum efficiency in different climatic conditions by means of hybrid energy systems. The high energy demand would be met from hybrid energy systems. Nowadays, a single structure that used solar and wind energy is needed in order to obtain energy with maximum efficiency. In this way, space will be saved in a place. Experimental investigation and manufacturing of the prototype for novel rotary system has been presented. Thus, the novel rotary system is contributed to a single structure energy systems.

# 3. TURKEY’s SOLAR ENERGY POTENTIAL

Solar energy is a type of energy that is classified as a clean and renewable energy source. The most important factor in benefiting from solar energy is the geographical location of the country and the potential to receive sunlight throughout a year. Various factors such as coming angle of the sun rays and the length of time that the sun rays arrive determine the efficiency and potential obtained from solar energy. Europe and other countries in the world with the benchmark when Turkey has a very advantageous position in respect of use of solar energy. Which manifests itself with a high productivity throughout the entire world's energy source of the sun and of life in many geographical regions of Turkey. A country that has the largest and highest level of efficiency in the utilization of solar energy potential in Turkey and the position 36°- 42° to the parallel 26° takes place between the meridians 45° East. Due to its location, it has regions that receive intense sunlight alternately throughout the 4 seasons of the year. Thanks to the solar power plants installed in large areas, a significant part of the energy need can be met.

Turkey has a place in a highly efficient solar energy due to geographic location. In a year, in terms of the high sun rays it is a very important source of clean energy in Turkey. Turkey has seven geographical regions. Among these, the first region where sun rays come the most is South East Anatolia Region. Then comes Mediterranean Region. Eastern Anatolia Region ranks 3rd after Mediterranean Region in terms of the angle of incidence of sun rays and the number of sunny days; followed by Central Anatolia Region and the Aegean Region, respectively. Black Sea Region is a geographical region with the least efficiency for solar energy. Solar energy obtained from Southeastern Anatolia Region, where the sun's rays come at right angles for most of the year, is determined as 1460 kW. The 1-year sunbathing period of this region was measured as 2993 hours (YEGM, 2018).

According to Turkey's Solar Energy Potential Atlas, an annual total of 2,737 hours of sunshine duration (7.5 hours per day total), the annual total incoming solar energy 1,527 kWh / m² (daily total of 4.2 kWh / m²) was determined. Figure 3.1 presents the Turkey's Solar Energy Potential Atlas. Using these data, theoretical solar energy potential for the country has been calculated as 380 billion kWh/year.

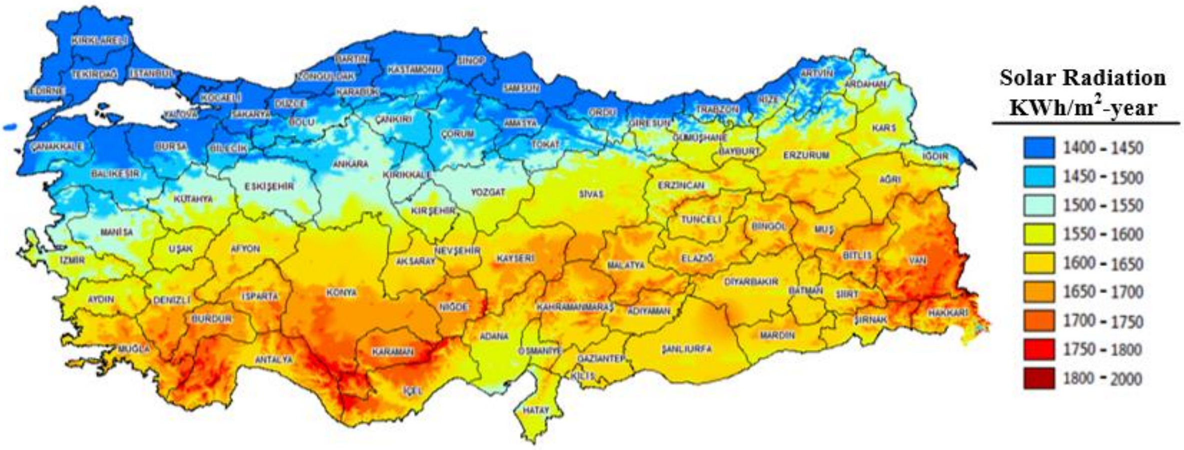


**Figure 3.1.** The solar energy potential of Turkey (YEGM, 2018).

Until 2014, Solar energy in Turkey is used to obtain hot water in houses and industry, drying and so on. It was used in off-grid areas such as operations and monitoring stations and for small electrical energy needs such as park and garden lighting. After this year, use of solar energy has changed in size and a power plant has been established for electrical energy production. With the decrease in cost of solar panels and the increase in panel efficiency, electricity production, which was only 40 GW in 2014, reached 81.7 MW as of the end of October 2018, of 9 licensed solar power plants. The development of solar energy continues unabated, and with the power plants that are about to be completed as of today, the installed power of unlicensed power has been reached in the sun, with a license of around 100 MW and a little over 5,000 MW. Electricity generation of licensed solar power generation facilities increased by 122 times 72 thousand kilowatt-hours (kWh) in 2018 compared to the previous year. In this way Turkey has risen to seventh place in the ranking of European countries in solar energy at the end of 2017. It has risen to thirteenth place in the world. In 2020, the maximum number of stations having the primary source of energy in Turkey is solar energy. These plants have number of 7058 total solar energy plants (6134.3 MW). Table 3.1 shows the solar energy sharing among the energy sources in detail.

**Table 3.1** Installed power capacity of the primary energy sources in Turkey as of April 2020 (TEIAS, 2020).

| **Primary Sources** | **Number of Power Plants** | **Installing Capacity (MW)** |
|---|---|---|
| Hydropower | 559 | 7.882,7 |
| Asphaltite Coal | 1 | 405,0 |
| Waste Heat | 84 | 363,8 |
| Dams | 126 | 20.830,7 |
| Biomass | 186 | 824,1 |
| Natural Gas | 331 | 25.654,0 |
| Fuel Oil | 11 | 305,9 |
| ***Solar Energy*** | ***7.058*** | ***6.134,3*** |
| Imported Coal | 15 | 8.966,9 |
| Geothermal | 54 | 1.514,7 |
| Lignite | 48 | 10.101,0 |
| LNG | 1 | 2,0 |
| Diesel | 1 | 1,0 |
| Nafta | 1 | 4,7 |
| Wind | 275 | 7.762,8 |
| Hardcoal | 4 | 810,8 |
| **Total** | **8.755** | **91.564,5** |

Solar cells are the most effective way to obtain electrical energy from the solar energy. A solar cell operating as a semiconductor diode converts the energy carried by sunlight directly into electrical energy by taking advantage of the internal photoelectric reaction. When photons hit the solar cells, they move to electrons, causing them to separate from their atoms. If conductors are connected to positive and negative sides of solar cells, an electrical circuit is formed and electricity is produced if electrons flow through such a circuit. A large number of solar cells come together to form a solar panel, and a large number of solar panels to form a solar energy system. The more solar energy modules there are in a solar energy system, the greater the installed power of the system. Today, semiconductor elements are getting more and more important. Solar cells such as diodes, transistors, thyristors, rectifier diodes are also made of semiconductor materials.

The structures of solar cells are similar to diodes that simply consist of a P and N junction. Based on the photoelectric phenomenon principle, electrons detached from the battery by photons move in the joint and create an electric current. Among the many materials that show semiconductor properties, the most suitable ones for making solar cells are materials such as silicon, gallium arsenide, cadmium telluride. In order to use the semiconductor materials as solar cells, N or P-type additives must be added. After the semiconductor joints are formed, thanks to the photons from the sun's rays, the electrons detached from the N-type move towards the P-type. This event continues until the load balance occurs on both sides.

Their electron shortage and their excess in the other cause an electric field to form on either side of this region. The photons of the light flux absorbed by the semiconductor form electron-hall pairs, which are collected separately on both sides of the semiconductor part. This results in an electric current proportional to the illuminated face of the joint and the intensity of the light falling there. The structure and working mechanism of solar cells will be explained in detail in this section.

## 3.1. Photovoltaic energy systems

Industrial applications and technological developments have been increasing in world rapidly. With this advance, energy demand increases in direct proportion to new applications and developments. This situation led to tend alternative renewable energy sources without reserve amount problem. Among renewable energy sources, photovoltaic energy is one of alternative energy sources. Photovoltaic energy systems have many advantages. Does not have moving parts of photovoltaic energy systems has facilitated its maintenance. Silent operation of these alternative energy systems, being able to work even in a non-gravity environment and being environmentally friendly are among the most important features. The most important parts of photovoltaic energy systems are photovoltaic panels, solar charge controller, inverter and batteries. There are different types of applications where different solar cells are used in photovoltaic energy systems. There are different types of solar power systems according to different installation types of solar panels. Solar power tower, parabolic groove type solar power system and Parabolic-dish solar are commonly known photovoltaic energy systems. Institutions of these energy systems are made to obtain high amount of power.

Many scientific studies have been carried out to increase the amount of energy to be obtained from photovoltaic systems. The amount of energy obtained from a solar panel varies over time depending on the amount of light reaching the panel. Recently, solar tracking systems are widely used in solar energy systems. Thanks to solar tracking systems, it provides maximum benefit from solar radiation. The impact of solar energy systems on their efficiency can be seriously observed. We can divide solar tracking systems into two groups as uniaxial and biaxial tracking.

In the following sections, the most important part of photovoltaic energy systems, the development processes of the photovoltaic panels, the internal structure of the panels and solar cell types are explained in detail.

### 3.1.1. The historical development process of photovoltaic panels

In this section, the historical development processes of photovoltaic panels from past to present are presented. Photovoltaic technology was discovered in 1839 by French physicist Alexandre Edmond Becquerel. The physicist introduced the concept of photovoltaics to the world by experimentally observed that the voltage between electrodes immersed in the electrolyte varies depending on the sunlight falling on the electrolyte. The effect of solar radiation on voltage formation between electrodes has been defined as photovoltaic. The origin of the word photovoltaic is Greek and consists of two words. Voltaic is used in the sense of voltage in terms of photo light. The next development in the field of photovoltaics was made in 1973 by Willoughby Smith. He discovered that the element selenium, which is a chemical element, has a photoconductive property. William Grylls Adams and Richard Evans Day tested the principle of photovoltaic effect observed by Edmond Becquerel in 1876 on selenium and obtained positive results. Then, in 1883, the American scientist Charles Fritts installed a solar array using a selenium cell with an efficiency of less than 1%. Many scientific studies on the concept of photovoltaics have been carried out over the coming years. 1946 The first person to patent the modern photovoltaic solar panel in the world is known as Russell Ohl. By 1954, silicon solar cell, whose efficiency reached approximately 6%, was invented by Bell Labs. Later, in 1957, Hoffman Electronics managed to increase its solar cell efficiency by 2% to 8%. In 1958, photovoltaic technology was integrated into the spacecraft, and photovoltaic cells were used in the Vanguard-I spacecraft. The properties of these photovoltaic cells are 0.1 W power and 100 $cm^2$ in size. In 1959, Hoffman Electronics made an improvement on efficiency and produced 10% efficiency solar cell. In 1960, the same company produced solar cells with 14% efficiency. When the researches made in recent years are examined, in 2007, Delaware University announced that it produced 42.8% solar cell production. After the oil crisis in 1973, interest and orientation to solar energy increased among renewable energy technologies. Today, it is possible to come across solar energy applications in almost every sector. State support given to solar energy investors in Turkey has also increased interest in the application of solar energy.

### 3.1.2. Structure of photovoltaic panels

The photovoltaic structure consists of a P-type material on the N-type base. The structure of solar panel includes anodized aluminum frame, tempered glass, encapsulant, photovoltaic solar cells, insulating material and junction box. Solar panel glasses are one of the most important components that protect the internal parts of solar panels producing electricity from solar energy from environmental conditions and directly affect the efficiency of solar panels with their high light transmittance performance. Generally, the high light transmission glasses used in solar panels have thicknesses of 3.2 mm and 4 mm. The solar radiation transmittance of tempered glasses used in these solar panels is approximately 91%.

The structure of photovoltaic cells is generally in square, rectangular and circle shapes. The thickness of these photovoltaic cells is 0.2 mm and 0.4 mm. The power value obtained from solar panels varies according to the number of cells in the panel. Solar cells can be connected in serial or parallel ways. These different connection shapes directly affect the output power of the panel. Solar modules are formed by connecting solar cells to each other. By providing the connection of solar modules, the solar panel is obtained. The solar array is formed by providing the connection of these solar panels with each other as shown in Figure 3.2. In other words, with the integration of the panels, the solar energy system has occurred.

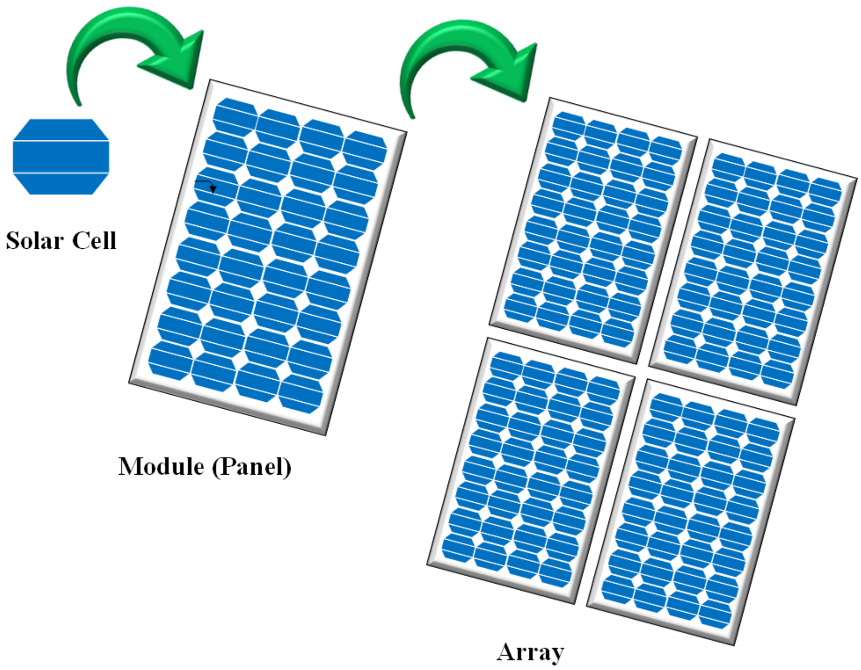


**Figure 3.2.** The solar cell, solar module and solar array.

### 3.1.3. Types of photovoltaic cell

Today, there are different types of solar cells used in solar energy applications. Photovoltaic cells are produced from various materials and solar panels are produced with different characteristics. It is the most used semiconductor material in the production of silicon photovoltaic solar cells. The raw material of this semiconductor and its reserve is abundant in nature. By using different techniques and various additives, different photovoltaic modules are produced. Among the widely used solar cell types, today are monocrystalline silicon cell, polycrystalline silicon cell, thin-film solar cells, group III-V compound photovoltaic cells, multi-junction cell and organic polymer cell.

The crystalline silicon photovoltaic cell has three different types. These photovoltaic cells are monocrystalline, polycrystalline and ribbon silicon cells. Thanks to the electrical characteristic of the semiconductor silicon material, it is widely used in solar cell technology. Monocrystalline cells are superior to other cell types due to their high efficiency. The efficiencies of monocrystalline cells vary from approximately 18% to 24%. The production process of monocrystalline cells is difficult compared to other cells. As a result of this situation, the production cost is high. Production processes are easier compared to single crystalline silicon cells. Thus, the production cost of the multi-crystalline cells is very low. The efficiency of the low crystalline cells is low as their structural and electrical characteristics are not homogeneous. The efficiency of these cells in mass production decreases to approximately 13%. In order to reduce losses due to the material while producing a single crystal cell, improved solar cells were produced by changing their structural features with a special method. These cells are known as ribbon silicon cells. The efficiency of ribbon silicon cells produced in different thicknesses is at acceptable rates.

Thin-film solar cells are known as low-cost solar cells with low light absorption and thin structure. The efficiency of these solar cells is approximately 18%. The structure of thin-film solar cells does not have a stable structure, so the application areas are not wide. There are 3 types of thin-film solar cells. These types are amorphous silicon solar cells, cadmium telluride (CdTe) solar cells and copper indium diselenide (CIS) solar cells. Amorphous silicon solar cells have been observed to be very good in terms of light absorption. It has been widely used in low energy electronic devices in recent years. Cadmium telluride (CdTe) is a solar cell obtained by using cadmium telluride compound composed of cadmium element and tellurium element as a building material. It has been observed that the efficiency of copper indium diselenide (CIS) solar cells is very low when experimentally analyzed. Therefore, the application areas are very limited. The compound consisting of copper, indium and selenium elements is used in the production of these cells.

Gallium arsenide (GaAs) is used in the solar cell structure. In the periodic table, solar cells are made from the compound formed by the element belonging to two different groups (III-V). The efficiency of gallium arsenide solar cells ranges from approximately 29% to 34%. In addition, these cells feature high light absorption. The production process cost of gallium arsenide solar cells is significantly high. Space research and solar cars are examples of the application areas of these solar cells.

Scientific studies have been carried out to increase the efficiency of solar cells. In order to make maximum use of solar radiation, materials with different light absorption properties are combined and multi-joint photovoltaic cells are produced. Thus, energy is obtained with high efficiency by absorbing different spectra of sunlight. The production costs of this type of solar cells are high. Multi-junction solar cells, whose efficiency is approximately 31% to 44%, are widely used in scientific studies.

### 3.1.4. Working principle of photovoltaic panels

Photovoltaic panels consist of solar cells. Working system for photovoltaic panel are based on semiconductor technology. The most used semiconductor materials in the structure of the PV panel are Arsenide, Silicon and Gallium. Because the structure of photovoltaic panels consists of N-type and P-type doped semiconductor material. Thanks to the properties of these semiconductors, voltage is generated by creating an electron flow. When the surrounding photons reach the solar cells, electrons are excited and separated from their atoms, creating an electron flow. Electron flow between N-type semiconductor with excess electron and P-type semiconductor with excess space creates an electric current. In other words, electrons move from the N-type semiconductor region to the N-type semiconductor region.

Anti-reflection building material is used for maximum absorption of sunlight. In addition, the outer part of the panel is covered with protection glass for protection from external factors. Thus, the damage of the semiconductor material is prevented. Solar cells come together to form the solar panel. According to the desired power value, many solar panels come together to form the solar energy system. In a solar energy system, the number of solar panels increases in direct proportion to the installed power.

### 3.1.5. Mathematical modeling of photovoltaic cells

Improving the efficiency of photovoltaic energy systems, the formation of I-V characteristics in photovoltaic panels, size and cost optimizations are based on mathematical modeling of photovoltaic cells. Therefore, the mathematical modeling of photovoltaic cells is an important research area for solar energy systems. The ideality factor used when performing the mathematical modeling of the photovoltaic cell varies according to the type of the series resistance and parallel resistance photovoltaic cells. The equivalent circuit of an ideal photovoltaic cell is as shown in Figure 3.3.

