GAZİ ÜNİVERSİTESİ

1926

DETERMINATION OF SOLAR POWER POTENTIAL IN TURKEY AND IMPACT OF SOLAR POWER PLANT IN KARAPINAR ON THE GRID

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
GAZI UNIVERSITY

BY
YUNUS CAN ÖLMEZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ELECTRICAL - ELECTRONICS ENGINEERING

APRIL 2017

The thesis study titled "DETERMINATION OF SOLAR POTENTIAL IN TURKEY AND IMPACT OF SOLAR POWER PLANT IN KARAPINAR ON THE GRID" is submitted by Yunus Can ÖLMEZ in partial fulfillment of the requirements for the degree of Master of Science in Electrical – Electronics Engineering Department, Gazi University by the following committee.

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Yunus Can ÖLMEZ
21/04/2017

DETERMINATION OF SOLAR POWER POTENTIAL IN TURKEY AND IMPACT OF SOLAR POWER PLANT IN KARAPINAR ON THE GRID

(M.Sc. Thesis)

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April 2017

ABSTRACT

Renewable energy sources are increasing their share in electricity generation. In the Turkish electricity system, the establishment of generation facilities based on renewable energy sources, especially wind and solar power, is encouraged. Turkey has a large wind and solar energy potential geographically. Western part of Turkey have enormous wind energy potential, while the middle parts of Turkey have huge solar energy potential. In this study, the total solar energy potential of Turkey was determined and the effects of the large scale solar power plant, which is planned to be completed in Karapınar district of Konya to the secondary frequency control performance were investigated. With this thesis study, the information about the compatibility of the secondary frequency control performance of power system in Turkey with the large-scale solar energy plant will be given and the necessary precautions for the future will be mentioned.

Science Code	:	90513
Key Words	:	Solar Potential, PV Power Plant, Frequency Control
Page Number	:	89
Supervisor	:	Lect. Dr. Süleyman Sungur TEZCAN

TÜRKİYE GÜNEŞ ENERJİSİ POTANSİYELİNİN BELİRLENMESİ VE KARAPINAR BÖLGESİNE KURULMASI PLANLANAN GÜNEŞ ENERJİSİ SANTRALİNİN ŞEBEKEYE ETKİSİ

(Yüksek Lisans Tezi)

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FEN BİLİMLERİ ENSTİTÜSÜ

Nisan 2017

ÖZET

Yenilenebilir enerji kaynakları elektrik üretiminde giderek payını arttırmaktadır. Türkiye elektrik sisteminde de başta rüzgâr ve güneş enerjisine dayalı üretim tesisleri olmak üzere yenilenebilir enerji kaynaklarına dayalı üretim tesislerinin kurulması teşvik edilmektedir. Türkiye coğrafi olarak büyük bir rüzgâr ve güneş potansiyeline sahiptir. Rüzgâr enerjisi bakımından özellikle batı bölgeleri, güneş enerjisi bakımından da orta bölgeleri önemli bir potansiyele sahiptir. Bu çalışma kapsamında Türkiye'nin sahip olduğu güneş enerjisi potansiyeli belirlenmiş ve Konya ili Karapınar ilçesine kurulması planlanan büyük çaplı güneş enerjisi santralinin sekonder frekans kontrolüne olan etkileri incelenmiştir. Bu kapsamda hazırlanan çalışma ile Türkiye elektrik sistemi sekonder frekans kontrolü mekanizmasının büyük çaplı güneş enerjisi santraline uygunluğu hakkında bilgi verilecek ve geleceğe yönelik gerekli önlemlerden bahsedilecektir.

Bilim Kodu	:	90513
Anahtar Kelimeler	:	Güneş Potansiyeli, PVGES, Frekans Kontrolü
Sayfa Adedi	:	89
Danışman	:	Öğr. Gör. Süleyman Sungur TEZCAN

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Lect. Dr. Süleyman Sungur TEZCAN for his guidance, advice, encouragement and support throughout the research.

I would like to thank İsmail Elma for his support and guidance throughout my M.S. study and studies of “Integration of Renewable Energy to the Grid and Ancillary Services in Turkey” carried out by TUBITAK MAM.

I also would like to thank all members of Power Systems Department of TUBITAK MAM Energy Institute for their support and friendship.

Finally, I owe my deepest gratitude to my parents, my beautiful sister, my brother and my beautiful wife for their support, love and encouragement throughout my life.

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LIST OF SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this thesis are presented in below with explanations.

Symbols	Explanations
f_0	Nominal frequency
f	Actual frequency
F_A	Actual frequency
F_S	Scheduled frequency
Δf	Amount of deviation in the system frequency
K	Network bias factor
NIA	Actual net interchange
NIS	Scheduled net interchange
P_{set}	Generator active power setpoint
P_{exch}	Power flow values on the ENTSO-E connection lines
P_{exch0}	Planned power flow values on the ENTSO-E connection lines
ΔP	Difference of power flow in ENTSO-E connection lines from planned
RP	Primary frequency control reserve capacity

Abbreviations	Explanations
ACE	Area control error
AGC	Automatic generation control
CF	Capacity factor
CSP	Concentrated solar power
ENTSO-E	European network of transmission system operators for electricity
PV	Photo-voltaic
PV-GIS	Photo-voltaic geographical information system
RGB	Red green blue
SCADA	Supervisory control and data acquisition
SEPA	Solar energy potential atlas
UTC	Coordinated universal time

1. INTRODUCTION

Aim of this thesis is to analyze the solar power potential in Turkey and to investigate the effects of solar power plant sample to Turkish electrical system from a load stability point of view.

Green energy becomes more popular in many developed countries because these countries' governments are more aware of that carbon emissions from other energy sources cause of climate change. In the last years, many countries canalize their money into renewable sources of electricity, such as solar, wind and geothermal plants. Especially China and United States are the main countries that use renewable energy in the world [1]. Brazil, Germany and Russia are the other countries that invest that invest in renewable energy.

There are six main renewable sources samples: bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy [2]. They are clean energy sources that have much lower environmental impact such as CO_2 emission than traditional energy technologies. Besides environmental benefits, renewable energy provides new job opportunities. Hydropower technology is an old and it has been used for a long time. On the other hand wind and solar power technology is developing day by day.

Solar energy is a major renewable energy source with the potential to meet necessities of the energy producing. This power source is increasing in popularity because it is versatile with many benefits to people and the environment.

The technologies developed to take advantage of solar energy not only increase the amount of solar energy utilization but also reduce infrastructure costs. Solar energy, which meets its investment in a short time with low investment cost and high efficiency, is also attractive as a cost-free and environment-friendly energy source.

In the Turkish electricity system, the establishment of generation facilities based on renewable energy sources, especially wind and solar power, is encouraged. Turkey has large wind and solar energy potential. Western part of Turkey have enormous wind energy potential, while the middle parts of Turkey have huge solar energy potential. In this context, in order to give information about the next years, analysis studies is carried out to determine the potential of solar power plants in Turkey.

Within the scope of the study, areas not suitable for solar power plant construction are identified then electrical and economic analyzes are made for the remaining areas. Total solar power plant capacity in Turkey is determined considering economic investment for suitable areas.

After determining the total solar capacity in Turkey, in this thesis, the influence of the solar power plants on the electricity grid is examined. In this context, the effect of solar power plant on the secondary frequency control performance is investigated.

