INTELLIGENT SOLAR ENERGY TOOLKIT

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INTELLIGENT SOLAR ENERGY TOOLKIT

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MANSUR ALP TOÇOĞLU

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Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Murat AŞKAR
Director

I certify that this thesis satisfies all the requirements for the degree of **Master of Science** in **Intelligent Computing Systems** option of **Intelligent Engineering Systems**.

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We have read the thesis entitled **Intelligent Solar Energy Toolkit** prepared by **Mansur Alp TOÇOĞLU** under supervision of **Prof. Dr. Murat AŞKAR** and we hereby agree that it is fully adequate, in scope and in quality, as a thesis for the degree of **Master of Science** in **Intelligent Computing Systems** option of **Intelligent Engineering Systems**.

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ABSTRACT

INTELLIGENT SOLAR ENERGY TOOLKIT

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In todays world, the trend of utilization percentage of the solar panel technologies is increasing day after day as its development process proceeds rapidly. As a result of that, the viewpoints of the investors change in a positive way in order to install new solar plants to create new investment areas. This thesis is developed under a SANTEZ Project "GEYOPA2" supported by the Ministry of Science, Technology and Industry, and Teknologis Ltd. Within the scope of the project, two solar plants in Ankara and İzmir have been installed together with data loggers for energy production and meteorological data. In order to foresee the produced solar energy, it is necessary to use prediction tools. In this thesis, a prediction tool is implemented artificial neural network (ANN) to predict the solar energy to be generated. To achieve this purpose, the ANN uses the produced solar energy and meteorological data as raw data, gathered from the solar plant installed in Ankara, to train itself. The outputs show that the accurate predictions can be obtained by using ANN. In addition, this thesis provides a solar plant investment payment chart for the users to give an idea about the reimbursements of a solar plant investments.

Keywords:Solar panel, solar energy, radiation, artificial neural network, energy prediction

ÖZ

INTELLIGENT SOLAR ENERGY TOOLKIT

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Güneş panel sistemlerinde teknolojinin hızlı gelişimiyle birlikte, bugünün dünyasında güneş panellerinin kullanım alanları artmaktadır. Bu gelişmeler, yatırımcılara güneş panel istasyonları kurarak yeni yatırım alanları açma yönünde pozitif bir bakış açısı kazandırmaktadır. Bu tez, “GEYOPA2” olarak adlandırılan, Bilim Sanayi ve Teknoloji Bakanlığı ve Teknologis Ltd. Şti tarafından desteklenen bir SANTEZ projesi olarak geliştirilmiştir. Proje kapsamında Ankara ve İzmir’de enerji üretimleri ve meteorolojik verileri kayıt altına alınan iki güneş panel istasyonu kurulmuştur. Üretilecek güneş enerjisini önceden tahmin edip yapılacak yatırımları öngörmek için, bilgisayar yazılımları kullanılması gereklidir. Bu tez çalışmasında, yapay sinir ağları (YSA) kullanarak, üretilen güneş enerjisini tahmin eden bir yazılım yapılmıştır. YSA Ankara’da kurulmuş olan güneş paneli istasyonundan elde edilen güneş enerjisini ve meteoroloji verilerini girdi olarak alıp kendini eğitmektedir. Sonuçlar YSA kullanarak doğru sonuçlara yakın tahminler elde edilebileceğini göstermektedir. Hazırlanmış olan bu tez, aynı zamanda kurulacak olan bir güneş paneli istasyonunun maliyetinin muhtemel geri ödemeleri ile ilgili kullanıcılara bir güneş enerjisi yatırım maliyeti tablosu da sunmaktadır.

Anahtar Kelimeler : Güneş panelleri, güneş enerjisi, radyasyon, yapay sinir ağları, enerji tahmini

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CHAPTER 1

INTRODUCTION

Today's world is addicted to the energy power as it has entered to the information age which requires to consumption of a huge amount of energy. Automobiles, electronical devices in homes, in offices and the ones are being used in factories can be given as examples. Briefly, it is inevitable for human beings to continue their lives without the absence of the energy. As it is that important for a human being, somehow it must be produced. To produce the energy needed, several resources are being used. Among these sources, the most important ones for today's world are petrol, natural gas, nuclear power and coal which are all nonrenewable energy resources. All of them are the raw materials of the power plants which are constructed to generate huge amount of electrical energy. While this production of energy processes are being proceeded, the nature of the World is being destroyed by the hand of humankind as these plants release toxic gases and nuclear wastes to the environment which causes the global warming and other disasters to be happened. Fortunately except the resource of the nuclear power, the resources of the others are not endless. The coal is the oldest one since it has been used throughout history. Conversely, natural gas and petrol are newer than the coal as they have being used only since from the last century. Even though, for today's world, the petrol and the natural gas seem to be the most important energy resources, they are not endless as mentioned above. They will be exhausted approximately in 50 years. On the other hand, the exhaustion process of the coal can take longer, but one day this process will be achieved. As this is the portrait of the situation of the Earth, it is a better idea to start to use the renewable solar, wind and water natural energy sources as they do not pollute the environment. Therefore, the governments of the developed countries are making investments in order to produce the required energy power by constructing different plant structures for each of these renewable energy resources such as for the solar power, it is an aggregation of solar panels. Hydroelectric power stations can be mentioned as an example of a plant structure for the water sources, and finally for the wind source, wind farms can be given as examples.

In this thesis, solar power is the focus of interest. It is one the most efficient way of producing energy power as the source of it is the endless sunlight comes to the surface of the Earth. The other charming way of the solar power is the huge amount of areas where the sunlight reaches. So all countries have the opportunity to make use of it, but this differs according to the coordination of countries since the power of the reaching sunlight is not same for everywhere because of the position of the Earth. The main component, which is used to convert the sunlight to the electrical power, is a solar panel. The detailed information of the structure of it is described in the Chapter 2. To make a profit of the sunlight, there are different ways of installing solar plants. The most efficient one is to install solar panels on wide fields, which have no slopes, so that it is possible to place the panels with wide ranges between them. The reason why this placement is the most efficient one is because it prevents the shadowing problems. In this case, the panel technology to be installed is the thin-film which is less efficient but cheaper than the crystalline silicon ones which makes it is available for large installation areas. The other way of installing solar panels is using the roofs and facades of the building in order to produce the solar energy for the consumption of the electricity of the buildings. In this case, crystalline silicon solar panel types are suitable for the installation process as they are most efficient ones. As it can be understood from the explanations, solar power can be the leading one among the other resources if the installations of the solar plants become widespread all over the World. To be so, the governments of the countries must give weight to lower the installation prices and to make accurate predictions of the energy productions of a solar panel plant before it is constructed.

There are many grid connected solar plants installed all around the World. Let give brief information about the first three of the largest ones which are Agua Caliente Solar Project (ACSP) in USA, Charanka Solar Park (CSP) in India and Golmud Solar Park (GSP) in China [1]. ACSP is the largest operational solar plant in the World. It is located in Yuma County, Arizona at 250 megawatts installed capacity, but maximum capacity is planned to be 397 megawatts in the following years. The thin-film technology is used for the types of the solar panels. The number of the photovoltaic modules is 5.200.000 and the land area is 2.400 acres [2][3]. The next solar plant to be discussed is CSP which is installed in Gujarat, India. Its installed capacity is 214 megawatt of photovoltaic solar panels which makes it the largest station of Asia. It covers an area of 2.700 acres. Thin-film and silicon solar panel technologies are used to construct the station [4][5]. The last station is called GSP, and it is located in Golmud, Qinghai Province China with a 200 megawatt of installed capacity. The land area of the station is 5,64 km^2. In addition, it can generate 317,2 GWh green energy every year [6][7].

The tilt angle plays an essential role for the efficiency of a solar panel when it has a fixed structure. The reason is that the coming angle of the sunlight differs according to the seasons. Therefore, there are several researches to determine the optimum fixed solar panel angle in order to achieve the highest efficiency. The first study named Calculation of the Optimum Installation Angle for Fixed Solar-Cell Panels Based on the Genetic Algorithm (GA) and the Simulated-Annealing (SA) Methods [8]. The goal of this study is to find out the monthly and annually optimum installation angles of a fixed solar panel located in different areas in Taiwan. The outputs gathered from these two algorithms are similar to each other which indicate that these algorithms are useful to determine the optimum installation angle of a fixed solar panel. In addition to that, the monthly results of the hardware experiments located in Chaiyi, Taiwan and the computer simulation are close to each other. The other study entitled Optimal the Tilt Angles for Photovoltaic Modules in Taiwan which is using the particle-swarm optimization method with nonlinear time-varying evolution (PSO-NTVE) in order to determine the tilt angle which maximizes the output power of the solar panels located in seven cities in Taiwan. The results showed also that the outputs of the computer simulation and the best annual tilt angle are very close to each other [9].

In the prediction software market, there are several tools which are used to make solar panel energy predictions. The pvPlanner [10] is one of these softwares which is selected to be explained in this thesis. It is a web site application implemented by the company called Solargis. The purpose of this tool is to give prediction outputs of a solar panel with selected specifications by the users. Sequentially, these specifications are the coordinations, installed power, solar panel type, percentage values of the inverter efficiency and other DC/AC losses, mounting system, azimuth and inclination values of the solar panel. After these entries, the software processes the required calculations in the light of the inputs and provides several graphs. These graphs are photovoltaics (PV) electricity potential for each month of the year, PV conversion losses and performance ratio, site horizon and sun path, air temperature and solar radiation and air temperature.

There are several works discussing the solar energy prediction process. These are divided into two groups which are short-term, and long-term predictions. Among them, the short-term solar energy prediction is the most well performed one. Because the accuracy of the long-term predictions are not precise as they are in short-term predictions. As an example of a short-term solar power prediction, “Short-term Prediction of Photovoltaic Energy Generation by Intelligent Approach” by the authors Stanley K.H. Chow, Eric W.M.Lee, Danny H.W. Li, can be given [11]. It gives brief information about a building integrated photovoltaic installed system from where produced solar panel power data is gathered. In addition to this system, pyranometers are used to collect the solar radiation data. To make short-term predictions the most commonly used supervised neural network is selected which is Multi-Layer Perceptron (MLP). There are three parameters for the input layer of the model which are the solar elevation and solar azimuth angles, temperature data and the solar radiation data. In the hidden layer, one layer is decided to be used with neuron numbers between 31 and 41. On the other hand for the output layer, only one neuron is placed which is the generated energy amount by the PV system. The performance indices used for this study is the correlation coefficient formula. To start the training of the model data set is gathered in the 10-min interval between dates 28 Jun 2011 and 25 July 2011. The model used 90% of this data set as the training data, and the rest of the data set is used for the testing process. To evaluate the short-term predictions, a total of 1106 samples are used for the 10-min short-term prediction and 1095 are used for the 20-min short-term predictions. For real-time prediction, the minimum and maximum values of the correlation coefficients are 0,842 and 0,9359. On the other hand, for the 10-min prediction, the minimum and maximum values are 0,8934 and 0,9862. For the last one which is for 20-min prediction, the minimum and maximum values are 0,8186 and 0,9509.

There is a risk of the production outputs of a solar panel plant as the weather conditions are too unsteady to effect the outputs. In order to achieve a healthy yearly energy prediction results and to make a investment and payment simulations of a estimated solar plant, in this thesis a tool is implemented. The main purpose of it, is to enable the users to foresee the approximate solar energy production and to make investments accordingly.

In this thesis, there are six chapters. In the Chapter 2 named solar energy harvesting information, it is given about solar panel systems and the tools used within a system. In addition to that, the effects of the movement of the sun, weather conditions, radiation types and shadowing problems are discussed. In the Chapter 3 entitled data collection, the explanation of how the collection of the data, which is used for the prediction process, is discussed. Besides this, the structure of the software tool, which is implemented for this purpose, is explained. In the Chapter 4 named energy prediction, detailed information of the implemented model is shared. In addition, energy output prediction results obtained by the model are displayed with several graphs and furthermore, comparison charts about the energy production performance of three different unit solar panel types are exhibited. In the Chapter 5 entitled energy monitoring, the implemented web site software is explained. Solar energy investment, prediction model, investment plan and comparison charts of performance and price&performance of different solar panel types are explained in details. The last chapter, Chapter 6 is devoted to the conclusions about the thesis and the future work to be done.

CHAPTER 2

SOLAR ENERGY HARVESTING INFORMATION

2.1. Solar Panels

Among the renewable energy systems, solar energy systems are the most popular ones due to higher vitality, little renovation, silence and nonpolluting features. They are used to supply hot water, electricity, heat, light, cooling and ventilation. The solar systems, which produce electricity, are the complex and lastly developed ones. There are two types of this conversion. First one is PV that directly uses sunlight. Second one is concentrated solar power (CSP) uses indirectly sunlight.

This thesis is developed by photovoltaic panels which have solar cells those convert sunlight into electric current using the photoelectric effect. By the help of solar cells, a solar panel is used to convert Sun's electromagnetic radiation energy (sunlight) into electrical current. Photons are the fundamental components of electromagnetic radiation energy. Thus, the obtained energy from a solar panel is depended on the energy in a photon which is inversely proportional to the wavelength of the sunlight.

Solar panels are firstly developed to use in satellite systems and now are used to gather solar energy for homes, commercial buildings, fields, power plants or telecommunication systems. Shortly they can be used everywhere where electricity is needed.

In a solar cell, the semiconductor material is generally 'silicon' which becomes charged electrically when subjected to sunlight. The conductivity of a semiconductor increases with increasing temperature. Besides silicon, gallium, arsenite, cadmium tellurid or cupper indium diselenide are used [12]. Solar panels absorb the photons and in doing so, they initiate an electric current. The resulting energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their atomic orbits and released into the electric field generated by the solar cells which then pull these free electrons into a directional current. This entire process is known as the Photovoltaic Effect. There are several factors that effect the energy production of the solar panels. The first factor is the type of the solar panel whether it is thin-film, monocrystalline or polycrystalline. The other factor is the cell size of the solar panel which is efficient for producing energy if the size is larger. The last factor is the solar radiation.

2.1.1. Types of Solar Panels

There are two common types of solar panels, and it is because the solar panels are made of the different types of solar cells which are crystalline silicon and thin-film. Crystalline silicon solar cells are comprised of monocrystalline and polycrystalline silicons.

2.1.1.1. Monocrystalline Silicon Solar Panel

The monocrystalline silicon solar panel technology is the oldest among the other types of solar panels. Besides, they are the most efficient and most expensive ones. They are usually more suitable for deficient areas. A single silicon crystal forms a solar cell and because of the rounded crystal form, the corners of solar cells are rounded. So the full surface area is not used because when these solar cells are combined to form a panel, void occurs between them. The color of these panels is dark blue due to the color of a single crystal silicon atom. The average lifetime for monocrystalline panel type is 20 to 25 years [13].

Figure 1. Monocrystalline Solar Panel Type

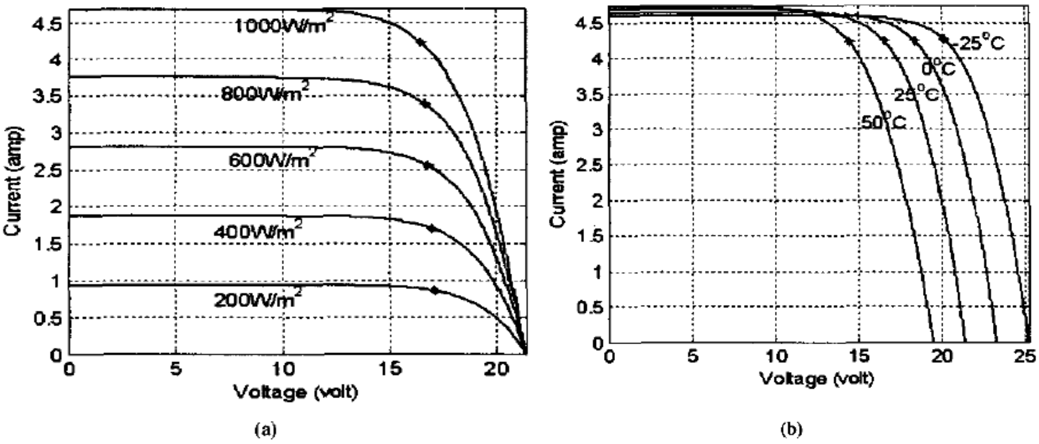

Figure 2. The Current-Voltage Characteristics of Monocrystalline Solar Panel Type [14]
(a) Different radiation levels at a constant temperature (25 °C),
(b) Different temperatures at constant radiation level (1000W/m^2)

In Figure 2, the current-voltage characteristics of the monocrystalline solar panel type are displayed. In the graph (a), reaction between the current and the volt is observed under the same temperature 25 °C, but different radiation amounts. On the other hand, in the graph (b), this time the radiation value is constant which is 1000 W/m^2 of radiation for different temperature values. This comparison data is same for the rest of the other solar panel types displayed in Figure 4 and Figure 6 [14].

2.1.1.2. Polycrystalline Silicon Solar Panel

The polycrystalline silicon cells consist of multiple silicon crystals. They are less efficient but cheaper than the monocrystalline ones. In addition, it is easier to install polycrystalline panel types compared to monocrystalline and thin-film types. On the other hand, it can operate more efficiently compared to other two panel types in extreme temperature [13]. When polycrystalline silicon cells are compared to thin-film cells, the efficiency values are higher and they are more expensive than the thin-film cells.

Figure 3. Polycrystalline Solar Panel Type

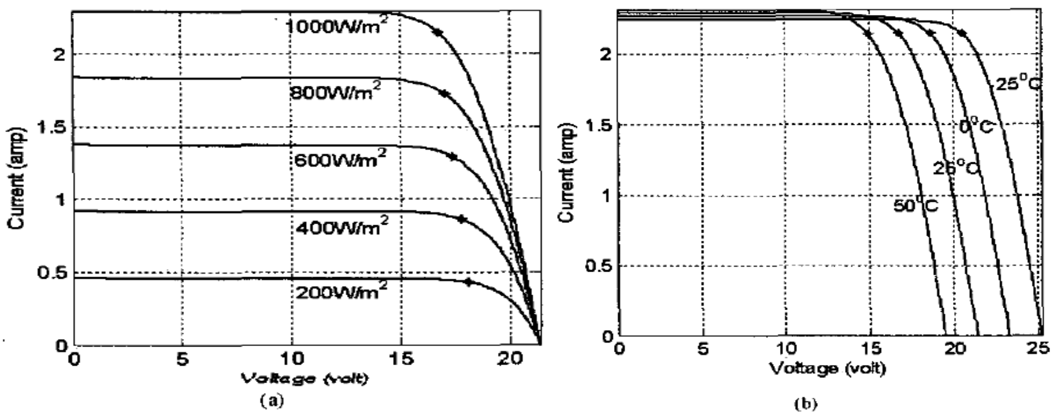

Figure 4. The Current-Voltage Characteristics of Polycrystalline Solar Panel Type [14]
(a) Different radiation levels at a constant temperature (25 °C),
(b) Different temperatures at constant radiation level (1000W/m^2)

2.1.1.3. Thin-Film Solar Panel

In the formation of a thin-film solar cell, silicon or another suitable material is dispersed on a bottom layer material. On this bottom layer material, thin layers are formed. The bottom layer material is generally made of ceramics and glass. The types of thin-film solar cells are determined according to the dispersing material and they can be amorphous silicon, copper indium gallium deselenide, cadmium telluride. Thin-film solar panels are less expensive and less efficient than the silicon solar panels [15]. As they are cheap, they are suitable to be installed onto large areas that have no space problems.

Figure 5. Thin-Film Solar Panel Type

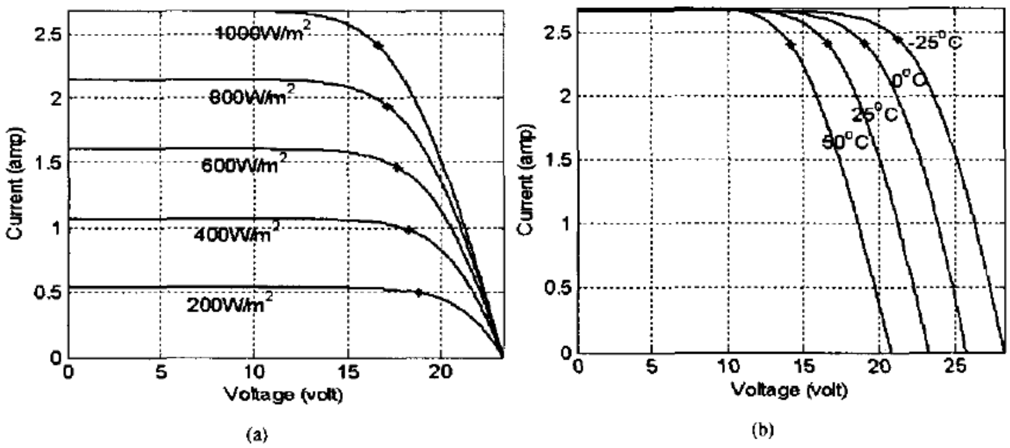

Figure 6. Current-Voltage Characteristics of Thin-Film Solar Panel Type [14]
(a) Different radiation levels at a constant temperature (25 °C),
(b) Different temperatures at constant radiation level (1000W/m^2)

2.2. Solar Plants

Solar panel systems are constructed in order to produce energy using sunlight as a raw material. The coordinations of the installation of these systems are very important to improve the efficiency of the solar panels. The most sunbathing regions around the world are between 45^{o} north-south latitudes and they have great potential about solar power. To talk about the sections of a solar plant, it consists of a solar panel, a charge controller, a battery system and an inverter (Figure 7). Here the main components of a solar panel system are the solar panels and the inverters as a solar panel generates DC (direct current) power and an inverter converts this DC power to AC (alternating current). The other two components mentioned above are additional to solar panel systems for safety and power back up reasons. The charge controller is used for safety reasons as it prevents the batteries to be overcharged and against over voltage. These two functionalities are crucial for the lifetime and the performance of the batteries to be used in the solar panel systems. The other additional component is a battery system as it can be seen from Figure 7 [16], it is placed between an inverter and the charge controller in order to back up the solar energy as DC power. In addition to a system displayed in Figure 7, there are alternative systems where the electric current generated by a panel can be directly headed to an inverter by omitting the charge controller and the battery system which is shown in Figure 8.

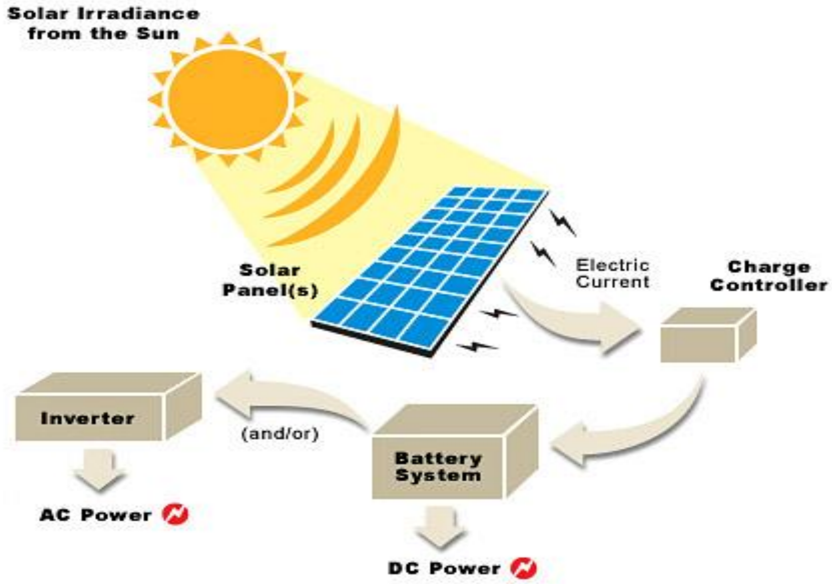

Figure 7. A Solar Panel System

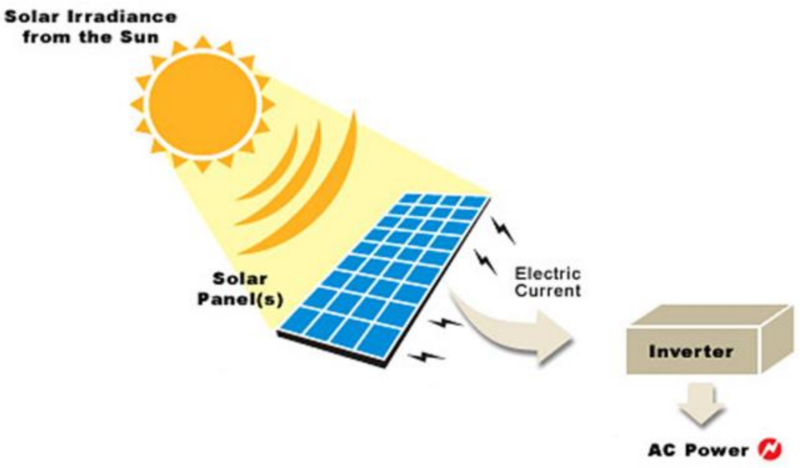

Figure 8. An Alternative Solar Panel System

2.2.1. Photovoltaic System Types

Generally solar panel systems are installed in two different types. These are on-grid and off-grid systems. The main difference between them depends on the location of the construction area. If a system is installed in a rural area where the electric utility grid is not close to be connected, then this system is considered as an off-grid photovoltaic system. On the other hand, if the system is close to a utility grid and is connected to it, then it is called an on-grid system. The another difference between these two types is that off-grid system must contain a battery component within the system to achieve to save the extra produced solar power in order to be used at nights and cloudy days when it is not possible to create solar energy. Conversely, on-grid systems are not mandatory to contain any battery to save energy because as they are installed connected to an utility grid, they can obtain any energy needs from that grid and in addition to that, on-grid systems are able to sell the extra energy they produced to the utility grids.

2.2.2. Solar Panels System Utilizations

The solar plants are installed all over the World. Of course there are some countries which are the leaders of this subject. These countries are sequentially Germany, Spain, Japan, United States, Italy, Czech Republic, Belgium, China, France and India. Here the main point to be discussed is the Germany as it is the leader in solar power among all these countries with a very low solar potential. According to Washington Post Journal, at the end of 2012, Germany has 30 gigawatts installed solar power. This amount provides the 3% to 10% of the overall energy need of Germany. The reason of this success is because of the government promotions, cheap installation payments and the bigger industry [17].

2.2.3. Solar Energy in Turkey

Because of its geographical location, Turkey's solar power potential is very high. Turkey's annual average sunbathing period is 2.640 hours (7,2 hours on a day), average total radiation is 1.311 kWh/m²-year (daily total 3,6 kWh/m²). In addition to that, Turkey has 110 days of a year with high solar energy potential. As a result of that, if required investments are done, Turkey has the potential to produce average solar energy of 1.100 kWh/m² for a year [18]. Here a short explanation must be given about the signatures of the tables and the figures displayed below. When it is written kWh/m^2, it indicates the radiation amount by kilowatt-hour for each m^2.