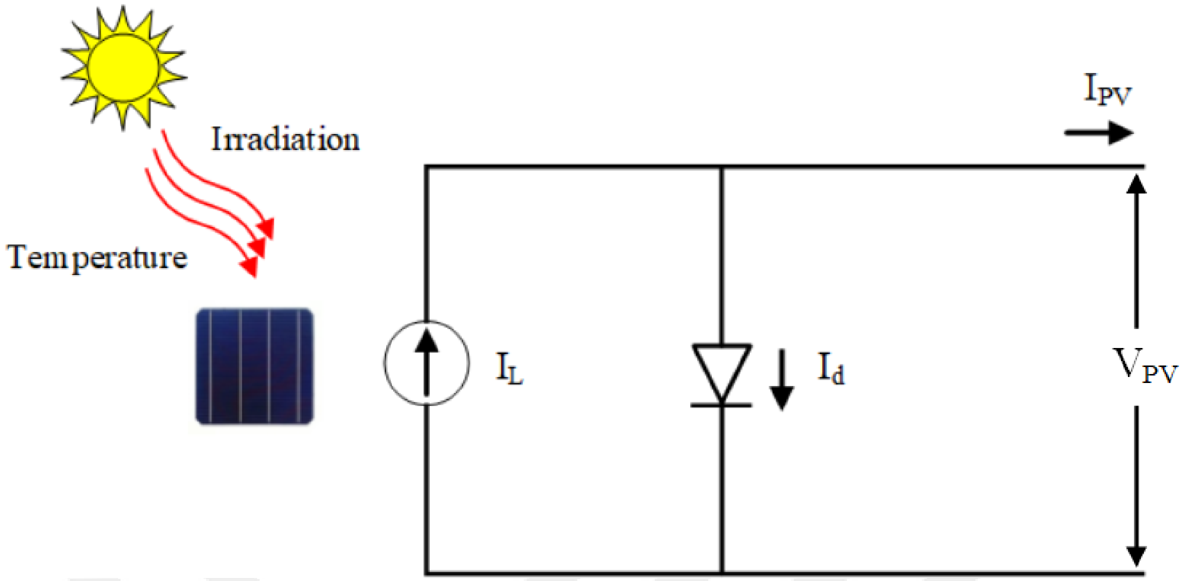


**Figure 3.3.** Equivalent circuit of an ideal photovoltaic cell.

Solar cells are semiconductor circuit elements. Solar cells are formed by thinning the P-N type semiconductor material into a thin layer. The equivalent circuit model of the solar cell was presented by Lorenzo in 1994 (Lorenzo, 1994). This model consists of a current source and a parallel diode connected to it. Here, the series resistor ($R_s$) refers to the internal losses of the solar cell resulting from the current flow and is desired to be small for maximum power generation. The diode-parallel ($R_p$) resistance refers to losses due to leakage currents to the ground and is generally neglected because it is very small. Modeling of cells in photovoltaic cell technology mathematical modeling with one diode and two diodes is performed as shown in Figure 3.4 and Figure 3.5.

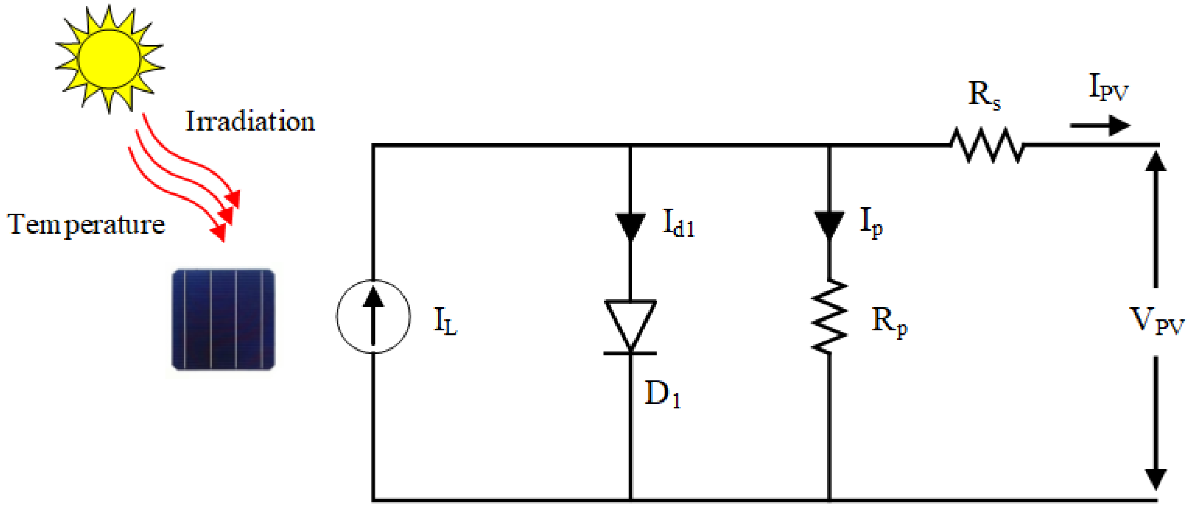


**Figure 3.4.** The electrical equivalent circuit of single diode photovoltaic cell.

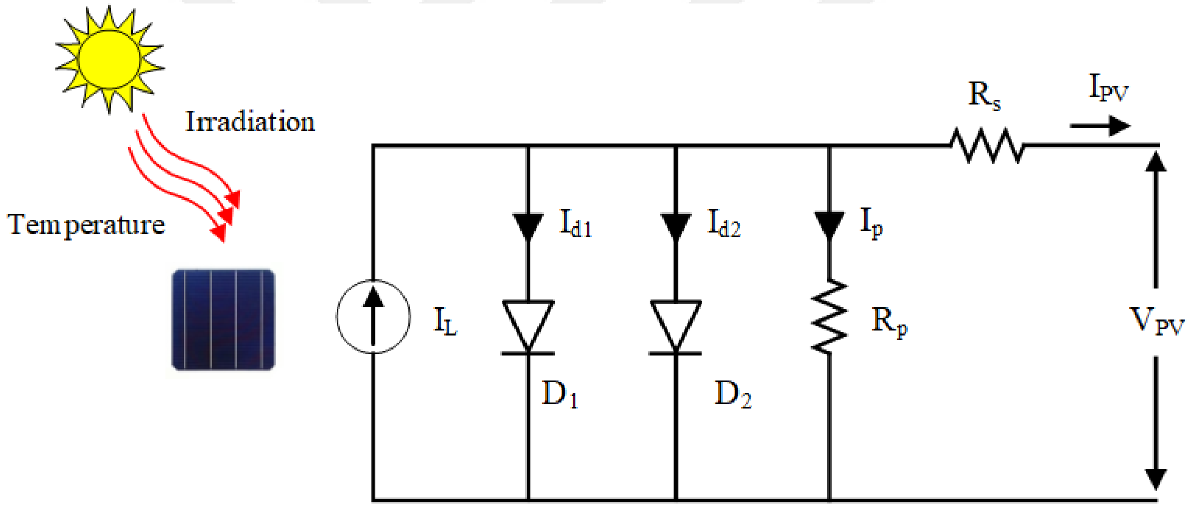


**Figure 3.5.** The electrical equivalent circuit of two diode photovoltaic cell.

The I-V characteristic of a solar cell is basically the practical model of PV cell based on Equations 1 and 2 below.

$$I_{PV} = I_{d1}\left[exp\left(\frac{q.V_{PV}}{kT} - 1\right)\right] \quad (1)$$

$$I_{PV} = I_L - I_{d1}\left[exp\left(\frac{q(V_{PV}+R_S.I_{PV})}{n.k.T} - 1\right)\right] - \frac{V_{PV}+R_S.I_{PV}}{R_p} \quad (2)$$

Where ideality factor is ($n$), series resistance is ($R_s$), parallel resistance is ($R_p$), Boltzmann constant is ($k$) (1.381x10$^{-23}$ J/K), electron charge is ($q$) (1.602x10$^{-19}$ C), and solar cell temperature is ($T$). The ideality factor ($n$), series resistance ($R_s$) and parallel resistance ($R_p$) parameters have different values depending on the type of solar cell. The voltage expression of the solar cell can be written as in Equation 3 by ignoring parallel resistor ($R_p$) by using Equation 2 and performing the necessary mathematical operations.

$$V_{PV} = \frac{n.k.T}{q} ln\left[\frac{I_L + I_{d1} - I_{PV}}{I_{d1}}\right] - R_s.I_{PV} \tag{3}$$

Photovoltaic cells are connected in series and in parallel, creating a solar cell module with different voltage and current. In this solar cell module, the number of serial cells is expressed as $N_s$ and the number of parallel cells is expressed as $N_p$. The equivalent circuit model in different configurations of photovoltaic cells is shown in Figure 3.6. Serial cells are increased in order to increase the voltage level in photovoltaic modules. The number of parallel cells is increased in photovoltaic modules to increase the current level.

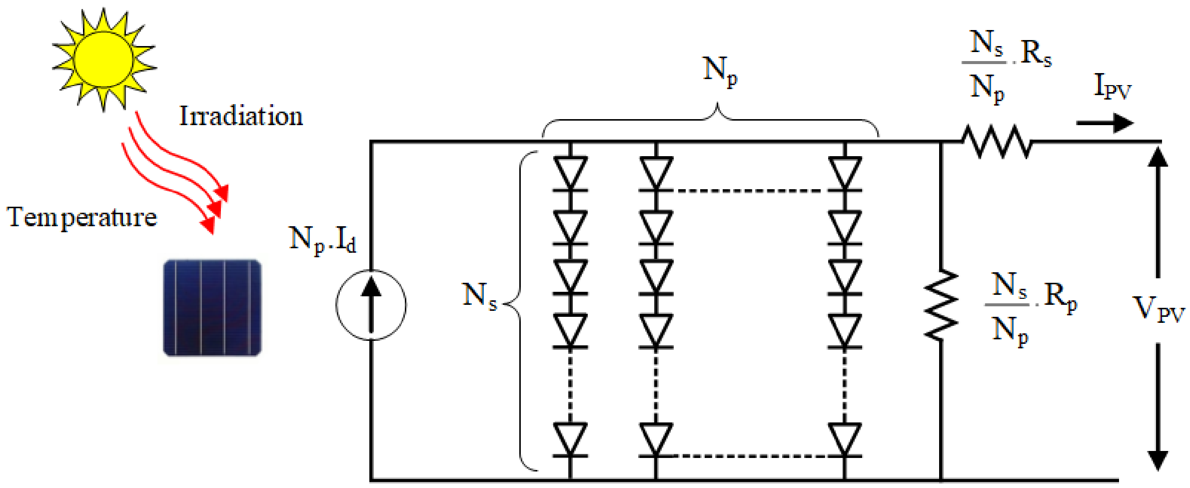


**Figure 3.6.** Electrical equivalent circuit of solar cell module with diode in series and parallel.

The total current and voltage expression of the solar cell module whose equivalent circuit is as in Figure 3.6 is shown in equation 5 and equation 6, respectively.

$$I_{PV} = N_p . I_d - N_p . I_{d1}\left[exp\left(q\left(\frac{V_{PV}}{N_s} + \frac{I_{PV}.R_s}{N_p}\right)k.T.A\right) - 1\right] - \left(\frac{N_p.V_{PV}}{N_s} + I_{PV}.R_s\right)/R_p \qquad (5)$$

$$V_{PV} = \frac{N_s.n.k.T}{q} ln\left[\frac{I_L + I_{d1} - I_{PV} + N_p}{I_{d1}.N_p}\right] - \frac{N_s}{N_p} R_s . I_{PV} \qquad (6)$$

Where $N_p$ is number of parallel cells, $N_s$ is number of series cells, $A$ is area of cell, the output current of the solar cell module is $I_{PV}$ and the output voltage of the solar cell module is $V_{PV}$.

In this part of the thesis, mathematical modeling of solar cells is presented in detail. By using the equivalent models of photovoltaic cells, electrically different information about solar energy systems is obtained.

### 3.1.6. Critical parameters affecting energy production from photovoltaic panels

There are many critical parameters that affect the efficiency of photovoltaic energy systems. These parameters include shading, dusting, reflection, humidity, temperature, panel location, panel angle, air pollution, environmental factors, location and panel cleaning. In order to obtain maximum efficiency from solar energy, the effects of these parameters on solar energy systems should be examined in detail. Because the changes in these critical parameters directly affect the amount of energy to be obtained from solar energy systems.

The energy produced by a grid-connected solar energy system changes over time depending on many factors. A concept called performance ratio is used as a criterion in determining the reliability and efficiency of these energy systems. The performance ratio of a grid-connected solar power system is the ratio of the energy produced at the Alternative Current (AC) output to the energy produced by the PV panels in the system under Standard Test Conditions (STC) (1,000 W/m² radiation value, 25 °C solar cell temperature and Air Mass (AM) 1.5 solar spectrum). Thanks to the concept of performance ratio, it is possible to compare grid-connected photovoltaic power systems installed in different parts of the world. Measuring the performance ratio of solar energy systems at certain time intervals makes the losses observable. A decrease in this rate means that losses increase. The causes of loss are examined in detail and efforts are made to eliminate the problem. Thus, system efficiency is preserved by reducing losses.

Before large-scale solar energy systems are installed, research in detail on some factors is required. Many of these factors cause losses in energy production in solar energy systems. Regions with high daily sunshine duration and high solar energy potential are suitable locations for solar energy systems. Turkey is in a good position in terms of these issues. Southeastern Anatolia and Mediterranean Regions are the two regions with the highest sunbathing time. The Black Sea Region is the region with the lowest sunshine duration. Consequently, sunbathing time and solar energy applications change in direct proportion.

The positioning of the photovoltaic panels also significantly affects the energy to be obtained. Because the angle of solar radiation reaching the panel is constantly changing during the day. Solar tracking systems have been developed to eliminate this problem. These solar tracking systems are widely used in solar energy applications today. Thus, the solar tracking system makes maximum use of solar radiation.

Some of the solar radiation reaching the photovoltaic panel surface is reflected back from the panel surface without being absorbed by the solar cells. This situation creates reflection losses. It is tried to minimize reflection losses by using an anti-reflection coating on photovoltaic panels. In a normal beam, solar modules reflect 4% of incoming light.

In solar energy systems, the radiation difference and the voltage difference between the shaded parts of the panels and the unshaded parts constitute the shading losses. There are many environmental factors on photovoltaic panels that will create the shading situation. These are trees, birds, buildings and mountains. When detailed research is done in the literature on photovoltaic energy systems, many scientific studies are observed on the shading situation. Because shading is the most critical parameter affecting efficiency in solar energy systems. Even the shading of a small area on the photovoltaic panel greatly affects the output power. In order to overcome this problem, a lot of research has been done on this subject. In solar energy systems, there are two different maximum power points in case of ghosting. These are the local maximum power point and the global maximum power point. The power at the local maximum power points (LMPP) point was observed to be considerably lower than the power at the Global

MPP (GMPP) point. Today, MPPT modules have been developed to monitor the maximum power point in the inverter in solar energy applications with grid connections. These modules ensure that the solar system operates at the optimum operating point. Thus, maximum power is obtained from the solar energy system and load is fed or energy is stored in the battery.

The cleaning of photovoltaic panel surfaces significantly affects energy production. Therefore, coating the photovoltaic panel surfaces with dust and snow reduces the amount of radiation reaching the solar cells. Thus, the amount of energy produced is negatively affected. In order to overcome this problem, the region chosen for the installation of solar energy systems should be chosen carefully. In addition, regular cleaning of the photovoltaic panel surface at certain time intervals will positively affect the energy obtained. In addition, rainwater helps panel cleaning. However, rain does not occur continuously in areas with high solar energy potential. Different types of panel surface cleaning machines have been produced to perform the cleaning of photovoltaic panel surfaces. Thanks to automatic solar system cleaner systems, losses caused by dusting are minimized.

One of the critical parameters that affect the performance of photovoltaic panels is temperature. In society, people think that the amount of energy obtained from solar panels will increase with the increase in temperature. However, this is a completely wrong idea. Because temperature increase in semiconductor technology affects efficiency negatively. In other words, there is an inverse proportion between the temperature and the output power of the solar system. As the ambient temperature rises, the solar cell temperature also rises, and the energy obtained from the panels decreases. The conditions where the photovoltaic energy system performance is optimum is when the solar radiation level is high, and the ambient temperature is approximately 25 ℃.

Solar radiation intensity is one of the parameters directly affecting the output power of photovoltaic panels. The amount of energy obtained at low radiation levels decreases. There are graphs that give the correlation between solar radiation intensity and the efficiency of solar cells. Solar cells to be used in photovoltaic panels should be determined according to the areas to be installed.

Direct Current (DC) and AC cables used in photovoltaic energy systems are used. Cable losses occur in solar energy systems due to ohmic losses in these cables. The properties of the cables to be used in photovoltaic energy systems vary according to the power of the panel and the energy system. Photovoltaic modules are connected to the inverter by DC cables in series and in parallel. While choosing the size of the conductor, the current carrying capacity of the conductor and the voltage drop that will occur along the conductor are taken into consideration.

The power produced by photovoltaic panels is DC. Thanks to the inverter, the direct current is converted into AC. There is some amount of power loss during this process. These losses are defined as inverter losses.

#### 3.1.7. The challenges encountered in photovoltaic energy systems

Among the alternative energy sources, solar energy is widely used in the industry and individual residences today, with decreasing production costs and improved efficiencies. With the continuous increase in pricing in the field of electrical energy, interest in solar energy applications is increasing among renewable energy sources. Thus, industrial firms and individual residences generate significant economic savings by generating electricity from solar energy. However, there are a number of problems encountered in solar energy systems. These problems vary according to the region where the photovoltaic panels are installed. There are many scientific types of research on these problems. Thus, it is aimed to eliminate or minimize these problems.

One of the important problems encountered in photovoltaic energy systems is fire. The vast majority of fires occurring in these energy systems are caused by electrical failures. Ground fault, cable insulation problems, short circuit fault and arc problems cause the fire to occur. It is also observed in fires caused by the incorrect installation of DC and AC inverters. There are three types of arcs in photovoltaic energy systems. These are serial arcs, parallel arcs, and ground arcs. As the current flows through the photovoltaic energy system, serial arcs are formed as a result of disconnection. Parallel arcs are formed due to abrasions occurring in the insulation between the cables used in the photovoltaic power system. Earthing arc occurs due to the error in isolation in the earthing system. In order to prevent such errors from occurring, it is very important that the materials used in the energy system have high quality and maintenance of this system.

Cloudiness directly affects the output power of solar energy systems. Different levels of solar radiation in solar cells in photovoltaic panels create a negative situation in energy production. Shaded cell or cells cannot produce current or produce very little current. Shading a certain area on the panel surface causes the panel power to decrease. To overcome this problem, bypass diodes are used in photovoltaic panel technology. Bypass diodes are generally used for increasing photovoltaic energy system performance and ensuring product safety. Thus, panel power is prevented from falling. Two types of bypass diodes are used in photovoltaic energy systems. These are PN-junction silicon diode and Schottky diodes. Transmission voltages of P-N polarized and Schottky diodes are 0.7 and 0.4 V. respectively.

Thanks to the use of bypass diodes, the solar cells in a shaded state are activated and the current is provided by passing through the transmission. The current flows over the diodes to prevent a decrease in panel power. Bypass diodes are connected inversely between the positive and negative output terminals of the solar panel. Connecting the bypass diode to each cell significantly increases the cost. Bypass diodes are connected to the panel outputs to reduce the cost.

Under the shading condition of the photovoltaic panel, the solar cells under the shading act like a load and the current flow in the opposite direction. This situation increases the solar cell temperature. Solar cell insulation and solders undergo deformation under high temperature. In this case, the solar cell shortens its life and efficiency decreases.