Frequency control of an interconnected system takes place on 4 stages: primary control, secondary control, tertiary frequency control and time control. The primary frequency control mechanism is carried out by measuring the difference between the rotor speed and the reference speed and by proportionally responding to this difference [3]. If the power balance in the electrical system deteriorates, the system frequency changes. For this reason, frequency control mechanism is applied in order to keep power balance in power systems. The primary frequency control is performed by the conventional generation facilities by reacting to the changes in the system frequency while the secondary frequency control is implemented by a central controller in response to the changes occurring in the system frequency and the load flow in the interconnection lines. Within the context of the ENTSO-E connection, power imbalances in the system lead to changes in the power flow over the interconnection lines rather than the system frequency. For this reason, the amount of secondary control reserves plays an important role to eliminate these imbalances. Secondary frequency control mechanism maintain the power flow over the interconnection lines at scheduled values and bring the frequency back to its nominal value.

Because the solar power plants use solar radiation as the primary source, the active power output of the solar power plants to the system is directly proportional to the solar radiation level reaching the solar panels [4]. For this reason, the active power levels of the solar power plants starts to increase with the sunrise in the morning, reaches maximum in the middle of the day, decreases in the evening hours, and goes down with the sun sinking. In addition, due to the effect of clouding during the day, solar power plants experiences sudden changes in the active power output levels.

In order to examine these effects on secondary control performance of 3 GW solar power plants, which is planned to be constructed in Karapınar, Konya, in the coming years, is designated as a model solar power plant. It is planned to build this plant approximately 60 km^2 surface area [5].

In this thesis study, the MATLAB program is used in necessary analysis to determine total solar power plant potential in Turkey. On the other hand, the effects on secondary control performance of 3 GW solar plant in Karapınar is observed by using DIgSILENT PowerFactory power system analysis software.

In chapter 2, solar power plant potential in Turkey is determined. The methods used in this thesis study are explained. First of all, suitable areas for PV plants are determined then solar radiation values are obtained automatically from PV-GIS web-site. Finally, there is economic analysis for suitable areas for solar power plant.

In chapter 3, general background on frequency control mechanism is provided. Frequency control mechanism in Turkey is explained in detail. On the other hand, working principle of AGC system and ACE performance criteria is described in this section.

In the fourth chapter, general properties of 3 GW solar power plant in Karapınar is explained. Solar power plants geographical and environmental properties are analyzed. In addition, solar power plant daily generation profile are obtained for each month.

In the fifth chapter, 3 GW solar power plant in Karapınar effects on secondary frequency control performance is determined. In this context, active power changing of solar power plant is investigated. Daily active power changing because of solar radiation and clouding effects on the solar power plant are analyzed in detail.

In chapter 6, the scenarios and simulation results are reported. There are 9 different scenarios to obtain the effects of 3 GW solar power plant on secondary frequency control performance. In addition, simulated scenarios results are shown in detail in this chapter.

In the concluding chapter, results of simulated scenarios are discussed. Moreover, it is decided whether the current secondary frequency mechanism is sufficient for the solar power plants to be built in the next years.

2. DETERMINATION OF SOLAR POWER POTENTIAL IN TURKEY

2.1. Determination of Areas That Can be Installed PV Plants in Turkey

When determining the total capacity of solar power plants that Turkey has, first of all, it is necessary to determine the appropriate areas for solar power plant installation. Then total capacity is achieved by considering the installation of a solar power plant for each of the appropriate areas. This capacity is correspond to the potential in the case of establishing a solar power plant in all of these appropriate areas. When the appropriate areas for the installation of the solar power plant are determined, areas which are not suitable for the installation of the plant are removed in accordance with the following criteria [6]:

- Areas with a land slope greater than 3 %
- Settlement areas and remaining areas within the 500 m safety lane
- Areas within the 100 m safety lane by land and railways
- Areas within the 3 km safety lane with airports
- Environmental protection, national parks and natural areas and areas within the 500 m safety lane
- Lakes, rivers, dam lakes and wetlands
- Protected forests, afforested areas, private forests, nurseries, reeds and marshes, conservation forests and arboretums.

The SEPA data of the General Directorate of Renewable Energy affiliated to the Ministry of Energy and Natural Resources is used to determine the appropriate areas for the construction of solar power plants [7]. In this context, Turkey's global solar radiation distribution map is shown in Figure 2.1.

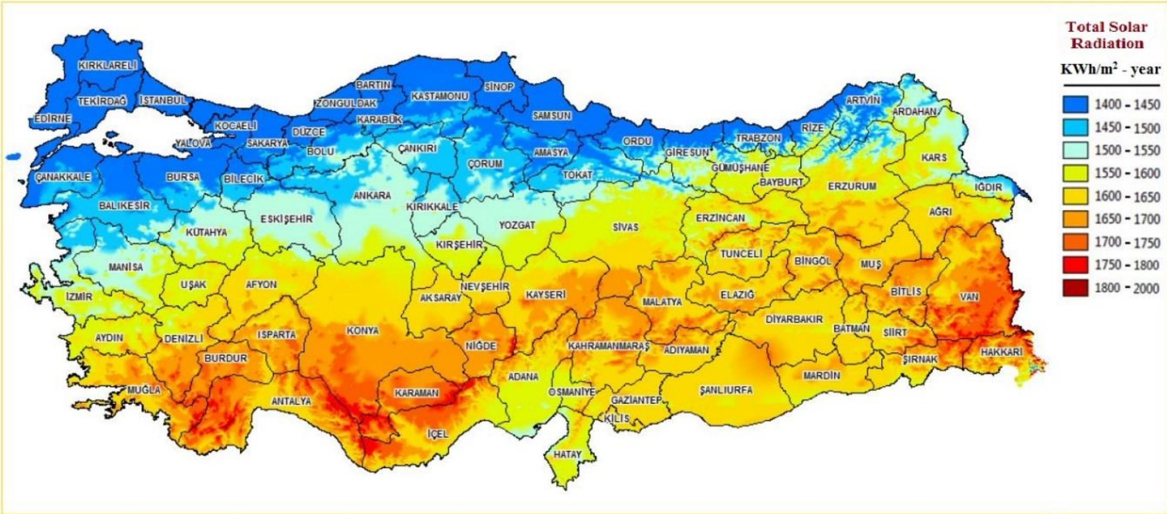

Figure 2.1. Global solar radiation distribution in Turkey [7]

The following figures can be shown as examples. Figure 2.2 shows the solar radiation distribution of Konya and Figure 2.3 shows the resultant solar radiation distribution of the areas determined by taking the above mentioned criteria into consideration.