Table 1. The Total Average Sun Power Potential of Turkey According to Months of the Year

MONTHS	MONTHLY TOTAL SOLAR RADIATION (kcal/cm²-Month)	(kWh/m²-Month)	SUNSHINE DURATION (Hour/Month)
January	4,45	51,75	103
February	5,44	63,27	115
March	8,31	96,65	165
April	10,51	122,23	197
May	13,23	153,86	273
June	14,51	168,75	325
July	15,08	175,38	365
August	13,62	158,40	343
September	10,0	123,28	280
October	7,73	89,90	214
November	5,23	60,82	157
December	4,03	46,87	103
Total	112,74	1311,00	2640
Average	308,0 cal/cm²-day	3,6 kWh/m²-day	7,2 hours/day

Table2. Solar Energy Potential According to the Regions of Turkey [18]

REGION	TOTAL SOLAR RADIATION	SUNSHINE DURATION
Southeastern Anatolia	1460	2993
Mediterranean	1390	2956
East Anatolia	1365	2664
Central Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2109
Black Sea	1120	1971

Figure 9. Map of Solar Energy in Turkey [18]

In Turkey, solar panels are used generally in the areas which have the installation cost of the electricity network system is too high. These areas are such as; telecommunication stations, fire watchtowers, lighthouses, chlorination stations, yachts, caravans, signalization stations, garrisons in a rural area and chalets. Recently, with the help of International Photovoltaic Technology Platform, (UFTP) which is supported from TUBITAK, investments and investigations are being done in Turkey. Some universities, research institutes, public corporations, industrial corporations, municipal governments are interested in this area. In all over the Turkey, on-grid and off-grid solar plants are constructed [19].

2.3. Solar Trackers

The efficiency of the solar panels is directly proportional with the coming angle of sunlight to the surface of the panels. If the sunlight hits the panel surface with a 90 degree, then the efficiency of the panel increases to the top level. This is verified with the calculations of the solar panel efficiency in the following sub titles. The purpose of the solar trackers is to enhance the efficiency of the solar panels which are in a fixed position. To achieve this goal trackers are attached to the solar panels to move the panels towards the sun in order to get more sunlight directly. Solar trackers are categorized according to their axises which are single and dual axises. The single-axis trackers have two types. The first one moves only horizontally and the other type moves only vertically. Among these two types, horizontally is more efficient as it follows the movement of the sun from east to west with a static vertical position. This vertical position is normally adjusted to 30 to 45 degree for the summer times and 45 to 60 for the winter times. On the other hand to improve the efficiency of the panels higher, it is a better choice to use dual-axis trackers which are able to move the panels vertically and horizontally. A dual-axis solar tracker increases the calculated annual energy of a solar panel by 48,982% compared to an immobile solar panel. In addition, there is a big difference between dual and single-axis trackers. Between these two types, the former one increases the gained annual energy for a solar panel by 36,504%, compared to latter one [20].

2.4. Effects of the Movement of the Sun Over the Sun Power

The movement of the Sun plays a key role in solar energy as it is the source of the sunlight. So the position of the Sun effects the efficiency of the solar panel directly. It is important to examine the detailed movement of the Sun. Even though it seems that the Sun is moving around the Earth, the real object, which is moving around the Sun, is the Earth. The Earth finishes its one round tour around the Sun in one year of a time. This one round tour around the Earth is called orbit and it has an elliptical shape. As the Earth is tilted with an angle on its vertical axis, this impacts how the Sun's rays strike various locations on Earth. This is the actual reason of why the appearance of a day light differs according to the seasons as it is lower in winter time and higher in summer time. December 21st is the lowest arc of the Sun and June 21st is the highest arc of the Sun. These are called summer and winter solstices. On the other hand there are Vernal Equinox March 21st and Autumnal Equinox Sept 21st which indicate the middle of the solstices [21].

To calculate the direct effects of the movement of the Sun over the efficiency of the panels, it is a must to calculate its mathematical position in the space in order to find out how directly the sunlight comes to the surface of the solar panel as it is a way to calculate the efficiency of a solar panel. There are several position data of the Sun which are required in the calculations. These are (i) azimuth angle represented by (A), (ii) altitude angle represented by (a) and the last one is (iii) zenith angle represented by (z). These angles are displayed in Figure 10. The altitude indicates the angle between the sunlight and the surface. It can take value between 0 to 90 degrees. On the other hand, the angle which completes the altitude angle with the normal of the surface to 90 degree, is called zenith. The last one to be considered is the angle called azimuth which is the angle between the projection of sunlight and the direction arrow showing the north.

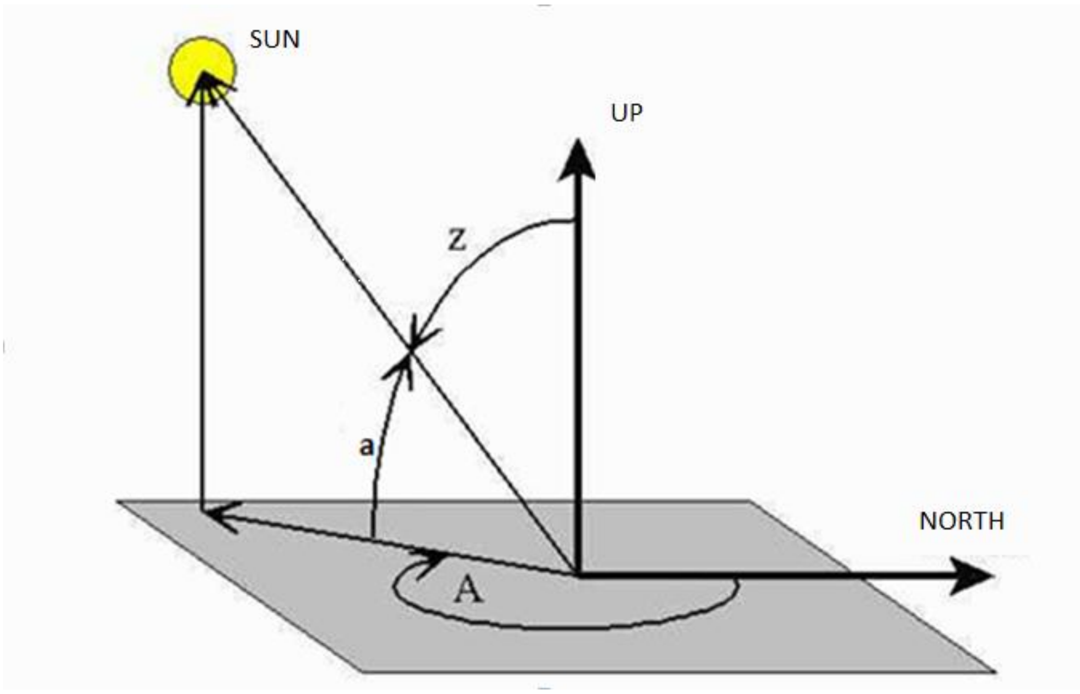

Figure 10. Angles Describing the Position of the Sun

2.4.1. Calculation of the Efficiency

As mentioned above, to find the effects of the movement of the Sun upon the efficiency of the solar panels, the first step to take is to create a mathematical model to represent the environment.

2.4.1.1. Calculation of the Equations of the Solar Panels and the Solar Light

The main step is to calculate the equations of the solar panels and the sunlight in a 3 dimensional platform to obtain the intersection points of these two objects. The reason why it has to be dealed is that, the intersection points are going to be used in future works such as calculation of the shadow ratios which occur on the solar panels, the efficiency of the panels and so on. The first step is to calculate the panel equation then, the sunlight equation will be handled.

2.4.1.2. Panel Equation

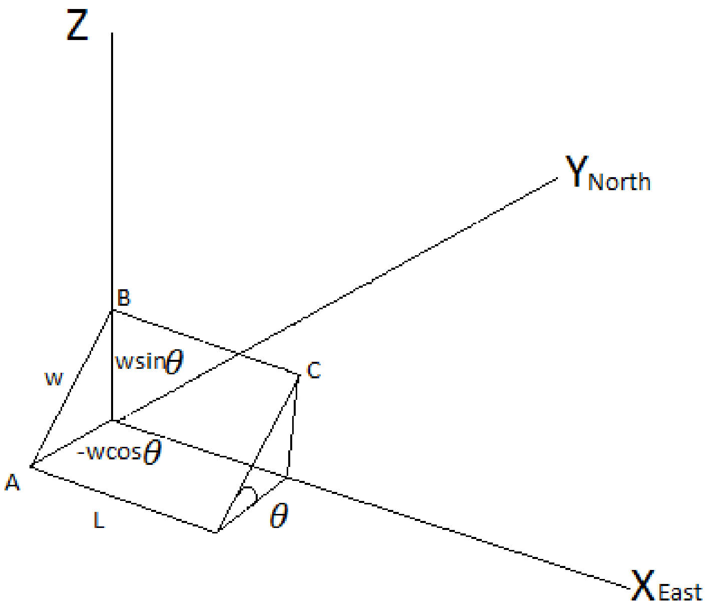

Figure 11. Coordination of a Solar Panel

To calculate the equation of a solar panel, first three points on the surface of it have to be found out. Let's say that these points are A, B, C as shown on Figure 11 above. Since these three points are the corner of the panel, the coordinates of these points are as follows:

$$A(0,-w\cos\theta, 0)\ ,B(0,0,w\sin\theta),\ C(L,0,w\sin\theta)$$

As a default start, the equation of a surface can be written with its dummy coefficients as follows:

$$a_1x + b_1y + c_1z = 1$$

After defining the equation, the next step is to find the coefficients a_1, b_1, c_1 by using the points A, B, C. What has to be done it is that, the coordinates x, y, z of each defined points above have to be written in the places of x, y, z in the default equation. As a result, values of the coefficients a_1, b_1, c_1 are calculated as shown below:

$$A\ (0,-w\cos\theta, 0) \rightarrow a_1x + b_1y + c_1z = 1 \rightarrow b_1 = \frac{1}{-w\cos\theta}$$

$$B\ (0,0,w\sin\theta) \rightarrow a_1x + b_1y + c_1z = 1 \rightarrow c_1 = \frac{1}{w\sin\theta}$$

$$C\ (L,0,w\sin\theta) \rightarrow a_1x + b_1y + c_1z = 1 \rightarrow a_1 = 0$$

So the final calculated panel equation can be displayed after placing the calculated values of coefficients a_1, b_1, c_1 in the dummy equation $a_1x + b_1y + c_1z = 1$.

$$\frac{1}{-w\cos\theta}y + \frac{1}{w\sin\theta}z = 1$$

2.4.1.3. Solar Light Equation

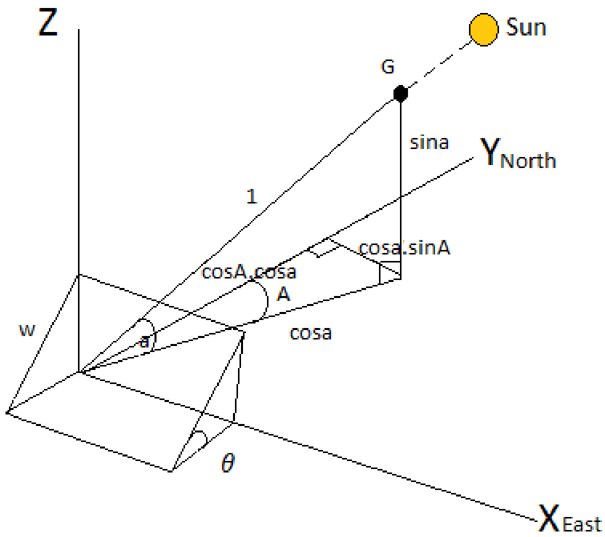

Figure 12. Coordination of the Sun

In order to calculate the equation of the solar light, firstly the coordination of Sun has to be calculated. As it can be seen from the picture above, the location of it is displayed with a yellow circle, but it has to be mentioned that this cycle is only a dummy of the Sun, and the lights coming from it to the surface of the 3 dimensional platform are making the same angle (a) in other words it is called altitude of the sunlight. The other parameter shown on Figure 12 is (A) stands for Azimuth value of the sunlight which is the degree between the geometric projection of sunlight and the north line of the 3 dimensional platform.

There are two triangles to be considered firstly. The first triangle is created by the edges which are the sunlight coming to do the origin of the platform, the geometric projection of the sunlight and the line from the Sun meets the surface of the platform vertically. Shortly it is the triangle vertical against the surface of the platform. On the other hand, the second triangle is horizontal to the surface of the platform. It contains the edges geometric projection of the sunlight, the Y edge of the platform and the line between the y edge of the platform and the point where the Sun meets the surface vertically. After the specification of these two triangles, the length of the edges are calculated with the help of the degrees (a) and (A). As a result, the coordination of the Sun is indicated with the letter (G) and the solar light equation (g) is calculated by the coordination of the Sun.

$$G\,(\text{cosa.sinA, cosa.cosA, sina}) \Rightarrow G\,(\frac{\text{sinA}}{\text{tana}}, \frac{cosA}{\text{tana}}, 1)$$

$$g = \frac{\sin A}{\tan a} i + \frac{\cos A}{\tan a} j + k$$

2.4.1.4. Panel Efficiency

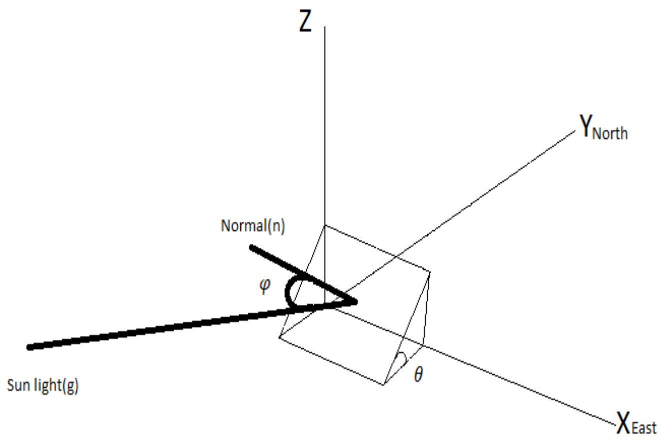

Figure 13. Angle Between the Normal of the Panel and the Sun Light

The calculation of the efficiency can be explained better with the help of the figure above since it is about the degree between the normal of the panel equation and the vector of the sunlight. As this situation can be seen clearly in Figure 13, the sunlight comes to the surface of the panel and creates a degree between the normal of the panel. The created degree is the main data to find out the efficiency of the panel since the efficiency is maximized as the φ degree is minimized. In order to figure out the panel efficiency, the dot product of the vectors of the normal ($\vec{n}$) of the panel and the solar light ($\vec{g}$) is computed. The calculation steps are displayed below:

$$\vec{g} = (\cos a.\sin A, \cos a.\cos A, \sin a) \rightarrow (\frac{\sin A}{\tan a}, \frac{\cos A}{\tan a}, 1)$$

$$|g| = \sqrt{\frac{\sin^2 A}{\tan^2 a} + \frac{\cos^2 A}{\tan^2 a} + 1}$$

$$\vec{n} = (0, \frac{-1}{wCos\theta}, \frac{1}{wSin\theta})$$

$$|n| = \sqrt{\frac{1}{w^2 cos^2\theta} + \frac{1}{w^2 sin^2\theta}}$$

$$\vec{g}.\vec{n} = |n|.|g|.\cos\varphi$$

$$\vec{g}.\vec{n} = g_x n_x + g_y n_y + g_z n_z \rightarrow (0 + \frac{-\cos A}{w\text{Cos}\theta\tan a} + \frac{1}{w\text{Sin}\theta})$$

To find the φ degree, $\cos\varphi$ is left alone and the final equation is shown as follows:

$$\text{Cos}\varphi = \frac{\vec{g}.\vec{n}}{|g|.|n|}$$

2.5. Shadowing Calculations

When the panels are placed back to back on a platform, the possibility of the shadow occurrence behind each panel arises. For that reason, if the distance between the panels is narrow, then the occured shadows fall over the posterior panels. In addition, the height of the shadows changes according to the movement of the Sun around the Earth as the angle and the height of the sunlight coming to the surface of the Earth alter. The shadow rate is calculated by summing up the shadow areas on all panels on the platform and dividing the calculated value with the total number of panels. In the program, a shadow is figured out by using 2 points where the equations of the panel and the sunlight intersect. This situation can be explained with 4 different positions according the falling coordinations of the sunlights over the panels.

One Intersection Point Over the B Corner

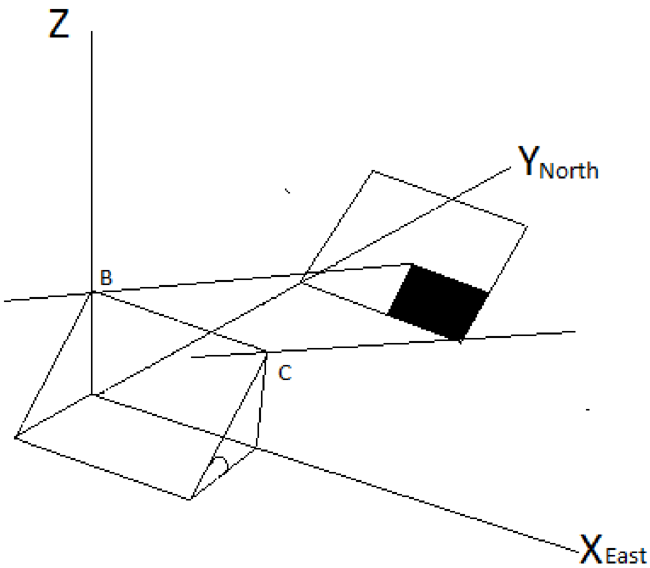

Figure 14. One Intersection Point Over the B Corner Shadowing Problem

In this position, the sunlight coming from the B corner creates the left most upper corner of the shadow but the other sunlight parallel to the first one passes from the C corner can not intersect with any panel since the second panel at the back is not at the sight. So the shadow is created as a half rectangle as shown in Figure 14.

One Intersection Point Over the C Corner

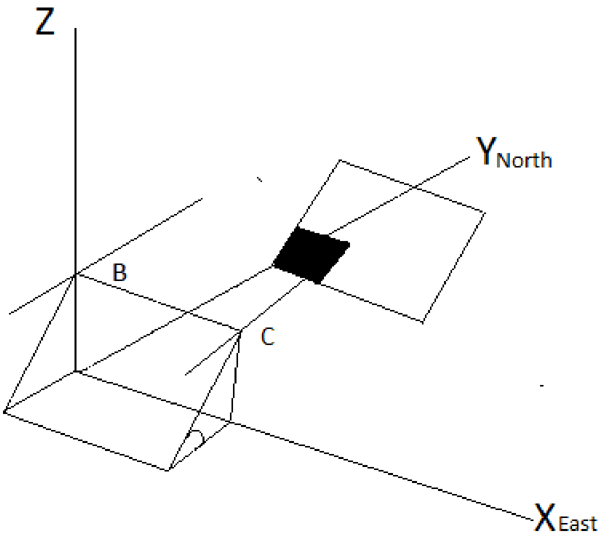

Figure 15. One Intersection Point Over the C Corner Shadowing Problem

In Figure 15 the sunlights come with a different direction and create again a half rectangular shape. Similar to the situation displayed in Figure 14, one sunlight out of two accomplishes to intersect with the panel behind.

Two Intersection Points On the Different Panels

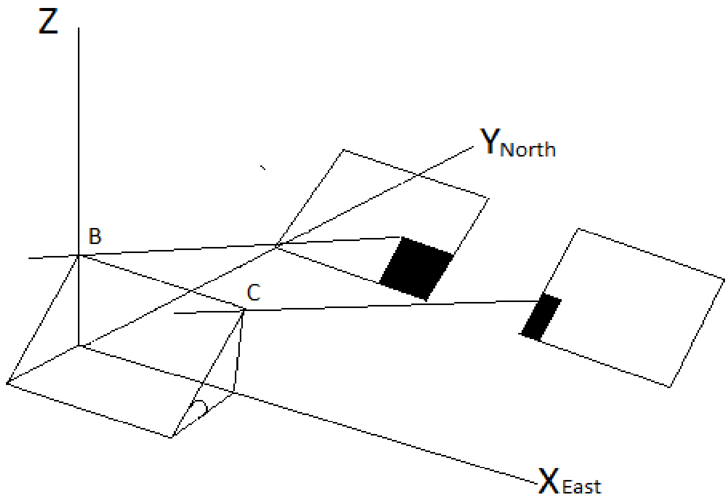

Figure 16. Two Intersection Points On the Different Panels Shadowing Problem

In Figure 16, both of the sunlights are passing from the most upper corners of the front panel, and intersect with different panels at the back. As a result, two rectangular shapes are created as shown.

Two Intersection Points On the Same Panels

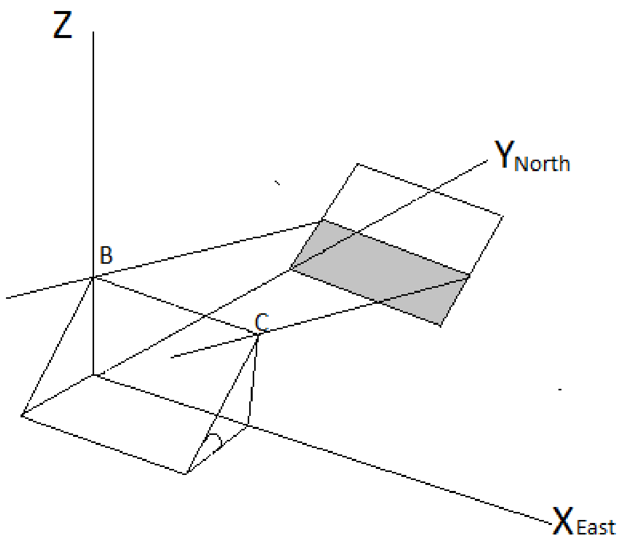

Figure 17. Two Intersection Points On the Same Panels Shadowing Problem

In Figure 17, the sunlights intersect with two points on the same panel at the back. This position only occurs when the Sun takes a position in front of the panels with a degree of 90.

2.6. Simulations

A simulation program is implemented in order to simulate the calculations explained above. To start the process, the user must enter several inputs which are (i) latitude and longitude values of a solar plant which are selected from an earth map, (ii) date interval of the simulation, (iii) interval value indicates whether the date interval is hourly or in minute format, (iv) zone value of the selected coordination, (v) dimensions of the solar panels, (vi) declination value of the panels indicates the angle between the the panel and the surface, (vii) row and column distances between the solar panels, (viii) solar panel number of columns and rows and the final entry is the (ix) panel max energy (W). After these entries, the application becomes ready to run the simulation. The results can be displayed by two different time intervals which are daily and monthly. A screen shot of this simulator can be seen in Figure 18.

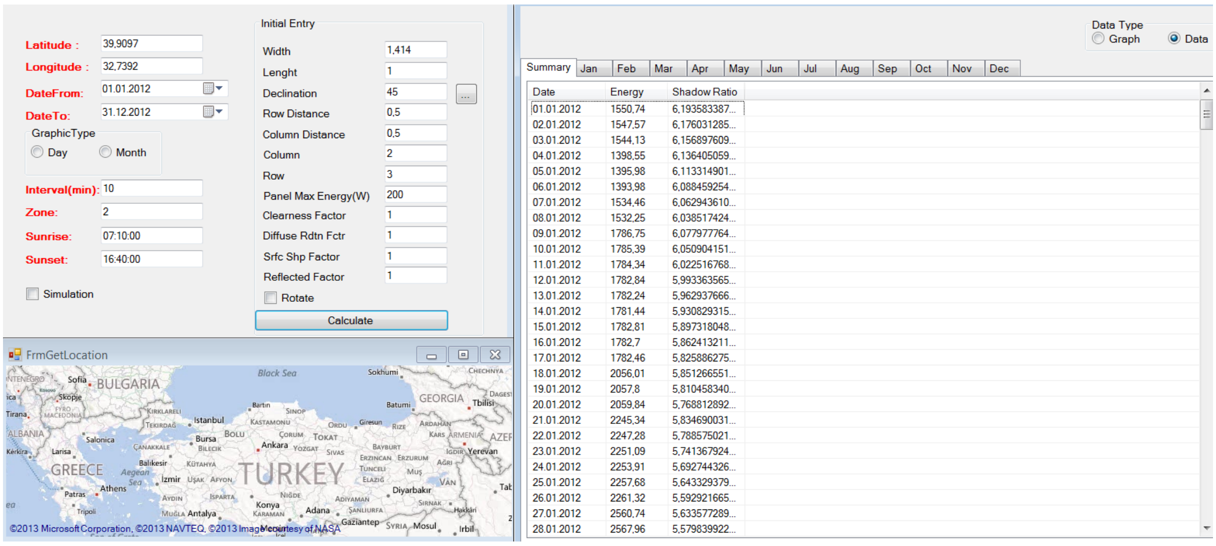

Figure 18. Simulator

A simulation is processed which has the default inputs as displayed in Figure 18. The results of the comparison of the produced energy and the shadowing percentage are displayed in Figure 19. Energy line indicates the total produced energy of all the panels in the station. The other line named as shadow stands for the percentage value of the total shadowing areas of all solar panels in the station.

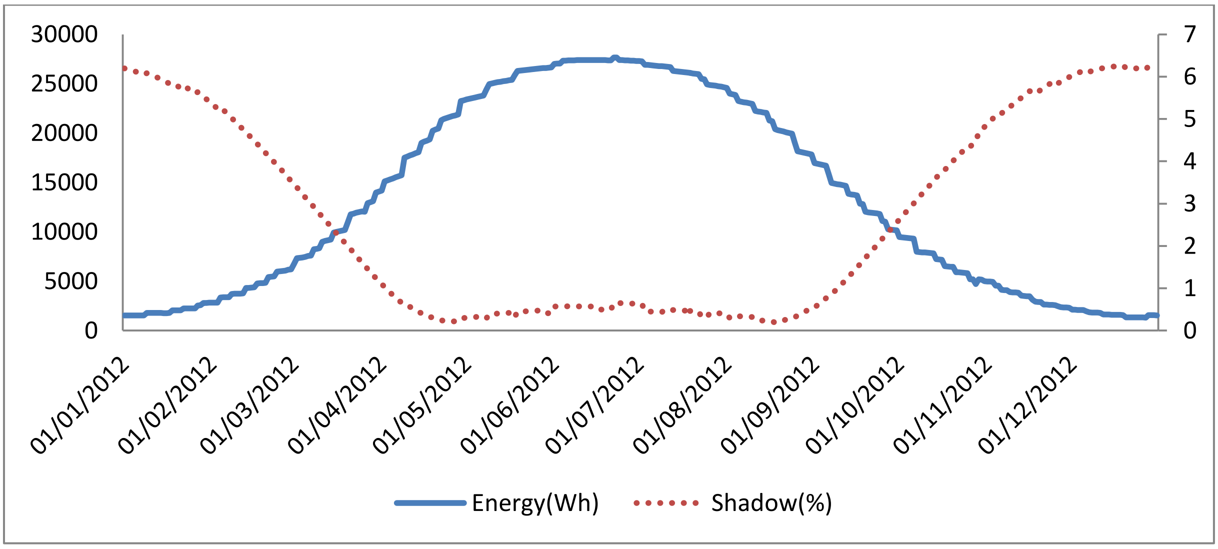

Figure 19. Comparison Between the Produced Energy and the Shadow Percentage

CHAPTER 3

DATA COLLECTION

In order to predict the energy produced by a solar panel type for a certain time of period, a prediction model is necessary which has a close relationship with weather conditions. In addition to that, it is very important to measure the solar radiation amount of the place where the solar panels are installed as it plays a key role in the production of the solar panel energy. Of course, if it is planned to make a prediction of the produced energy amounts of a selected solar panel type, it is also mandatory to gather produced energy amounts of the same solar panel type of the previous years. Briefly, the prediction model studied requires two different data which are (i) meteorological data and (ii) produced energy data. The meteorological data consists of (i) solar radiation, (ii) temperature, (iii) humidity and (iv) wind speed. It is obtained either from Turkish State Meteorological Service or from the local meteorological station which is a combination of several sensors installed on a special pole located next to the solar panels to measure the weather conditions of the environment. Normally it is accurate to obtain this data set from a local meteorological station placed next to the solar plant in order to train the prediction model more accurately as the local meteorological station data set indicate the the weather condition of the environment more precisely. But, it costs money to install a local meteorological station in every place user wants to make a prediction of. Therefore, in this thesis it is planned to obtain the meteorological data set from Turkish State Meteorological Service. But this time, the solar radiation data set could not be acquired from the State Service, so it is decided to collect the meteorological data set from both of the stations. The solar radiation data set is acquired from the local meteorological station installed next to the solar panel plant and the rest of the parameters which are temperature, humidity and wind speed are obtained from Turkish State Meteorological Service.