Installation of panels is very important in high power solar systems. Depending on the movement of the sun during the day, the shadows of the panels are formed. The shadow of one panel should be installed in the other panel without any shadow effect. The fact that the panels have a shadow effect reduces the output power significantly.

There are some problems in solar energy systems in regions where snowfall occurs. When there is a lot of snow, snow will accumulate on the photovoltaic panels. This situation affects the performance of the energy system negatively. Photovoltaic panels cannot bear the weight of the accumulated snow-mass in some cases and cell breaks occur.

Storage units of solar energy systems with energy storage units should be regularly maintained. Gel batteries are generally used in solar energy systems. The maintenance and lifetimes of these batteries increase the cost of energy production.

## 3.2. The photovoltaic system connection types

Photovoltaic energy systems are divided into two groups, basically off-grid solar PV system and on-grid solar PV system. The components used in these systems vary according to the system type. In addition, different topologies are used to feed AC and DC loads at different voltage levels at the solar energy system output.

### 3.2.1. Off-grid solar PV systems

In rural areas where there is no electricity network, electricity is needed. There are different methods and options to meet this demand differently. Separate systems from the grid ensure that the energy generated from photovoltaic panels is stored in batteries as shown in Figure 3.7. Energy stored in the batteries is used at night when there is no solar energy. Since the energy is obtained from the battery outlet or direct photovoltaic panels, only DC loads can be fed in these systems. If AC loads are desired to be fed, a different topology must be used for this. Systems separated from the grid are generally used in lighting, electric vehicle technology, railways and prefabricated houses to meet energy needs.

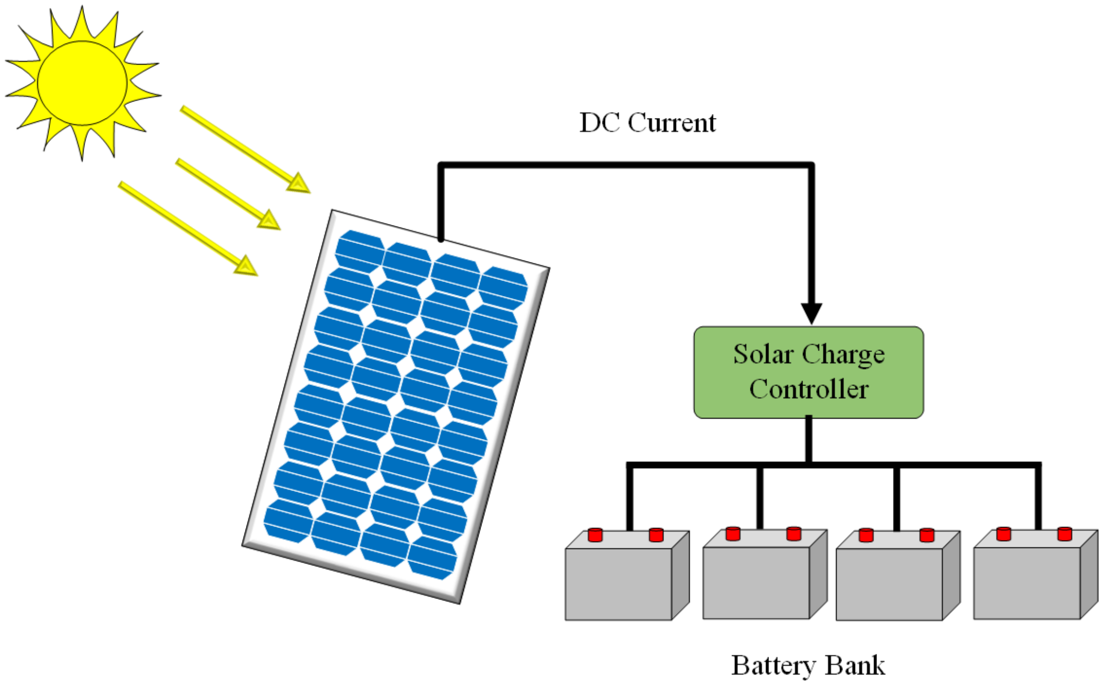


**Figure 3.7.** Off-grid solar PV system.

Generators and battery devices can be integrated into photovoltaic energy systems without the grid connection. The choice of loads to be used in systems without a grid connection is very important. The working times of loads such as lamps to be connected to the system, refrigerator heaters should be carried out in a planned manner. Also, it is important for battery life not to be discharged completely. In order for the chemical structure in the battery to have a longer life, 100% discharge is not recommended. In systems without a mains connection, it is recommended to discharge the batteries up to 50% in general.

Off-grid solar PV systems have some advantages compared to grid-connected systems. Since these systems do not have a connection with the network, they are not affected by the power cut in the grid and continuous energy flow is provided. However, in grid-connected systems, the photovoltaic energy system is also affected by negative situations in the grid.

The charge control device is used in photovoltaic energy systems separate from the grid. The charge controller is connected between the battery and the panel. It is a device that provides efficient charging of batteries and prevents reverse current flow from batteries to panels. The transistors in the electrical circuit of this device do not allow any current passage unless the voltage of the panels is higher than the battery voltage by switching.

### 3.2.2. On-grid solar PV systems

As it is known from the output of photovoltaic energy systems, DC voltage is obtained. However, AC voltage is used in the grid. Therefore, the inverter is used in grid-connected photovoltaic energy systems. Electric energy produced from solar panels is transferred to grid-connected inverters and converted into a form that can be transferred to the electric line as shown in Figure 3.8. The electricity produced from the solar panel is used directly in DC loads. However, excess energy produced in some time is transferred to the grid. The bidirectional meter is used in these systems. When the energy obtained from the photovoltaic panels is low, the loads are fed from the grid. Thus, these systems provide mutual electricity energy exchange opportunities with the grid. This situation provides energy producers with financial income.

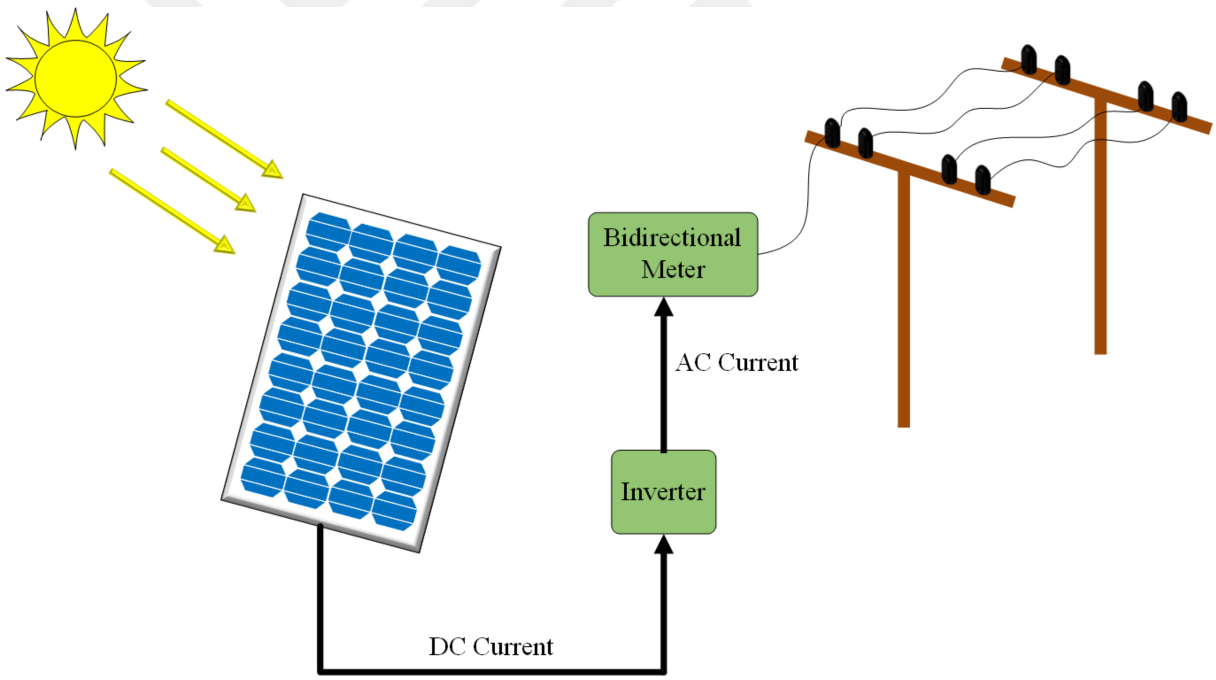


**Figure 3.8.** On-grid solar PV system.

Grid-connected systems can operate without the need for batteries. There is no obligation to use the battery and the initial installation costs are lower than the battery-powered systems. However, optionally, batteries can be integrated into these systems. In these systems, when energy demand cannot be met from photovoltaic panels, it is benefited from the grid. Inverters used in these systems work synchronously with the mains frequency and voltage. If there is a power outage in the grid-connected systems due to negativity in the city grid, the energy system will also be disabled during this period.

### 3.2.3. Hybrid applications

Energy systems where different energy sources are used together are called hybrid systems. Today, solar and wind energy is used the most in hybrid energy systems. By using these two energy sources together, electrical energy is obtained with high efficiency. Although the installation cost is high, continuous energy production can be provided from the hybrid energy system. During the day, moments with high solar energy and wind energy potential are in different time periods. When solar energy potential is high, energy production is provided from photovoltaic panels. Energy production from wind turbines is provided when wind energy potential is high. Thus, the continuity of energy production is ensured during the day.

Hybrid energy systems are installed to increase system efficiency in energy production and also to meet the energy demand continuously. The purpose of the hybrid systems is to create a system from different energy sources that feed and supplement each other. Hybrid power generation systems can be used for efficient energy production in rural areas and remote areas where distribution and production are inadequate. Hybrid energy systems can be installed as on-grid or off-grid.

In hybrid energy systems, renewable energy sources are used as well as fossil sources are used as energy sources. However, because of the superiority of renewable energy sources over fossil fuels, renewable energy sources are preferred in hybrid energy systems. Many experimental and numerical scientific types of research are carried out to increase the efficiency of these systems. Cost, size and efficiency optimizations of these systems are realized. HOMER and MATLAB software programs are widely used in simulation studies on hybrid energy systems. In line with the simulation results, optimum setup planning cost analysis is performed comparatively for different cases.

# 4. ARTIFICIAL INTELLIGENCE IN SOLAR ENERGY

## 4.1. The developments in artificial intelligence from past to present

AI is a set of software and hardware systems that imitate human intelligence to perform various tasks. In other words, it enables these systems to think like people. AI is a technology that understands and imitates the working principle of the human brain. In addition, there are different scientific fields that work integrated into AI technology. This technology uses scientific fields such as computer science, probability, linear algebra, optimization, neuroscience, cognitive science, control theory and linguistics. AI technology has different application areas such as production, factories, robots, automation, service robots, energy, law, education and health.

Boolean circuit model of the brain was realized by McCulloch and Pitts in 1943 as the beginning of scientific studies on AI. Thus, the historical development process of AI begins. The name “Artificial Intelligence” was used for the first time in 1956 after the Dartmouth Meeting and was recorded in the literature. Between 1952 and 1969, International Business Machines brought the first program that could play chess to the literature. With AI technology, the human brain is simulated and chess competitions against AI have been held (McCorduck et al., 1977).

AI is a concept that covers concepts such as Machine learning and Deep learning. Artificial intelligence technology is used in different application areas. Today it is widely used in industry and scientific studies. It is used in industry to increase production efficiency and cost analysis, especially for investors. In addition, voice recognition, image processing, image processing and reasoning are areas where artificial intelligence technology is frequently used.

Significant improvements have been made in voice recognition technology in recent years. Thanks to artificial intelligence technology, it recognizes sound with high accuracy rate. In addition, this technology is capable of responding to incoming voice (received voice). Computer's recognition of sound, turning sounds into letters, understanding and responding to letters can be shown as the advantages of artificial intelligence technology. Voice recognition technology is used in smartphones, for customer service and security purposes. It is possible to see products about voice recognition technology at every point in our lives.

The image processing technology is used in many points of our life with the help of artificial intelligence technology. Image Processing is a technology that has been rapidly increasing in use recently, which analyzes images as if they were viewed with the human eye. Thanks to image processing, pixels are converted to code. Image processing is used in driverless vehicles, face recognition, security systems, demographic information analysis, radiology and radar technology.

Natural language processing is one of the sub-branches of artificial intelligence technology. As in other artificial intelligence application areas, natural language processing is used in many different application areas. Google search engine is the most common field we encounter with natural language processing technology. The Google search application warns the user with the natural language processing technology by saying “Did you mean this?”. Web search, machine translation and information retrieval are different application areas.

Usage areas of artificial intelligence are increasing rapidly day by day. This technology is used in different application areas. We may encounter technological applications that are the subject of science fiction movies in the future. This situation is no longer surprising. Because artificial intelligence technology has reached a very high level.

#### 4.1.1. Types of artificial neural network

Artificial intelligence is a technology that mimics the biological and anatomical structures of the human. The structure and function of biological neural networks are studied by scientists to create an artificial neural network model. Because the artificial neural network is similar to the structure of biological neural networks of humans. It consists of interconnected artificial neurons. ANNs are defined as software systems that can perform learning, which is one of the most important features of the human brain. ANNs are widely applied in many scientific fields such as engineering, economics, medicine, psychology, meteorology and mathematics. These applications are mostly used for estimation, data filtering, optimization and system control.

Today, ANNs are classified according to different criteria. ANNs are divided into two categories as feedforward networks and feedback networks according to their structure as in Figure 4.1. In addition, artificial neural networks can be classified according to learning techniques and the number of layers.

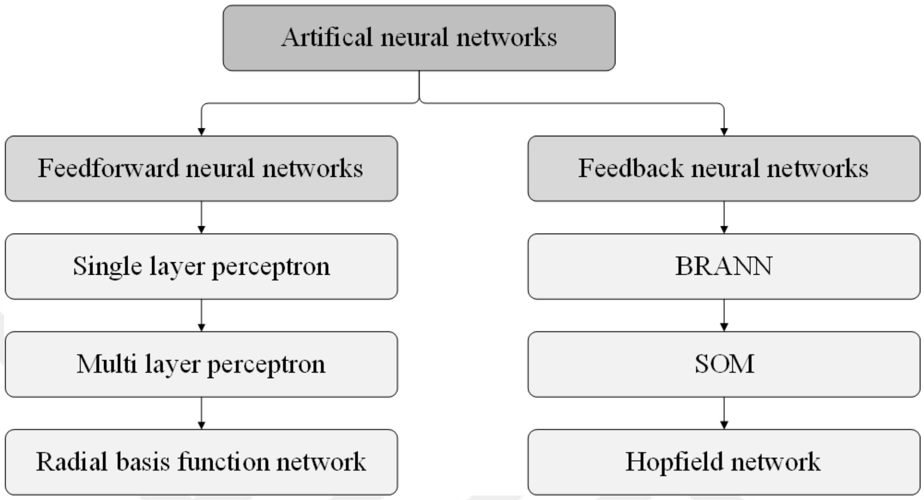


**Figure 4.1.** Types of artificial neural networks (Atkinson and Tatnall, 1997).

In Feedback Neural Networks, it is the type of network in which the intermediate layer and the output layers are connected to it or to another previous layer. In other words, neurons in a layer have connections not only with the next layers but also with their layers and layers behind them. Thus, inputs are transmitted in both forward and reverse directions. The basic structure of the feedback neural network is as shown in Figure 4.2.

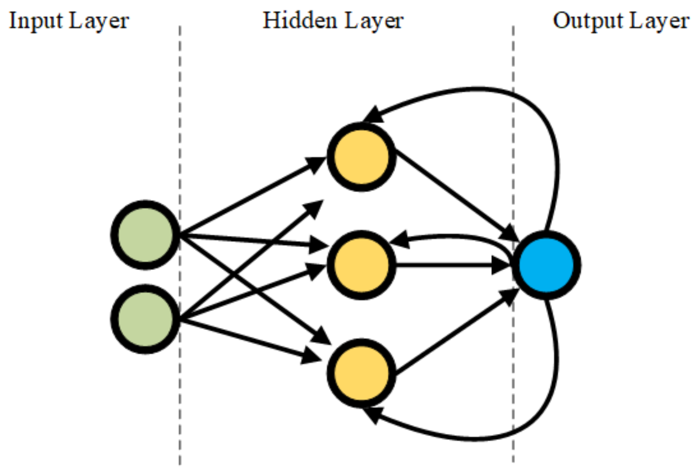


**Figure 4.2.** The basic structure of the feedback neural network.

Feedback networks have dynamic memories. Feedback loops create a certain delay across the network. As a result of this situation, it is observed that the transmission speed is lower in the feedback networks than in the feedforward networks. Feedback neural networks are mostly used for different applications for predictive purposes. Examples of feedback networks are networks such as Bayesian regularized neural network (BRANN), Kohonen self-organizing maps (SOM), and Hopfield.

The Feedforward Neural Network that one of the artificial neural network types has been used for output power prediction of the prototype system. It is presented in detail the FFNN methodology in section 5.2.

### 4.1.2. Artificial intelligence in renewable energy systems

Artificial intelligence technology is used in almost all of the renewable energy systems. In renewable energy systems, artificial intelligence technology is used for different purposes. These are widely used for the design, size optimization, cost optimization, energy management and estimation methods of renewable energy systems.

Artificial intelligence-based algorithms are developed to perform wind power prediction, wind speed prediction and error diagnosis in wind energy systems. Scientific fields such as data mining methods, probability models, neural network models, fuzzy logic are used in wind power prediction. Wind speed prediction is one of the most important studies in wind energy systems. Wind speed repairs are carried out for different time intervals. As a result of these analyzes, the most suitable wind turbine type is determined for the region where the wind energy system will be installed. ANFIS and GA are used for wind speed estimation. By integrating ANN method and wavelet transform, error diagnosis is made in wind power systems.

Artificial intelligence is widely used in solar energy systems for different purposes. ANN method is mostly used in solar energy systems. In solar tracking systems, artificial intelligence technology is used to estimate the amount of solar radiation and to estimate the power of the photovoltaic energy system. Genetic algorithm (such as PSO) based simulations are performed in power estimation and solar tracking systems of photovoltaic energy systems. The use of artificial intelligence technology in solar energy systems is increasing rapidly day by day. New developments are taking place with the increase in the demand and demand for solar energy. This increases the number of studies on solar energy systems. The results obtained from simulations based on artificial intelligence guide the installation of solar energy systems. In addition, it helps to increase the efficiency of solar energy systems.

The number of scientific studies using artificial intelligence technology in geothermal energy systems is less than studies on wind and solar energy sources. However, in recent years, thanks to the developments in artificial intelligence technology, the use of artificial intelligence in geothermal energy systems have been increasing. ANN method, evolutionary algorithms, fuzzy logic, ANFIS and hybrid methods are mostly used in geothermal energy systems.

Improvements of this energy system are realized by integrating artificial intelligence technology hydroelectric power plants. With the data obtained from these plants, artificial intelligence technology is used for different purposes. In general, different methods such as ANN method, genetic algorithms, fuzzy logic and ANFIS are widely used in the design and energy management of hydroelectric power plants. Thus, an optimum design is suggested, and hydroelectric power plants are installed at optimum cost. It is necessary to use the ANN method to calculate the peak discharge and time of this energy system and to realize water flow modeling. In addition, ANFIS methods are used to estimate the flow of water in hydroelectric power plants. In order to achieve the optimum material selection, it was aimed to reach optimum installation cost by using fuzzy logic method. In addition, in recent studies, it is observed that the ANN method, trained with Ant herd optimization, is used in estimating the output power of hydroelectric power plants.