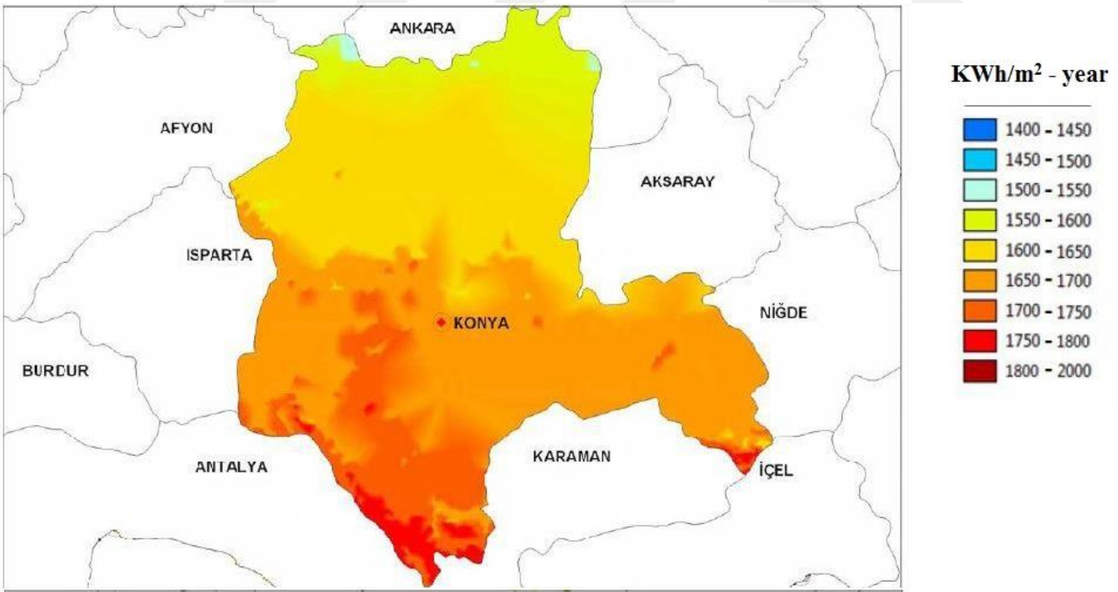

Figure 2.2. Solar radiation distribution in Konya [7]

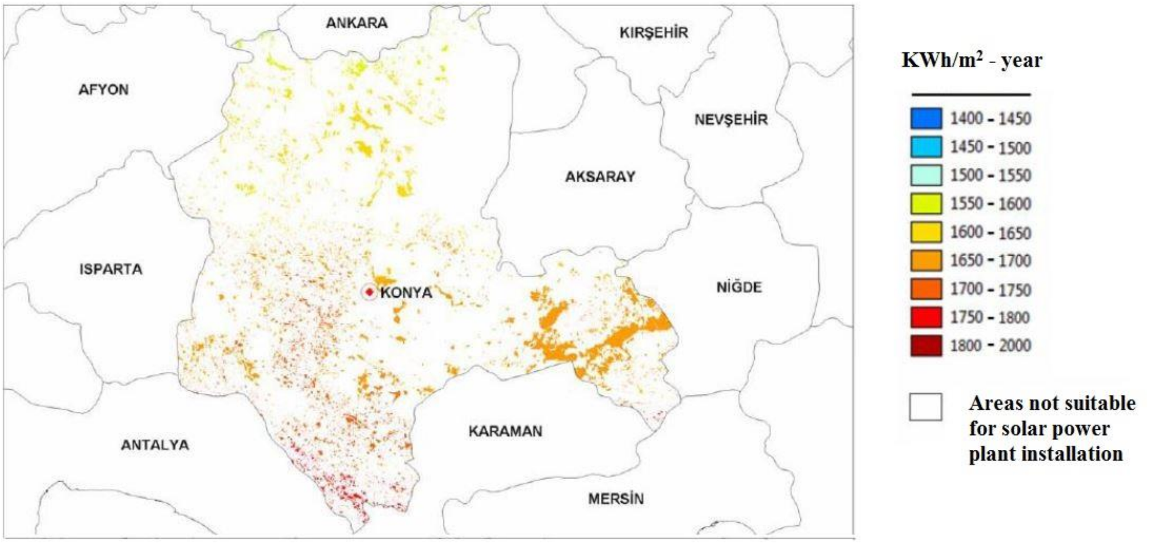

Figure 2.3. Solar radiation distribution of suitable points for the solar power plant installation in Konya [7]

For all cities in Turkey relevant city maps showing solar radiation distribution and areas suitable for solar energy plant installation are obtained from SEPA as shown in the graphs above.

The areas where the solar power plant can be installed in Turkey are determined form the map for Turkey. In the next steps, the coordinates of the points that are appropriate for solar plant construction and the values of radiation at these coordinates is determined. For determining the total solar energy potential in Turkey, first of all, superimposing the map obtained from SEPA with the map obtained from Google Earth for each cities in Turkey is applied, then appropriate areas are find out by eliminating the improper areas for installation.

2.1.1. Superimposing SEPA and Google Earth maps for each cities in Turkey

To determine the coordinates of the geographical points from SEPA map image's each pixels, superimposing method is applied for Google Earth image and SEPA image for each cities in Turkey. Thus, the form of the SEPA map image have the same projection as the Google Earth image for each cities. The coordinates of the extreme points of the cities are determined. The coordinates of the westernmost, northernmost, eastern and southernmost points of the city are obtained and the map image of the city is considered as a rectangular shape.

The coordinates of the endpoints of the city are divided by the pixel numbers of the SEPA map image, and the coordinate change corresponding to each pixel changing is determined. In this figure, the longitude change of the SEPA map in horizontal pixels and the latitude change in vertical pixels are calculated. It is assumed that the latitude for horizontal pixels and longitude for vertical pixels are not changed.

Figure 2.4 shows a sample Google Earth image of Adana and the coordinates of the endpoints.

Figure 2.4. Google Earth image of Adana and the endpoints coordinates

Figure 2.5 shows a sample SEPA image of Adana with suitable areas for solar power plants installation and global solar radiation for these areas.

Figure 2.6 shows a sample of superimposing images of SEPA and Google Earth maps for Adana.

Figure 2.5. Solar radiation distribution of suitable points for the solar power plant installation in Adana

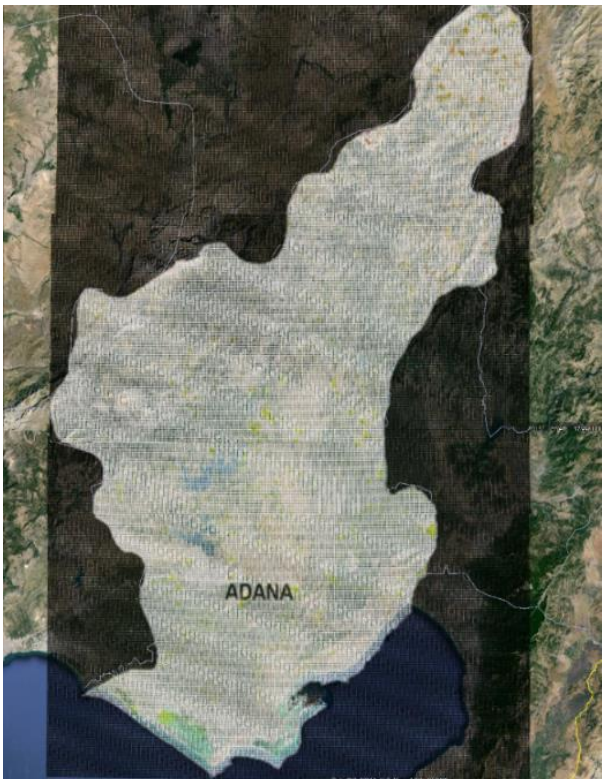

Figure 2.6. Superimposing images of SEPA and Google Earth maps for Adana

It is possible to examine the SEPA map in detail after superimposing the maps of the Google Earth and SEPA. The coordinates of each pixel in SEPA map image is determined because it is known in which coordinate range the horizontal and vertical pixels are located. After determining the coordinates of each pixel of the image, the RGB codes of these pixels are obtained through the MATLAB program. By removing the black pixels, only the color and coordinate information of the related pixels in relevant city are obtained.