All weather condition data and the solar panel energy production values are in hourly format. In other words, hourly average values of each parameters are calculated. The reason why the data is prepared in hourly format is because of lack of minutely received values of the weather conditions. In the following sections it will be explained in details.

3.1. Energy Generation and Meteorological Parameters

As mentioned below, in order to make a produced solar panel energy prediction, it is required to obtain the weather condition parameters of the environment, where the solar plant is installed, as they influence directly the solar panel efficiency. The most affecting parameters are solar radiation, humidity and temperature. The relationship of the efficiency of a solar panel is compared with these parameters by the graphs displayed below. As the power is the result of the multiplication of the current and the voltage, the graphs compare these values with the weather condition parameters [22].

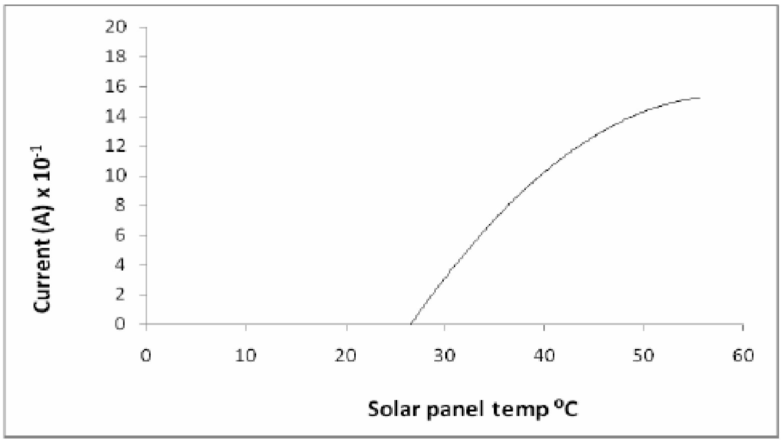

Figure 20. Current and Solar Panel Temperature

In Figure 20, the current and the temperature of a solar panel have been considered. As it can be seen that the current value increases with the temperature until 43 °C, then it starts to slow down. This indicates the maximum operating temperature value of a solar panel [22].

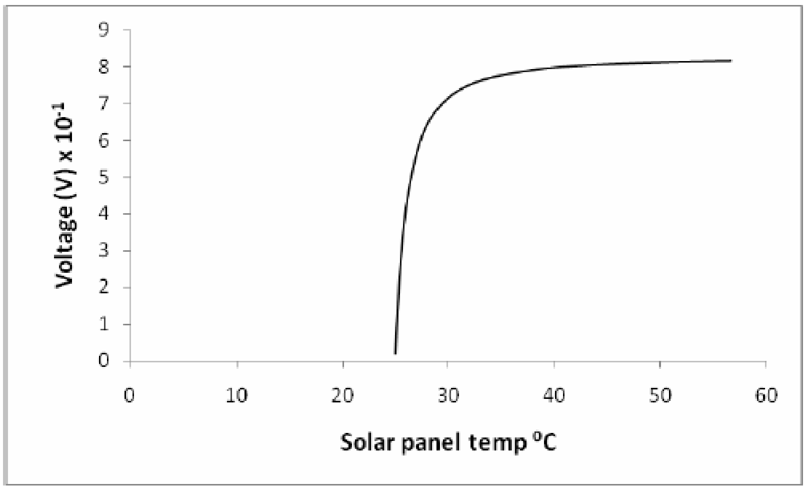

Figure 21. Voltage and Solar Panel Temperature

In Figure 21 voltage value increases between the temperature 25 °C and 35 °C and then stops to increase. Beyond the temperature value of 44 °C, the voltage value starts to drop. This explains that the temperature value has an insignificant effect on the voltage output [22]. In addition to that, as it is displayed in Figure 22, highest temperature does not mean always the highest efficiency [22].

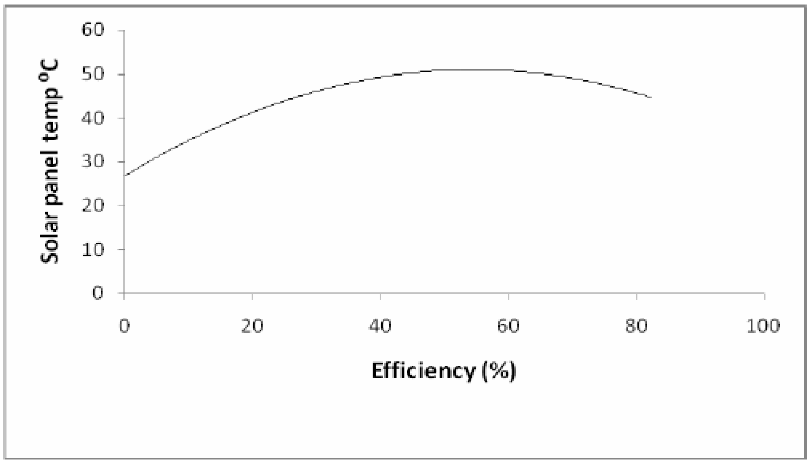

Figure 22. Solar Panel Temperature and Efficiency

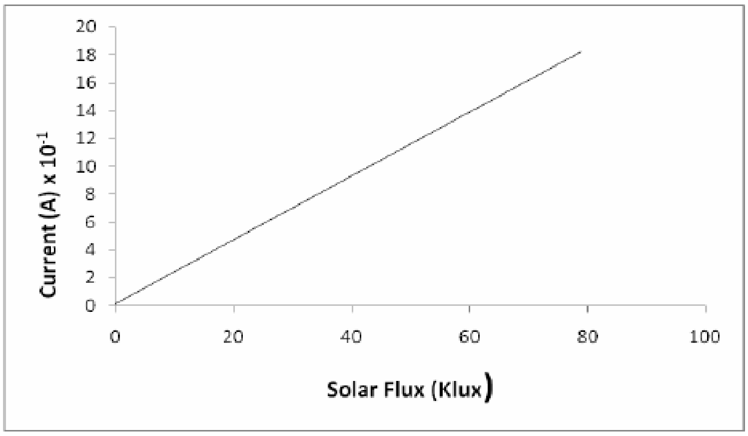

Figure 23. Current and Solar Flux

In Figure 23 it can be observed that solar flux (illumination) is directly proportional with the current. But the same thing can not be said for the relationship between the voltage and the solar flux as it can be seen in Figure 24 [22].

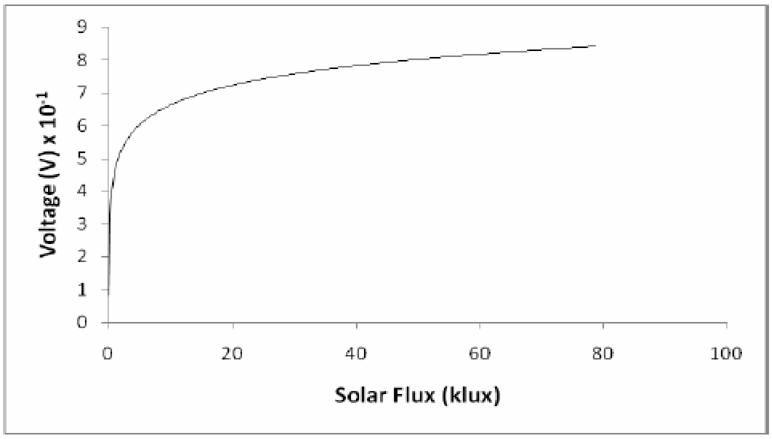

Figure 24. Solar Flux and Voltage

In Figure 25, it indicates that the efficiency of a solar panel is directly proportional with solar flux just like the graph in Figure 23 which means that the current outputs determine the efficiency of a solar panel [22].

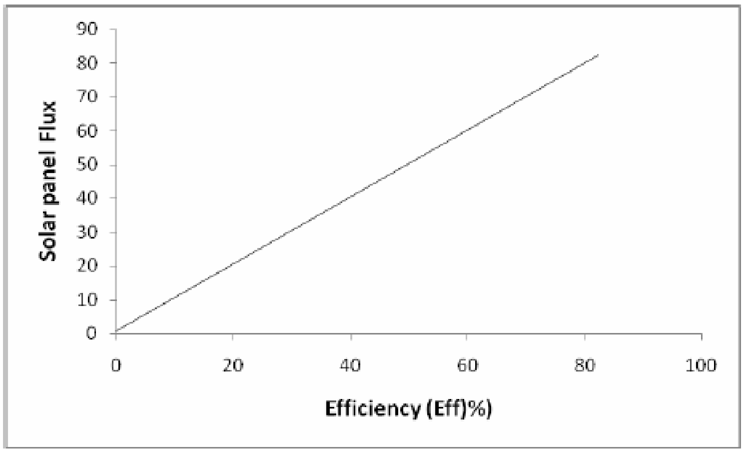

Figure 25. Solar Flux and Efficiency

The humidity has also effects on the energy production of a panel. This can be explained by examining the graph displayed in Figure 26. In the graph, as the humidity drops, the current value increases which means that as the percentage of the water in the air drops, the solar flux finds more empty spaces to penetrate and this increases the production of the panel [22]. Beside this, similar situation can be observed from Figure 27 as the percentage of the humidity decreases in the air, the voltage value increases. Overall result is that, the efficiency percentage of a solar panel is higher in low relative humidity cases. This result is displayed in Figure 28 [22].

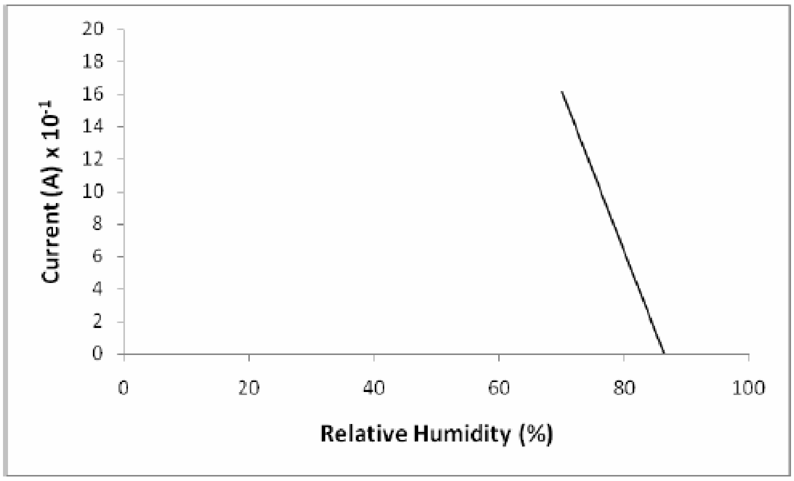

Figure 26. Current and Relative Humidity

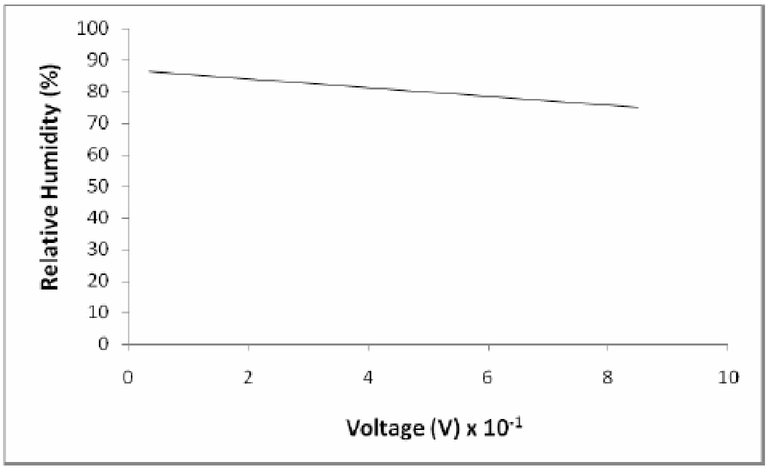

Figure 27. Relative Humidity and Voltage

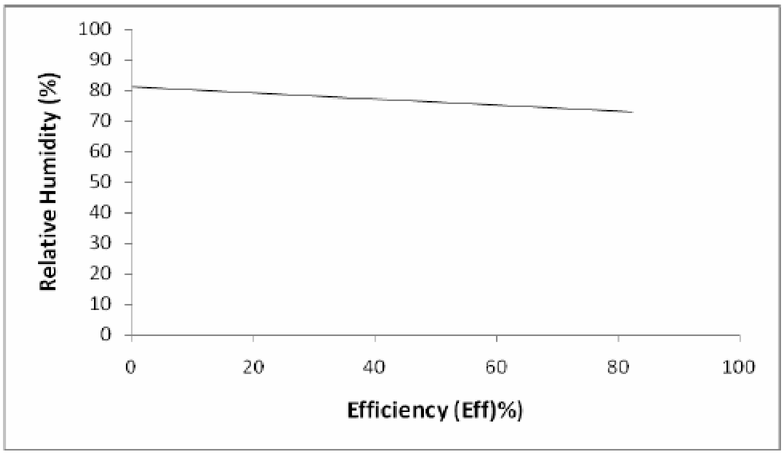

Figure 28. Relative Humidity and Efficiency

3.1.1. Solar Radiation

The sunlight has a strong effect on the energy production of a solar panel as it is influenced by the solar irradiance directly. To talk about what is irradiance, it is a composition of three objects. These are visible light, ultraviolet and infrared radiations. The percentages of these objects are sequentially about 40% for visible light, 10% for ultraviolet radiation and 50% for infrared radiation. On the way to the surface of the Earth, the solar irradiance loses its energy as it interacts with the atmosphere which contains clouds, aerosols, water vapour and trace gases. The solar irradiance loses 35% of its energy when the weather conditions are clear and dry. On the other hand when the weather is cloudy and the clouds are thick, it is hard for the solar irradiance to pass through. So it loses about 90% of its energy [23].

3.1.2. Calculation of Solar Radiation and Types

When the solar irradiance comes to the surface of the Earth, it is divided into two types of irradiance which are beam and diffuse solar irradiances. Beam, in other words, directly solar irradiance is the one which directly comes from the disk of the Sun and the diffuse irradiance is the one comes from the sky except the disk of the Sun [23]. In addition to these two main radiation types, there is reflected solar radiation which is created by the reflections of the sunlight from the objects located on the surface of the Earth. These objects can be anything which is able to reflect the light such as water, white stones and so on. The calculation formulas of this radiation types are displayed in the following sub sections.

<u>Direct Solar Radiation</u>

In a clear sky condition, huge amount of solar radiation passes from the atmosphere to the surface of the Earth. In this situation air clearness factor (F_c) is equal to one. At sea level, the intensity of direct radiation (I_D) is;

$$I_D = F_c \, I_{DN} \cos\Theta$$

Where I_{DN} is;

$$I_{DN} = \frac{A}{e^{\frac{B}{m\beta}}}$$

Where A is apparent solar irradiation (W/m^2), B is atmosphere extinction coefficient [24].

Diffuse Solar Radiation

Some portion of solar radiation are scattered downwards by the molecules in the atmosphere that means diffuse solar radiation. During extremely cloud days only diffuse radiation may reach the surface of the Earth. Then, Diffuse Radiation (I_d) is calculated as;

$$I_d = C \ I_{DN} \frac{(1+cos \sum S)}{2}$$

Where C is diffuse radiation factor, S is the tilted angle of the surface [24].

Reflected Radiation

When the solar radiation irradiates upon a surface which is opaque, a portion of radiation is absorbed and the remaining portion is reflected. The reflected Radiation (I_{ref}) is calculated as;

$$I_{ref} = p_{ref} \ F_{r-s} \ (I_D + I_d)$$

Where p_{ref} is the reflectance of reflected surface, F_{r-s} is shape factor between reflected surface and the receiving surface, I_D is direct solar radiation and I_d is diffuse solar radiation [24].

Total Intensity of Solar Radiation

Total intensity of solar radiation falling on the surface, is the sum of the direct radiation I_D, diffuse radiation I_d and reflected radiation I_{ref} [24].

$$I_T = I_D + I_d + I_{ref}$$

3.2. Turkish State Meteorological Service Data

Meteorological weather data plays a very important role in the energy prediction of a solar panel type. Because the energy production structure of a solar panel depends on gathering the energy of the photons of sunlight and since the sunlight can be influenced by the outside conditions, it also effects the production of the solar panel. As mentioned above meteorological service data is received from Turkish State Meteorological Service in Ankara. It consists of three different weather conditions; (i) humidity, (ii) weather temperature and (iii) wind speed. This information is obtained as a text file in hourly format which means that the hourly values are the average of each hour of a day. The data can be received for a desired time interval. For this thesis the demanded hourly data is for the year of 2012. To explain the format of the text files received from Meteorological Service, it is better to mention the columns of the text file. There are six columns for each type of weather condition data. These are as follows; (i) station number, (ii) year, (iii) month, (iv) day, (v) hour and the (vi) hourly average value of the current weather condition data. Station number represents the station which receives the current weather data. These stations are located all over Turkey. The one used in this project is placed in Ankara as the solar plant is also located in Ankara. Next column is the year and it stays for the year of the values in the text file, as mentioned above for this thesis only the data set of the year 2012 is used. The other columns are month, day and hour. These are the descriptive columns of the current time of the weather data.

Station Number	Year	Month	Day	Hour	Humidity	Temperature	Wind Speed
17130	2012	1	1	6	99	3	3,6
17130	2012	1	1	7	99	3	3
17130	2012	1	1	8	99	4	3
17130	2012	1	1	9	99	4	3,6
17130	2012	1	1	10	99	2	3
17130	2012	1	1	11	99	0	2
17130	2012	1	1	12	99	4	0
17130	2012	1	1	13	99	6	0,5
17130	2012	1	1	14	99	1	1,5
17130	2012	1	1	15	99	1	1,5
17130	2012	1	1	16	99	9	1
17130	2012	1	1	17	99	2	0,5
17130	2012	1	1	18	99	3	0,5
17130	2012	1	1	19	99	5	0,5

Table 3. A Sample of Data from Turkish State Meteorological Service in Ankara

3.3. Local Meteorological Station Data

Local meteorological station is a pole which is placed nearby the location where the solar plant is constructed. On a normal local meteorological station pole, it contains several sensors to measure the weather conditions. These are as follows: (i) pyranometer, (ii) wind speed sensor, (iii) humidity sensor, (iv) raingage and (v) temperature sensor. To explain shortly what are the goals of these sensors, let start with pyranometer which is one of the most important sensor among the others. It is responsible of collecting the solar radiation of the environment. Solar radiation is the energy density of the sunlight reaches on the surface of the Earth. As the radiation is related with sunlight, confusion can occur whether it is the same object with the temperature. However solar radiation and temperature indicate different purposes. The difference is that, temperature is a numeric scale which is used to measure the air condition whether it is hot or cold. The relationship between solar radiation and the temperature is directly proportional as more amount of solar radiation comes to surface, more the temperature will increase. It is also same for the vice versa condition. As maximizing the efficiency of a solar panel depends on the solar radiation, pyranometer plays a very important role in prediction of solar panel type energy value. Next tool to be considered is the wind speed sensor. It is used to collect the speed and direction of the wind of the current location.

The wind speed data can be useful to understand how harsh the environment. It is important for constructing solar panel fields because wind has potential of cooling the solar panel which effects the efficiency of a solar panel in a positive way. On the other hand, according to its direction, wind can be dangerous for the solar panels since it can turn the solar panels upside down. Humidity sensors are also very important for a local meteorological station as the relative humidity is directly related with the reduction of the global radiation [25].

Next sensor that is placed on a local meteorological station pole is the raingage to determine the rainy weather conditions. It is important for a solar panel to be located in a non rainy place. There are two important cases when the efficiency of a solar panel decreases because of rain.

- The first one is when the rain washes the surface of the solar panel, it gets wet and the possibility of sticking dust on the surface of a solar panel increases and this decreases the efficiency of the solar panels.
- The second problem with the rain is the cloudiness. The reason for this is because the efficiency of a solar panel can be effected by rainy weather conditions as clouds do not let the sunlight to the surface of the Earth which decreases the solar radiation.

It is the reason why the raingage tool plays an important role for understanding if the environment around the panels is suitable or not. Last tool is the temperature sensor and it is used for measuring the temperature around the the solar panels since the local meteorological station pole is installed in a place close to solar panels. The temperature data is very essential for the efficiency of a solar panel. Normally the standard working temperature value for a panel changes between 20 °C and 25 °C [26], but since the temperature of the weather varies in many cases, the production of energy of a solar panel is affected deeply in different weather conditions. In very hot weather conditions, the efficiency of a panel decreases but on the other hand, in cold and sunny weather conditions, the efficiency of a solar panel increases [27]. After these explanations of the tools placed on the local meteorological station pole, it is easier to explain why local meteorological station pole has to be installed nearby the solar plant.

The local meteorological station pole used in this thesis is located next to the solar plant constructed in Gölbaşı Gazi Teknopark in Ankara. It consists of a pyranometer and temperature sensor. These sensors measure the solar radiation and the temperature from the current environment and save the data into a database located in a server in Gazi Teknopark. The data is saved in every ten minutes and it is a combination of similar data collections which are (i) average radiation, (ii) maximum radiation, (iii) average temperature, (iv) minimum temperature and (v) maximum temperature. In the thesis, the time interval of this data set is reformed by changing its form into hourly data. This process is achieved by taking the average of every each hour. The reason why it is done is because the data gathered from the local meteorological station pole is a little bit corrupted. The data, in normal situations has to be saved into a database in every 10 minutes but in this case there is no stable interval between local meteorological station data for every instances. When the data is not stable as explained, the combination of the local meteorological station data, meteorological service data and solar panel power data are not possible. They all have to be in the same form such as hourly or minutely to be able to be used in the prediction model.

3.4. Solar Plant Data

Generally the main parts of a solar plant are solar panels and inverters. The panels are the ones generate direct current (DC) power from sunlight and the inverters are the ones convert DC power generated by the solar panels to alternating current (AC) power. In addition to the sensors explained above, there is another tool called tracker that can be installed in a solar plant to improve the solar panel efficiencies. It has two main types which are single-axis and dual-axis. Single-axis tracker moves the panels on only the x-axis (horizontal) or only on y-axis (vertical) and dual-axis tracker moves the panels on both x-axis and y-axis [28]. It is normally attached to a group of lined up solar panels to move them to the direction where sunlight comes from. As a result, solar panel creates more energy since the sunlight comes more directly to the surface of it.

For this thesis, a solar plant is installed in Gölbaşı Gazi Teknopark in Ankara. The total panel number placed in this station is 536 with three different solar panel technologies which are explained in the Chapter 2. There are 12 different panel specifications and 9 different brands among the solar panels. The reason for installing this solar plant with such differences is to measure how the different solar panel types react under the same environmental circumstances. The obtained produced energy shows that the efficiency differences between solar panel types play an important role in constructing solar plants as the size of the construction area and the prices of the panels effect the cost of a station dramatically. In addition to panels in a station, a tool, which is called inverter, is needed to save the produced panel energy to a installed server. In this system the produced solar panel energy data is saved in xml file format in every five minutes. Each xml file contains data about how much energy is produced within the five minutes interval of a time by all the solar panels connected in the solar plant. These XML files are saved in a server in a shape of three xml files zipped together.

There are two different types of inverters with a number of 22 in total. Among these inverters, only one is the main inverter and the rest ones are sub inverters. What makes main inverter different from sub inverter is its high capacity property which is called installed power. Briefly installed power of an inverter shows how much energy (Whr) produced by solar panels can be handled by an inverter. In other words, it indicates how many panels can be connected to an inverter. In the system located in Ankara, each sub inverter is connected to only one type of solar panel with an energy producing limits in total not exceeding the installed power limitations of the connected inverter. In addition, all these sub inverters are connected to main inverter. From a different point of view, main inverters are like the opening gates of the solar plants. From this gate, it is possible to see overall production of a station and also the energy produced by the solar panels can be sold to the nearest power distribution units or vice versa.

3.5. Data Formating

As mentioned above, three types of data sets are used to create the prediction model. These data sets are gathered in different time intervals. Since the prediction model requires all data sets in the same format in order to use them as an input, it is decided to reform all them in hourly interval. To achieve this goal, some changes have to be done in the data of the local meteorological station and solar plant since they are in different intervals. On the other hand, nothing has done about the meteorological service data as it is provided from Turkish State Meteorological Service in whatever type it is requested. The logic to invert the data to hourly format is to take the average of each hour.

3.6. Data Collector Program

The data collector program has the functionality to collect data sets from the servers where all raw data of local meteorological station, solar plant and meteorological service data are located. It is implemented as a windows form application to be used only for the admin of the server where the database of the program is installed. Visual Studio 2010 is used as IDE (Integrated development environment) and C# is used as the programming language in this program. As database, Microsoft SQL Server (MSSQL) 2008 is chosen. The database connection between the program and the database is achieved by ADO (ActiveX Data

Objects) database connection. It is in the following sections where the screen shots of this program will be displayed with brief explanations.

Main Page

A screen shot of the home page of the Data Collector Program is displayed in Figure 29. The program has two main menus which are Setup and Plant Setup. The Setup menu consists of (i) inverter, (ii) local meteorological station, (iii) meteorological service data, (iv) user setup and (v) database connection sub menus. On the other hand, plant setup menu is where user can update, delete or save information about the plants. It consists of (i) plant, (ii) inverter and (iii) panel sub menus.

In addition to menus of the program, the home page displays brief information to its users about the servers where the data sets are collected. Two server information can be seen here. The first one is solar plant servers and the other one is local meteorological station servers. The functionality of these two information lists plays an important role in order to use the program. The reason of this is because if the user wants to setup a timer in order to gather raw data from a solar plant server, the user has to select one of the solar plant servers from the list which helps program to understand from where the raw data will be collected. In addition to choosing a server in order to collect raw data, the servers can be also selected from the list to be updated or deleted their connection specification.