The number of energy systems producing electricity from ocean energy is less than other renewable energy sources. The location of the countries is very important for the installation of these energy systems. These energy systems are installed in regions with high ocean energy potential. In ocean energy systems, estimation of water level, wave height, wave parameters and dispersion coefficient estimation are important to study areas. ANN and ANFIS methods are widely used in water level estimation. Studies are carried out to increase the accuracy of the results obtained from these two methods. In addition, ANN methods are widely used in wave height prediction.

In renewable energy systems where biomass is used as an energy source, artificial intelligence technology has an important position. Artificial intelligence technology which is the most used in bioenergy is the ANN method. It is observed that artificial intelligence technology is used in bioenergy systems for different purposes in different application areas. Biogas production optimization, methane gas estimation, $H_2S$ and $NH_3$ detection in biogas, price estimation of biomass used as energy sources are very important topics in bioenergy systems. Many scientific studies have been carried out on these issues. ANN, GA, PSO, fuzzy logic-based simulations are performed in biomass energy systems.

Hydrogen energy is also among renewable energy sources. Environmentally friendly hydrogen energy has been increasing in different fields in recent years. It is a combustible energy source such as hydrogen, gasoline and natural gas. Petroleum derivatives became an environmentally friendly energy source by emitting superiority compared to fuels. It is widely used in vehicle and fuel cell technology for military and industrial purposes. Artificial intelligence is used in hydrogen energy systems to increase efficiency, reactor heat prediction and energy consumption management. When the artificial intelligence methods used in hydrogen energy systems are examined, it is seen that the methods used in other renewable energy sources are used. Hydrogen energy source is also called as environmentally friendly fuel of the future. The number of interests and applications of hydrogen energy systems will increase day by day.

An overview of artificial intelligence technologies used in renewable energy systems is presented in this part of the thesis. In recent years, many applications have been observed in which artificial intelligence technology is integrated into renewable energy systems. By developing new generation genetic algorithms, these algorithms are used to make improvements in renewable energy systems such as efficiency, size and cost.

Interest in renewable energy systems has been growing significantly in recent years. With technological developments, the need for energy is increasing day by day. Thus, the trend towards alternative energy sources is observed to obtain energy. Renewable energy sources are superior to other energy sources thanks to their lack of a certain amount of reserves and a minimal negative impact on the environment. However, there is no continuity in the output power of renewable energy systems. Fluctuations and variations in output power are observed at different time intervals of the day. Many scientific research and development studies are carried out to eliminate this situation observed in renewable energy systems or to minimize losses.

Output power estimation in renewable energy systems enables planning for energy management. Different methods and algorithms are widely used to perform this output power estimation. In the literature review section of the thesis, estimation techniques used in renewable energy systems are presented comprehensively.

#### 4.1.3. The power prediction in solar energy systems

Among the renewable energy sources, solar energy usage areas and its applications are quite numerous. Due to many advantages of solar energy, the installation of solar energy systems is quite high. The lack of a limited amount of solar energy reserves, quiet, reliable and zero gas emissions are among its most important advantages. Many scientific studies are carried out by using AI technology in different application areas to increase the performance of solar energy systems.

In the developing and specialized electricity market, it is vital to increase the efficiency of solar power plants and to maintain the supply-demand balance and to know the amount of electricity to be produced in order to trade electricity under better conditions. For this purpose, hourly, daily values, production capacity, percentage and other relevant parameters for total power for solar power plant operators should be estimated. Energy obtained from solar energy systems is constantly changing according to different weather conditions. Thus, it is observed that the amount of electricity produced is at very different levels during the day. This situation increases the importance of the subject of estimation in solar energy systems. In solar energy systems, estimations are generally made on issues such as output power, solar radiation and installation cost. The data obtained as a result of estimation methods guide the energy management and installation. In today's conditions, it is important for the profitable sustainability of the electricity trade that every power plant knows how much it will produce during the day and at the end of the day and notifies the production amount to be realized to the relevant institution. In addition, daily, weekly, monthly and annual energy production plans can be made thanks to the solar power output estimation. Different input parameters are used to estimate solar output power. In general, input parameters such as air temperature, sunshine time, solar radiation, air humidity, current, voltage and air pressure are used to realize this estimate.

# 5. MATERIALS AND METHODS

## 5.1. The design and manufacturing of prototype system

Solar energy systems can be installed in a different way such as roof PV system, ground PV system, floating PV system and carport solar system. In recent years, new energy systems have been installed in which solar panels are integrated with other renewable energy sources. In particular, hybrid energy systems can be consisted in different structures where solar energy and wind energy are used together. Renewable energy applications with photovoltaic panels integrated on wind turbines are offered as new generation alternative energy systems in the literature. Such hybrid systems are widely used on trains, electric vehicles and rural areas. These energy systems feed the loads for different purposes according to their installed powers. In addition, topologies of hybrid energy systems differ according to AC and DC loads. The experimental setup for the prototype of novel rotary system is as shown in Figure 5.1.

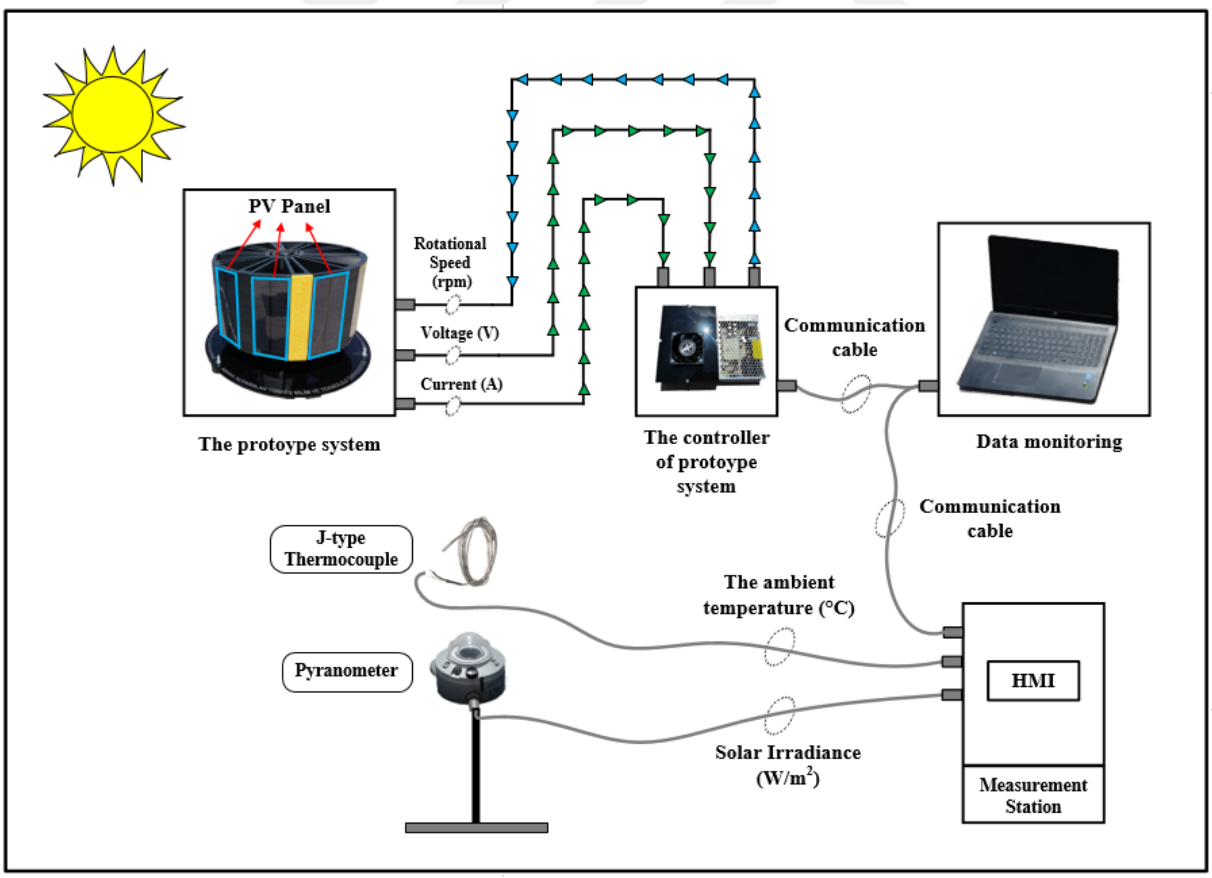


**Figure 5.1.** The experimental setup for the prototype of the novel rotary system.

In the thesis, a novel rotary hybrid energy system is presented in detail. There are two effective parameters for performance of PV panel: temperature and solar radiation. The rise in solar radiation increases energy production. Increasing ambient temperature means the losses of the solar cells increase and decrease their efficiency. So, high temperature is an undesirable situation in photovoltaic energy systems. To increase panel temperature in order not to negatively affect energy production. So, in this work overheating of the panels is prevented thanks to the rotation movement with the prototype rotary system. Thus, the negative effect of high-temperature levels on energy production was overcome.

The dimensions of the prototype are determined specifically according to the dimensions of the solar panels. The manufacturing of some parts for prototype was produced using 3D printer technology. Product productions such as difficult geometries, molds and hollow designs that standard production techniques do not allow are made possible with 3D printers. With many future improvements, 3D printer technology is likely to be integrated into many different application areas.

The advantages of 3D printer technology are as follows;

- Flexible Design
- Rapid Prototyping
- Print on Demand
- Strong and Lightweight Parts
- Minimising Waste
- Cost Effective
- Fast Design and Production
- Environmentally Friendly

Due to the many advantages described above, the proposed rotary system is produced by the 3D printer. Since 3D printer technology has many advantages, this technology is used in this thesis. Firstly, it is an important issue that the parts of the rotary system are easy to manufacture. In addition, manufacturing was realized at less cost. The rotary system manufactured has lightweight parts. Photovoltaic panels were designed to be mounted on the side surfaces of the rotary system. The height and diameter of the prototype rotary system 210 mm and 295 mm, respectively.

After some parts of rotary system was produced by the 3D printer, the panels were mounted on surfaces. A total of 10 solar panels were integrated on the rotary system at certain intervals. The dimensions of these solar panels are 140x60x2.5 mm. There is a 30 mm distance between each panel. The photovoltaic panel in the rotary system is as shown in Figure 5.2.

**Figure 5.2.** The photovoltaic panels in the rotary system.

**Table 5.1.** The properties of photovoltaic panel.

| Properties | Values |
|---|---|
| Rated Voltage | 6 V |
| Rated Current | 100 mA |
| Material Type | Polycrystalline Silicon |
| Conversion Efficiency | ≥17% |
| Weight | 33 g |
| Dimension | 140x60x2.5 mm |

Special air ducts are designed to prevent the rotary system from being adversely affected by the high temperature. Thanks to these air ducts, heat accumulation is prevented by providing airflow. Air ducts in the proposed rotary system are as shown in Figure 5.3. There are also a total of 10 air ducts. The length and depth of the air duct are 95 mm and 150 mm, respectively.


**Figure 5.3.** Air ducts in rotary system.

The output cables of the panels mounted on the proposed rotary system are entangled during the rotational motion. In order to overcome this problem, a slip ring was used in the prototype. The used prototype slip ring model is the hollow shaft series RH50.S0605. The properties electrical and mechanical of the slip ring are presented in Table 5.2. The position of this slip ring in the rotary system is as shown in Figure 5.4.

**Table 5.2.** The electrical and mechanical properties of Slip ring.

| Properties | Values |
|---|---|
| Rated Voltage | 240V DC / 240V AC |
| Rated Current | 5A/Ring |
| The cable Material | AWG22 |
| The cable Size | 250 mm |
| The dielectric constant | 500VAC@50Hz, 60s |
| The resistivity of insulating materials | ≥500MΩ/ 500VDC |
| Electrical noise | ≤0.01Ω |
| Rated Speed | 0~400rpm |
| The operating temperature | (-)20°C (+)80°C |
| IP code | IP51 |

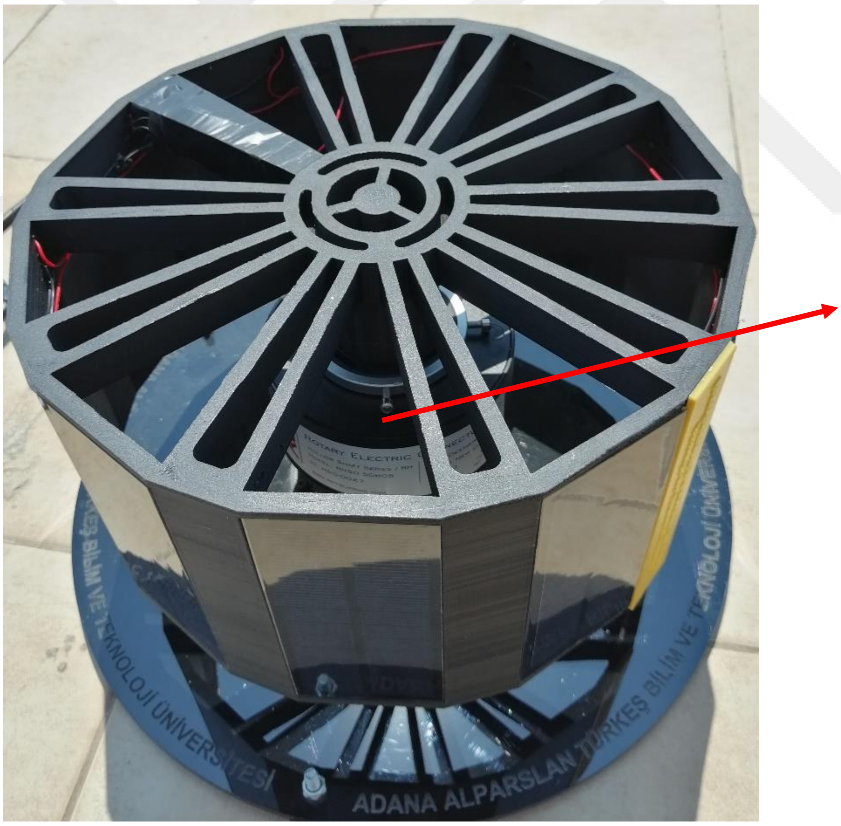


**Figure 5.4.** The position of slip ring in the rotary system.

The slip ring used in various application areas is available in different sizes. A slip ring in the size suitable for the dimensions of the rotary system produced by the 3D printer was used. The slip ring dimensions used are as shown in Figure 5.5. Each of the output cables of the photovoltaic panels is connected with a slip ring. In addition, the performance analysis of the slip ring used in the rotary system was carried out in the laboratory environment. According to the experimental data obtained, the efficiency of the slip ring was approximately 96%.

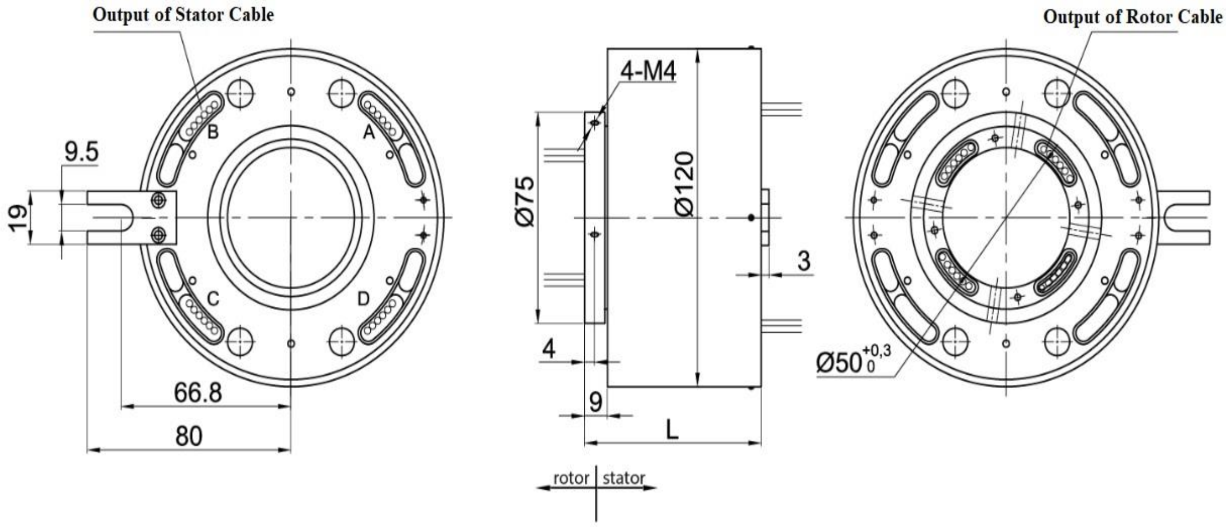


**Figure 5.5.** Slip ring dimensions in millimeters used in the rotary system (Demirdelen et al., 2020).

The successful integration of the rotary system, photovoltaic panel and slip ring components manufactured by the 3D printer was realized as in Figure 5.6.


**Figure 5.6.** The slip ring, photovoltaic panel and rotary system integration.

In the next step, a controller design has been realized for the proposed rotary system. In addition, an interface program has been created for the controller. The designed controller is connected to the rotary system. The controller mainly consists of power supply, processor, stepper motor and motor driver parts. Mean Well LRS-150-12 model is used as the power supply. The features of this power supply are as shown in Table 5.3. The controller designed and manufactured for the rotary system is as seen in Figure 5.7.

**Table 5.3.** The properties Mean Well LRS-150-12 power supply of controller.

| Properties | Values |
|---|---|
| Input Voltage Range | 85~132V AC / 170~264V AC<br>240 ~ 370V DC |
| Input Leakage Current | <0.75 mA / 240V AC |
| Output Voltage | 12V DC |
| Output Current | 12.5 A |
| Output Rated Power | 150 W |
| Efficiency | 87.5 % |
| Operating temperature | (-)30 ~ (+)70°C |
| Dimension | 159x97x30 mm |
| Net weight | 0.48 kg |

Atmel ATMEGA328P is determined as the processor of the controller device. The ATMEGA328P microprocessor is suitable for low power needed projects. The properties of this microprocessor are as shown in Table 5.4.

**Table 5.4.** The properties ATMEGA328P microprocessor.

| Properties | Values |
|---|---|
| Supply Voltage | 1.8 V ~ 5.5 V |
| CPU type | 8-bit AVR |
| Flash memory | 32 KB |
| Maximum operating frequency | 20 Mhz |
| Pin count | 28 |
| Maximum I/O pins | 23 |
| Operating temperature | (-)40 ~ (+) 85 |

The NEMA 23 stepper motor is integrated into the system to carry out the rotational motion of the proposed prototype system. There are some advantages of the used this stepper motor in controller of the rotary system. Since the mechanical structure of stepper motors is simple, the maintenance of these motors is easy. It can be controlled by electronic devices such as computers and microprocessors. The features of NEMA 23 stepper motor are as shown in Table 5.5.