After analyzing the color information for all pixels in the SEPA map image, following information are obtained for each pixels remaining within the city boundaries:

- Coordinate information
- Compliance with solar power plant installation
- General information about radiation values

Afterwards, for each city in Turkey, the white areas on the SEPA map image would be eliminated, then the annual solar radiation value for the other areas would be obtained and the total capacity would be determined.

2.1.2. Elimination of improper areas for solar power plant installation

After obtaining the coordinates and the color information of each pixel of the cities by using SEPA map images, it is necessary to extract the areas which are improper for solar power plant construction. Hence, white pixels in the SEPA map are eliminated. As a result, only the areas where solar power plant can be installed and the coordinate information of these areas are obtained.

After this election, 120 184 coordinates which are suitable areas for solar power plant construction are obtained for the entire Turkey. Annual solar radiation data for each coordinate correspond to 1 km^2 area as mentioned in the next section. Therefore, the total area solar power plant installation in Turkey is 120 184 km^2.

Table 2.1 shows 5 sample coordinates and its color information in terms of RGB code.

Table 2.1. Sample coordinates and its color information

Latitude	Longitude	Red	Green	Blue
41,0703	30,8462	106	180	144
40,3230	30,7357	115	225	251
39,7392	27,2607	176	213	238
39,3161	38,0279	231	222	174
38,8462	44,2238	212	81	81

2.2. Obtain Solar Radiation Data for Particular Coordinates

As well as determining the areas suitable for the solar power plant installation, color information about these areas is also obtained from SEPA map image. Color information corresponds to the yearly radiation value in the color scale from blue to red. These colors vary according to the solar radiation values between 1400 kWh/m^2 – year to 2000 kWh/m^2 – year. However, it is not possible that the colors have accurate information about the annual solar radiation data of suitable areas for solar power plant construction. Because the color values in the maps obtained from SEPA are general information about annual solar radiation. Therefore, annual solar radiation values should be obtained in more detail. In addition to annual solar radiation, monthly solar radiation also provides information about the seasonal generation of solar power plants.

After detailed investigations, solar radiation values are obtained from the PV Geographical Information System, which is prepared by the European Union Joint Research Center, has been used to examine annual radiation value [8]. These data are calculated using measurements taken at specific measurement points [9].

According to the descriptions in the PV Geographical Information System, it is seen that the solar radiation values have 1 km^2 area resolution. The previously determined 120 184 coordinates are also considered to be suitable for construction in the area of 1 km^2 in this direction. Therefore, it is thought that the solar radiation values obtained from the PV Geographical Information System correspond to the area of 1 km^2 suitable for construction.

As a result, it is found that 120 184 km^2 area for the 120 184 coordinates are obtained after find out suitable areas for solar power plant construction. It is known that Turkey surface area is 780 043 km^2 [10]. Therefore it is seen that the areas suitable for solar power plant installation corresponds to about 15% of the whole country area.

The solar radiation values obtained from the PV Geographical Information System are obtained after entering the coordinate information as in Figure 2.7. This process is performed for each of the 120 184 coordinates, and the radiation values of suitable areas for solar power plant construction in Turkey are obtained in detail.

The radiation value obtained for the determined coordinate is like Figure 2.8.

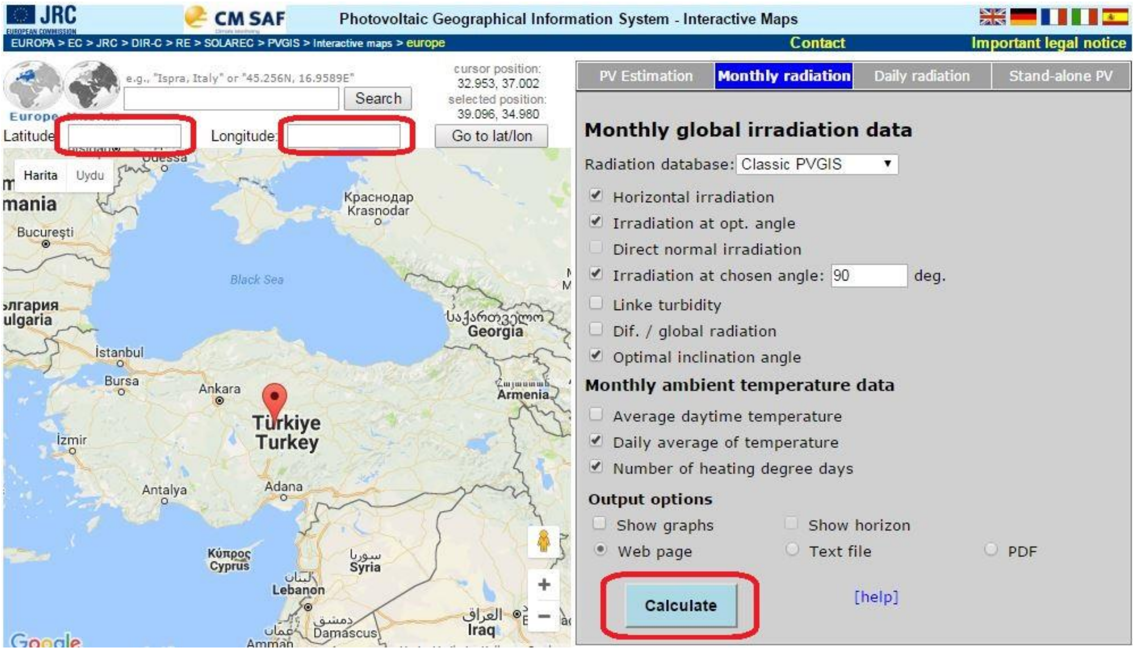

Figure 2.7. PV Geographical information system - interactive maps [8]

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 38°28'45" North, 34°6'5" East, Elevation: 1207 m a.s.l.,

Solar radiation database used: PVGIS-classic

Optimal inclination angle is: 31 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.1 %

Month	H_h	H_{opt}	I_{opt}
Jan	2130	3050	58
Feb	2890	3790	50
Mar	4470	5280	39
Apr	5110	5380	24
May	6240	6060	11
Jun	6900	6460	5
Jul	6820	6510	9
Aug	6210	6390	20
Sep	5340	6200	35
Oct	3810	4970	48
Nov	2490	3530	57
Dec	1890	2740	59
Year	4530	5040	31

H_h: Irradiation on horizontal plane (Wh/m^2/day)
H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)
I_{opt}: Optimal inclination (deg.)

Figure 2.8. Solar radiation data for specific coordinate [8]

As seen in the above figure, there are two different radiation values and an optimal inclination value. One of these radiation values is the solar radiation on horizontal plane and the other one is the solar radiation on optimally inclined plane. In all PV plants installation, the panel is positioned at the optimum angle in order to benefit from the solar energy more than the horizontal plane. Therefore, when the necessary analysis is carried out, the radiation on optimally inclined plane is taken into account.

After the removal of the points that are not suitable for the solar power plant construction, the remaining area corresponds to 120 184 km^2 and the map is shown in Figure 2.9 which is created by coloring according to the values of horizontal radiation.