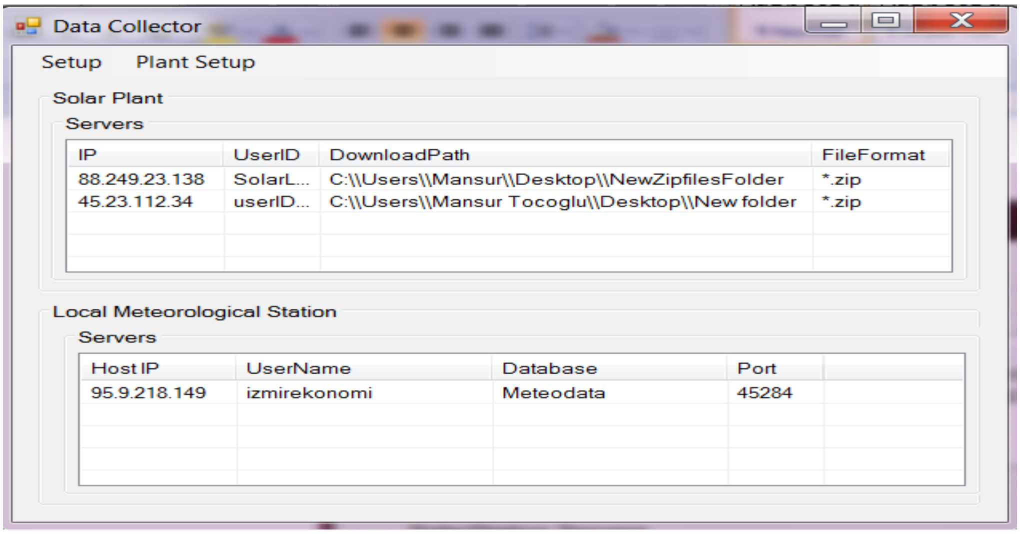

Figure 29. Main Page of the Data Collector Application

Setup Menu

The Setup Menu as mentioned above consists of five different sub menus as it is displayed in Figure 30. By using the sub menus of the setup menu, user can connect to database, update or insert user information, set new specifications for a selected solar plant, local meteorological station and meteorological service data.

Inverter Sub Menu

The purpose of this sub menu is to make changes for a solar plant server. The admin can change or add connection specifications for a solar plant server. In addition to that, the time interval for receiving XML files from a solar plant server can be adjusted. Download all data sub menu is selected for gathering all XML files from the server in the initialization process when the connection with the server is set recently, but it can be used only when there are low amount of XML files in the server. The last sub menu save inverter data from XML file is implemented for extreme cases such as when there is a connection problem with the solar plant server, admin can be able to download XML files from the server to a local directory with any FTP solutions and then from this sub menu, user can select the local directory to save the data into the database.

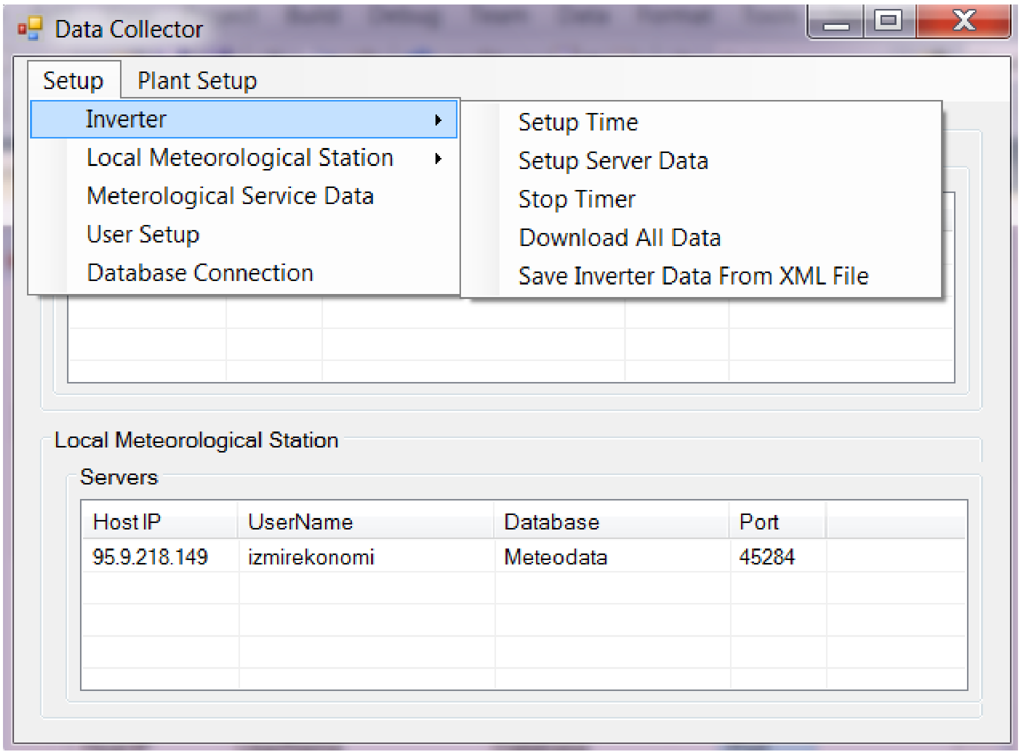

Figure 30. Sub Menus of the Setup Menu

Setup Time Sub Menu

This sub menu is used by the admin in order to set the initial day of the timer which has a daily time interval. In other words, the initialized timer gathers solar plant data from the connected server once a day. The timer does not stop collecting data for each day unless the admin selects the sub menu stop timer.

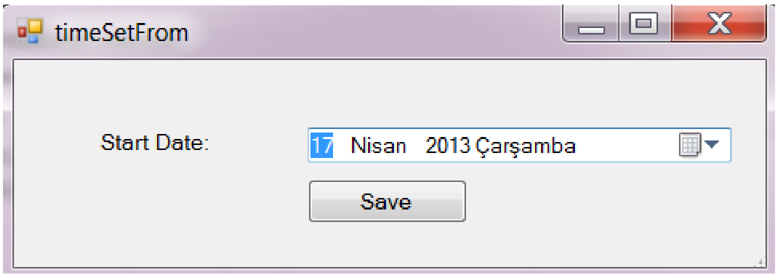

Figure 31. Timer Start Page for the Inverter Results Collection Process

Setup Server Data Sub Menu

This sub menu is used to make changes for the connection specifications of a solar plant server. As a screen shot of the windows form is displayed in Figure 32, the admin can add a new connection specification or update the one already saved. It can be seen from Figure 32 that there are several parameters. User id and user password are the most important ones because they are keys to connect to the ftp server where all solar plant data is kept. File path to download is the path where the admin decides the ZIP files from the ftp server will be downloaded into the local server. As explained above the solar plant data is downloaded from ftp server in a ZIP file format. To get the data inside of each ZIP file, the program has to unzip the ZIP files to a folder in the local server. So admin must decide the folder path where to unzip these raw data in unzip target file parameter field. Download type field indicates the file formats hidden in the ZIP files downloaded from the ftp server. RemoteDir field is updated by the admin to indicate the path of the sub folders where the ZIP files in the ftp server are located. Normally the ZIP files are located in the root file, but in some cases they can be in sub folders. Lastly file format field stands to indicate the format of the files located in the ftp server.

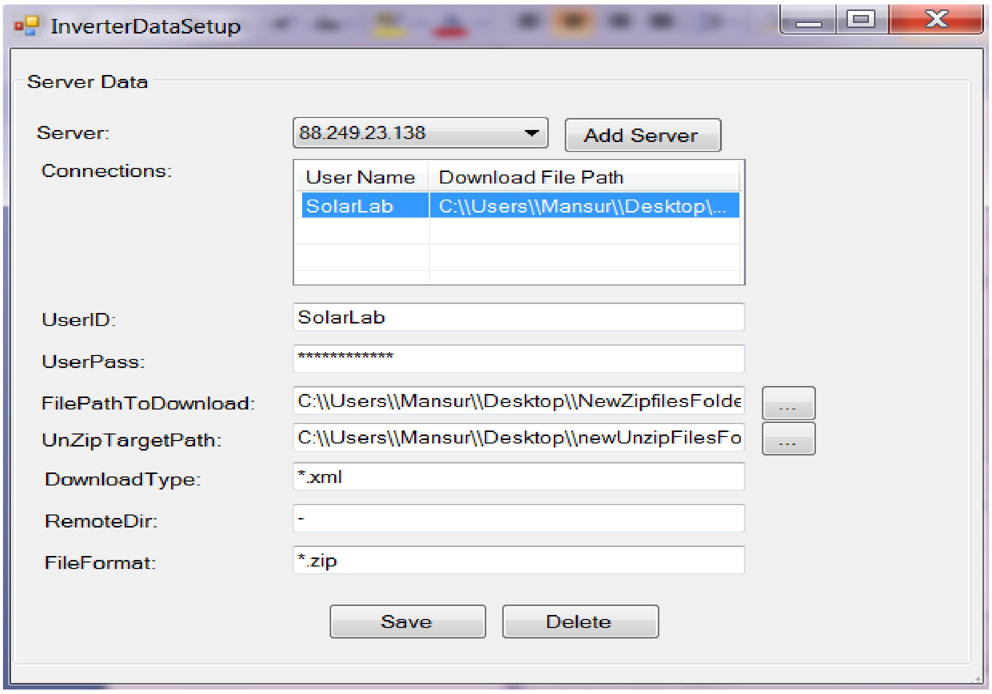

Figure 32. Inverter Data Server Setup

<u>Local Meteorological Station Sub Menu</u>

This sub menu consists of three different sub menus which are setup time, setup server data and stop timer as they are displayed in Figure 33. Shortly setup time and stop timer are used to trigger the timer which helps to program to collect local meteorological station data from the server for a specified time of period. In addition to that setup server data sub menu is used to change or add server connection specifications.

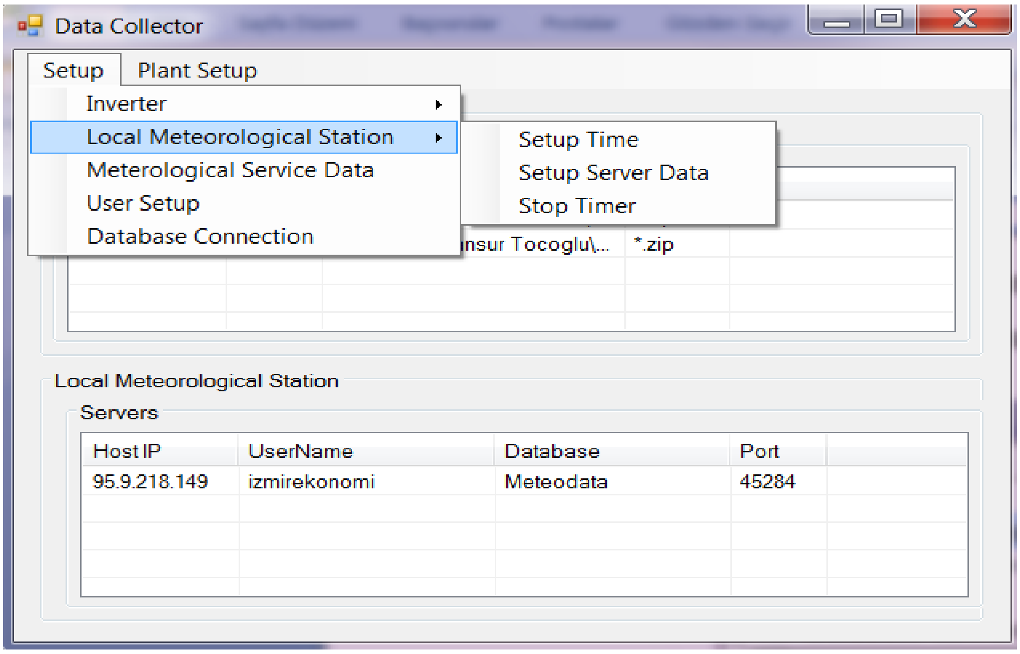

Figure 33. Sub Menus of the Local Meteorological Station Menu

Local Meteorological Station Setup Time Sub Menu

The local meteorological station data is kept in a database as mentioned before and here the admin decides the time interval in a daily format to get the data to local database. Whenever the timer is set, it never stops fetching the local meteorological station data from the server unless the admin selects to stop the timer by clicking the sub menu stop timer.

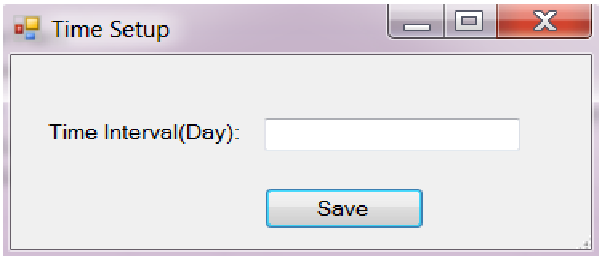

Figure 34. Local Meteorological Station Timer Setup

Local Meteorological Station Setup Server Data Sub Menu

The purpose of this sub menu is to make changes on the connection specifications for a local meteorological station server. To do so, the admin have to determine the IP number of the server where the target database is installed. After determining the IP address of the server, in order to connect to the database where all local meteorological station data is located, the admin must enter the user id, user password, database name and port id which indicates the port number from where the database server is listening the requests for gathering data.

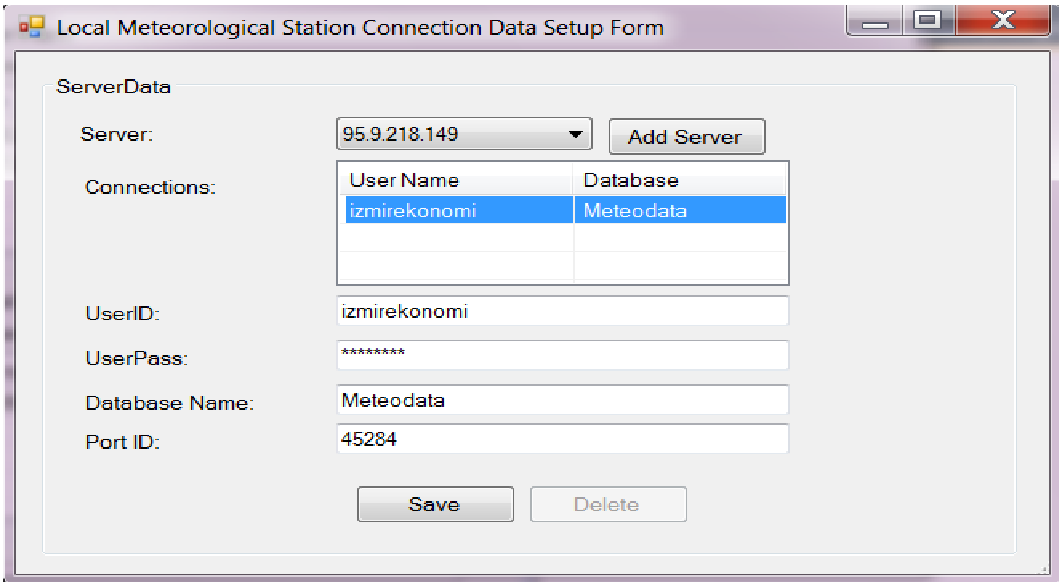

Figure 35. Local Meteorological Station Connection Data Setup

Meteorological Service Data Sub Menu

As mentioned above, the data of a meteorological service is obtained from Turkish State Meteorological Service in a text file format. To use this data in the prediction model, it must be inserted into the local database. To do so, from the windows form displayed in Figure 36, the user must select the location of the meteorological service station and then enter the local path of the text file in order to save it into the database.

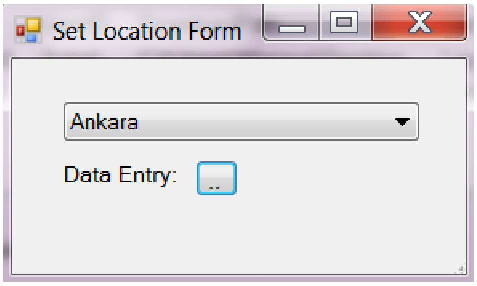

Figure 36. Set Location of the Meteorological Service Station

Plant Setup Menu

This menu is implemented for making changes about the properties of the selected solar plants. It has got three main sub menus which are plant, inverter and panel sub menus.

Plant Sub Menu

The goal of this sub menu is to fill the properties of a selected solar plant or define a new solar plant. There are several fields user can enter such as IP number of the server where inverter data is collected, plant name, location which indicates where the solar plant is installed, initialization date represents the first day when the solar panels start to produce energy for the first time, plant power field stands for representing the total power of the installed solar panels in kilowatt-hour format, communication field indicates the communication type between the server and the inverters, latitude and longitude fields are filled in order to indicate the coordination of the solar plant, picture is a field where admin can enter a picture of the current plant to be displayed in web page, and finally the last area left is the list at the bottom of the page which only has the functionality to display the web users assigned to the selected solar plant. The screen shot of this page is shown in Figure 37.

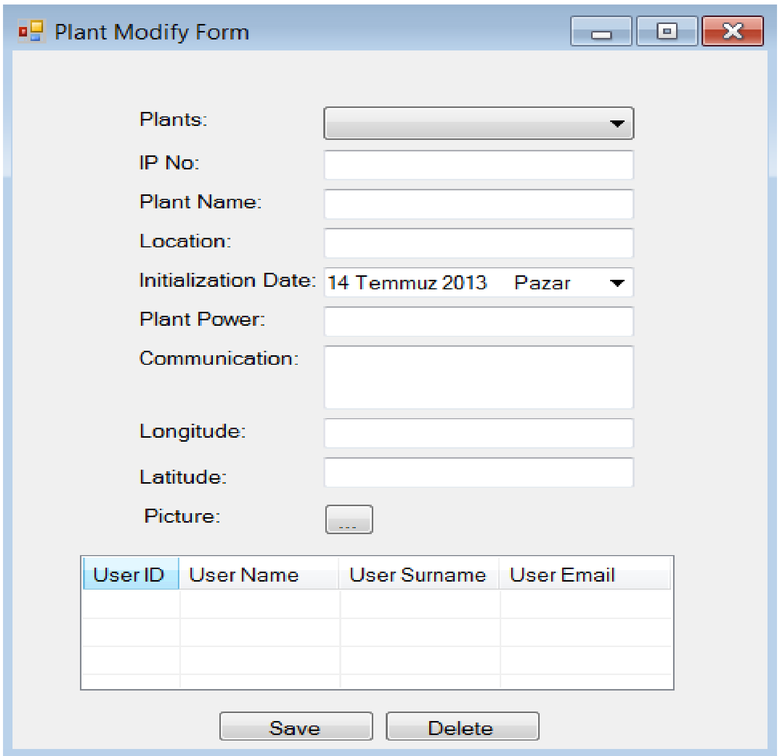

Figure 37. Plant Modify

<u>Inverter Sub Menu</u>

Inverter sub menu consists of two different sub menus which are showed in Figure 38. The intention in this sub menu is to define a new inverter and inverter type data or update the properties of the present inverters and inverter types.

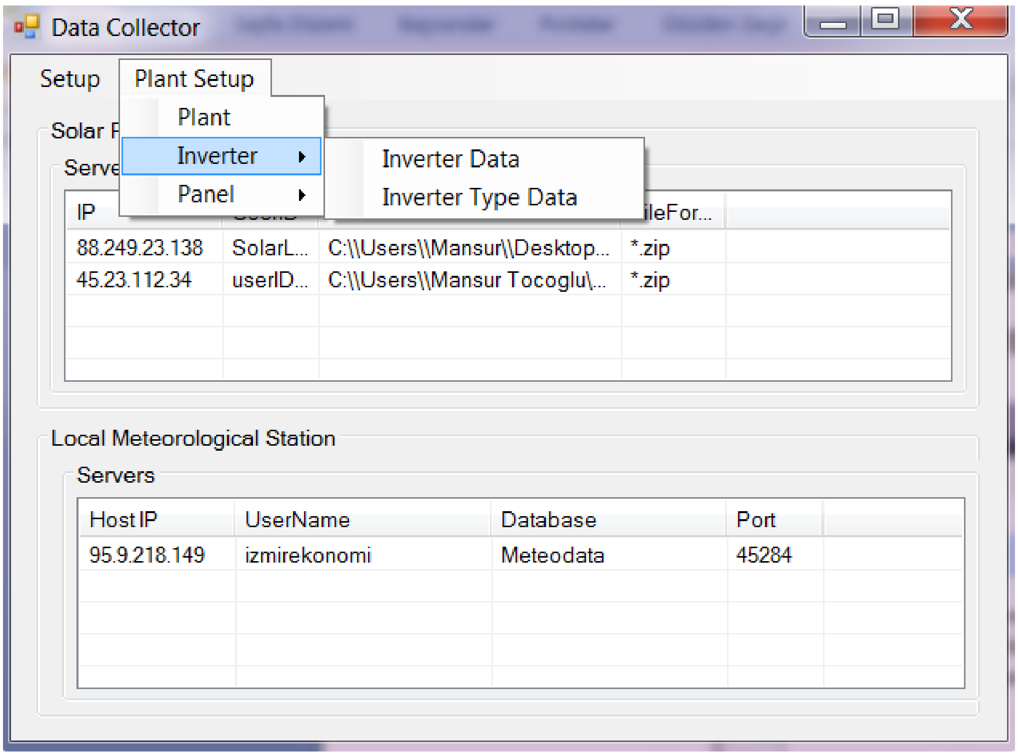

Figure 38. Sub Menus of the Inverter Menu

Inverter Data Sub Menu

The admin has two different functionalities to start using this sub menu. If the admin wants to change the properties of an inverter, he/she can search for an inverter by first selecting a plant name and as a result, the inverter combo box will be filled by a list of inverters of the selected solar plant. Then, an inverter name is selected to make changes of the properties of it. On the other hand, if the admin wants to add a new inverter, all he/she has to do is to define a new inverter name, calculate the installed power of the newly defined inverter which is the sum of the total power of the panels connected to the inverter. After, the admin selects an inverter type which is defined in the inverter type data sub menu and a solar plant name is selected to which newly entered inverter is connected to. A screen shot of the windows form is displayed in Figure 39.

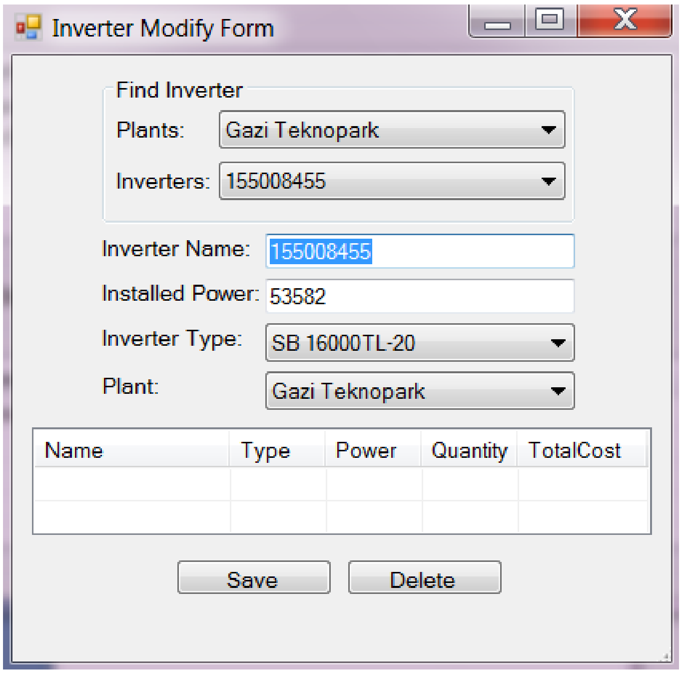

Figure 39. Inverter Modify

Inverter Type Data Sub Menu

The form displayed in Figure 40 is for making changes of the specifications of the inverter types. The capacity field is the most important one which indicates the total power that an inverter can handle. By defining the capacity of an inverter the admin also defines the limited number of the solar panels that can be connected to that inverter because the total power of the connected solar panels can not exceed the capacity of the inverter.

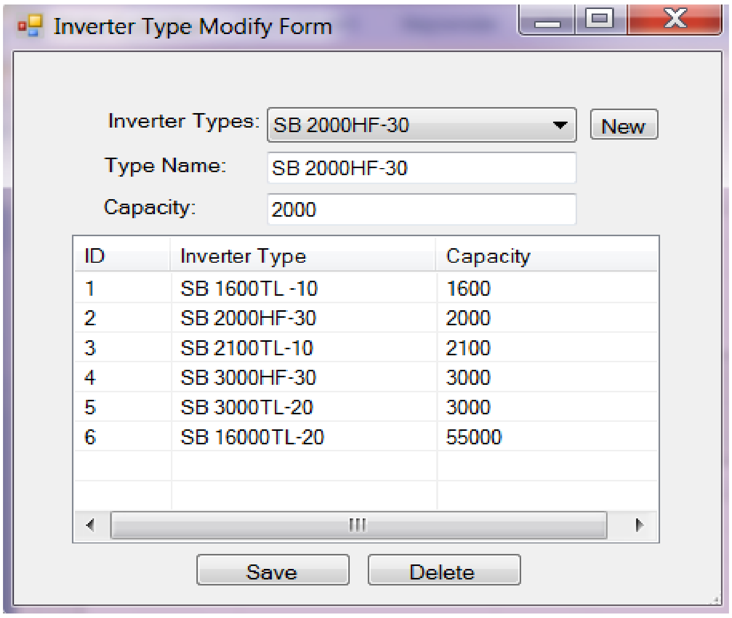

Figure 40. Inverter Type Modify

Panel Sub Menu

Panel Sub Menu has two sub menus which are panel data and panel type data as they are displayed in Figure 41. The main goal of this sub menu is to make changes or to enter new data for the solar panels of a selected solar plant.

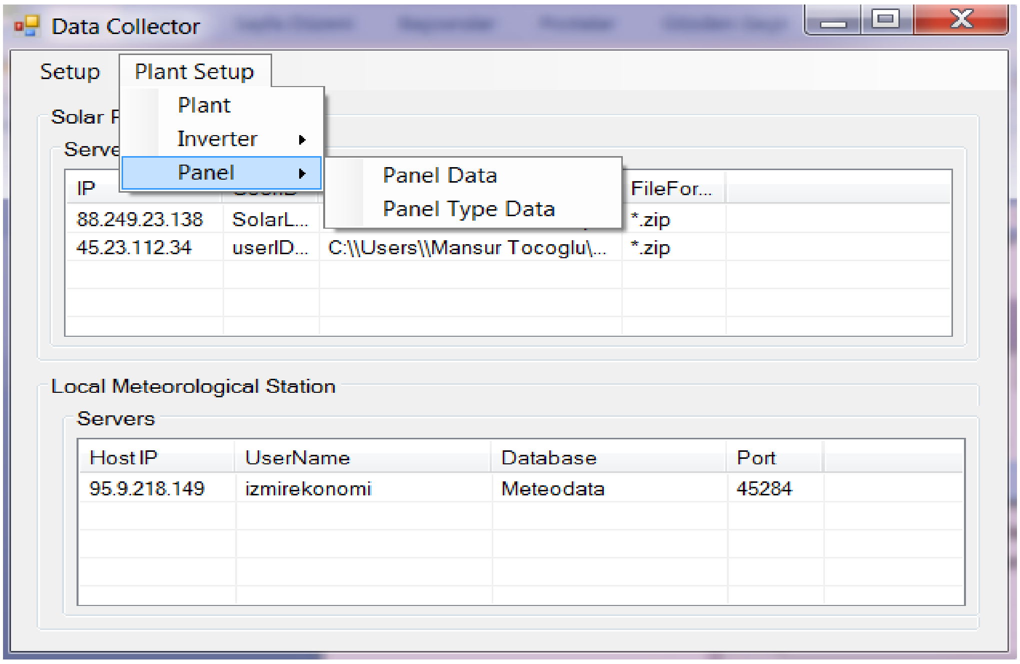

Figure 41. Sub Menus of the Panel Menu

Panel Data Sub Menu

If any specifications of a solar panel are required to be changed, the panel data sub menu is the right menu to enter. When the admin enters the sub menu, a windows form is opened as it is displayed in Figure 42. This form has three main functionalities which are updating, adding and deleting a solar panel. If the admin wants to update the specifications of a solar panel, he/she can search it by selecting the nickname of it from the combobox menu. As a solar panel is selected from the combobox menu, its specifications which are name, panel type, solar plant, inverter, picture, price and the number of solar panels connected to the assigned inverter are filled into the fields below. On the other hand, when the admin has a purpose to add a new panel, all he/she has to enter new values for the following fields. Lastly, if it is required to delete a solar panel from a solar plant, similar to the updating process, the admin has to select a nickname of a solar panel and if it exists then he/she clicks to the delete button.