**Table 5.5.** The features NEMA 23 stepper motor.

| Properties | Values |
|---|---|
| Operating voltage | 8.6 V |
| Operating current | 1 A on each phase |
| Step number for each tour | 200 |
| Step angle | 1.8° |
| Phase resistance | 8.6 Ω |
| Phase inductance | 14 mH |
| Cable length | 30 cm |
| Dimensions | 56.4x56.4x76 mm |
| Weight | 1 kg |

The TB6600 stepper motor driver is used for rotation speed adjustment. The step number for each tour is 200. Step settings are adjusted as 1/64 on the motor driver. The step resolution of the stepper motor is increased by dividing a single step into 64 parts. Since the motor used is a step motor, a separate sensor is not used for speed verification. The specifications of TB6600 stepper motor driver are as shown in Table 5.6.

**Table 5.6.** The specifications of TB6600 stepper motor driver.

| Properties | Values |
|---|---|
| Input current | 0 ~ 5 A |
| Output current | 0.5 ~ 4 A |
| Drive mode | Dual constant current PWM drive output |
| Micro Step | 1, 2/A, 2/B, 4, 8, 16, 32 |
| Operating temperature | (-)10 ~ (+)45℃ |
| Dimension | 96x56x33 mm |
| Humidity | No Condensation |
| Weight | 0.2 kg |

The rotational speed of the proposed prototype system in the present work is adjusted by this controller. The rotating speed can be adjustable up to 0 to 100 rpm. The rotating speed of the prototype system is determined by the controller interface.

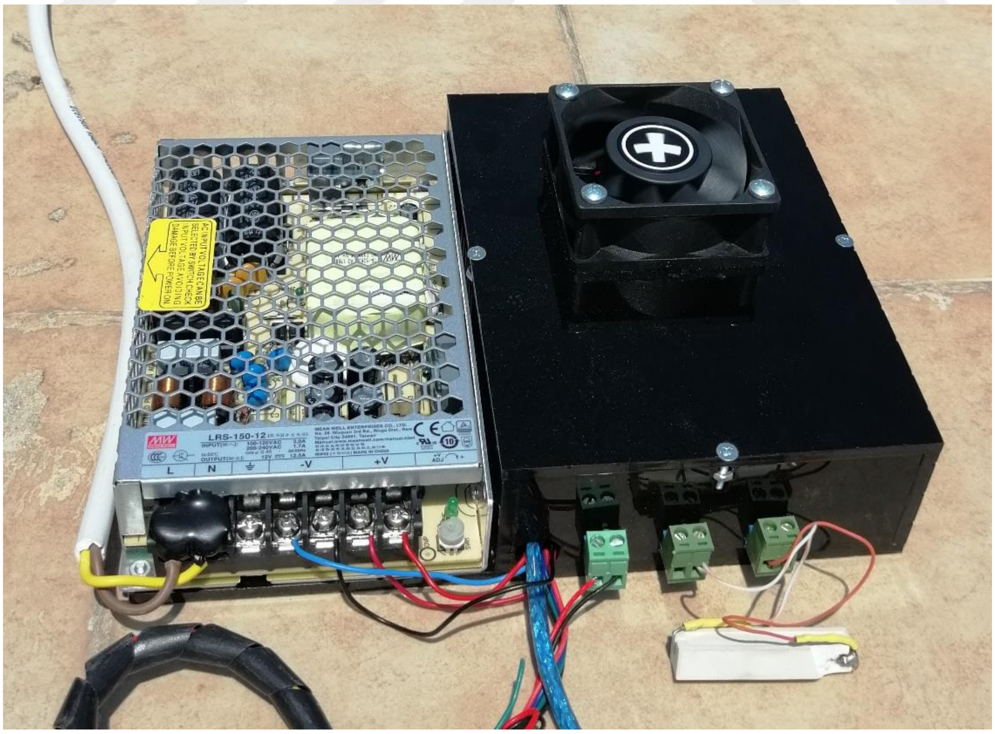


**Figure 5.7.** Designed controller for rotary system.

Thanks to the controller, current and voltage data for the proposed rotary energy system are observed instantly. In addition, the graphics of current and voltage values are created instantly. In this way, the current and voltage values of the proposed rotary system can be observed on the time. The interface of controller program, where the speed is adjusted and the data (current and voltage) change can be observed, is as seen in Figure 5.8. This program instantly saves current, voltage and power data in a file.

The interface of controller program was developed in Microsoft Visual Studio 2019 software in "C Sharp" (C #) programming language. The data flow between the program and experimental setup is provided by the "RS-232" serial communication. In this serial communication, the program interface receives the output voltage and current data of the rotary system. Rotational speed (rpm) data is sent to the controller through the program interface. This program shows the time-dependent graph of the current and voltage values it receives. The received and sent data are recorded in the Comma Separated Values (CSV) format. Thus, this data can be used in data processing programs such as Matlab, Excel, etc.

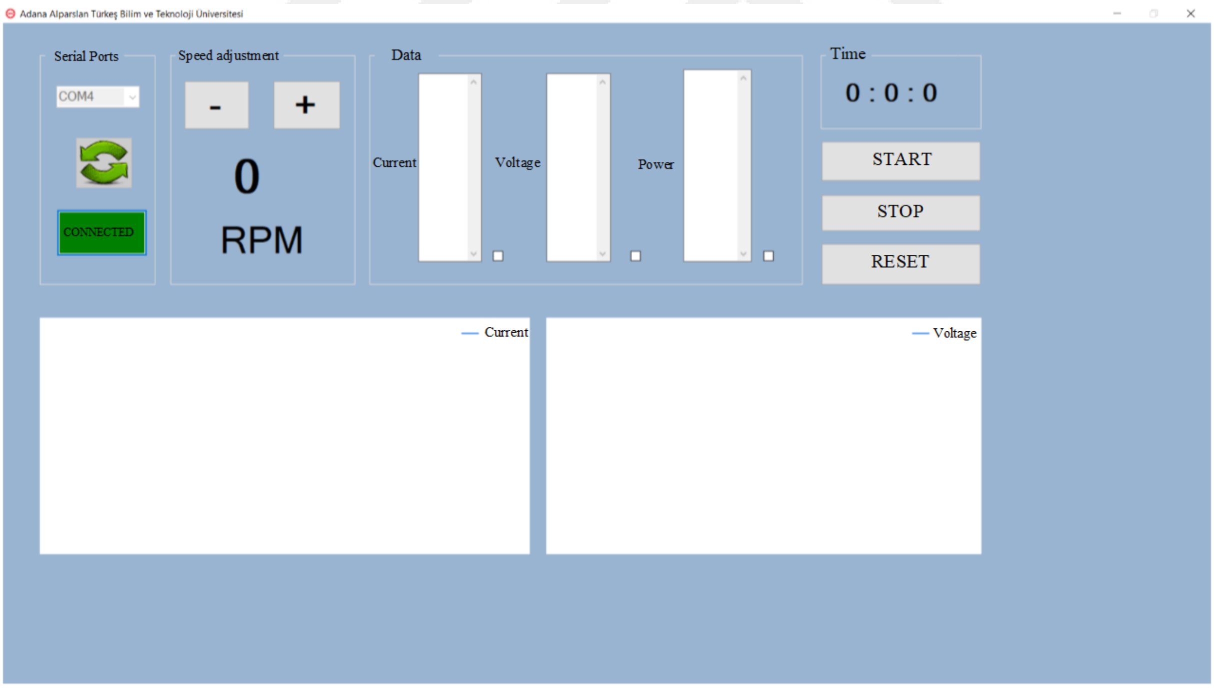


**Figure 5.8.** The interface of the controller program.

The controller records the instantaneous current, voltage and output power data of the rotary system. Ambient temperature and solar radiation data are recorded by the measurement station. The measurement station and the internal structure of the measurement station are shown in Figure 5.9 and Figure 5.10, respectively. Thanks to the Human-Machine Interface (HMI) display on this measuring station, ambient temperature and solar radiation data can be displayed instantly. Solar radiation and temperature data are recorded by the data logger one second logging interval in the measuring station. Pyranometer and J type thermocouples were used for solar radiation and temperature measurement, respectively. The used pyranometer model is Lambrecht version 00.16131.1000000. The properties of used pyranometer are as shown in Table 5.7. The sensitivity of pyranometer is 15,07 μV/Wm-2. Thermocouple model is IEC 584 Fe-Const type J version TC-M06-L030-K03.J Emko.

**Table 5.7.** The properties of Lambrecht pyranometer.

| Properties | Values |
|---|---|
| Power supply | 24VDC |
| Power consumption | < 48 mW |
| Measuring range | 0 ~ 3000 W/m$^2$ |
| Inclination error | < ± 2 % |
| Power consumption | < 48 mW |
| Measuring elements | Thermopile |
| Measuring principle | Thermal difference measurement |
| Operating temperature | (-)40 ~ (+)80℃ |
| Weight | 0.64 kg |
| Protection class | IP67 |

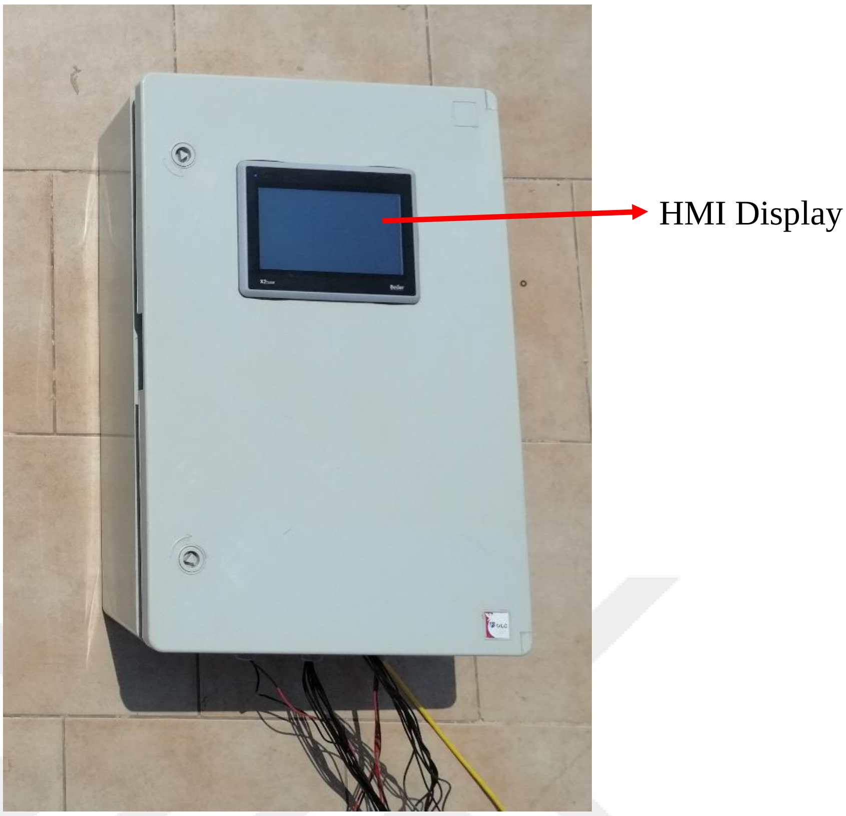


**Figure 5.9.** The measuring station.

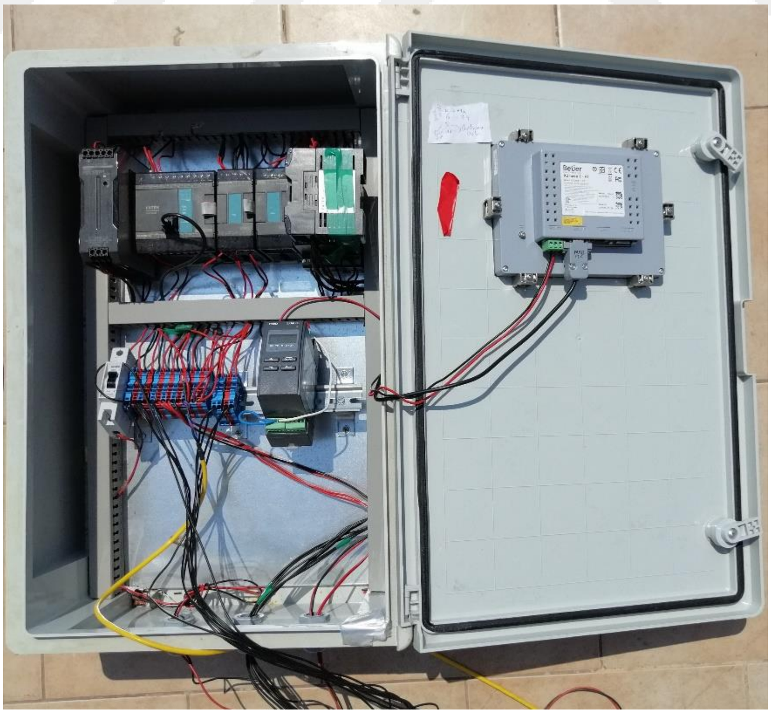

**Figure 5.10.** The internal structure of measuring station.

The proposed rotary system consists of photovoltaic panels, slip ring, controller and measuring station components. These components have been successfully connected as shown in Figure 5.11. Thus, energy production and control of the proposed rotary system are provided in the roof of the building.

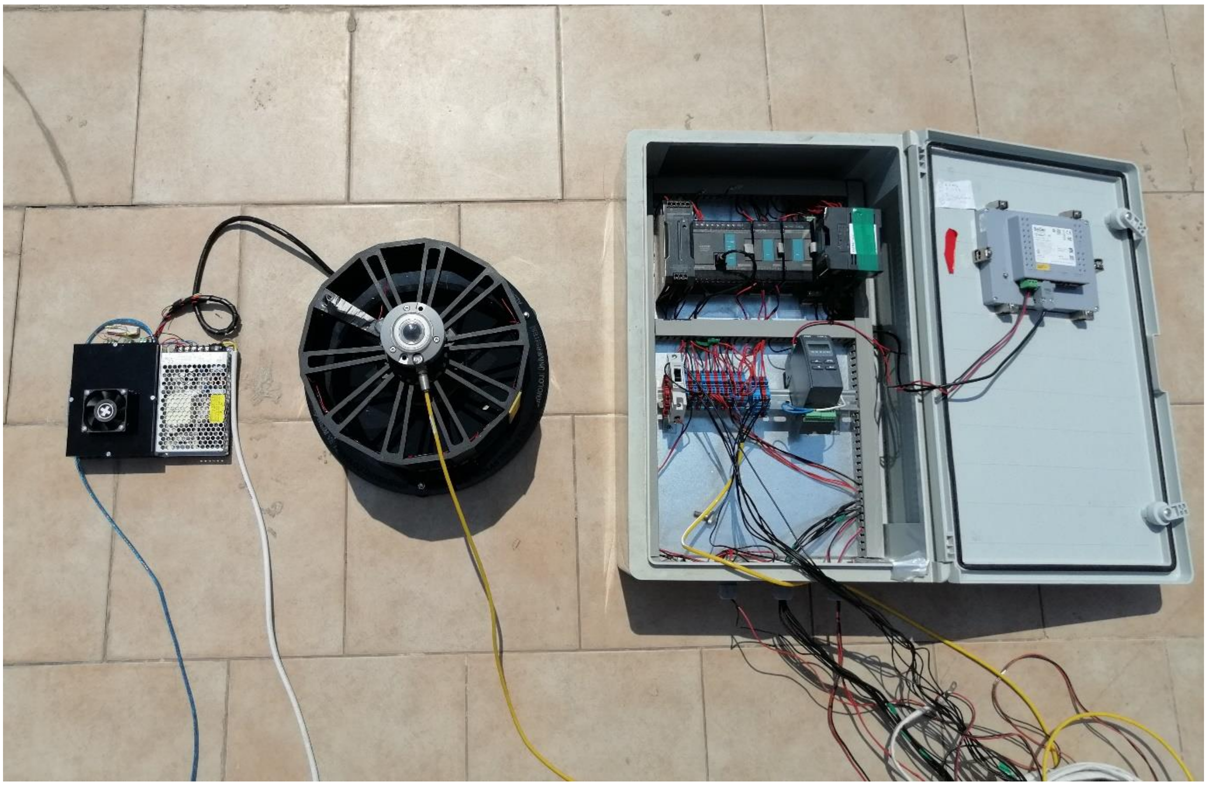

**Figure 5.11.** The whole system of the prototype for the proposed system.

The design stages and components of the proposed rotary system are presented in this section. In the design process, firstly, the dimensions of the rotary system were decided. According to the determined dimensions, the manufacturing of the rotary system was carried out using a 3D printer. The rotary system produced by the 3D printer has strong and lightweight parts. Later, photovoltaic panels were mounted on the rotary system. The slip ring was used as the most important part of the rotary system. Thanks to slip ring technology, the problem of entanglement of the cables of photovoltaic panels has been overcome. In addition, a controller design was realized for the rotary system. Thanks to this controller, the rotation speed can be adjusted. The rotary system was operated at the desired rpm values. In addition, the controller instantly records current, voltage and power values. Thanks to the program of the controller, the time-dependent graph of the current and voltage can be observed. Part of the proposed rotary system is the measuring station. Thanks to the measurement station, the rotary system records the ambient temperature and solar radiation with the help of a data logger while generating energy. In addition, ambient temperature and solar radiation data can be observed instantly from the HMI display of measurement station.

After all these design stages, proposed rotary system is presented in detail. As a result of the improvements to be made on this rotary system, the proposed prototype will turn into an industrial product. This prototype product will be installed in a rotary system with high power levels in the future. The proposed prototype rotary system can meet the energy demand of the buildings integrated into the roofs. The proposed rotary system has become a reliable, silent, environmentally friendly and long-life energy system.

## 5.2. Feedforward Neural Network

Feedforward Neural Networks (FFNN) are the type of networks in which processes between neurons in a layer are continuously flowing forward. In this type of network, neurons have connections with the layers ahead. In a feedforward network, artificial neural cells are usually separated into the input, hidden and output layers. Neurons in the input layers are transmitted unilaterally by the artificial neural cells to the output layer, without connection in the same layer. The information transmitted along the hidden layers is processed in the output layer and the network's output is created. Thus, the artificial neural network output can be observed in a short time. Feedforward networks have a static network structure. The basic structure of the feedforward neural network is as shown in Figure 5.12.

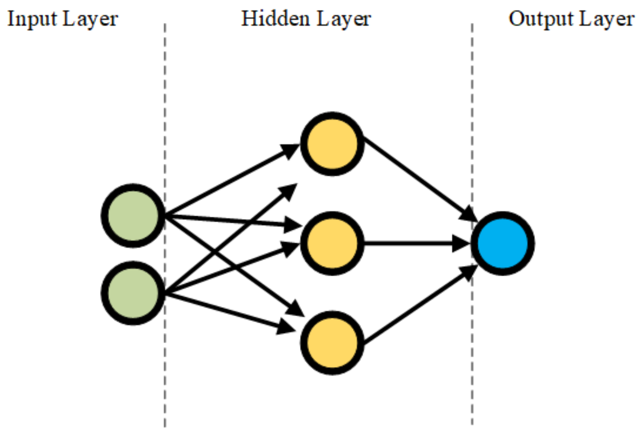


**Figure 5.12.** The basic structure of the FFNN.

The number of input data is equal to the number of neurons in the input layer. Each input neuron represents data. In this layer, data is transferred to the next layer without processing. The hidden layer performs the basic function of the network. In some applications, there may be more than one hidden layer in the network. The number of hidden layers and neurons vary in different applications. Using an unnecessary number of neurons in the hidden layer results in less sensitive output than input data. On the other hand, if more neurons are used than necessary, difficulties arise in processing new types of data groups in the same network. The output layer processes the data received from the hidden layer with the function of the network and outputs it. The values obtained from this layer are the output values of the artificial neural network for the problem in question. In the feed-forward phase, neurons in the input layer transmit data values directly to the hidden layer. Each neuron in the hidden layer calculates the total value by weighting their input values and transmits them to a forward layer or directly to the output layer by processing them with a transport function.