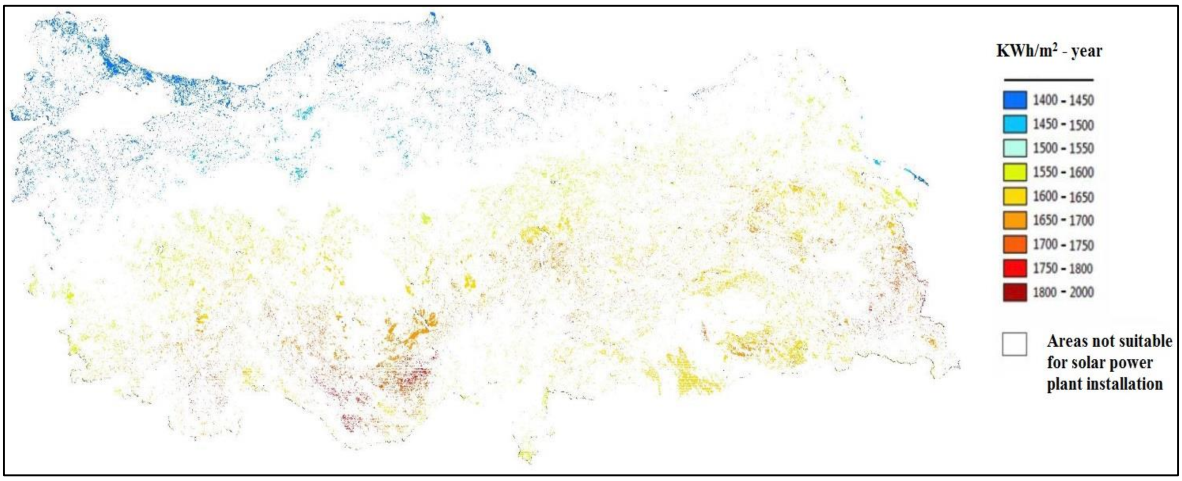

Figure 2.9. Annual solar radiation on horizontal plane distribution of suitable areas for solar power plant installation in Turkey

2.3. Analyzing of Solar Power Plant Potential from Investment Point of View

Different technologies are available for electricity generation from the sun. The main ones are PV systems and concentrated solar power systems. PV cells are semiconducting materials that convert the solar radiation coming directly to their surfaces into electrical energy. PV panel works with the photovoltaic principle, that is, when light falls on them, voltage is generated at their ends [11]. On the other hand, CSP system follow the sun in two axes, concentrating the sunlight into focus area. At this point, electricity generated by heating the water [12].

Generally PV power plants are currently installed in Turkey because it is more economic and feasible. Within the scope of the thesis study, it is thought that the plants to be installed in the suitable areas would be the PV power plant. Therefore the studies are carried out in this direction. On the other hand it is assumed that each 1 MW solar PV plants has 20000 m^2 plant area. For example 1 GW solar PV plants is constructed in 20 km^2.

Considering the map in Figure 2.9, for each 1 km^2, annual solar radiation on optimally inclined plane is obtained. While calculating the capacity factor in this direction, the use of the radiation on optimally inclined plane is deemed suitable and the capacity factor of each point is calculated by using this radiation value as mentioned in the previous section. The capacity factor is unitless and corresponds to a percentage value and is calculated according to the following formulation.

$$C\,F = \frac{Radiation\ Value\ on\ Optimmaly\ Inclined\ Plane\ \left(\frac{kWh}{m^2 \times year}\right)}{365 \times 24\ \times\ \frac{1kWh}{m^2}} \tag{2.1}$$

Each coordinate covers an area of 1 km^2 and it is possible to install a 50 MW PV solar plant in this area. When these PV plants are considered economically, the capacity factor depending on the annual solar radiation value gains importance. In this context, the economically gains of power plants with high capacity factor would be constructed for the priority investments.

Table 2.2. Installable PV plant capacity according to minimum C.F. is required in Turkey

Minimum Capacity Factor (%)	Installable PV Capacity Over Turkey (GW)
12	6009
13	6009
14	6008
15	6007
16	5997
17	5488
18	5100
19	4876
20	4333
21	2647
22	1009
23	162
24	16
25	3
26	0,05

As a result, when the minimum capacity factors is required for solar PV plants, the total installed power of the solar PV plants that can be established in Turkey is like Table 2.2.

It is known that the minimum capacity factor should be around 20% in order to economically reasonable return of the PV power plants. In this aspect, it is considered that this value would be taken into consideration when possible solar power plants that would be established in Turkey in the coming years. It is thought that the PV power plant investments which has annual capacity factor greater than %20 are priority investments. It is seen that in Table 2.2, installable PV plant capacity over Turkey for minimum 20% capacity factor is about 4300 GW. It is obvious that Turkey has a great solar potential when it is considered that the installed power capacity of Turkey is about 80 GW at present.

3. FREQUENCY CONTROL MECHANISM IN TURKEY

The frequency of a power system depends on the active power balance. Active power demand change will lead to a change in the frequency. In interconnected systems, active power is required to control the frequency, that is, control of power generated by the power plants.

In an electrical power system, the power system demand constantly changes throughout the day. This variation may depends on conditions, working hours, day length, special holidays, etc. These changes in demand can be predicted by various means depending on the historical statistical data. Moreover, the demand change rate as a consequence of the above-mentioned causes is not high enough to change the state of the system from a stable point to an unstable point [3].

If generation is more than demand, frequency increases, on the other hand, if generation is less than demand, frequency decreases. With the frequency control system, the amount of generation is increased or decreased to keep the system frequency in the desired level. These changes at the active power generation level are provided by the plants with obligations.

The frequency control of the interconnected system takes place on 4 stages; primary, secondary, tertiary frequency control and time control according to ENTSO-E regulations [13].

In this context, in order to ensure that the system frequency in Turkey is maintained at the determined levels, the ancillary services for frequency control are deployed in a certain hierarchy. The cycle for frequency control mechanism in Turkey is shown in Figure 3.1.