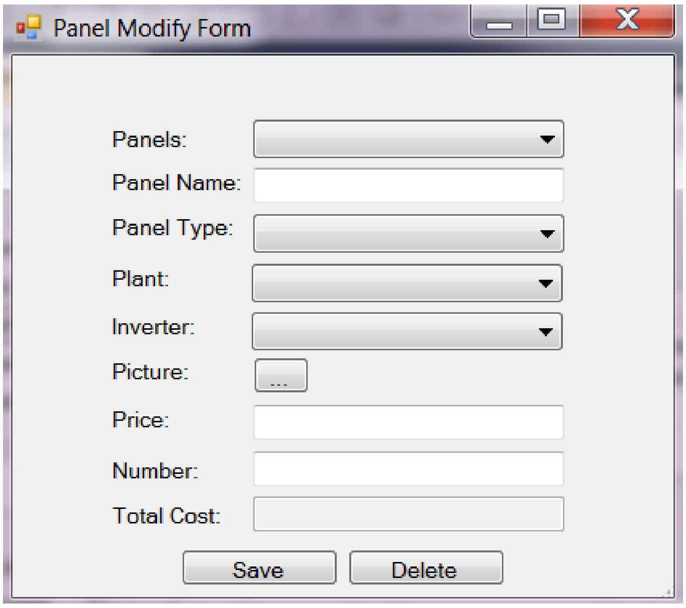

Figure 42. Panel Modify

Panel Type Data Sub Menu

In order to enter a solar panel to a plant, first of all the admin has to enter a panel type to define a solar panel with a kind of nickname. The reason to this is to hide the brand of each panel since it is forbidden for clients to see the brands of the solar panels. So for each panel with different specifications, a unique panel type must be existed. When the admin creates a panel type name, he/she must consider the manufacturing types of the solar panel in mind which are thin-film, mono or poly crystal. In addition, the capacity of the solar panel type also must be filled by the admin. Here the capacity (W/hr) indicates the limit amounts of the possible gained energy of a solar panel under normal conditions.

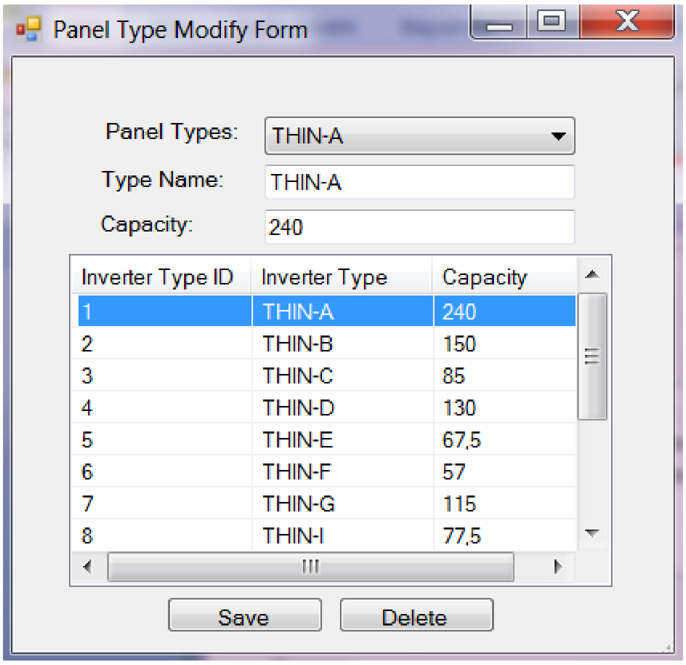

Figure 43. Panel Type Modify

CHAPTER 4

ENERGY PREDICTION

Recently it is highly popular to install solar plants in order to produce solar energy. Even though, it seems a highly guaranteed way of earning money, there are some risks to earn the planned money. Here it is very crucial to earn it, because in some cases the produced solar panel energy does not match with the planned energy amount and this causes a problem in paying the repayments of the received loans since the gained money is directly proportional with the selling of the produced solar energy by the solar plant. Therefore, it is very essential to make an accurate prediction for the energy to be produced by the installed solar plant to have less problem with paying the repayments of the loans.

4.1. Prediction Model Using ANN

In order to predict the energy to be produced by a solar plant, the software tool named Weka is used. Weka stands for Waikato Environment for Knowledge Analysis [29]. It is a program implemented in JAVA. The windows form application which is designed to offer an easy usage for the users is not used in this thesis but, the dll files of it are used within the web site.

There are many machine learning algorithms in Weka application which offer users to try different algorithms. In this thesis, multilayer perceptron is used which is one of the most distinctive and commonly used supervised algorithm among the artificial neural networks [29][11]. The traditional training algorithm of the multilayer perceptron model is the back-propagation algorithm (BP). It feeds the prediction errors from the output layer back to the input layer, and the weights of the links between the neurons are adjusted according to the BP algorithm. Upon completion of the weight adjustments, a new prediction is carried out to evaluate a new prediction error for the next epoch of weight adjustments. These procedures are repeated numerous times until a satisfactory prediction results is achieved [11]. There are many fields where the artificial neural networks (ANN) are used such as mathematics, engineering, medicine, psychology, neurology, meteorology, economics and in adaptive control and robotics, in electrical and thermal load predictions and many other subjects [30][31]. The core elements of an ANN are neurons which have the same fundamental processing as the ones located in a human brain [31]. This processing is displayed in Figure 44.

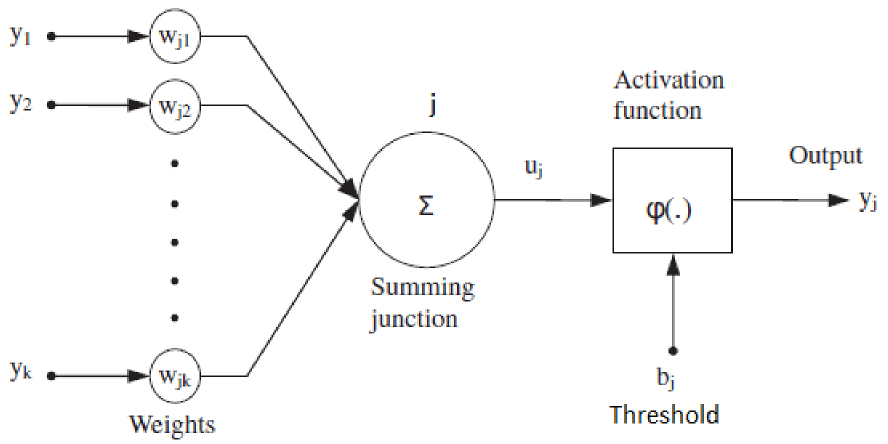

Figure 44. Description of a Neuron [31]

In Figure 44, k stands for the total number of the input signals, each y represents an input signal. In addition, w_{ji} stands for the weight which indicates the connection strength of the neuron i to j. The u_j is the output signal [31]. The description of a neuron is

$$u_j = \sum_{i=1}^{k} w_{ji} y_i$$

and

$$y_j = \varphi(u_j - b_j)$$

where φ(.) stands for the activation function and b_j is the threshold value. In addition to that, the tangent sigmoid is used as activation function which is displayed below [32]. Here v stands for the input of the activation function.

$$\varphi(v) = \frac{2}{1+\exp(-2v)}$$

A multilayer perceptron is a model with a layered structure where the artificial neurons are interconnected to each other. In other words, a neuron is multi-input and single-output computational unit [11]. Under normal circumstances, a neural network has three layers which are (i) input layer, (ii) hidden layer and (iii) output layer. Input layer represents the parameters which are entered into the network. The parameters, used for the model of this thesis, are displayed in Figure 46. The other layer to be considered is the hidden layer. The reason why it is called hidden layer is because of the neurons, which are located in this layer, have no relation directly with the environment. In this thesis, in order to compute the number of the hidden neurons, the "rule of Thumb" is used. The formula is displayed below where N_h stands for the number of the hidden neurons, N_i and N_o represent the numbers of the input and output parameters, and N_p stands for the amount of samples [11].

$$N_h = \frac{Ni + No}{2} + \sqrt{Np}$$

The last layer that it is used in the model is the outer layer. This layer also must be located in an ANN since the created model must give a prediction output via this layer. A small demonstration of the three layered structure of a neural network is displayed in Figure 45 below.

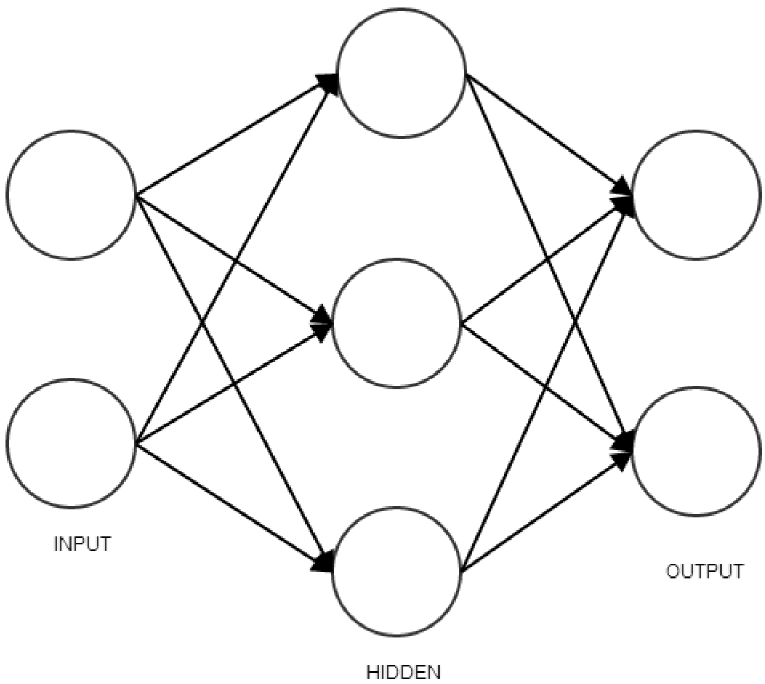

Figure 45. Description of an Artificial Neural Network

4.2. Implementation of the Prediction Model in WEKA

As mentioned above, artificial multilayer perceptron is chosen for the model in the thesis. The network contains three layers which are input, hidden and output layers. This structure can be seen from Figure 46. In the input layer there are nine attributes in total. They are collected from different sources. Among these nine attributes the efficiency is a special one which is calculated for each instance of the input data set. To mention briefly, the efficiency attribute indicates the efficiency of a solar panel. The details for the calculation of the efficiency parameter are touched on in the Chapter 2. The rest of the parameters are gathered from a local meteorological station and the State Meteorological Service in Ankara. This process is explained in details in the Chapter 3. On the other hand, the hidden layer can contain neurons in different numbers. In Figure 46, it can be seen that there are twenty of them. The last layer, in other words output layer consists only one neuron which is called inverter power. Here inverter power parameter indicates the energy produced by the solar panels grouped in an inverter located in the selected solar plant. The model implemented has two main steps which are training the model and making predictions.

The first step is the train process, it is where the data set, to be used in train process, is prepared and the neural network is trained by using backpropagation algorithm. As the Weka application is used to implement the neural network, it is a must to give the input data in an arff file format which stands for Attribute-Relation File Format. This file is created by the Machine Learning Project at the Department of Computer Science of The University of Waikato in order to define the attributes and instances of the arff file [33]. The main point here is that, the data set written in train arff file must contain the overall data set of all the parameters of the input and output layers of the selected inverter. After this creation, the next step is to make the ANN to train itself. Before starting the training process there are several parameters that must be entered into the weka application. These are (i) hidden layers, (ii) learning rate, (iii) momentum, (iv) normalizeAttributes, (v) normalizeNumericClass, (vi) seed, (vii) training time and (viii) the validationSetSize. The hidden layer, as mention before, is constructed as one layer and the "Thumb Formula" [11] is used to calculate the neuron numbers of it. The learning rate is one of the most important parameters, because it plays a key role in the process of training the model since it indicates the amount of the update process of the calculated weights between neurons. The next parameter is the momentum which is the value applied to the weights during updating. The normalizeAttributes parameter is used to improve the performance of the neural network. Another parameter is the normalizeNumericClass. The job of it is to normalize the attribute which is assigned in the output layer. It is only done when the attribute is numeric. This normalization process happens internally between the values -1 and 1. At the end, the output is scaled back to its original interval. It also improves the efficiency of the network. The next parameter to be considered is the seed. It is also one of the most important parameter among the others since it is used to initialize the random number generator. Here this generator is very essential as it adjusts the initial weights of the connections located between nodes of the network and the other purpose of it is to be used for shuffling the training data. The next parameter is the training time. It actually indicates the number of the epochs for the training of the network. The last parameter is the validationSetSize. The user gets the ability to stop the training of the model by entering a percentage value of the error that can be occured in the training process. The training terminates itself by two factors. The first one is when the number of epochs run out. The second case is when the error percentage entered for the validationSetSize is exceeded consistently. The validationSetSize parameter is activated as the user enters a non-zero value between 1 and 100 [34]. After these entries for the model, it is trained by the dll file of the weka in the web site. This train process divides the train data set into two parts. These are train and test sections. For instance, the decided percentage of the train section is 80 and the test section is 20. In this segmentation process, the data set is divided after it is shuffled by using the random number generator. This helps the neural network to be well trained because the trained section contains data from both train and test sections. In the train process, actually the system uses this 80 percentage of the overall train data and after the model is trained, the rest of the train data, here it is 20 percentage of it, is used to test the trained model. The main goal of this test section is to understand how accurate the model is created. The result of the test section is understood by several outputs. These are (i) correlation coefficient, (ii) relative absolute error and (iii) mean absolute error. The formulas of them are displayed below. In the formulas p stands for the predicted value, a stands for the actual value and n stands for the instance number of the test section data. The first formula stands for the calculation of the mean absolute error. As it can be seen that the absolute values of the subtraction of the predicted and actual values are added to each other for all instances of the test section data and then this summation is divided by n [29].

$$\frac{|p_1 - a_1| + \ldots + |p_n - a_n|}{n}$$

The next formula to be considered is the correlation coefficient which is displayed below. The goal of it is to measure the statistical correlation between the a's and p's. By doing it like that, it is achieved how much the results are correlated. The best correlated results are represented with a value 1 and 0 is the value indicates that there is no correlation. In addition, -1 stands for the results perfectly correlated negatively [29].

$$\frac{S_{PA}}{\sqrt{S_P S_A}}, \text{ where } S_{PA} = \frac{\sum_i (p_i - \bar{p})(a_i - \bar{a})}{n-1},$$

$$S_p = \frac{\sum_i (p_i - \bar{p})^2}{n-1}, \text{ and } S_A = \frac{\sum_i (a_i - \bar{a})^2}{n-1}$$

$$\bar{a} = \frac{1}{n} \sum_i a_i$$

The last formula to be considered is relative absolute error. Here the absolute total error is divided by the total error of the default predictor for normalization process. The predictor is the average of the actual values from the training data [29].

$$\frac{|p_1 - a_1| + \ldots + |p_n - a_n|}{|a_1 - \bar{a}| + \ldots + |a_n - \bar{a}|}$$

At the end of the train process, the goal is to get the correlation values close to 1. If the model gives a correlation value close to one, then it means that the predictions will be accurate. As the training process is examined in details, it can be understood that the created neural network is supervised because it learns in the light of a produced energy data for a specified time of period. Here the model uses this real data set to train itself as it has every parameter available for output and input layers.

The second step of the model is to make predictions after its creation. This process is done when a user wants to have a prediction value of a panel type for a selected time interval. To do so, the system requires several inputs from the user. These are (i) solar radiation, (ii) humidity, (iii) temperature and (iv) wind speed data set of a certain location. Actually the only difference between the train process data set and prediction process data set is the inverter power value. The train process data set contains it in order to create the model since it is a supervised model. On the other hand, prediction process data set does not contain the inverter power values of each instances since the purpose of this model is to predict these inverter power values corresponds to each instances. Briefly, as a result of the entries of these data sets mentioned above, the system creates a new arff file, but there are several points have to be handled by the system before creating this arff file in order to maximize the efficiency of the prediction of the trained model. The first problem is the mismatch date intervals between the data sets which are entered by the user. Shortly, time intervals in other words year, month and hour data information of each instances of the data sets entered by the user must match to each other. To solve this problem, the system first enters all inputs individually into the buffer database tables and then takes the join of these tables with each other related with the matching date interval information. The second problem is the mismatch date intervals between the meteorological data sets entered by the user as input and the overall current produced energy from the inverter. This is very important in creating the arff file for the prediction process. The date intervals of the instances of these two data sets must match to each other as the model is trained according to the data set of the current inverter. After this matching process, the arff file is created to be used in the prediction model. As soon as it is created, the system uses this file as an input to the trained model and calculates prediction values of each instances of this file. This all process is done for all the inverters which have the same type of installed solar panels with the selected solar panel type. Since the purpose is to calculate an average prediction value of the selected solar panel type, the system must take the sum of the calculated prediction values of each instances of each related inverters and then must divide this total predicted value with the total number of the installed solar panels of each related inverters. As a result of all, the system gets a predicted value of a selected solar panel type for a certain time of interval.

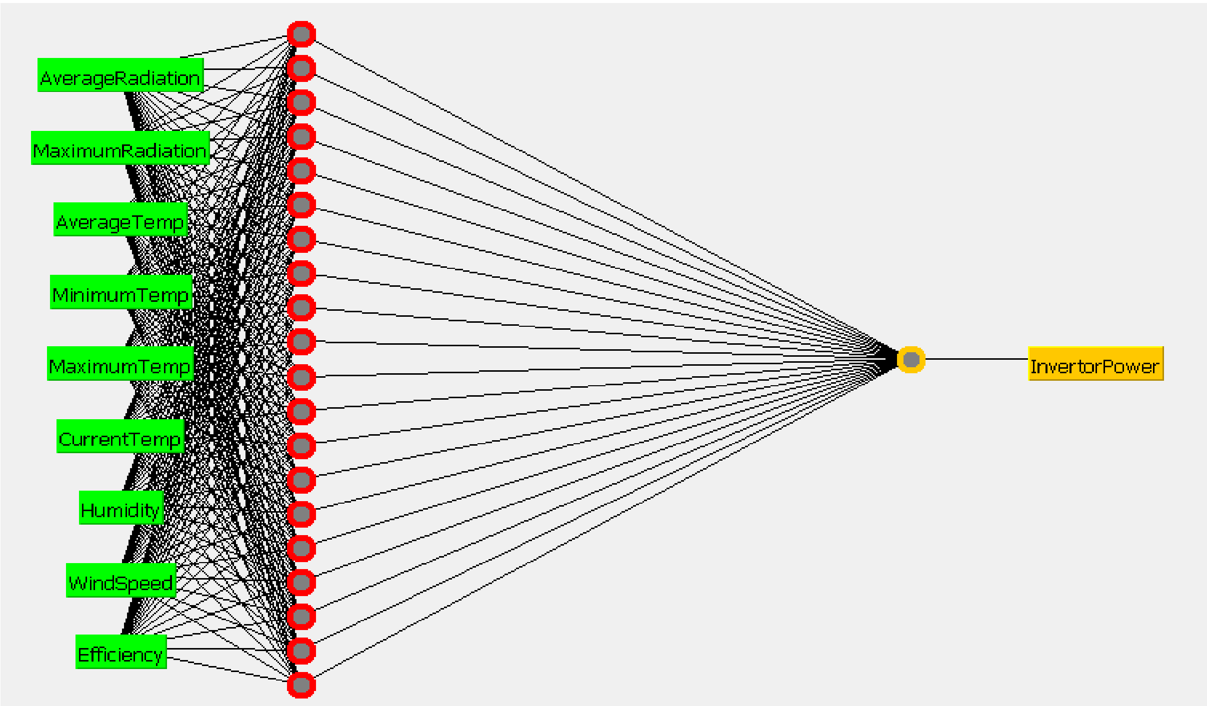

Figure 46. An Example of an Artificial Neural Network

4.3. Energy Output Predictions

There have been several experiments done in order to show how the created artificial neural network module reacts under different circumstances. The data to train and to test the module are arranged in two different time intervals which are hourly and 10 minutes time intervals. So the results will show which data interval is more efficient for the limited data of this thesis. In addition to the different intervals, the trainings and the testing processes are done for short-term and long-term date intervals. For the short-term date interval between 01/07/2012 and

31/07/2012 is selected and for the long-term date interval between 24/01/2012 and 14/10/2012 is selected. There are also specifications used for all training processes which are 2000 for the epochs number, 0.05 for learning rate and 0.08 for momentum parameters. On the other hand, other parameter stands for the number of neurons of the hidden layer has dynamic value which is changing according to the calculation of the "Thumb Formula" [11]. To evaluate the output testing results several formulas are used. These are correlation coefficient, relative absolute error and the last one is mean absolute error.

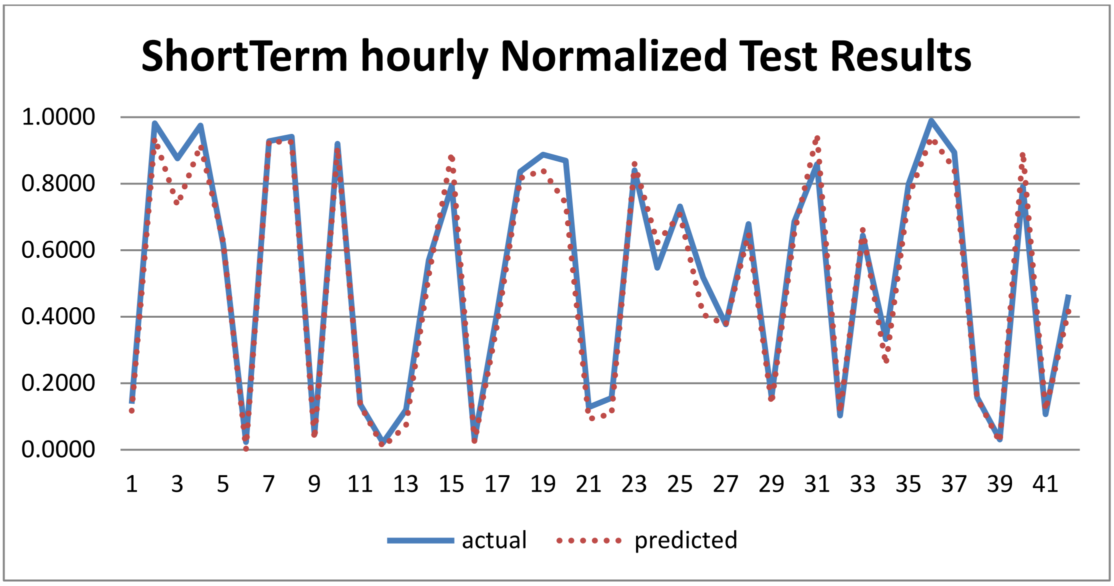

Figure 47. Short-term Hourly Normalized Test Results

Figure 47 displayed above is showing the test results of short-term hourly data set for the date between 01/07/2012 and 31/07/2012. The overall instance number of this data is 441 and 90% of it is used for the training process and the rest of it is used for the testing process. On the graph above, normalized actual and predicted values of the test data are compared to each other. As it can be understood from the results that, the predicted and actual values are matching to each other with high correlations. The correlation coefficient result for this case is 0.9903, the relative absolute error percentage is 12,2267 and the mean absolute error percentage is 0,0395.

The correlation coefficient values of the two data sets, with the same date interval but a different time interval, are compared in Figure 48. One data set represents the 10-min interval time while the other data set represents hourly interval. Both of them are short-term data sets which are between 01/07/2012 and 31/07/2012. The output again shows that hourly data set gives better a correlation value which is 0,9907 against the 10-min interval data set with a correlation value of 0,9851.

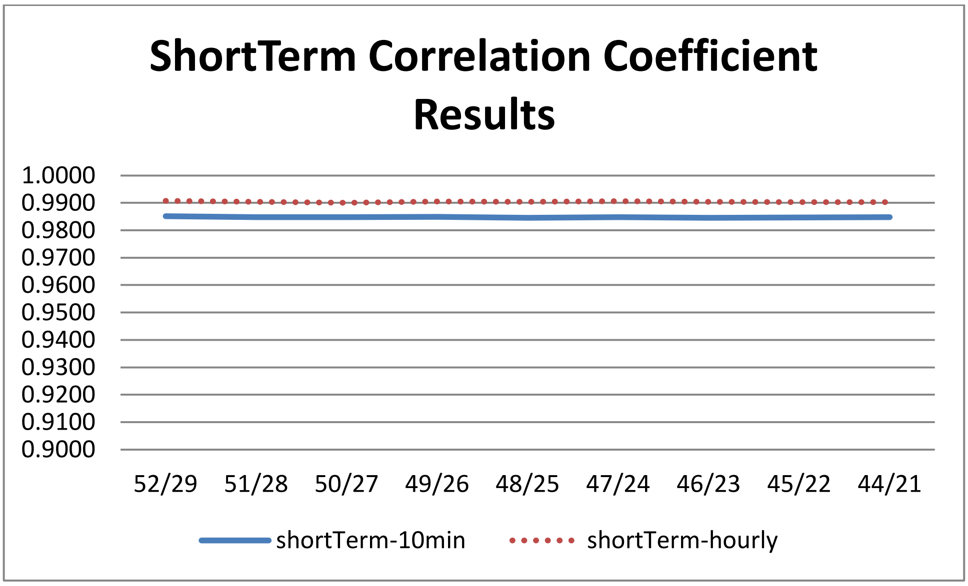

Figure 48. Short-term Correlation Coefficient Results vs 10 min. Hidden Neurons/Hourly Hidden Neurons

Similar to the chart in Figure 48, the outputs of the correlation coefficient values of 10-min and hourly time interval data sets are compared in the chart displayed in Figure 49. There is only one difference between them and it is that the data sets considered in Figure 49 are long-term intervals between 24/01/2012 and 14/10/2012. The highest correlation for the 10-min interval is 0,9645 and on the other hand, it is 0,9832 for hourly time interval. On the graphic, x-axis indicates the same training data set having different neuron numbers of the hidden layers. Here it can be understood that the changes of the number of the neurons of the hidden layers do not make crucial changes on the correlation coefficient outputs.