## 5.3. Particle Swarm Optimization

Particle Swarm Optimization (PSO) was developed in 1995 by Kenedy and Eberhart scientists, inspired by the behavior of animals such as fish and insects moving in swarms (Eberhart and Kennedy, 1995). PSO is basically an optimization method based on swarm intelligence. It has been observed that the random movements of the animals moving in herds to meet their food and safety needs enable them to reach their goals more easily. PSO algorithm is based on social information sharing between individuals. In this optimization algorithm, each individual of the swarm is called a particle, and the population of particles is called a swarm. Each particle adjusts its position to the best position in the swarm, based on previous experience. PSO is basically based on approximating the position of individuals in the swarm to the best-positioned individual of the swarm. Generally, individuals in the swarm have been observed to be better than according to the previous position in their new movements.

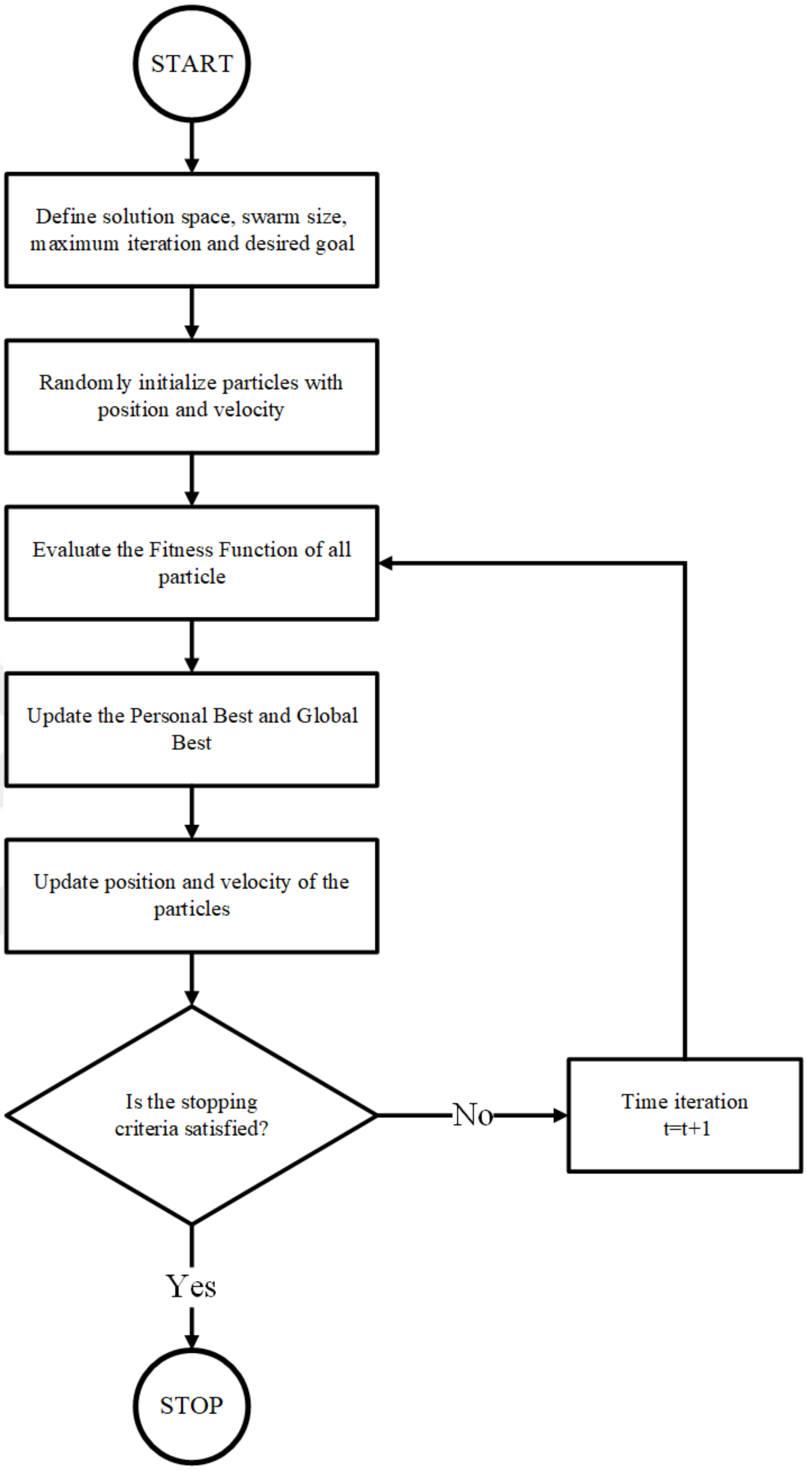


**Figure 5.13.** The basic flowchart of the PSO (Esenboga and Demirdelen, 2020).

In the PSO algorithm, new solutions are produced as much as the number of particles in each iteration. For this reason, it has been observed that the proposed algorithm is very fast in searching for the optimum result. The number of particles and iterations are directly proportional to the complexity of the problem. The increase in the number of particles and iterations means that the algorithm increases the time to search for the solution. PSO is an algorithm used in the literature in many scientific fields including non-linear equations such as artificial neural network training, fuzzy system control, antenna design.

In PSO, first of all, the swarm that will search the solution and the necessary parameters are determined. With the help of the fitness function, the proximity of the particles to the solution is measured and the personnel best and global best values are updated according to these values. Then, the movement of each particle is determined with the rate of change function and its new states are set. The approach to the solution is checked with the repeat fitness function. This cycle is repeated until the desired conditions are reached. The basic flowchart of the PSO is shown in Figure 5.13.

# 6. RESULTS AND DISCUSSIONS

The performance analysis of the prototype have been carried out and the results are presented in detail.

## 6.1. Experimental performance analysis of the prototype

The prototype of the novel rotary system was designed and manufactured. Experimental studies have been carried out to observe the reliability and efficiency of the prototype system. The experimental studies of the prototype were carried out on the roof of the faculty building.

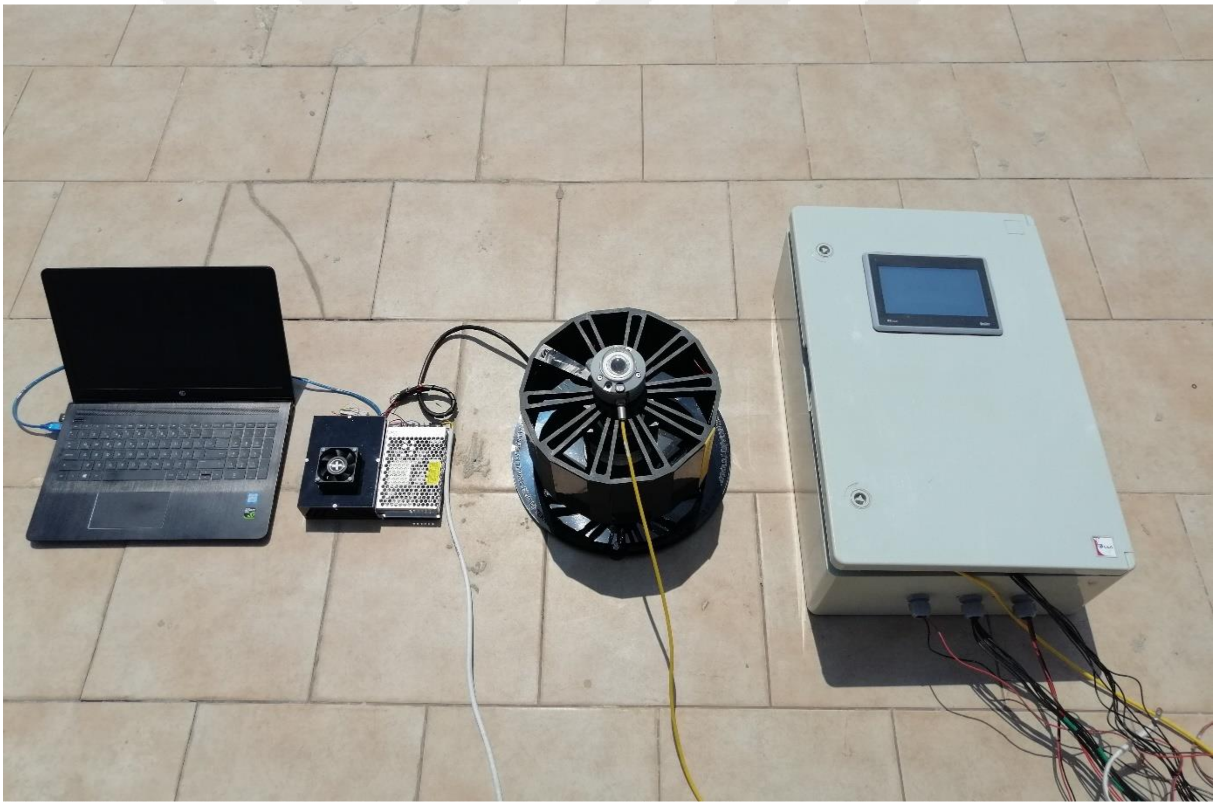

**Figure 6.1.** All equipments for experimental setup.

The controller of the proposed rotary system is connected to the laptop via a USB port. In this way, the rotary system is provided to rotational motion in the desired rpm value. Output power, current and voltage data are recorded by the controller of the rotary system one-second logging interval.

### 6.2. The data collection technique from the proposed prototype

The proposed rotary system was installed on the faculty building roof. Then experimental studies were carried out to collect data. These are current and voltage of the prototype, solar radiation and temperature. Experimental studies have been carried out under the different climate conditions in order to demonstrate the applicability of the proposed system. I-V and P-V characteristics of the solar panels were obtained from experimental studies. I-V and P-V curves of the panels that mounted on the proposed rotary system are as shown in Figure 6.2 and Figure 6.3, respectively.

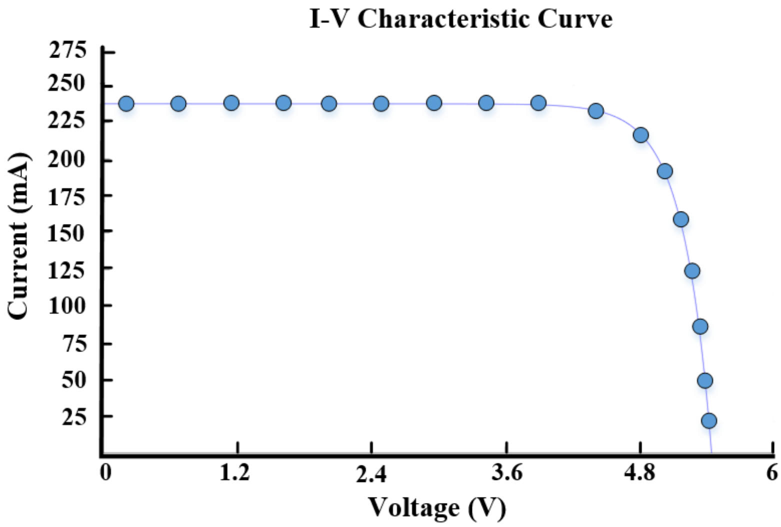


**Figure 6.2.** I-V curves of the panels that mounted on the proposed rotary system.

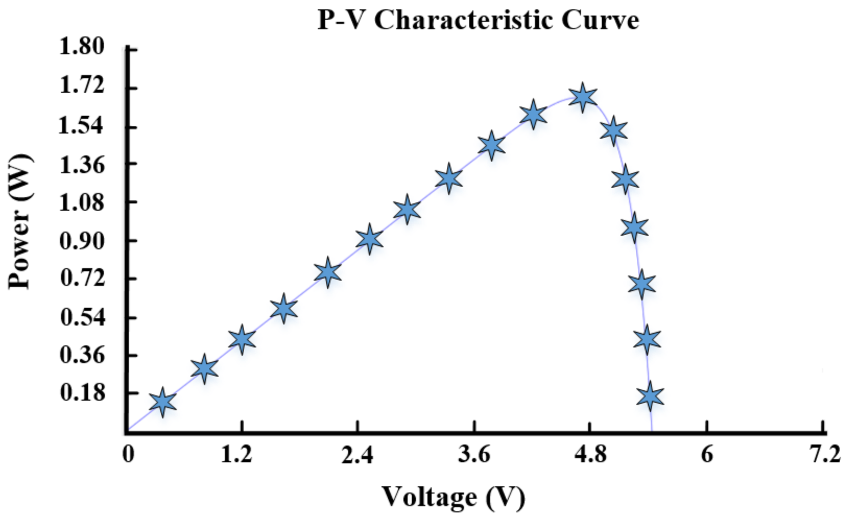


**Figure 6.3.** P-V curves of the panels that mounted on the proposed rotary system.

The output power, current and voltage values of the proposed rotary system are realized by the designed the controller. The controller is designed to read and save data in one second. Thus, changes in current and voltage are more clearly observed. The proposed rotary system was operated at different rpm values and the current and voltage values were observed using the software of the controller. The proposed rotary system was operated at 0, 10, 50 and 100 rpm.