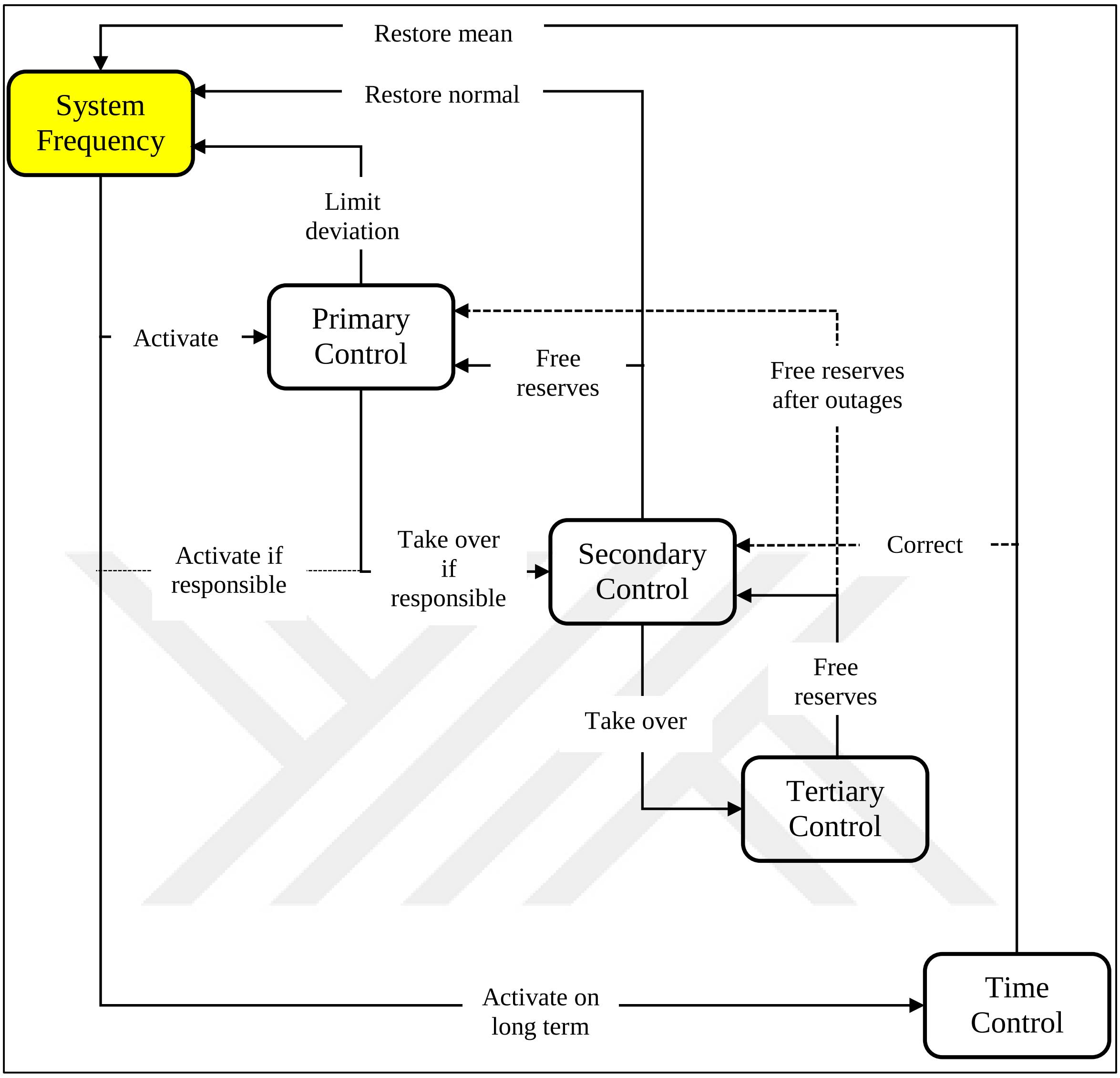

Figure 3.1. Frequency control philosophy in Turkey [13]

3.1. Primary Frequency Control

Primary frequency control provides the frequency of the system to be stabilized at the equilibrium point by increasing or decreasing the active power outputs of the generator by the speed governors in case the system frequency in the out of determined range.

The primary frequency control response starts within a few seconds following the frequency deviation and reaches its maximum value without exceeding 30 seconds. The primary frequency control response keep its maximum value during 15 minutes.

In order to meet the ENTSO-E standards the ancillary services need to be provided correctly and adequately. Primary frequency control service has great importance in terms of system security since it is the first service to be offered in case of decrease or increase of system frequency.

All generation facilities with an installed capacity of 50 MW or more must participate in primary frequency control. Generation facilities based on the following renewable energy sources are exempt from this obligation [14]:

- Run of the river hydroelectric generation facilities
- Wind energy based generation facilities
- Solar energy based generation facilities
- Wave energy based generation facilities
- Tidal energy based generation facilities

The active output power change according to the frequency deviations of the generators providing the primary frequency control service should be as shown in Figure 3.2.

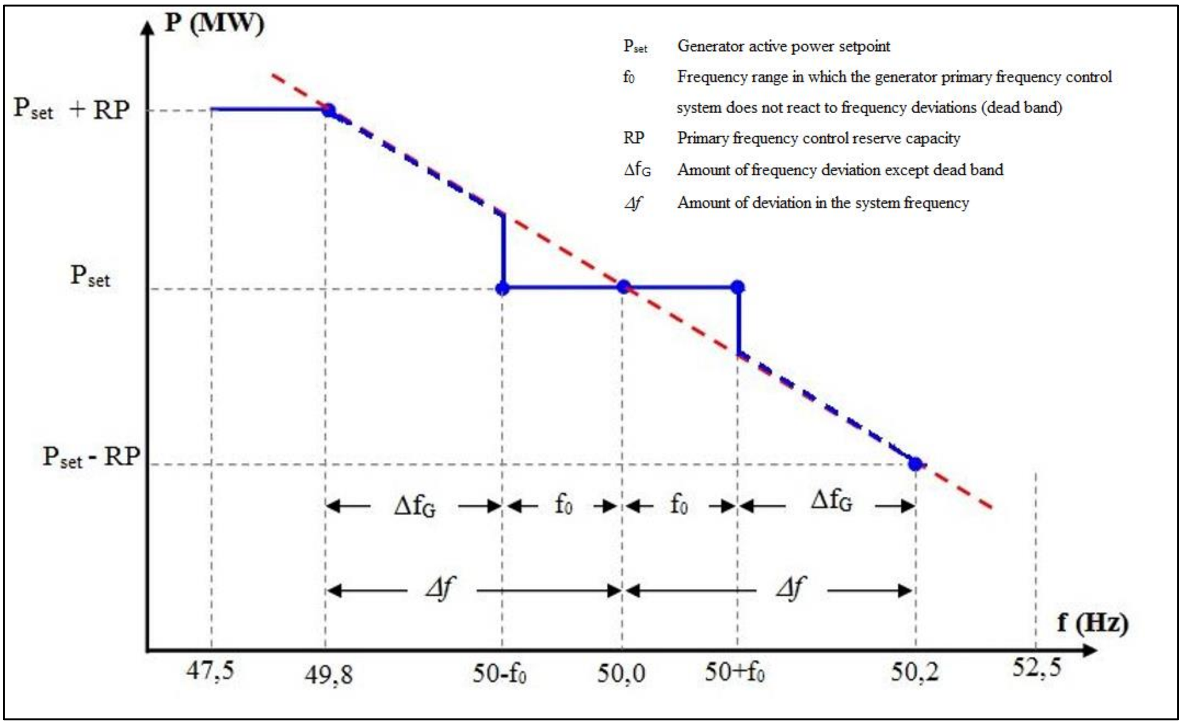

Figure 3.2. Change of generator active power output according to frequency change [14]

3.2. Secondary Frequency Control

As understood from the previous section, primary frequency control aim is to stop the deviation of frequency from its nominal value. However, the frequency is not be able to recover to its nominal value without any other active power supplementation. For recovering frequency to its nominal value, there must be change in active power output of the system. This can be applied by assigning new power setpoints to some generators in the system.

In order to bring the system frequency to the nominal value and the power flows of interconnection lines to the scheduled value, the active power outputs of the generation facilities which are obliged to participate in the secondary frequency control are arranged by AGC in power system.

It is imperative that all generation facilities with installed capacity of 100 MW and above have the capability of providing secondary frequency control service. The generation facilities indicated below are exempt from this obligation [14]:

- Run of the river hydroelectric production generation
- Wind energy based production generation
- Solar energy based production generation
- Wave energy based production generation
- Tidal energy based production generation
- Cogeneration generation
- Geothermal production generation

AGC computes the ACE signal from interchange and frequency. ACE tells whether a system is in balance or needs to make supplements to generation. AGC software, automatically determines the most economical output for generating resources while observing energy balance and frequency control, usually by sending setpoints to generators during observing ACE. Some generators also use pulse-accumulator methodology to derive a setpoint from pulses sent by AGC, but they are less common over time [15].