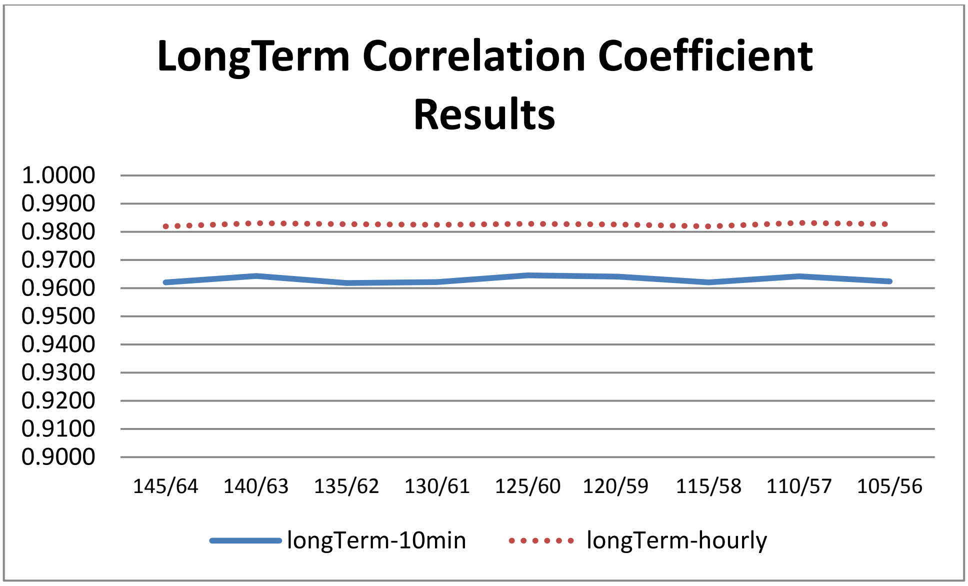

Figure 49. Long-term Correlation Coefficient Results vs 10 min. Hidden Neurons/Hourly Hidden Neurons

The purpose of the chart displayed in Figure 50 is to make a comparison between the normalized actual and predicted long-term test data set between the date interval of 24/01/2012 and 14/10/2012. As it is hourly data set, it has 3178 number of instances. 10 percent of this data is used for the testing process as the 90 percent of it is used for the training process. X-axis indicates the 10 percent instances of the data set and y-axis specifies the normalized values between 0 and 1. The calculated correlation coefficient of this module is 0,9832. In addition, the percentage of the relative absolute error is 13,9053. Finally the mean absolute error is calculated as 0,0413.

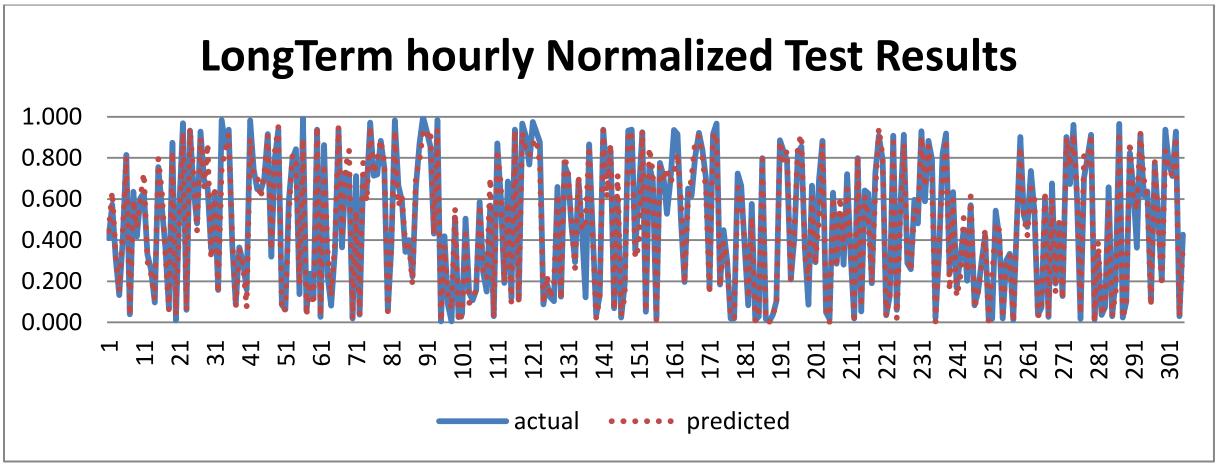

Figure 50. Long-term Hourly Normalized Test Results

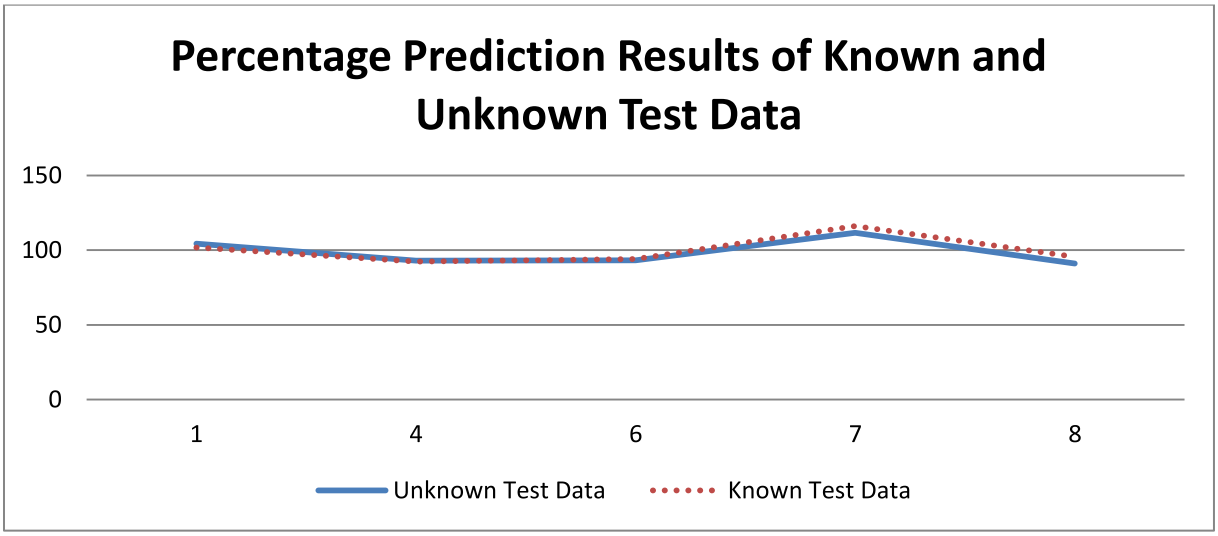

Figure 51. Prediction Results of Known and Unknown Test Data

The purpose of the chart displayed in Figure 51 is to show the prediction output similarities of two different prediction data sets. X-axis of the chart indicates the ids of different inverters and y-axis stands for the percentage of the total predicted value compared to the total percentage of the actual value. The difference between these two data sets are occured because of the training data sets of the models. The first one called unknown test data in the chart, indicates the prediction percentage results containing training data between the time interval of 24/01/2012 and 30/09/2012, and test data set between 01/10/2012 and 14/10/2012. Here as it can be understood that, the model trained by a neural network does not contain any data from the testing data set. So the testing prediction results are realistic as the model has not seen the test data before. But on the other hand, the second one called known test data has the training time interval of a data set between 24/01/2012 and 14/10/2012, and test data set between 01/10/2012 and 14/10/2012. In this case, the model is trained with a data set also includes the test data which is used to test the accuracy of the model. So this causes a problem which is that, the trained model has already seen the test data. As a result of this, the prediction of it is easier for the model. But at this stage, the purpose of the chart above can be explained straightforward as the prediction results of both different training data sets follows similar paths on the graph. The average percentage error between these two paths is 2,6119%.

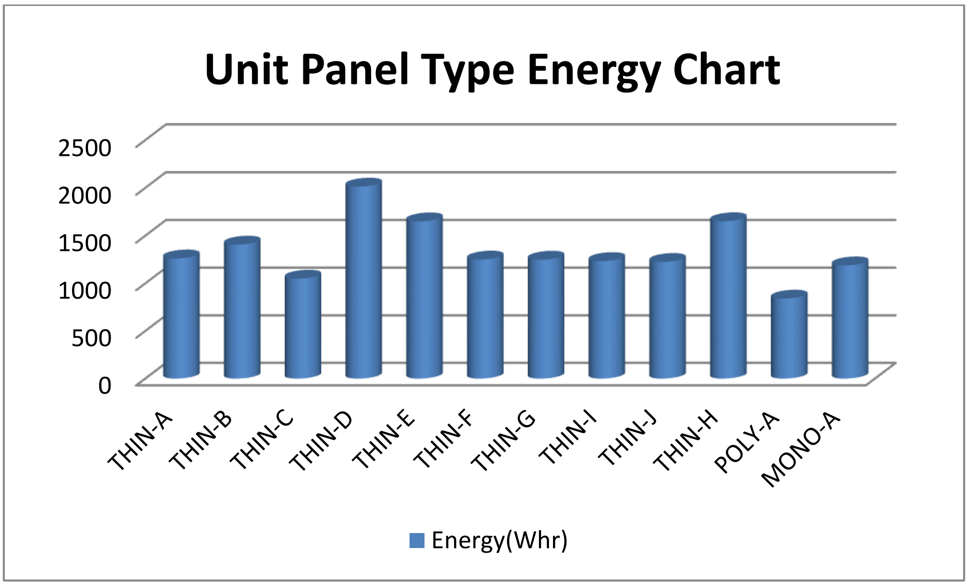

Figure 52. Unit Panel Type Energy Chart

The chart displayed in Figure 52 is created in order to show the total produced unit energy amounts of each solar panel types for the date interval between 24/01/2012 and 14/10/2012. So it is possible to learn which solar panel technology type is more efficient. It is calculated by summing up the produced energy amounts of all inverters containing the same panel type and then this summation value is divided into the total panel number and the production capacity of the panel type. This information helps to make easier solar panel type selections as the investment and payment part of the web site requires a yearly total prediction energy amount for a selected solar panel type to make a payment chart.

A chart displayed in Figure 53 shows the total prediction results for each inverter which are achieved by training a neural network with a data set for the date interval between 24/01/2012 and 14/10/2012. After this training process, again the same data set, but this time without the actual solar panel production values, is used for testing the trained model in order to see how well the trained model predicts for the absent solar panel energy production values. The percentage of the total predicted results compared to the percentage of the total actual results are displayed in Figure 53 where the 100 percentage error value indicates the total actual values. As it can be seen that the error percentage interval is between positive 6 and negative 5 and the average total percentage error is 1,9499%.

This prediction results are generated by using known test data which is explained above. So this means that if unknown test data had been used for testing the model, the interval error percentage can be larger.

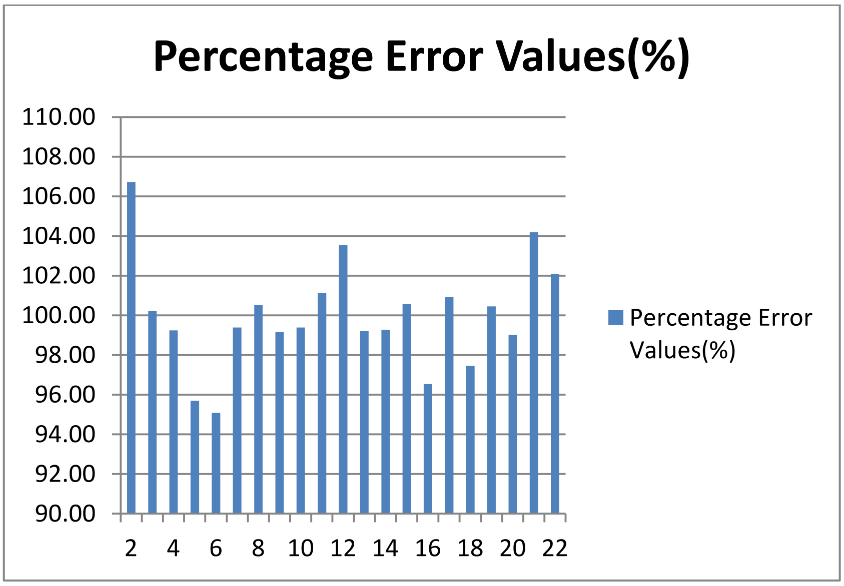

Figure 53. Percentage Error Values for Each Inverter

4.4. Unit Solar Panel Type Performance Comparison Outputs

The goal of this section is to share several charts which are related with the unit energy productions of solar panel types and the comparison between thess energy amounts with the unit prices of each solar panel types. The first chart to be considered is displayed in Figure 54. It is about the comparison of the unit performance and the price of a solar panel type. Here three types are selected. These are polycrystalline, monocrystalline and thin-film solar panel types. As it is explained in the Chapter 5 in details, to draw this chart, first the system calculates the energy production of a unit cell of the specified solar panel type in watt-hour format, then it finds out the price of the current unit cell by dividing the price of the solar panel with the capacity power of that panel. So x-axis of the graph in Figure 54 indicates the unit price and y-axis denotes the unit energy performance of the selected solar panel type. Here the reason why only the three types are selected is because they represent all type of solar panels.

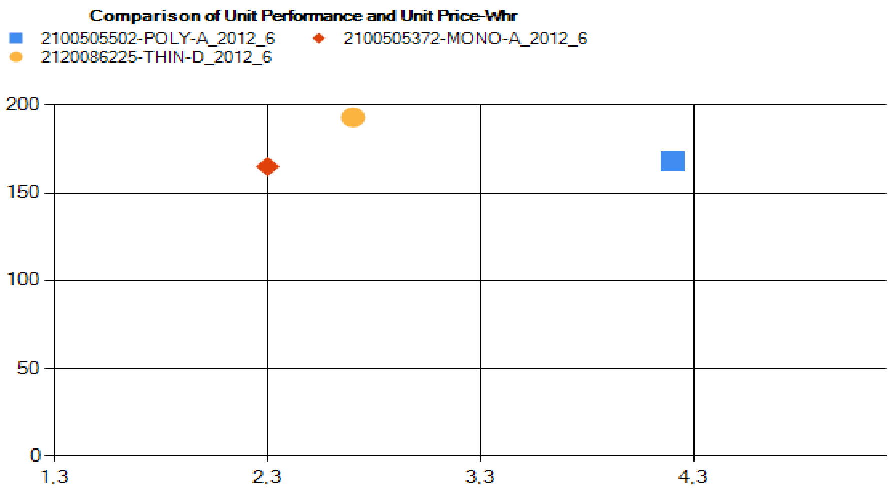

Figure 54. Chart of Comparison of Unit Performance and Unit Price

The chart displayed in Figure 55 deals with the comparison of the produced solar energy of the unit cells of three different solar panel types for the date interval between 24/01/2012 and 20/03/2013. These types are polycrystalline, monocrystalline and thin-film types as it can be observed from the chart. This chart provides an overview about the performance of the unit cells of each type. In other words, the different technologies are compared to each other. The observation results of the chart below indicates that there are no big differences between these three technologies for the overall the interval excluding the date period between the fourth and eighth months for the thin-film technology where it produced energy more than others.

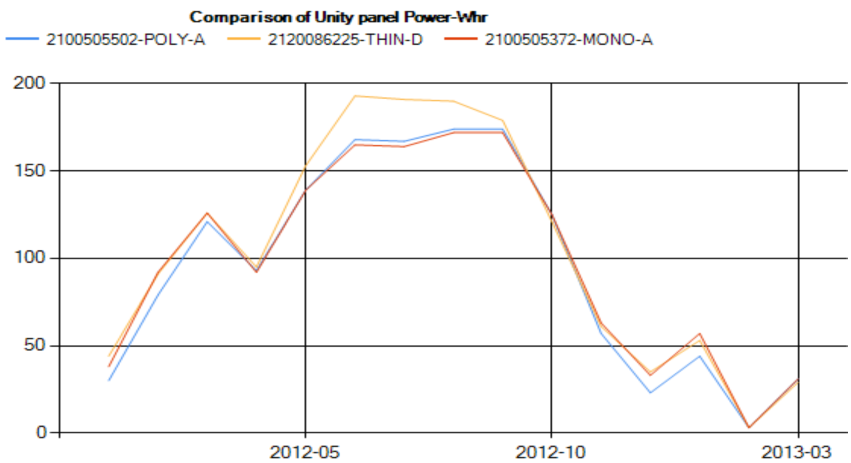

Figure 55. Chart of Comparison of Unity Panel Power

CHAPTER 5

ENERGY MONITORING

A web site is implemented in order to display several applications about the data received from the solar plants, local meteorological station and meteorological service station. The menu which is also shown with Figure 57 displays these applications. These are (i) plant operation watcher, (ii) power prediction, (iii) investment and payment, (iv) comparison of unity panel power and (v) comparison of price and performance menus which will be explained in details on the following sections.

5.1. Authentication

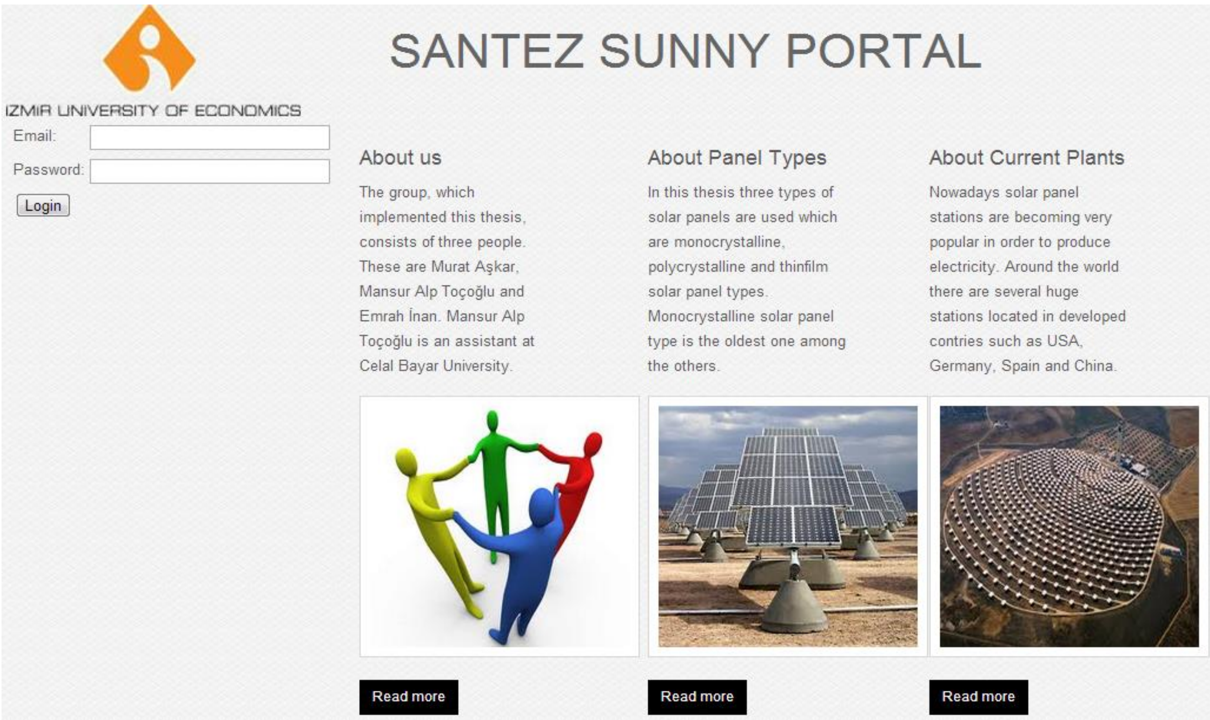

Figure 56. Login

The first page that meets the users is the login page displayed in Figure 56. It consists of (i) authorization, (ii) about us, (iii) about panel types and (iv) about current plants sections. In authorization section authorized users enter their email and password information to login the system. In other sections left, all type of users can read about the curriculum vitae of the implementers of the web site, can obtain information about the different type of panel technologies and current solar plants installed all over the World. The users who are able to use this web site, firstly must be related to at least one solar plant to be able to use the functionalities of the web site displayed on the menu on the left side of it. Otherwise, user will not see any data displayed. Secondly, user must contact to the admin of the system for the registration process for the web site. This process can only be done by the admin. The reason why it is done in a way like this is because of security reasons.

5.2. Energy Monitoring Web Site

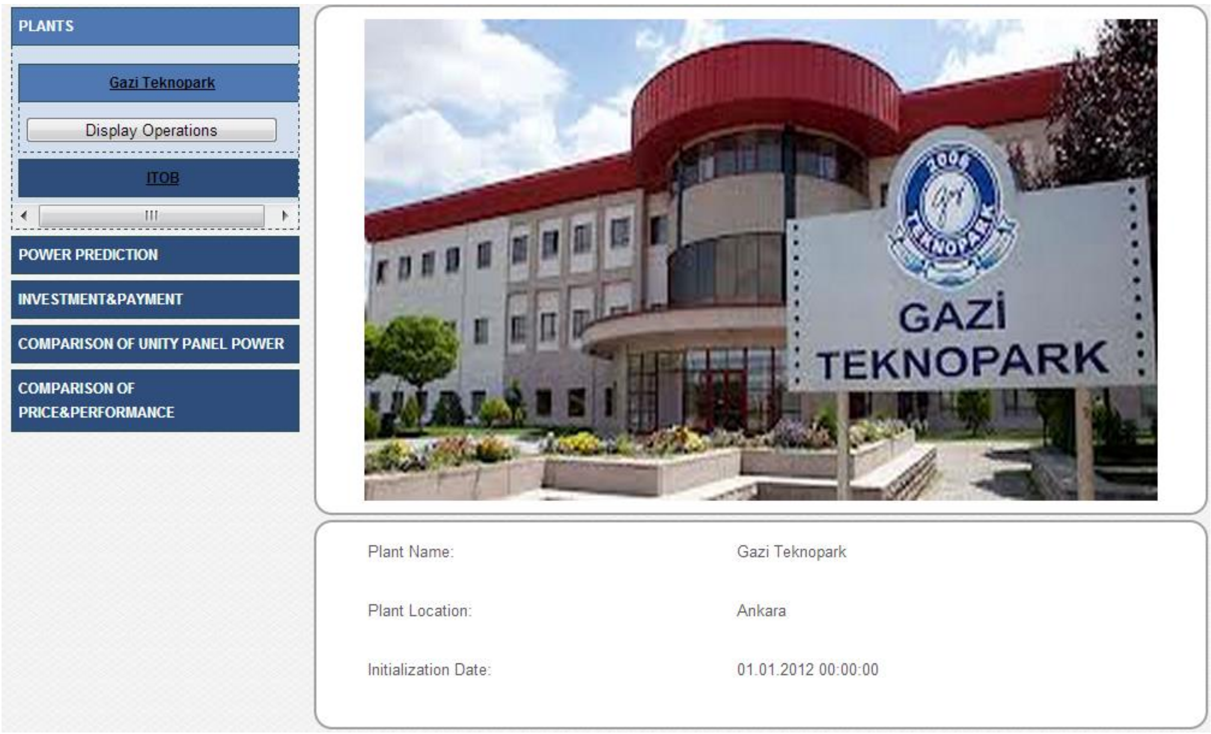

Figure 57. Main

When authorized users login the system, the first page appears to them is shown in Figure 57. From the menu located on the left side of the page, user can select several operations which are (i) plant operation watcher, (ii) power prediction, (iii) investment and payment, (iv) comparison of unity panel power and (v) comparison of price and performance menus as mentioned above.

5.2.1. Solar Plant

When the user enters for a solar plant, the page displayed in Figure 58 appears to the user. This page presents several sub pages which are (i) plant profile, (ii) plant overview, (iii) comparison of radiation and power, (iv) information of the installed inverters and (v) types of the solar panels used in the selected solar plant. The detailed explanations of these sub pages are written in the following sub sections.

5.2.1.1. Solar Plant Profile

The plant profile sub page shown in Figure 58 is displayed whenever user selects a plant which makes it the first page to be exhibited to the users. It gives brief specifications of the selected plant such as name, location, initialization date which indicates the first time when the plant starts to produce energy, plant overall power of the plant, communication tools which indicates the connection tools used between the inverters and the servers, and the last specification about the plant is the name of the inverter types used for the inverters.

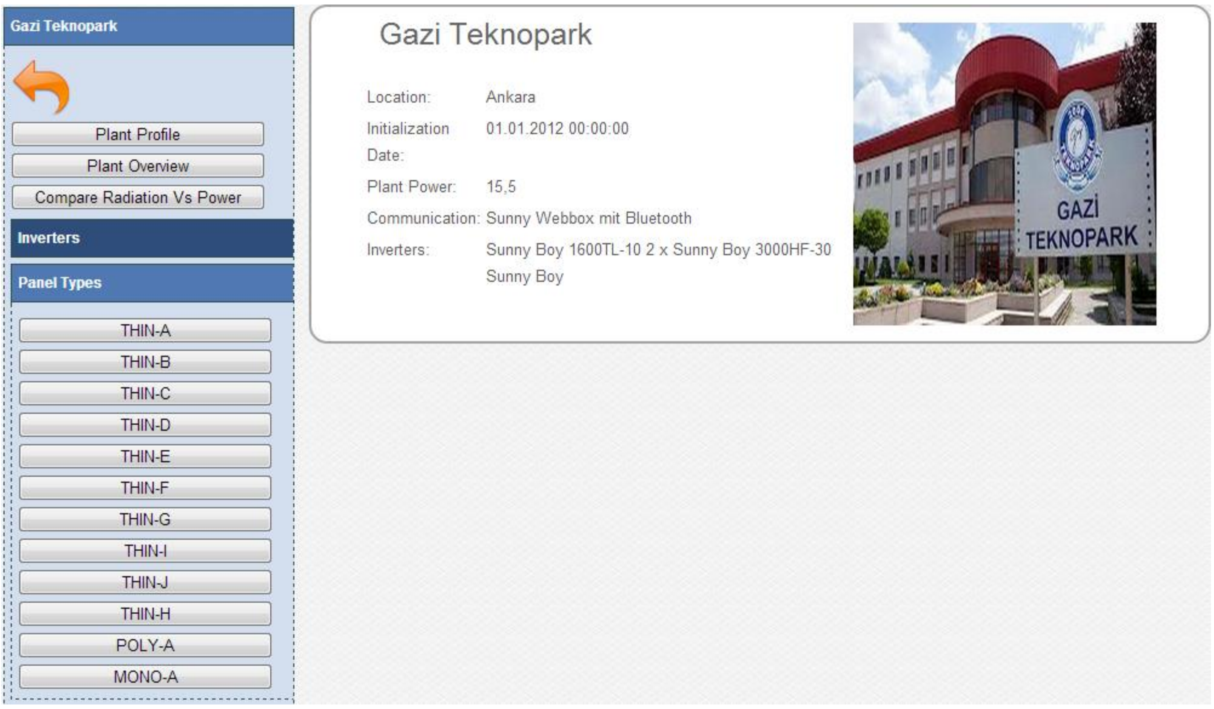

Figure 58. Plant Profile

5.2.1.2. Solar Plant Overview

This sub page has three main sections which are yearly total power graphic, overall plant calculations and monthly power graphic. These sections are displayed in Figure 59. The reason for implementing this page is to inform users about the overall power production of the selected plant.