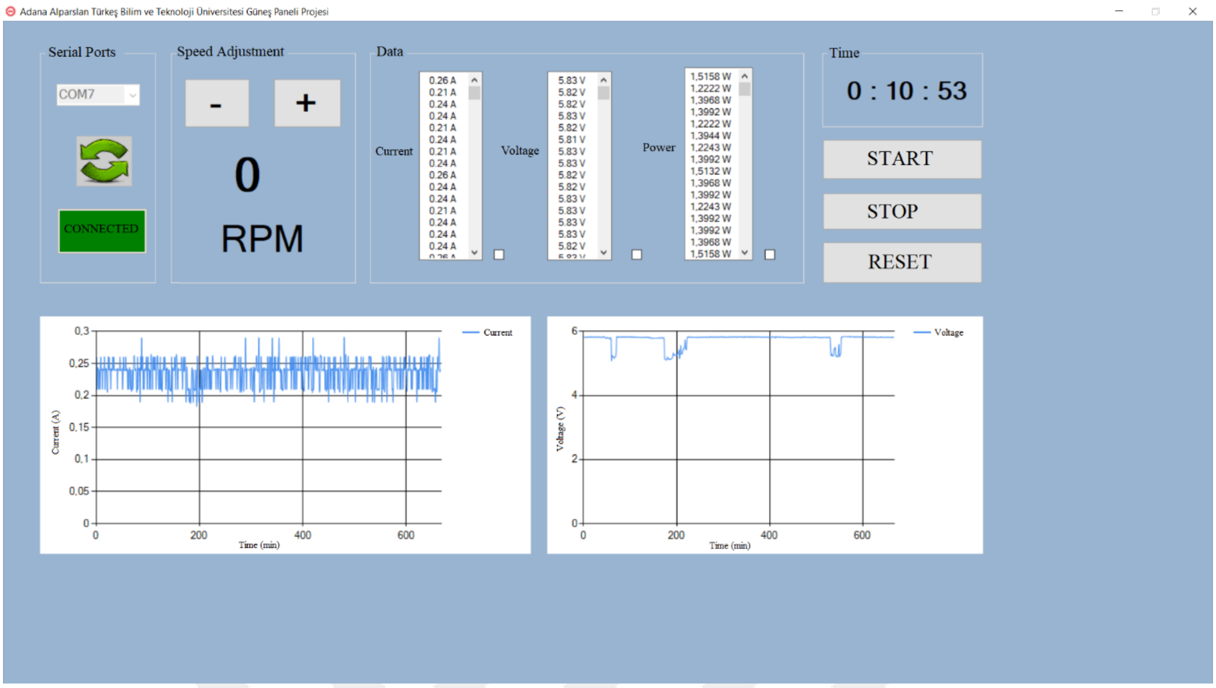


**Figure 6.4.** The current and voltage graphs of the rotary system without rotation (0 rpm).

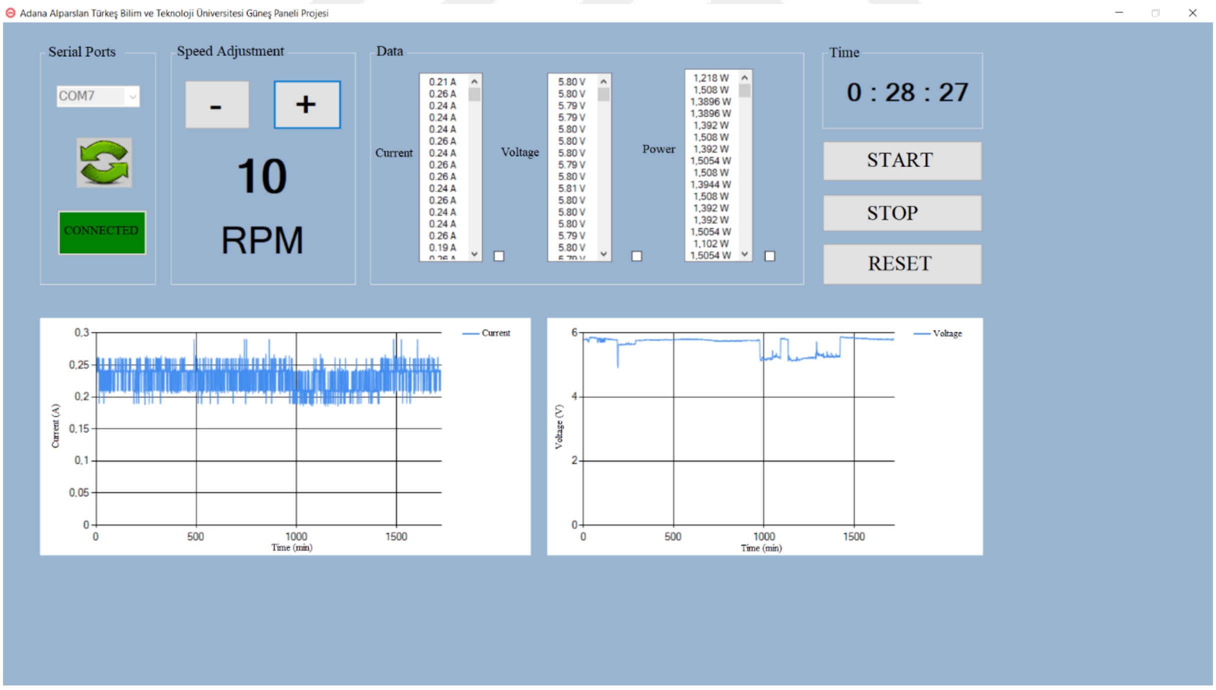


**Figure 6.5.** The current and voltage graphs of the rotary system at operated 10 rpm.

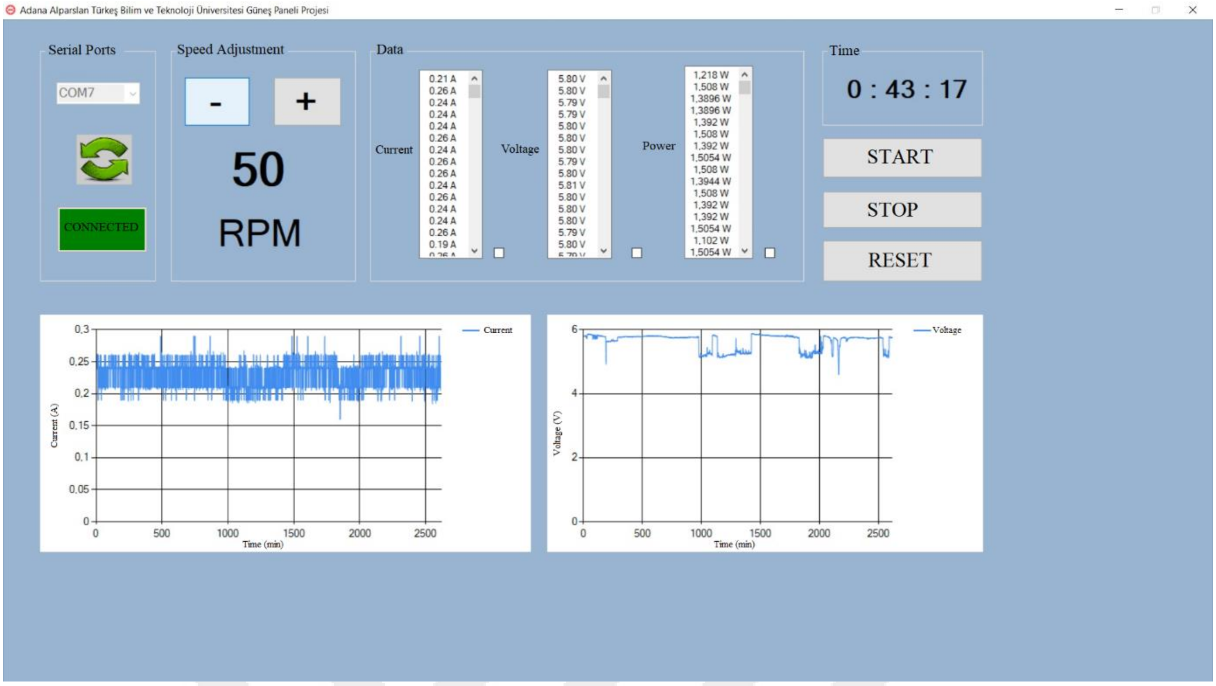


**Figure 6.6.** The current and voltage graphs of the rotary system at operated 50 rpm.

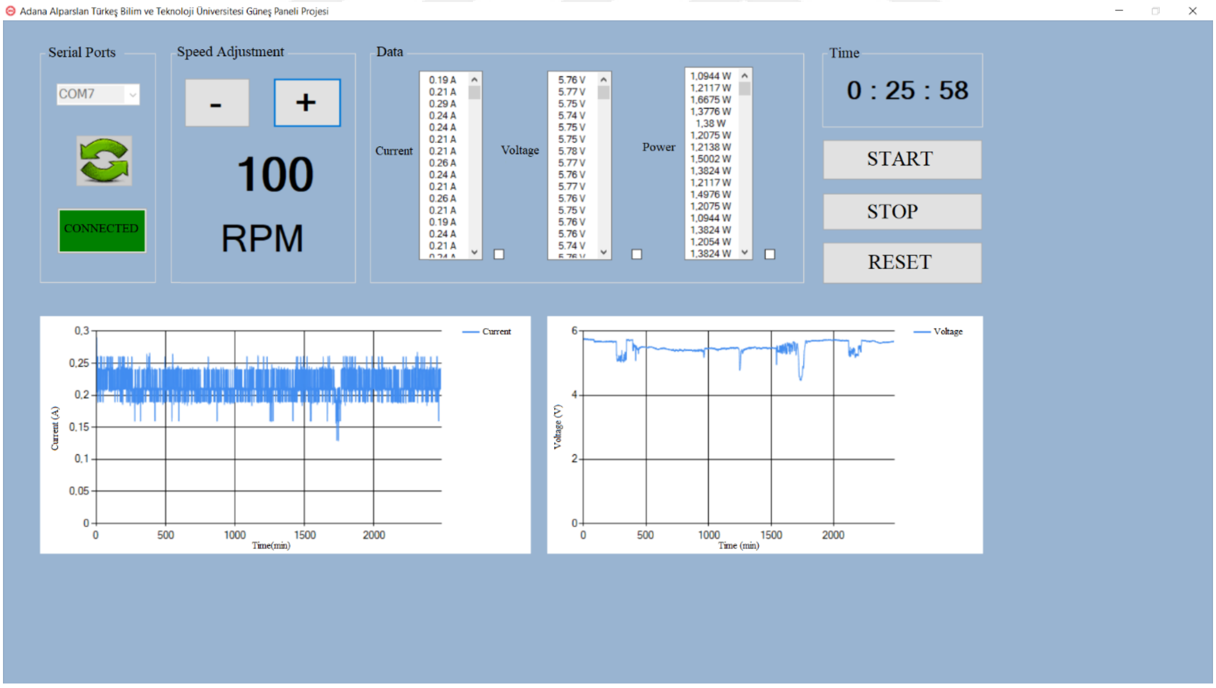


**Figure 6.7.** The current and voltage graphs of the rotary system at operated 100 rpm.

The current and voltage graph of the proposed rotary system operating at 0, 10, 50 and 100 rpm values are shown in Figure 6.4, Figure 6.5, Figure 6.6 and Figure 6.7, respectively.

The rotary system was operated on different days and hours to perform the output power prediction. The current, voltage and output power data of this energy system were recorded by the controller. The data repository was created to predict the output power of the proposed rotary system. A part of the output power data repository recorded by the controller is presented in Figure 6.8, Figure 6.9, Figure 6.10 and Figure 6.11. Experimental studies of the rotary system at operated 0, 10, 50, and 100 rpm have been carried out between 110 W/m$^2$ and 1210 W/m$^2$ solar radiation. The lowest and highest output power and solar radiation values of the rotary system operated at 0, 10, 50 and 100 rpm are shown in Table 6.1.

**Table 6.1.** The lowest and highest output power and solar radiation values of the rotary system operated at 0, 10, 50 and 100 rpm.

| **Rpm** | **Solar Radiation** | | **Output Power** | |
|---|---|---|---|---|
| | The lowest value (W/m$^2$) | The highest value (W/m$^2$) | The lowest value (W) | The highest value (W) |
| 0 | 207 | 1155 | 0.7872 | 1.6120 |
| 10 | 121 | 1210 | 0.5698 | 1.7893 |
| 50 | 110 | 1035 | 0.8480 | 1.7777 |
| 100 | 191 | 1089 | 0.6513 | 1.8067 |

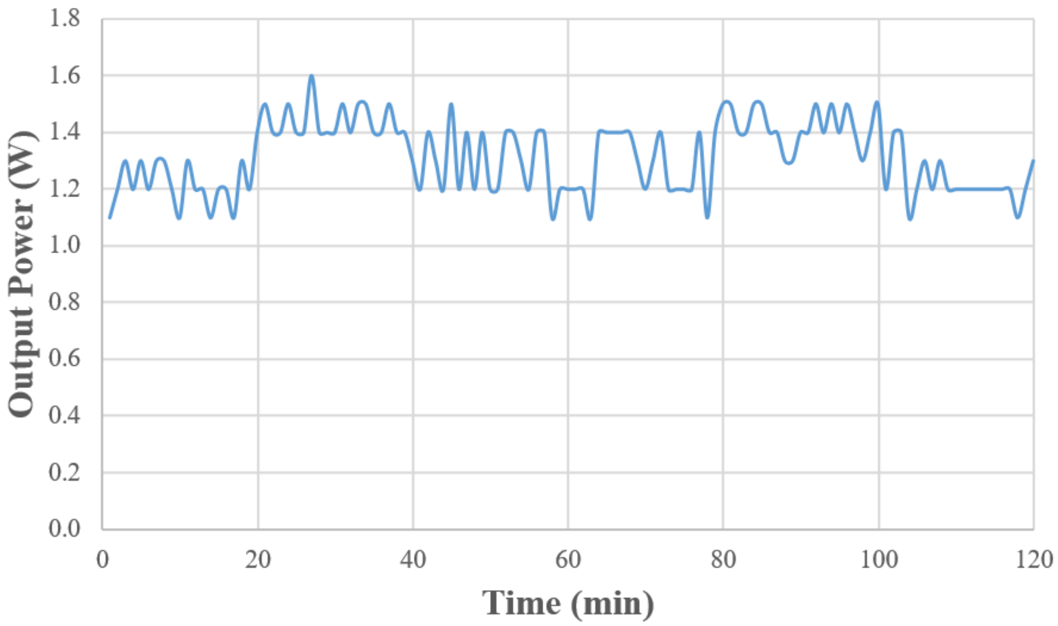


**Figure 6.8** A part of the output power data recorded by the controller operating at 0 rpm between 230 W/m$^2$ and 848 W/m$^2$ solar radiation on 22 April 2020.

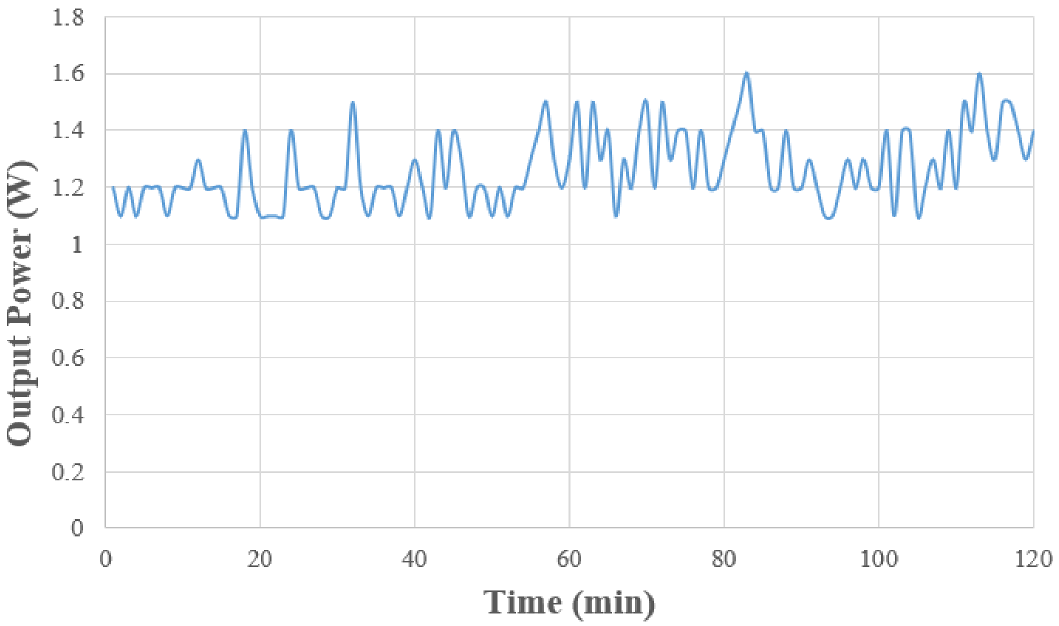


**Figure 6.9** A part of the output power data recorded by the controller operating at 10 rpm between 215 W/m$^2$ and 577 W/m$^2$ solar radiation on 23 April 2020.

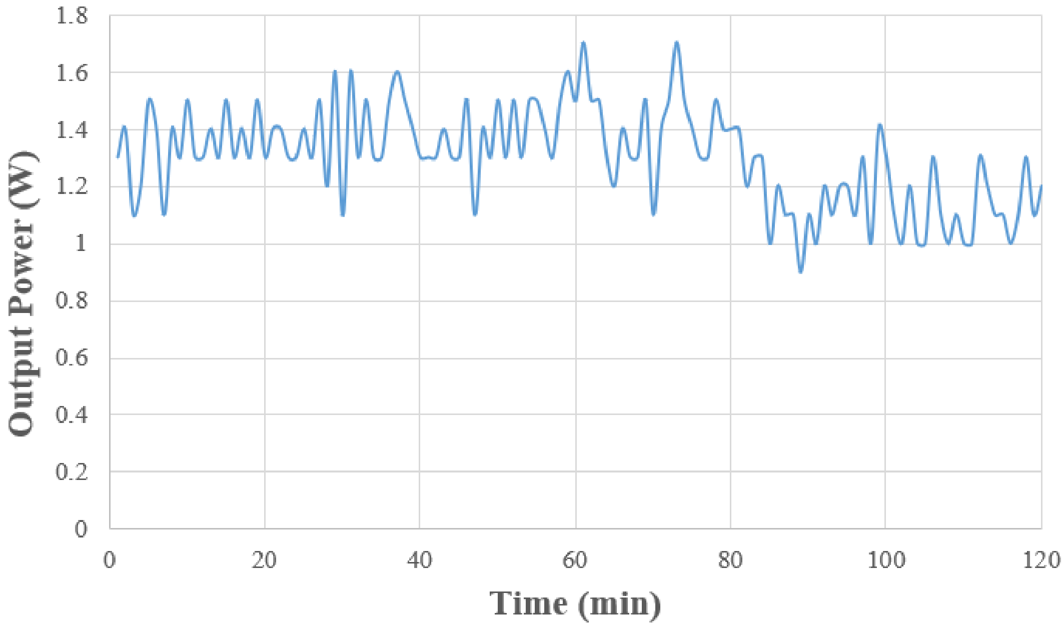


**Figure 6.10** A part of the output power data recorded by the controller operating at 50 rpm between 186 W/m$^2$ and 745 W/m$^2$ solar radiation on 24 April 2020.

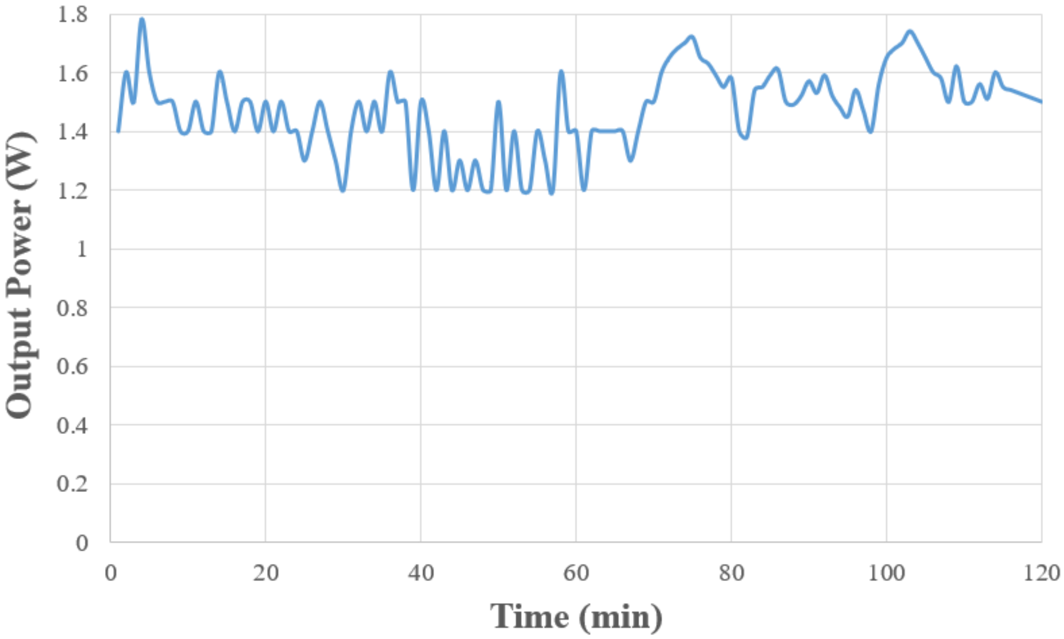


**Figure 6.11** A part of the output power data recorded by the controller operating at 100 rpm between 245 W/m$^2$ and 1115 W/m$^2$ solar radiation on 25 April 2020.

Ambient temperature and solar radiation data were also recorded to use as input data for power output prediction of the prototype. These data were carried out by the measuring station. Furthermore, solar radiation and temperature data were instantly observed from the HMI display in the measurement station. The data repository was created for the data obtained from the measurement station. A part of the solar radiation and ambient temperature data obtained as a result of experimental studies repository recorded by the measurement station is presented in Figure 6.12 and Figure 6.13, respectively.

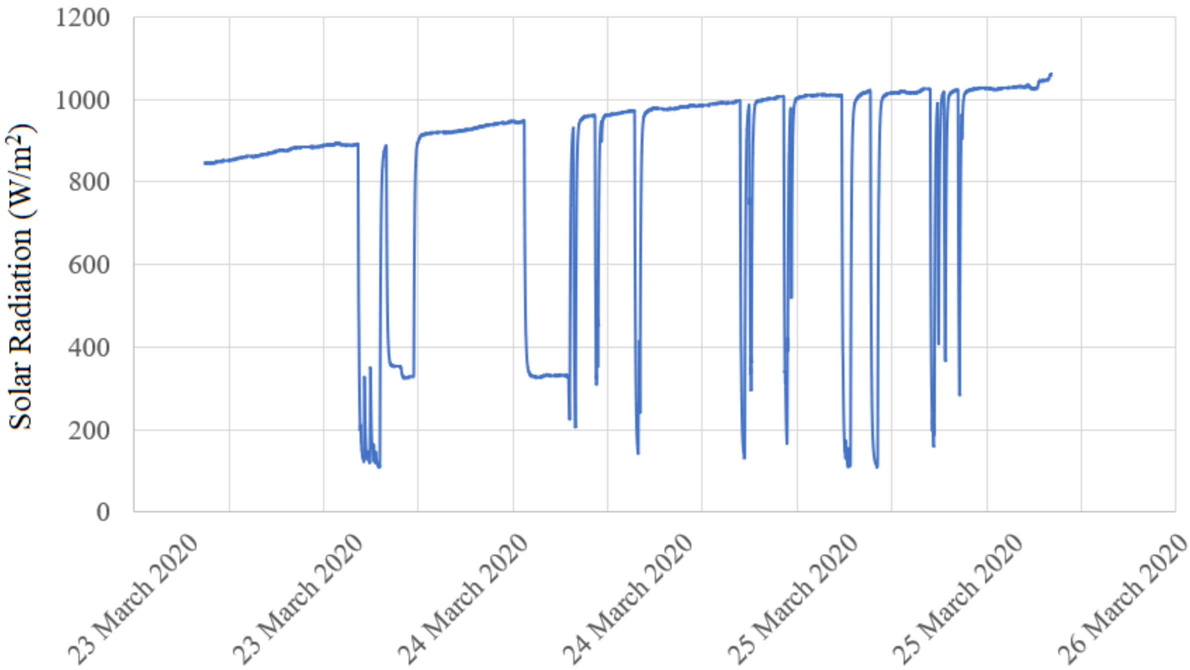


**Figure 6.12.** Graph of a part of the distribution of solar radiation data.

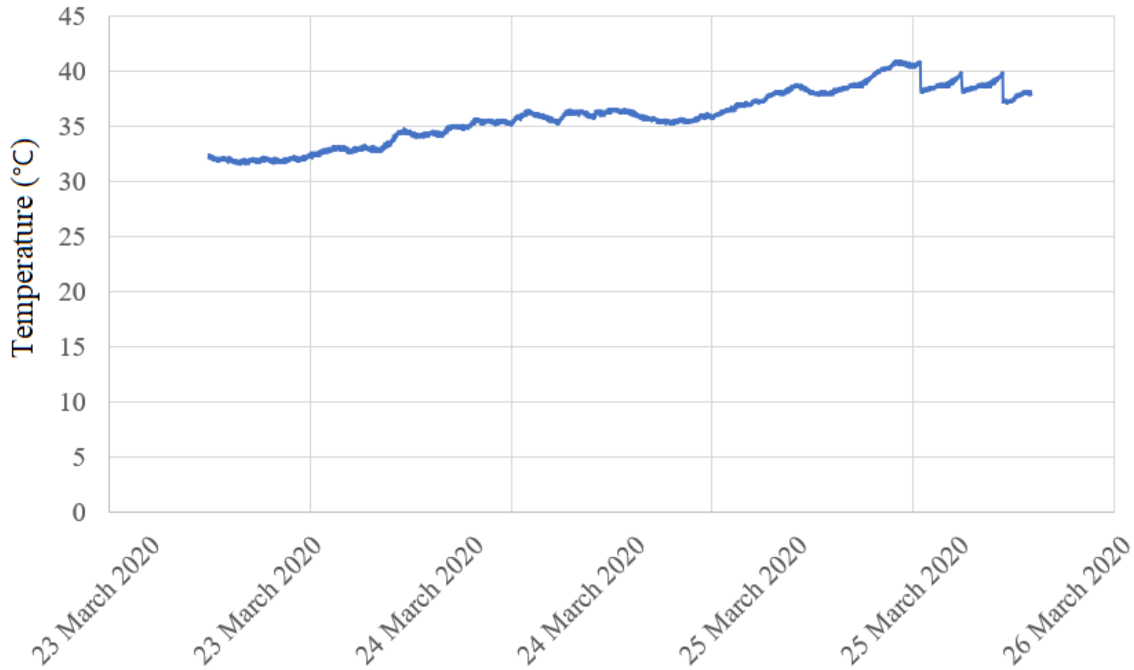


**Figure 6.13.** Graph of a part of the distribution of ambient temperature data.

## 6.3. Output power prediction of the prototype based on Feedforward Neural Network

Feedforward Neural Networks have basically three layers. These layers are input, hidden and output layers. The input layer is the layer that holds the data entering the artificial neural network. It is the hidden layer that training itself according to the desired result. Finally, it is the output layer that shows the output values. How many levels a hidden layer will be is completely determined by the problem. Each layer and level can contain one or more neurons cells.