The AGC program running at the National Load Dispatch Center calculates an ACE every 2 seconds. AGC performs PI control.

$$ACE = (NIA - NIS) + K(FA - FS) \tag{4.1}$$

Where:
NIA is Actual Net Interchange
NIS is Scheduled Net Interchange
K is Network Bias Factor (chosen 2256 for Turkey)
FA is Actual Frequency
FS is Scheduled Frequency (50 Hz in Turkey)

Average value of ACE for one hour is calculated as shown below:

$$ACE_h = \frac{1}{n}\sum_{i=1}^{n} ACE_i \tag{4.2}$$

ACE performance criteria plays an important role for evaluating these scenarios. This criteria is assumed to be a daily assessment for the ACE signal, as well as daily if provided for each hour. In this direction, 1-hour simulations are performed. At the end of the 1 hour period, if the ACE values which are greater than 175 MW is more than 11%, the ACE criterion for that hour is not provided. Similar condition must be provided for 100 MW, with a 33 % limit condition

The summary of the ACE signal performance criterion is as shown in Table 3.1. In order for relevant hour to be successful, it must meet the ACE criteria set by ENTSO-E in the table.

Table 3.1. ENTSO-E ACE performance criteria

ACE Performance Criteria	Maximum Acceptance Ratio
$\|ACE\| \geq 175$ MW	% 11
$\|ACE\| \geq 100$ MW	% 33

3.3. Tertiary Frequency Control

Tertiary frequency control is that changing active power outputs of generators by the system operator. In addition, it is much slower when compared to primary and secondary frequency control. Using tertiary control, the following objectives are targeted:

- Always release secondary reserves when necessary to have sufficient reserves,
- Distribution of secondary reserves through economic preparations.

Active power output of generators changing can be made as fallows in tertiary frequency control:

- Load shedding
- Start up the generator
- Switching off the generator
- Redistribution of secondary frequency control reserves

3.4. Time Control

Time control is a control action carried out to return an existing time deviation between synchronous time and UTC time to zero. This differences must not exceed 30 seconds.

Table 3.2 summarizes the frequency control mechanism in Turkey.

Table 3.2. Frequency control mechanism summary [15]

Control	Ancillary Services	Timeframe
Primary Control	Frequency Response	30 Seconds – 15 Minutes
Secondary Control	Regulation	30 Seconds – 15 Minutes
Tertiary Control	Imbalance/Reserves	15 Minutes - Hours
Time Control	Time Error Correction	Hours

In this context, it is thought that solar energy power plants have negative effects on the secondary frequency control system after integrating to the power system. With the sunrise and sunset, the rapidly changing in active power level becomes important when considered from secondary control reserve capacity.

In the following chapters, the impact of the solar power plants on the grid is analyzed in terms of the effects on secondary frequency control performance.

4. 3 GW SOLAR POWER PLANT IN KARAPINAR

Renewable energy sources are increasingly contributing to electricity generation in Turkey. The power system in Turkey, the establishment of renewable energy sources, especially generation facilities based on wind and solar power, is encouraged. In this context, it is planned to establish a 3 GW solar power plant in Karapınar in 2025 by Turkish government.

The active output power level given by the solar power plants to the system starts to increase with the sunrise in the morning because of the direct proportion to the radiation and decreases in the evening hours with the sun setting. On the other hand, because of clouding on a large-scale solar power plant, active power output level of the solar power plant also decreases with the amount of sunlight falling on the panel. And this would lead to generation demand imbalance in the power system.

The connection of large scale PV plant to the electricity system from a single point is thought to have a great effect on the system in the morning and evening hours.

Disruption of the generation demand balance in the power system leads to changes in grid frequency. The active power balance in the Interconnected Turkey electrical system, is maintained by the primer, secondary and tertiary frequency control to keep the frequency within the determined range.

In this chapter of thesis, the characteristic of the solar PV plant planned to be installed in Karapınar, Konya and the effects of the active power output changing of PV plant electricity generation on power system in Turkey is examined.

4.1. Properties of Planned PV Plant in Karapınar

Until 2025, it is planned to establish a large-scale solar power plant in Karapınar, Konya in Central Anatolia region. In accordance with the decisions of the government, it is planned to build a solar PV plant with a capacity of 3 GW in approximately 60 km^2 area. The total surface area of Karapınar is 3030 km^2 and the altitude of the country is 1026 meters. In addition the population of the city is about 50000 [16]. When the SEPA is analyzed, the regions with the highest solar radiation are: Muğla, Burdur, Antalya, Konya (South), Karaman, İçel (North), Niğde, Kayseri, K.Maraş, Malatya, Adıyaman, Elazığ, Bingöl, Mus, Bitlis and Van. Among these regions, one of the area with the largest and least mountainous areas is undoubtedly the Karapınar region.

The areas where the 3 GW solar PV plant would be constructed are published in the official gazette dated 08.09.2012. In this context, these areas is approximately 60 km^2. The specified areas which have totally of approximately 60 km^2 is shown in Figure 4.1. These blue areas have been designated as suitable areas for solar power plant investment by government.