The main goal of the yearly total power section is to graph the sum of the energy produced by all the solar panels installed in the selected solar plant in monthly kilowatt-hour format for the current year. This helps users to understand the yearly performance of the present of the solar plant. Second section is the overall plant calculations which give a brief idea of the energy production results. It has four main information areas. These are current date, energy production, carbon dioxide avoided and the last one is reimbursement. To start with the energy production area, it is the total sum of the energy production of the selected solar plant in kilowatt-hour format. As the user obtains the overall production value of the total solar panels, he/she can predict the future of the energy production roughly. Next area to be considered is the carbon dioxide avoided area. It is one of two vital areas of this page as the user can gain the release of the carbon dioxide amount in metric tons format as if the selected solar plant uses the coal as the raw material to produce the energy. It is calculated with the following formula below where 0,7 coefficient value is the amount of the avoided CO_2 per one kilowatt produced solar energy in one hour. This coefficient is calculated by the data displayed in the web site of the ITOB Sunny Portal of SMA Company [35]. These are the overall energy production in kilowatt-hour of the solar plant located in ITOB and the total amount of the avoided CO2 in kg. In order to calculate the 0,7 coefficient value, the overall energy production is divided by the total amount of the avoided CO_2 [35].

$$\text{Total produced energy (kWh)} * 0{,}7 \text{ (kg)}$$

The last area is the reimbursement. It is where the system calculates the total amount of the earned money in dollars to inform users to get an idea of the money performance of the current solar plant. The result is calculated by multiplying the dollar amount of one watt of energy with the total produced solar panel energy.

The last section of this page is the monthly power graphic. This graph is used to get overall energy production information of the solar plant in details. It is a detailed graph as it provides the ability to the users to enter date interval and enables them to examine the data easily. Y-axis stands for the numeric energy production values in kilowatt-hour format and x-axis indicates the date interval.

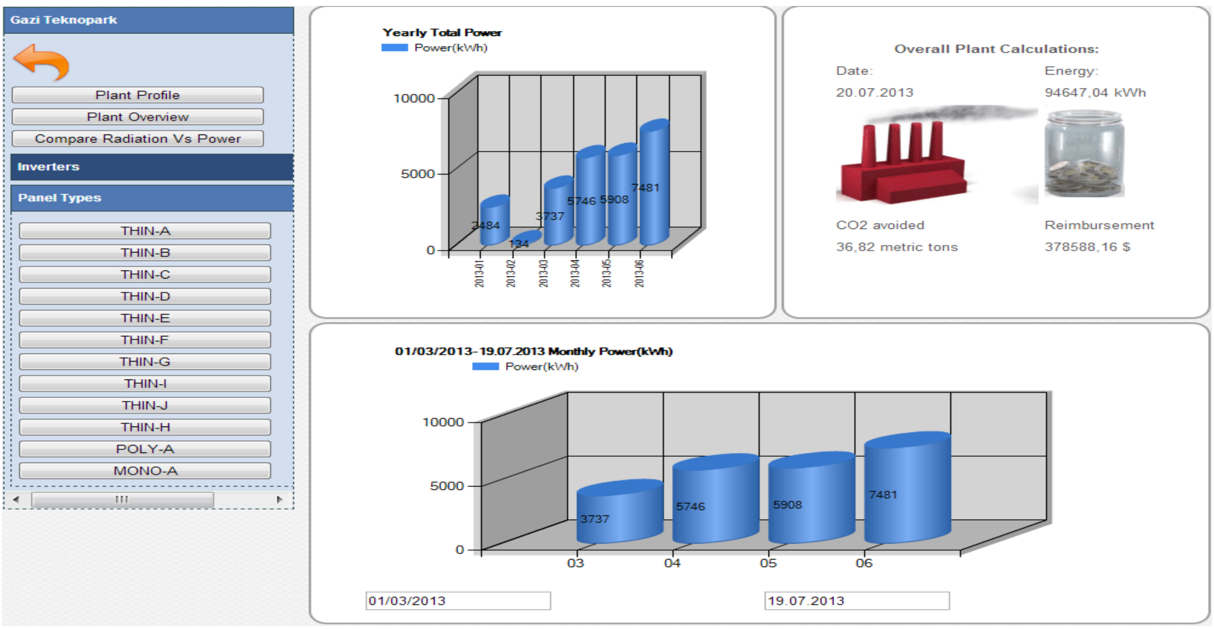

Figure 59. Plant Overview

5.2.1.3. Radiation vs Power

The main goal of this page is the monthly comparison of the radiation data, which is obtained by the local meteorological station located near by the solar plant, and the power produced by the solar panels installed in the current solar plant. The reason why this section is implemented is because of the need of showing whether the radiation data is directly proportional with the produced energy or not. This is important because under same circumstances, these two parameters follow similar paths. More insolation is gathered, more energy is produced by the solar panels [36]. If the lines on the graph displayed in Figure 60 follow different paths, then it can be understood that the data compared is odd. But from the graph displayed below, the user can figure out that there is no mistake in the data set since both red and blue lines follow the similar paths. Left scale stands for the produced energy power in watt-hour and the right scale stands for the solar radiation data in watt-hour obtained from a near local meteorological station. In addition, the data of both units can be arranged between a selected date interval by the user. This gives the opportunity to users to analyze the data set with a comprehensive point of view.

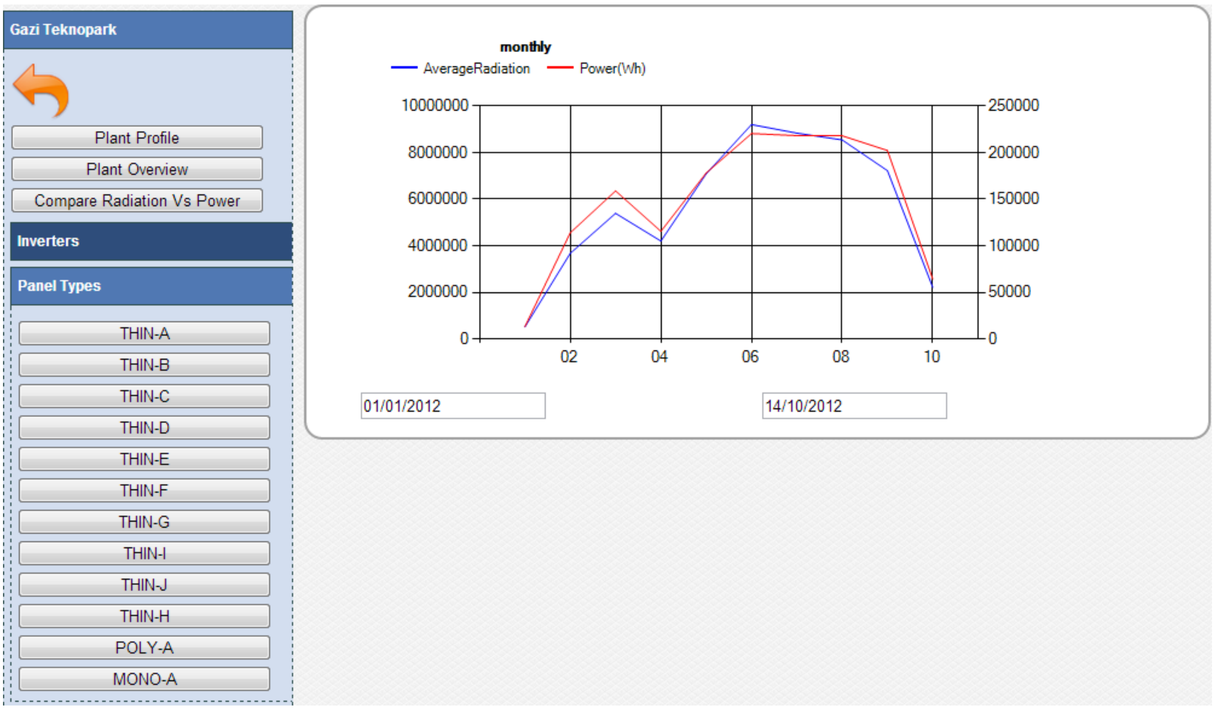

Figure 60. Compare Radiation and Plant Power

5.2.1.4. Panel Types

This page appears when the user decides to get some information about the panel types of the solar panels installed in the current solar plant. This done by clicking any of the panel types listed on the left side of the page which can be seen from Figure 61. There are unique panel types for each panel in a solar plant. Actually, the names of the panel types stand as nicknames of each solar panel in order to hide the real brand of them. The first part of each nickname indicates the real panel type name of the solar panel. For example in Figure 61, most of the panel type nicknames start with a thin word which stands for the thin-film solar panel type. Besides this, poly and mono words stand for polycrystalline and monocrystalline solar panel types.

When the user clicks one of the panel types displayed on the left side, the inverters which are connected to the solar panels with the same panel type, are listed on the right side of the page as it can be seen from Figure 61. There is some information of the inverters listed on the gridview list such as inverter name, inverter type name, installed power in watt-hour which is the total power of connected solar panels to the current inverter, panel quantity indicates the panel numbers connected to the current inverter and panel type power represents the power of the current installed panel. The user can select one of the inverters from the gridview and can get detailed energy production information of the selected inverter. This data is displayed in the tab menu below the gridview as it can be seen from Figure 61.

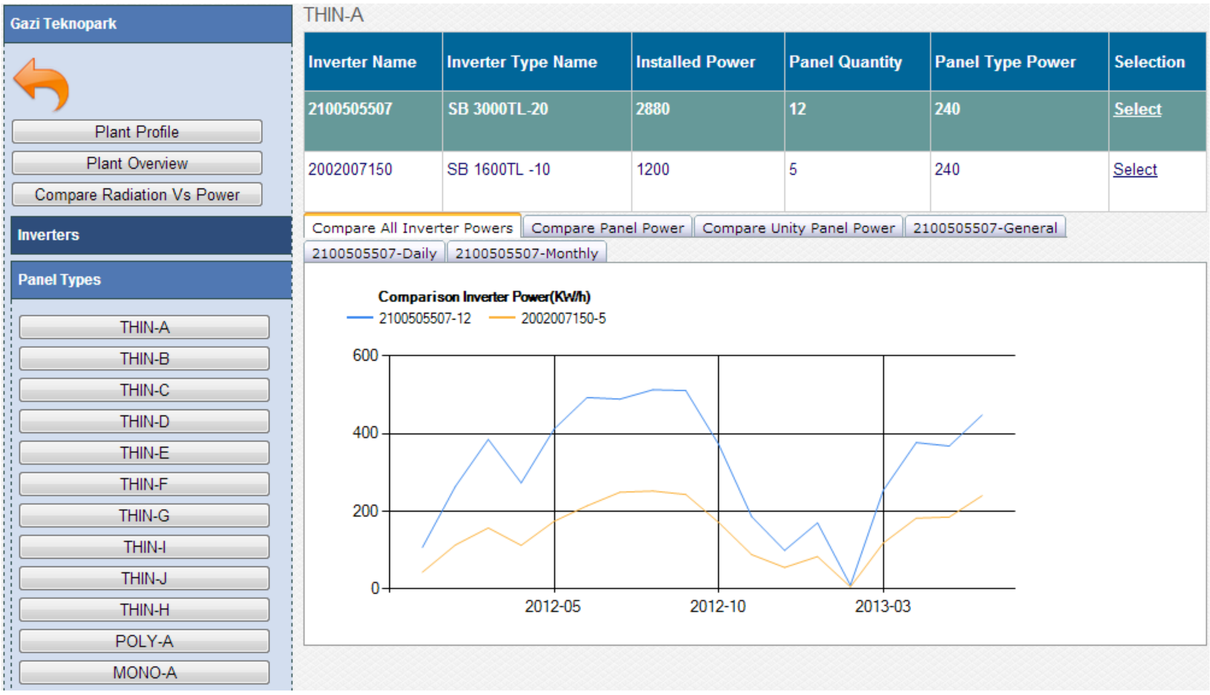

Figure 61. Panel Types

Compare All Inverter Powers

The compare all inverter powers tab menu which is displayed in Figure 62, contains a graph to show the comparison of the power data in kilowatt-hour of each inverter of the selected panel type. Y-axis stands for the energy power and x-axis stands for the date in monthly format. In this graph the user can not select any date interval to adjust the graph. Therefore, user is only able to observe and compare the overall generated energy data of each inverter. For example as it can be examined from Figure 62, there are three inverters compared to each other with different colors. This graph ignores the number of solar panels connected to the inverters. In other words, it does not take the mean of the total energy power of each inverter which depends on the number of the solar panels. That is why, it is normal to see lines with different paths for each inverter as the number of the connected solar panels are different.

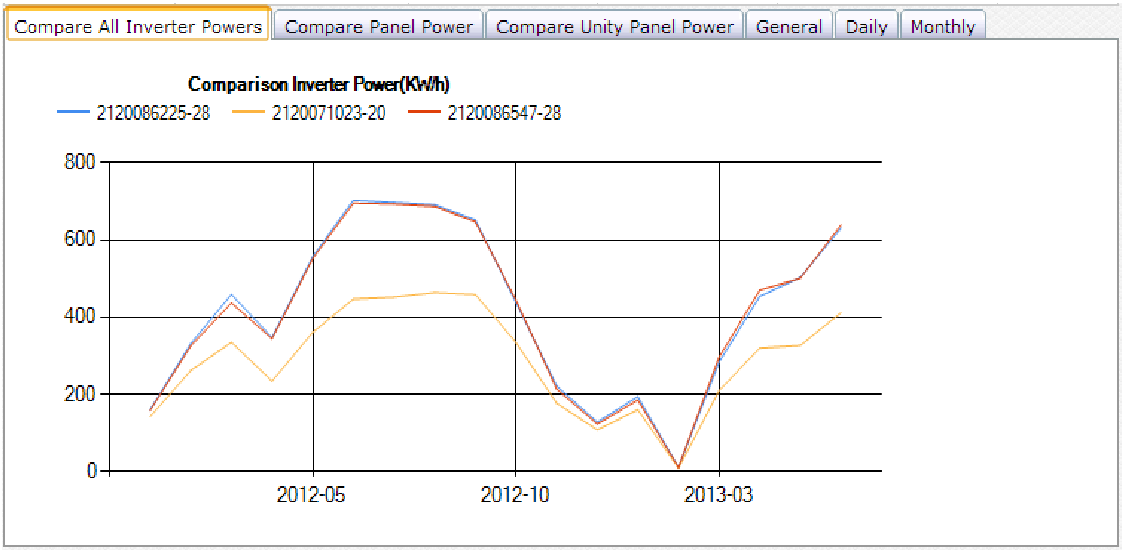

Figure 62. Compare All Inverter Powers

<u>Compare Panel Power</u>

The goal of the compare panel power tab menu displayed in Figure 63 is to compare the energy power of one solar panel of each inverter. This is done by dividing the total generated energy power of each inverter by the number of solar panels connected to them. This tab has one graph with y-axis indicates the total energy in watt-hour of each solar panel and x-axis presents for the overall date interval in monthly format. Under normal circumstances in this graph, the differences between the lines are in minimal level since the panels have the same panel types. If the diversity of the paths drawn by the lines is high, then the reason of this is because of the shutting down specification of each different inverter. This specification can be explained in details. When the energy produced by the connected solar panels decreases under shutting down level, inverters shut themselves. In other words, they ignore the low level of energy production of the connected solar panels. In Figure 63, the yellow line has some diversity from the other two lines. It is because since the number of the solar panels of the inverter numbered “210071023” are lower than the other two inverters, it easier for that inverter to fall under the shutting down level. So that the diversity between lines increases.

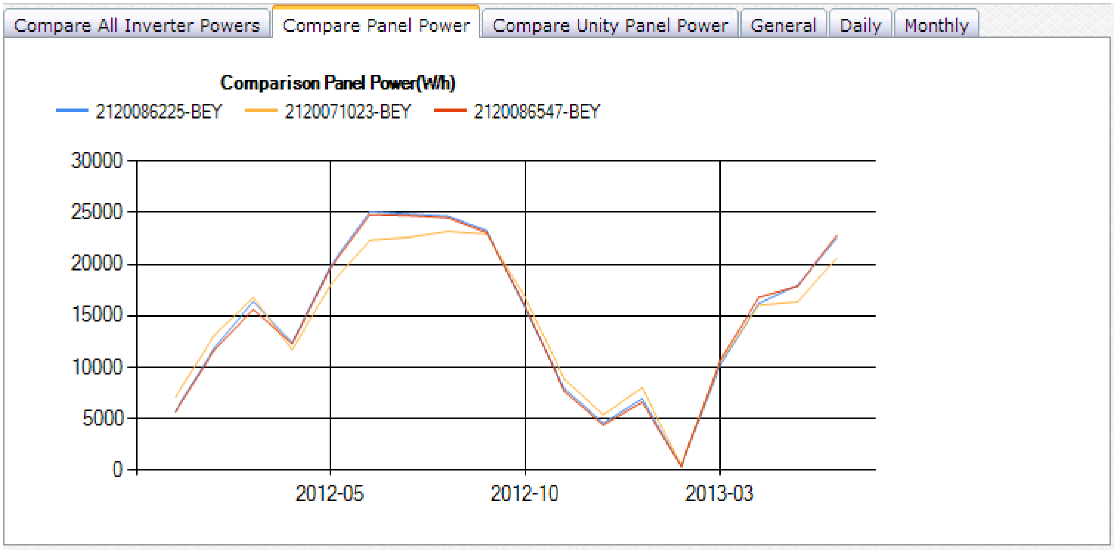

Figure 63. Compare Panel Power

<u>Compare Unity Panel Power</u>

The tab displayed in Figure 64 is chosen by the user in order to learn how much energy is produced by 1 watt (cell) of a solar panel for each inverter. To calculate this output, first the system divides the total energy production of each inverter by the number of solar panels attached to each of them. This way the energy produced by each solar panel, within each inverter, is obtained. This outcome is shown in the tab named Compare Panel Power which is discussed in the previous sub section. After calculating the energy production amount of each solar panel, the next step is to calculate the energy produced for each watt of the solar panels. It is done by dividing the energy production amount of each solar panel to the panel type power value of each panel. The graph as it is shown has two axises which are x-axis and y-axis. Y-axis indicates the energy production amount of each watt of a solar panel in watt-hour format. On the other hand, x-axis indicates the overall time interval.

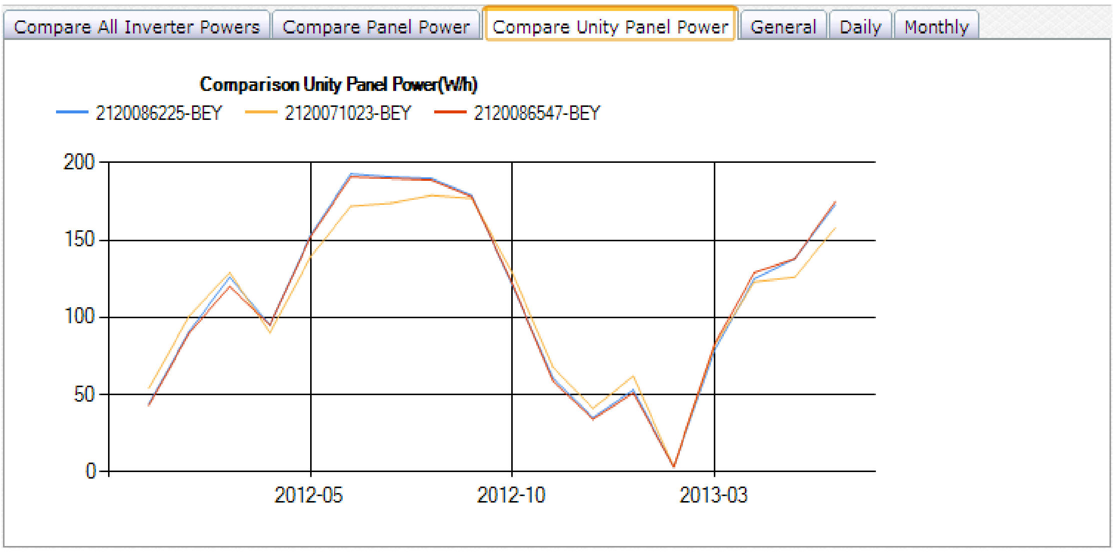

Figure 64. Compare Unity Panel Power

<u>General Inverter Power</u>

The tab shown in Figure 65 is displayed only when the user selects one of the inverters listed in the gridview explained in the previous sub sections. The number of the selected inverter is displayed on the name section of the related tab menus as it is shown in Figure 65. As it can be understood from the name of the tab, this tab is implemented in order to display the general energy production of the selected inverter. In other words, overall monthly energy production amount of the selected inverter in kilowatt-hour format is displayed. This helps users to get an overview of the overall energy production of the solar panels connected to the selected inverter.

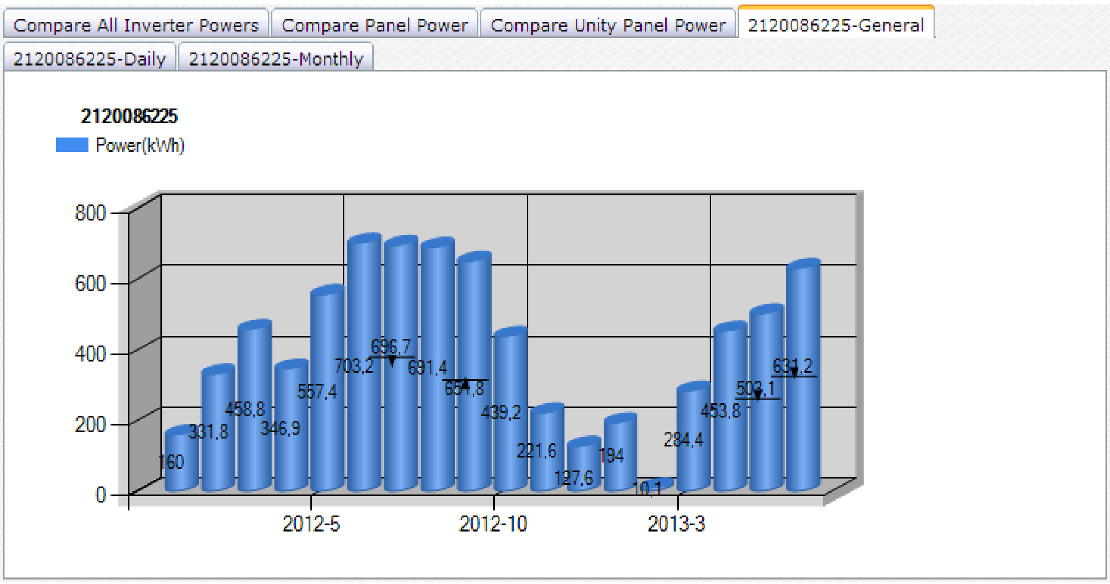

Figure 65. General Inverter Data Displaying

Daily Inverter Power

The purpose of this tab is to provide a useful graph about the daily data of the selected inverter. The graph in this tab displayed in Figure 66 can be considered as a dynamic one since the user has the opportunity to choose a date in order to make the graph show the produced energy in watt-hour format for the selected date. Y-axis stands for the energy data as it is same with the graphs discussed in the previous sections, but x-axis is different for this graph as it is representing the hours of the selected date.

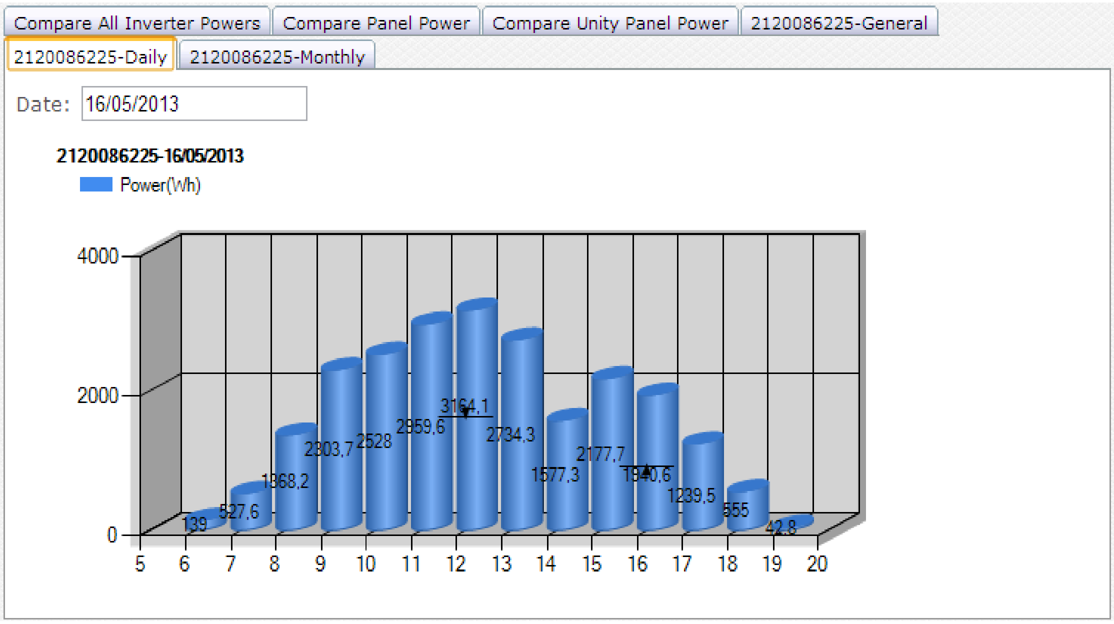

Figure 66. Daily Inverter Data Displaying

Monthly Inverter Power

This tab has three components in it. These are the graph that shows the energy production data, year selection combobox and the last one is another combobox for selecting a month value. To display a graph, user must select a year and a month values from the comboboxes. The goal of this tab is to display the total energy production of each day of the selected month. In other words, each column displayed in Figure 67 represents the total power of each day. In addition to that, the power of each column is in kilowatt-hour format.