In the thesis, Feedforward Neural Network structure is used for the output power prediction of the proposed prototype. In this network structure, it is carried out that output power prediction of the prototype system for four input layer neurons, eight hidden layer neurons, one output layer neurons and 300 epochs. Solar radiation, temperature, current and rpm values were determined as input data. Moreover, output power was determined as output data. The structure of the proposed FFNN is as shown in Figure 6.14.

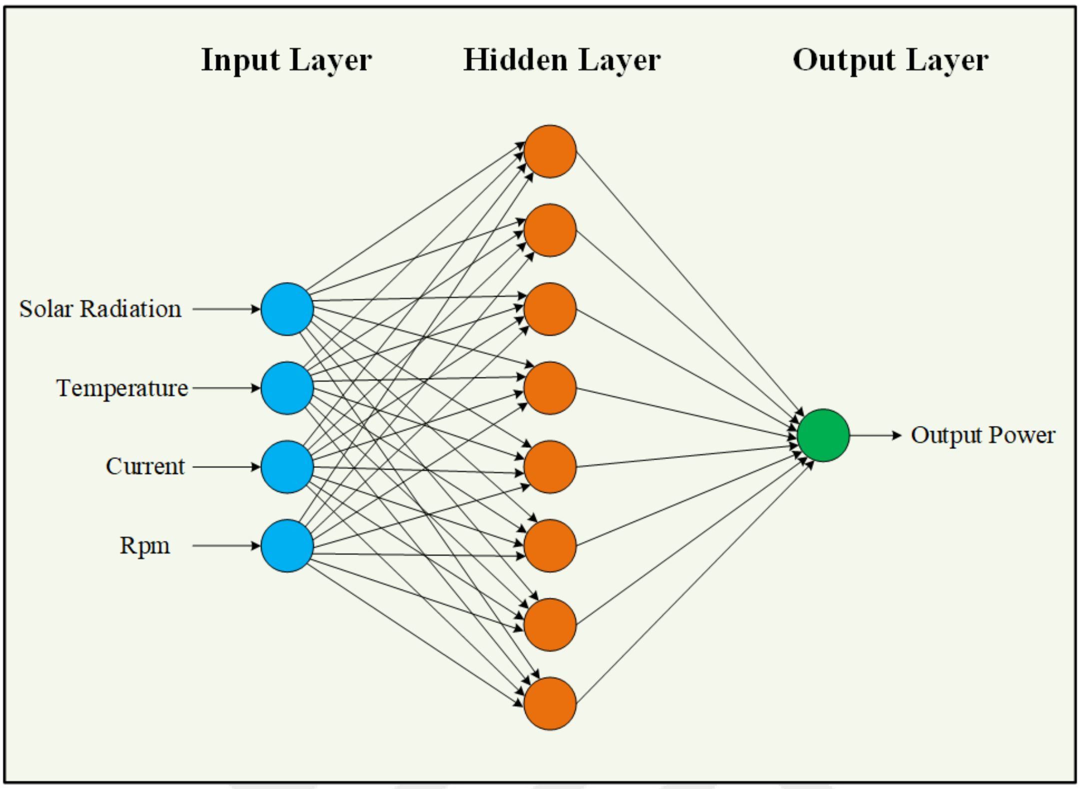

**Figure 6.14.** The structure of the proposed FFNN.

One-minute data from the proposed rotary system was used for this network structure. The total number of data for this network structure is 712. Among these data, 612 data were used for training, and the remaining 100 data were used for the test process. Three different error criteria such as Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Theil's Inequality Coefficient (TIC) are determined for the proposed rotary system's output power prediction.

In the power prediction of the rotary system error distribution of the power data are shown in Figure 6.15. The actual data and predicted data graphics obtained as a result of the FFNN based power prediction are as shown in Figure 6.16.

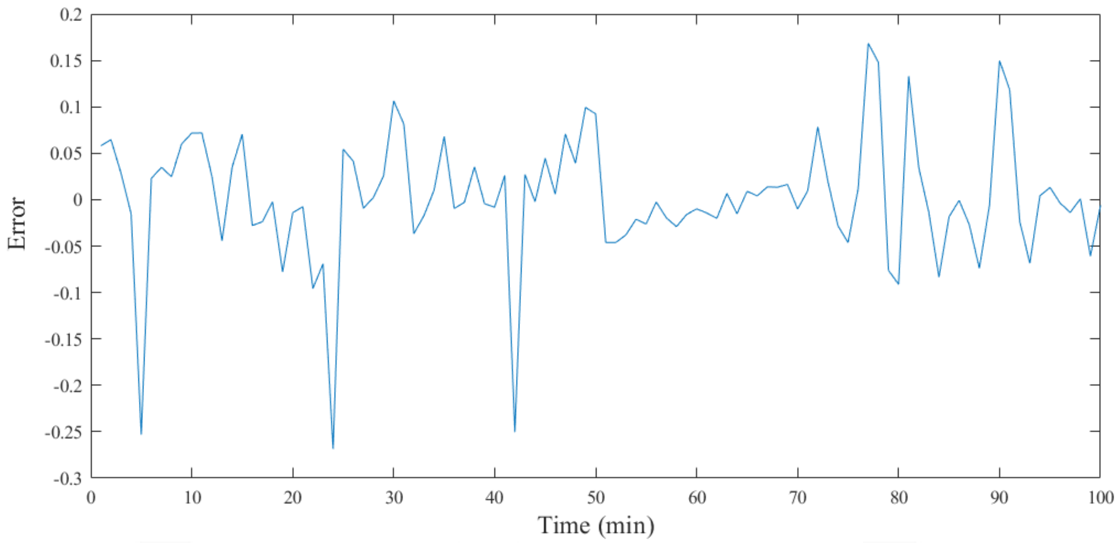

**Figure 6.15.** The error distribution graph of output power prediction based on FFNN.

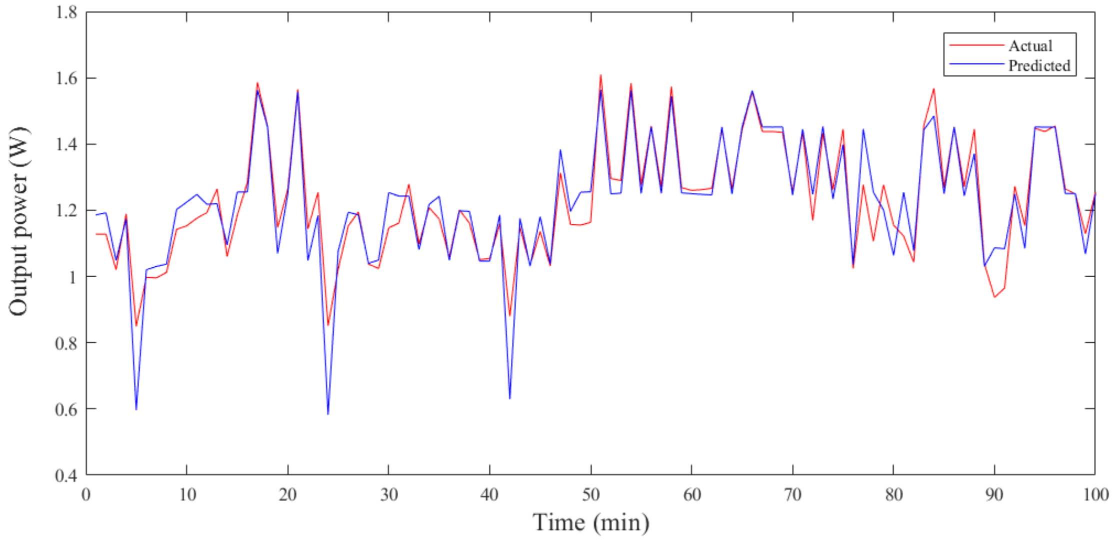

**Figure 6.16.** Output power prediction of prototype system based on FFNN.

## 6.4. Output power prediction of the prototype by using Feedforward Neural Network based on Particle Swarm Optimization algorithm

PSO is a method developed for continuous optimization problems inspired by the behavior of fish, flocks and some animals. When fish herds, birds herds and other social animals were examined, it was seen that these animals interacted while looking for food, and when one found food, others changed their positions in the direction they would eat and update their speed accordingly. This social interaction is modeled with PSO. This algorithm has a wide range of applications. Particle Swarm Optimization in the literature; It is an algorithm used in many fields including non-linear equations such as artificial neural network training, fuzzy system control, antenna design.

For the output power prediction of the proposed rotary system, the coefficients of the FFNN are trained with PSO. The twelve particles were used during the operation of the PSO algorithm. (In general, Particle Number is used between 20 and 40 in PSO) Results of power prediction based on PSO-FFNN are shown in Figure 6.17 and Figure 6.18. Moreover, RMSE, MAPE and TIC values are calculated to compare the accuracy of two prediction methods.

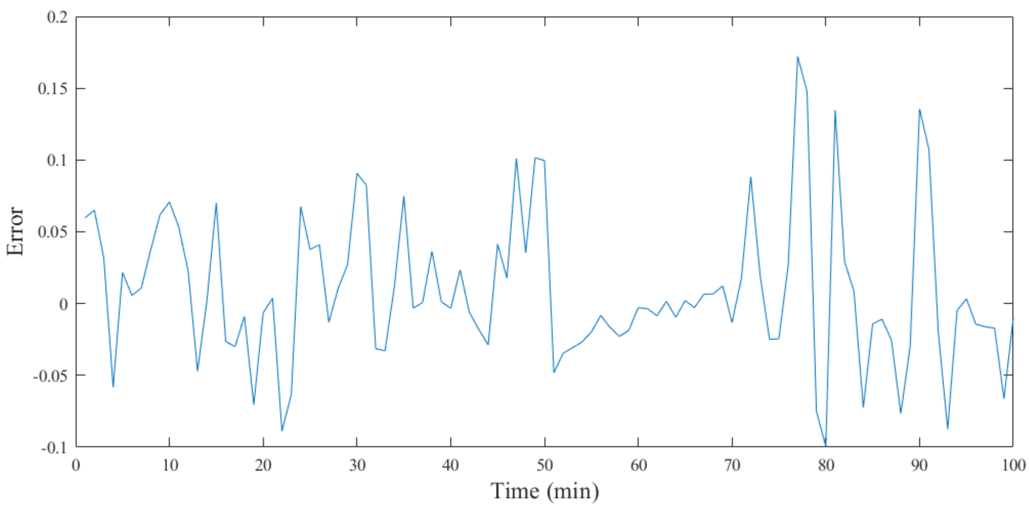


**Figure 6.17.** The error distribution graph of output power prediction based on PSO-FFNN.

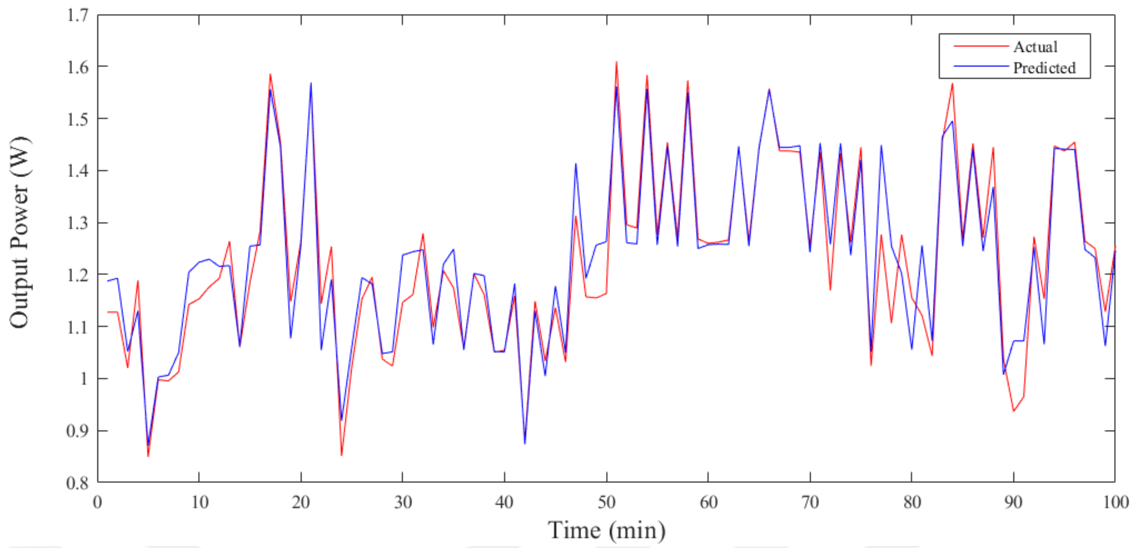


**Figure 6.18.** Output power prediction of prototype system based on PSO-FFNN.

## 6.5. Comparison of error criteria of two methods used in output power prediction

Two different methods for the output power prediction of the proposed rotary system were carried out using MATLAB software. RMSE, MAPE and TIC were determined as error criteria in the output power prediction obtained using FFNN and PSO-FFNN. The RMSE, MAPE and TIC values calculated for these two methods are shown in Table 6.2. It observed that output power prediction based PSO-FFNN is better than FFNN. RMSE, MAPE and TIC values are improved in percentage 3.077, 9.524 and 2.816, respectively, with PSO-FFNN.

$$RMSE = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(X_i^A - X_i^P)^2\right)} \tag{7}$$

$$MAPE = \frac{1}{n}\left(\sum_{i=1}^{n}\frac{|X_i^A - X_i^P|}{X_i^A}\right) x\ 100 \tag{8}$$

$$TIC = \frac{\sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(X_i^A - X_i^P)^2\right)}}{\sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(X_i^P)^2\right)} + \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(X_i^A)^2\right)}} \tag{9}$$

where $X_i^A$ is actual data, $X_i^P$ is predicted data and $n$ is sample size. The three criteria such as RMSE, MAPE, and TIC are employed in feedforward based on FFNN and PSO-FFNN output power prediction.

**Table 6.2.** The comparison of error criteria for output power prediction based on FFNN and PSO-FFNN.

| **The Methods** | **The Error Criteria** | | |
|---|---|---|---|
| | **RMSE** | **MAPE (%)** | **TIC** |
| Feedforward Neurol Network (FFNN) | 0.0690 | 0.0455 | 0.0278 |
| Particle Swarm Optimization (PSO) - Feedforward Neurol Network (FFNN) | 0.0530 | 0.0383 | 0.0213 |
| **Improvement (%)** | 23.19 | 15.82 | 23.38 |

It is observed that improvement of accuracy of output power prediction based on PSO-FFNN of the prototype system. RMSE, MAPE and TIC values with PSO-FFNN output power prediction are improved by 23.19%, 15.82% and 23.38%, respectively.

# 7. CONCLUSIONS

Due to the increasing interest in renewable energy sources, many academic studies have been carried out in last decade. Use of the hybrid systems has been increasing in these studies. Energy systems consisting of a single structure will find a place in the market as a product in the following years. With this thesis, we aimed to bring a novel rotary hybrid system to the literature and to provide the necessary data for the transformation of this porotype into a product. A detailed evaluation has been made thanks to the data obtained from experimental results. Many experimental studies have been carried out under the different climate conditions in order to demonstrate the applicability of the proposed system. 3D printer technology is used in the manufacture of the proposed rotary system. Thus, minimum cost, lightness, long life and reliability are provided. In addition, a study was conducted on the output power of the rotary system. The prototype was operated from 0 rpm to 100 rpm for effect of the rotation speed on the output power. The output power data of the operated prototype at 0 to 50 rpm in approximately 500 and 1000 solar radiation levels were compared. According to the experimental results, the effect of rotation speed (rpm) up to 50 rpm on the output power can not be changed significantly. Experimental studies of the rotary system at operated 0, 10, 50, and 100 rpm have been carried out between 110 W/m$^2$ and 1210 W/m$^2$ solar radiation. The highest output power of the rotary system is 1.8067 W at operating 100 rpm and 756 W/m$^2$ solar radiation. The lowest output power of the rotary system is 0.5698 W at operating 10 rpm and 234 W/m$^2$ solar radiation. Output power prediction based on PSO-FFNN and FFNN of the proposed rotary system has been performed. For output power prediction, RMSE, MAPE and TIC value are determined as error criteria. Using the FFNN, RMSE, MAPE and TIC values are 0.0690, 0.0455 and 0.0278, respectively. RMSE, MAPE and TIC values are 0.0530, 0.0383 and 0.0213, respectively in the PSO-FFNN. For the prototype, the better results were observed in PSO-FFNN Model. It is possible that the prototype rotary system will be transformed into an industrial product with higher power levels. In the thesis, it is presented that in detail an energy system that can be integrated into rotary systems in high buildings. With the manufacturing of the prototype, the experimental investigation and output power prediction is to become an industrial product of the proposed rotary system in the future.

# 8. RECOMMENDATIONS

A rotary system can be easily integrated thanks to its easy installation in buildings. The dependence on fossil fuels will decrease with the environmentally friendly the proposed novel rotary system. This novel rotary system has proven to be an energy system that can be used to feed different electrical loads in high buildings. Energy generation can be achieved by installing rotary hybrid system in the future. It can be demonstrated applicability to install the rotary system on wind turbines that will be integrated in high buildings in the future.

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# CURRICULUM VITAE

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