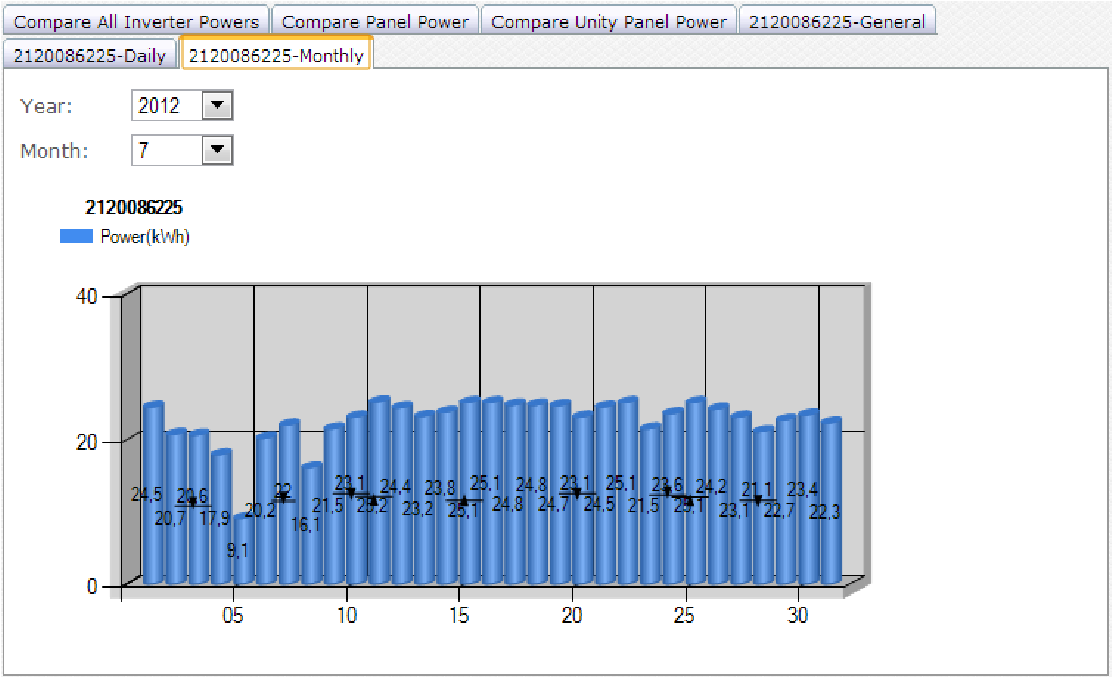

Figure 67. Monthly Inverter Data Displaying

5.2.2. Power Prediction

The power prediction can be selected by the user right after the authentication process. Figure 68 is showing the screen shot of the power prediction page. The purpose of this page is to enable users to make a power prediction of a selected panel type for a given date interval. In order to make the system ready to make a prediction, the user must enter several input data. These are as it can be seen from Figure 68, the longitude and latitude text areas, local weather, humidity, temperature, wind speed, solar plant selection and the last one is the panel type selection. The inverter combobox is filled with the numbers of the inverters related with the selected panel type every time a new solar panel type is selected.

To explain these inputs in more details, it is better to start with the first two text areas displayed on the page which are longitude and latitude values. These two parameters are not written by the user into the text areas but are written automatically by selecting a place from the earth map which is next to these text areas. These two areas indicate the coordination of the place from where the user wants the energy prediction. By giving the coordination data, the system calculates the azimuth and altitude values of each instance of the given date interval. This information is used to calculate the efficiency of the solar panels. The calculation of the efficiency of a solar panel is explained in the Chapter 2.

After deciding the coordinates of the prediction place, user has to enter the hourly local meteorological data in a text file which is a data set received from a local meteorological station close to the selected coordinates. It must be in a very close distance to the coordinates of the selected area to get the prediction more accurate. Because the radiation of the Sun obtained within the data set of local meteorological station plays a key role in the prediction process. In the local meteorological data, there are seven parameters which are date, hour, average radiation, maximum radiation, average temperature, minimum temperature and maximum temperature as mention in the Chapter 3.

The next three inputs humidity, temperature and wind speed for the selected location are received from the Turkish State Meteorological Service in Ankara. The data must be in hourly format since the prediction model is created in hourly format. The user must input these three parameters in different text files with a formation of year, month, day, hour and the hourly average value of the three input parameters. The prediction date interval is adjusted automatically by the date interval of the data sets entered by the user.

After several meteorological inputs, user must make a decision on choosing a solar plant name which is very essential in order to make a prediction. The system must first create a prediction model as explained in the Chapter 4. To do that, a real generated power data set is required. So by selecting a solar plant name, this data set is provided from the selected plant for the system. In other words, the system uses the real energy production data set of the selected solar plant. Here the main point to be paid attention is to choose a solar plant close the selected coordinates for an accurate prediction result.

At last, here comes for the last input of the prediction page which is the selection of a panel type name. Here the reason to choose a panel type name is to give an opportunity to the users to create their own prediction model depends on the data set of the technology they want as each panel type represents different technologies. When a panel type is selected, the inverter list is filled with the inverter numbers which are connected to solar panels with the same selected panel type. The inverter list is unselectable because in order to set the prediction model, the overall generated energy of each inverter is used. As a result of this page, a predicted energy amount is calculated and saved into the database for the selected panel type.

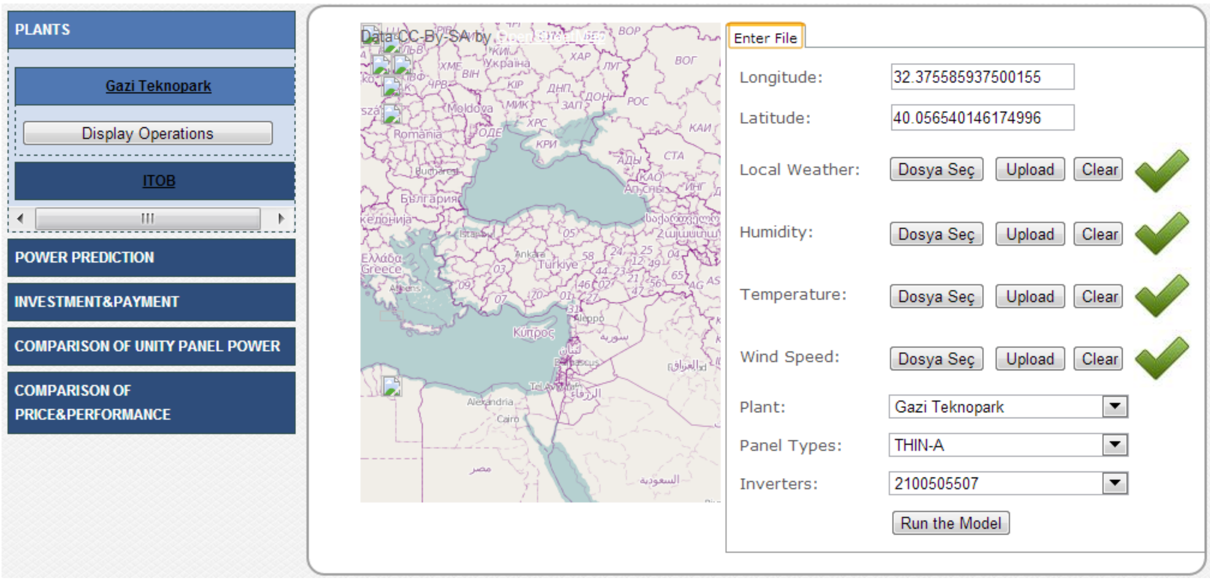

Figure 68. Power Prediction

5.2.3. Investment & Payments

The Investment and Payments Page has two sections which are investment settings section and payment result section. Shortly, the goal of this page is to provide a payment chart of a planned solar plant.

5.2.3.1. Investment Plan

The investment plan part of the Investment and Payment page provides users to create the solar plant in mind with its initial expenses. The key word here is the initial expenses because the main goal of the user is to get an idea of the repayments of the newly installed solar plant, so the prices entered into the cost fields must be taken seriously. After entering all the fields for each row of the table, user needs to click the calculate button in order to make the system calculate each sub totals. After calculation of all sub totals for each row, the overall cost is computed and written into the investment text field located in the payment section below. These rows of the table, contain several input areas, are displayed in Figure 69. These are information about panels, inverters, cables, connection, labor and other expenses.

In the panel sub section, first of all the user has to select a panel type name from the list. This list is filled according to the different types of solar panel that are installed in the solar plants related with the current user. As soon as a type is selected, the capacity of it can be seen from a textbox below. Here the capacity is important because the multiplication of the capacity with the number of the solar panels indicates the total power of the new solar plant and this calculation is written into the textfield named required inverter capacity. In addition to that, user should not forget to enter the unit cost of each solar panel. By the way, the user can only select one type of solar panel as the solar plants are constructed with only one type.

In the inverter sub section, there are several fields to be filled by the user. These are type of the inverters to be used, the cost and the amount of the each inverter. The user can select more than one inverter type. As soon as the type is selected, the capacity of the inverter type is displayed automatically in the capacity field. After that the cost and the number of each inverter must be entered. Then to add this inverter into the system, user has to click to the add button. The names of appendant inverter types are listed in the listbox. Each time the user add an inverter type with its number value, the system automatically subtract the multiplication value between the inverter type capacity and the number of the selected inverter from the value displayed in the text area required inverter capacity. Actually general purpose of this process is to balance the total capacities of the inverter types and the solar panels.

The rest of the parameters that the user must enter are mandatory but easy to fill. These are the costs of cables, connection, labour and other expenses. The cable area stands for the total costs of the used cables in the construction. The next one is the connection cost which indicates the expenses of the connection process of the solar panels and the inverters to each other. The other cost is the overall labor expenses paid to the workers. The last one called the others is implemented for the users to enter for unpredictable costs.

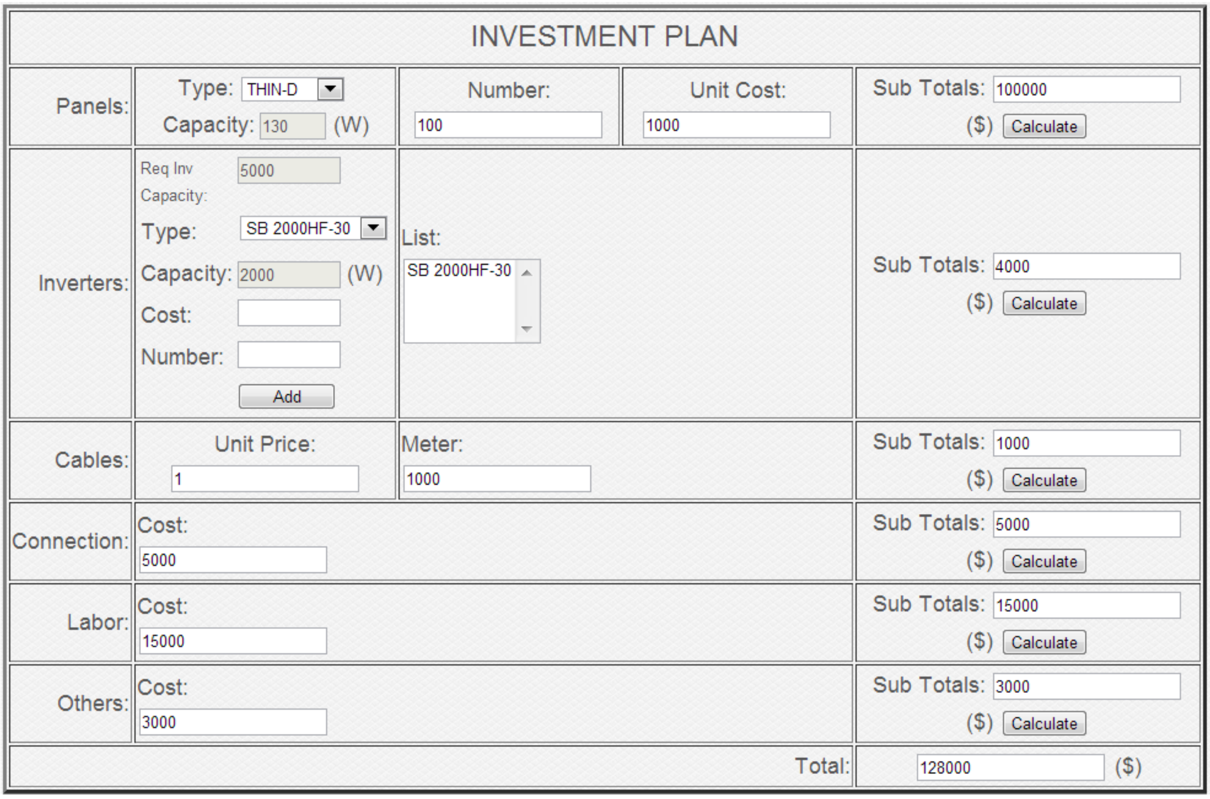

Figure 69. Investment Plan

5.2.3.2. Payment Plan

After entering the fields about the initial expenses of constructing a new solar plant in the investment plan, it is time to pass to the payment section where a payment chart for an expected number of years will be created for the users. There are also several fields must be filled such as yearly operational cost, energy unit price, interest rate and prediction process selection. The values entered for the mentioned areas are considered same for all the years within the following expected number of years.

The first field to consider for the user is the yearly operational cost which is an expense that can be made for a solar plant after it is initialized for the production of solar panel energy. For example, operational costs might be a cost for repairing a broken inverter, or paying money to a cleaning company in order to clean the dust placed on the surface of each solar panels. The other field to be filled by the user is the energy unit price. It is very important because it is used to calculate the yearly income which is computed by multiplying the total predicted energy amount with the energy unit price. The money value entered by the user is in the format of dollar per kilowatt. The next field to be considered is the interest rate. It is one of the key parameters that must be entered correctly because it directly effects the calculations of the payment of the user. The payment calculation will be explained in the following sub section. Finally, the last and the most important parameter called prediction process selection will be considered. Here the user does not enter any value but makes a selection from a combolist. This combobox is filled dynamically when the user makes a panel type selection up above the page. In other words, the content of the combobox is related with the panel type selections. The data entered into the combobox by the system indicates the prediction outputs made for the selected panel types by the user in the Prediction Page. There can be more than one prediction results for each panel type since they can be done for different date intervals. If there are more than one prediction results for the same date interval for a panel type, the average is taken. The job of the combobox is to display these different date intervals to the user to select one of them. After this selection is done, plant name, predicted total power, prediction start date and prediction end date fields are filled automatically by the system.

The reason to calculate the payment chart is to give user an idea of his/her repayments over the following expected number of years. The payment chart consists of several data which are remainings, credit payment, energy produced, energy unit price, yearly income, operations costs and income. For each year of the chart, there are corresponding values of these areas.

The remaining value is the most important area since it indicates the dept of the solar plant over the following years. Here the goal is to make the dept 0 at the end of the expected number of years by paying the money earned from the yearly income. The remaining and the credit payment values are calculated with the formula displayed below. (A) stands for the total the investment expenses, (r) stands for the percentage value of the interest rate. Let say the interest rate is %8, then (r) is calculated as 0,08. (B) stands for the yearly payment amount. (n) indicates the expected number of payment years.

$$x = 1 + r$$

$$Y = \frac{x^n - x}{x - 1}$$

$$B = \frac{A * x^n}{Y}$$

$$\sum_{i=1}^{n} A * x^i - \sum_{j=i-1}^{0} B * x^j$$

The calculated value of (B) is same for the expected number years of the chart as the yearly payment. The remaining value is calculated for each year of the payment chart with the help of the last formula. To explain some part of it, the second accumulation area is within the first one. The summation process starts from i-1 and goes down until j equals zero.

The energy produced area displays the average energy produced value of the selected solar panel type in kilowatt-hour format. To do that first, the predicted total power of the selected panel type is converted to kilowatt-hour format. Then, the calculated energy is multiplied with the number of the panels which is filled in the investment plan. The yearly income is calculated by multiplying the energy produced value with the energy unit price. On the other hand, the operation cost comes from the yearly operational cost area which is filled by the user. The last one is the income area. The value that it displays is very important for the solar plant because it must be higher than 0 for each year, otherwise if it is vice versa, then it means that the solar plant loses money and this is not an acceptable situation. The value of the income is calculated with the following formula:

Income = Yearly Income – Credit Payment – Operational Cost

PAYMENT										
Investment:	128000 ($)									
Yearly Operational Cost:	2000 ($)									
Energy Unit Price:	2 ($/KW)									
Interest Rate:	8 (%)									
Prediction Process Selection:	24.01.2012--14.10.2012									
Plant Name:	Gazi Teknopark									
Predicted Total Power:	162871 (Whr)									
Prediction Date:	Start Date: 24.01.2012			End Date: 14.10.2012						
	1	2	3	4	5	6	7	8	9	10
Remaining($):	138240	127169,8	115214	102301,7	88356,4	73295,5	57029,7	39462,6	20490,2	0
Credit Payment($):	20490,2	20490,2	20490,2	20490,2	20490,2	20490,2	20490,2	20490,2	20490,2	20490,2
Energy Produced(kW):	16287,1	16287,1	16287,1	16287,1	16287,1	16287,1	16287,1	16287,1	16287,1	16287,1
Energy Unit Price($/kW):	2	2	2	2	2	2	2	2	2	2
Yearly Income($):	32574,2	32574,2	32574,2	32574,2	32574,2	32574,2	32574,2	32574,2	32574,2	32574,2
Operations Costs($):	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Income($):	10084	10084	10084	10084	10084	10084	10084	10084	10084	10084
Calculate Payment										

Figure 70. Payment Chart

5.2.4. Comparison of Unity Panel Power

It is essential to compare the energy production of the solar panel types to get an idea of their efficiencies. It is very important for users to get some knowledge about different solar panel technologies in order to be able to make solar panel type selections when it is time to install a new solar plant. But, if this comparison happens only between solar panel types not considering the production capacity of them, there occurs a big mistake as the capacities are different for most of the solar panel types. To get rid of this problem this page is implemented. The purpose of this page is to examine the energy production value of a solar panel type by considering the only one watt of its capacity. It helps users to understand and compare the exact efficiencies of the solar panel types. This process is called the comparison of the unity panel power. As it can be seen from Figure 71, the comparison of unity panel power page consists of several components. These are solar plant and panel type selection comboboxes and a graph component to display the results. Here the comboboxes enable this page to be a dynamic one as the user can select any solar plant and any panel type related to the selected solar plant. When the user selects a solar plant name, the content of the panel type combobox changes according to the selected solar plant. It is possible to select more than one panel type in a graph as it can be seen from Figure 71. On the graph, the y-axis indicates the produced energy of one watt of the panel types in watt-hour format. On the other hand, x-axis stands for the overall date interval. The produced energy of one watt of each solar panel type is calculated in several steps. First the system selects the inverter which generates the highest power among the ones which are connected with the same selected panel type. After this selection, the total generated power of the selected inverter is divided by the quantity of the solar panels connected to that inverter. This calculation gives the produced energy for one solar panel. The last step is to divide the calculated produced energy by the production capacity of the selected solar panel type in order to find out the produced energy of one watt of the selected solar panel type. By achieving that, the number of solar panels connected to an inverter or the capacity of a solar panel type are no longer matter to consider because, the produced energy is set to the level of a watt of a solar panel type. This gives opportunity to users to compare the efficiencies of different solar panel type technologies.

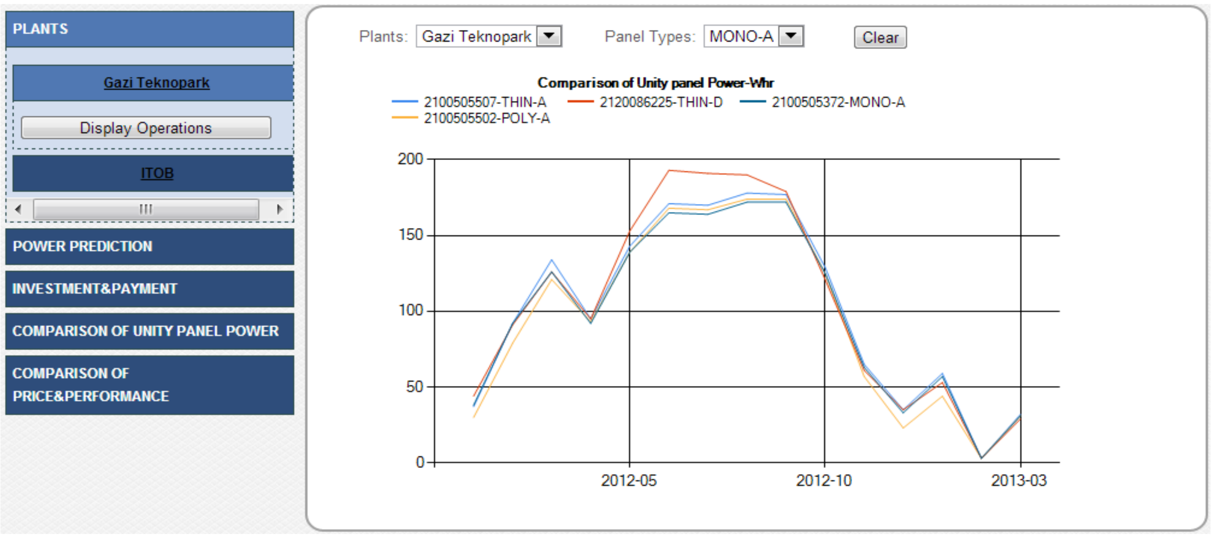

Figure 71. Comparison of Unity Panel Power

5.2.5. Comparison of Price & Performance

This page is the last item of the main menu which is displayed to the users on the first page after the authorization process. The main purpose of this page is to compare the price of a solar panel with its energy production value. It is important for users to obtain information like that as the performance related to price plays a key role in deciding which technology to use for installing new solar plants.

Comparison of Price & Performance page is implemented with several components to make the page more usable and dynamic for the request of the users. In other word, these components give users the opportunity to select solar plants, panel types and a date in a format of month of a year. In addition to these components, there is the graph component to show the comparison of price and performance of different solar panel types. Each comparison for a solar panel type is demonstrated with a different unique shape as it can be examined from Figure 72. The y-axis indicates the produced energy of one watt of the selected solar panel type in watt-hour format. On the other hand, the x-axis indicates the price amount related to a watt of the selected solar panel type. The price corresponds to a single watt of the selected solar panel type is calculated by dividing the price of the solar panel to the capacity value of its type.

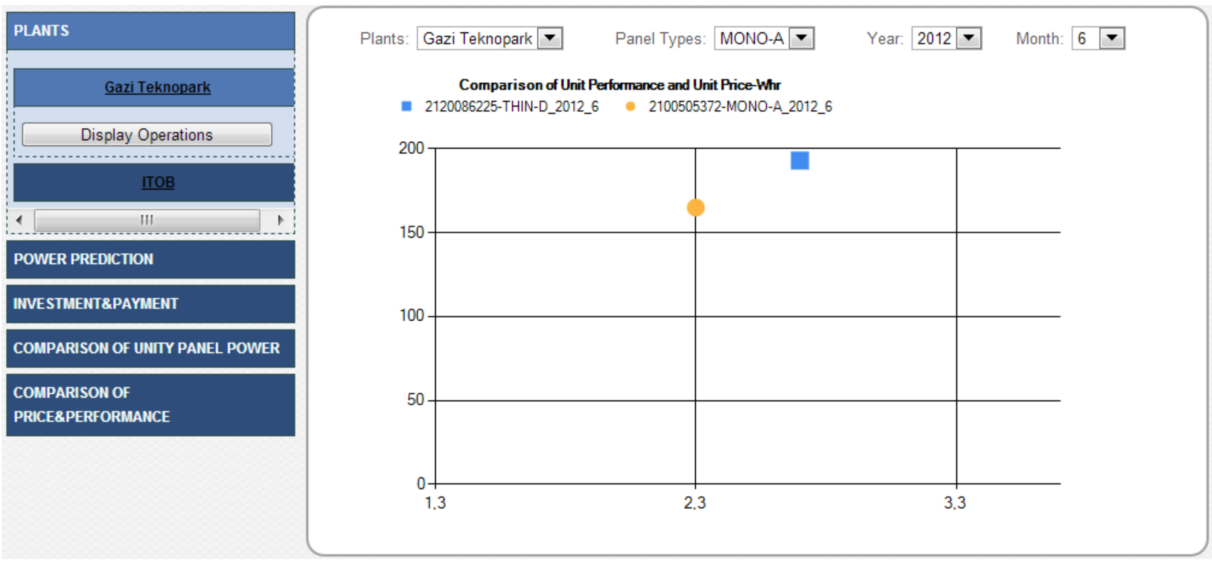

Figure 72. Comparison of Price and Performance

CHAPTER 6

CONCLUSION

In today's world, the trend of utilization percentage of the solar panel technologies is increasing day after day as their development process proceeds rapidly. As a result of that, the viewpoints of the investors change in a positive way in order to install new solar plants to create new investment areas. At this stage, one crucial requirement emerges and it is the reimbursement process of a loan received. Under normal circumstances, it is expected that the installed solar plant pays back the received loan and covers the yearly expenditures by the income obtained from the sales of the solar energy produced. The risk in this payments is that the energy production depends on the the solar radiation unsteady weather conditions. Therefore, it is extremely hard to foresee the future solar energy production amounts. If this case is not taken care seriously, it is not a wise idea to make expensive investments, otherwise it is inevitable to be faced with a failure.

Nowadays, the prediction algorithms become more popular in order to be used in the prediction process of the produced solar plant energy. In this thesis, multilayer perceptron artificial neural network is used within the Weka application to create a prediction model to find a solution for this problem. The layer number of the model has been chosen as 3 which are input, hidden and output layers. In each layer different numbers of neurons are located. In the input layer there are nine hourly attributes in total which are (i) average radiation, (ii) maximum radiation, (iii) average temperature, (iv) minimum temperature, (v) maximum temperature, (vi) current temperature, (vii) humidity, (viii) wind speed and (ix) efficiency. The source of this data set is obtained from two different stations which are Turkish State Meteorological Service and a local meteorological station located in Gazi Teknopark, Ankara. On the other hand, the neuron number of the hidden layer is not constant as they are in input and output layers. The hidden layer neuron number is decided with the "Thumb Formula" [11]. Lastly, the neuron number of the output layer is the produced hourly solar panel energy amount which is obtained from the solar plant located in Gazi Teknopark, Ankara. The epoch number is decided as 2000 which indicates the iteration number of the model.

In order to make simulations of a solar plant under normal circumstances, a software tool is implemented. To do so, a 3-dimensional mathematical platform has been created. This platform consists 3-dimensional objects which are solar panels and solar light. The solar panels are placed on the surface of the platform with several placement parameters entered by the user such as declination angle, row and column distances between solar panels. In addition, the coordination of the platform is selected from an Earth map and a date interval is selected in order to calculate the position of the Sun, so that the solar light, hits the placed panels, can be calculated. As a result, the software produces the calculated energy with the percentage of the shadowing on the placed solar panels for the selected date interval. This program can be used to measure the performance of the solar panels under different conditions in order to find the optimum panel placement. The different conditions are generated by entering inputs for panel placement, different declination angles, and different time intervals such as summer and winter time.

A website application is implemented to serve its users to make predictions of a selected solar panel type for a certain time of period. Several parameters are required for users to enter, which are (i) solar radiation, (ii) humidity, (iii) temperature and (iv) wind speed values in hourly format. After this prediction process, users are enabled to create a payback chart for the expected number of years. In order to do that, firstly the users must select a solar panel type and a yearly total predicted energy output of the related solar panel type and then it is required to be entered the expenditures of the installation of the solar plant to be used in the payback chart. As a result of these entries, the system provides a payback chart for the expected number of years to the users. Briefly, this application helps users to simulate their ideas for the installation of a solar plant in order to give them a clear foreseeing ability about the solar plant investment. The comparison graph of the energy performance and the cost of a selected panel type offers another opportunity to the users. The purpose is to help investors to make a reasonable selection among different panel types at the time of a new solar plant investment.

For the future work process, this model may be improved by using more raw data, collected from different solar plants all over Turkey over a long time of period. This way the model can be trained more accurately. Cosequently, the error in the prediction outputs and the payments chart will be more optimized.

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