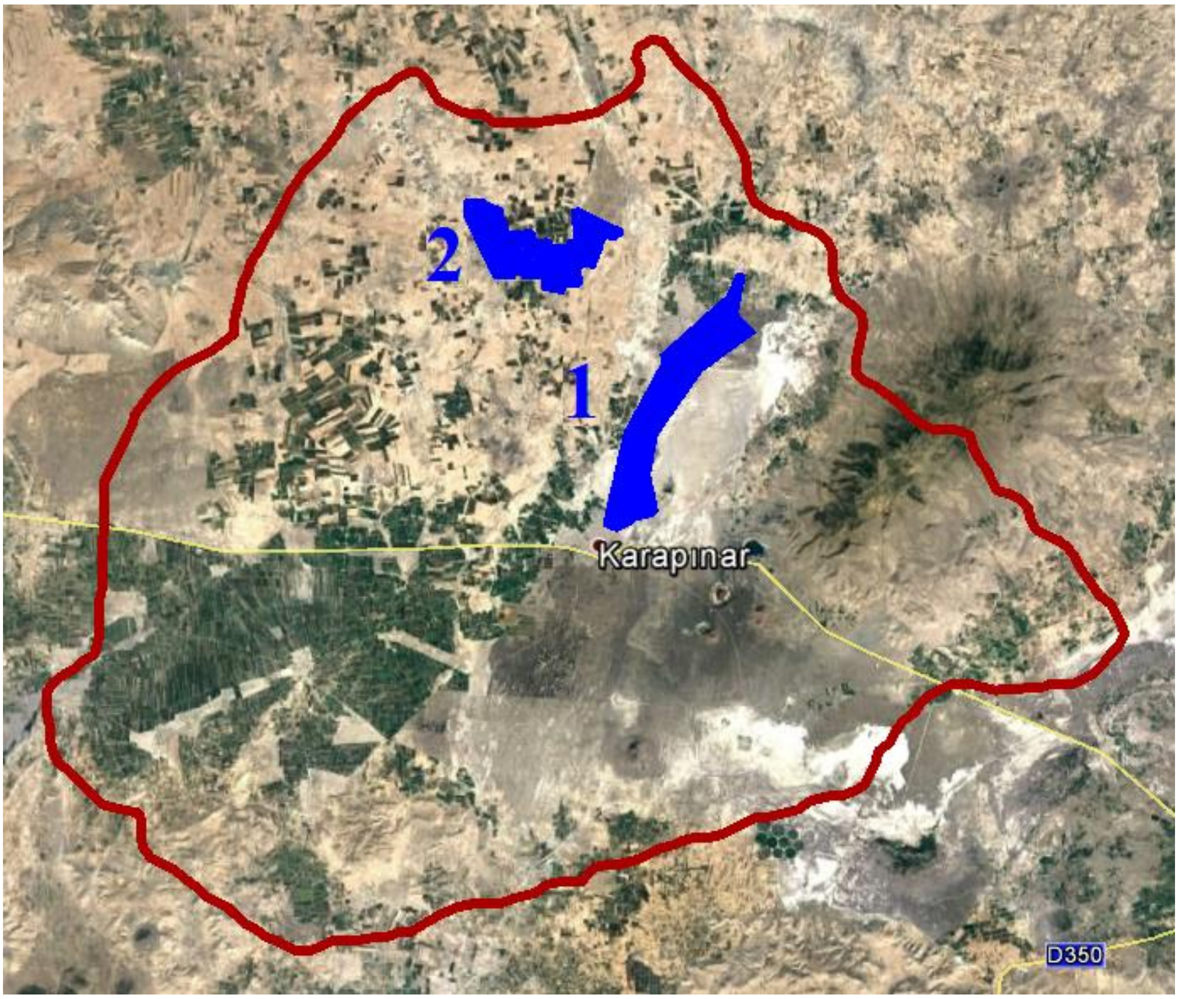

Figure 4.1. Specified areas for 3 GW solar power plant investment in Karapınar [17]

The sum of the two areas shown in the figure above is approximately 60 km^2. Description about the areas is shown below [16].

First area: It is 3 km distance from the town center and it is located in the Fatih neighborhood. The size of this area is 27 186 031 m^2. The slope of the area is 1%.

Second area: It is 19 km distance from the town center and it is located in the Reşadiye neighborhood. The size of this area is 32 400 845 m^2. The slope of the area is 1%.

In PV solar power plants, the structure type of PV panels are directly affects the amount of energy produced. If fixed-plane PV is preferred, the optimum plane angle must be found and installation must be done in this respect. Even if installation is carried out by determining the most suitable angle, generation is reduced at times when sunlight does not come directly during the day. Within this context, new technologies have been developed to make more use of solar energy. Two-axes PV panels developed to produce maximum energy from the solar radiation by moving according to sun position. For this reason, the capacity factors of two-axes PV panels are higher than fixed PV panels. However, given the investments made, it is expected that Karapınar 3 GW solar PV plant is going to consist of fixed plane PV panels only. Therefore, considering the effects of active power changing of 3 GW solar PV plants on frequency control, only changes in fixed-plane PV plants is considered and the results are evaluated accordingly.

When the annual solar radiation of these regions are considered, it is seen that these areas have a high capacity factor. The annual solar radiation value for region 1 is shown in Figure 4.2.

In Figure 4.2, the average daily radiation value for each month is displayed. In this context, it is seen that the solar radiation coming to the optimum angle is quite much. Furthermore, when the 1 year period is considered, the average daily radiation value is 5180 W/m^2/day. This corresponds to an annual output of 1890 kWh/m2/year. Therefore, this area has a capacity factor of 21,5%, which is a pretty good value for a fixed-plane PV plant.

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 37°48'27" North, 33°38'4" East, Elevation: 986 m a.s.l.,

Solar radiation database used: PVGIS-classic

Optimal inclination angle is: 31 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.0 %

Month	H_h	H_{opt}	I_{opt}
Jan	2260	3300	59
Feb	3010	3980	51
Mar	4590	5440	39
Apr	5210	5490	24
May	6390	6170	10
Jun	7040	6550	4
Jul	6900	6560	8
Aug	6260	6420	19
Sep	5420	6280	35
Oct	3960	5190	48
Nov	2590	3720	57
Dec	2020	3000	60
Year	4650	5180	31

H_h: Irradiation on horizontal plane ($Wh/m^2/day$)
H_{opt}: Irradiation on optimally inclined plane ($Wh/m^2/day$)
I_{opt}: Optimal inclination (deg.)

Figure 4.2. Annual solar radiation for region 2 [8]

The above figure also shows the optimal inclination angle for fixed plane PV for each month. This value indicates that the panel would be positioned to maximize the benefit from the solar radiation. However, when large scale PV plants are considered, PV panel position cannot be changed every month, so the panel positioning is made according to annual optimum angle and remains constant for all year. The annual optimally inclination angle for these region is about 30 degrees.

4.2. Karapınar PV Plant Generation Profile

The monthly averages daily data obtained from the PV Geographic Information System to examine the change of the Karapınar solar PV plant active output power. The daily active output power change for each month is calculated by using "Clear-Sky" solar radiation data, in which clouding effect is neglected from these data. The total installed power of the fixed-plane PV solar power plant is assumed to be 3 GW. In this direction, Karapınar solar PV power plant daily active power output curves for each season are given in Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6.

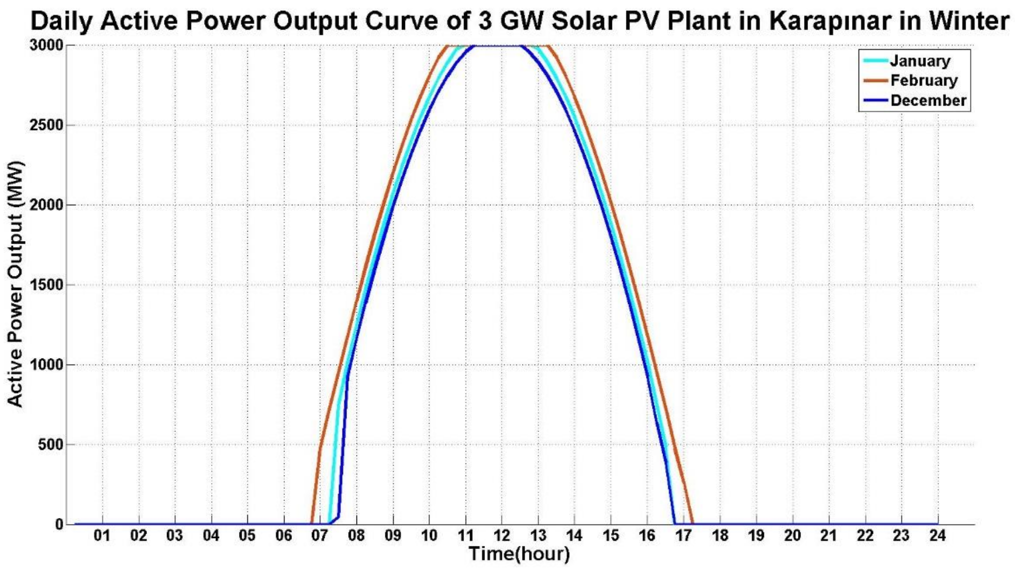

Figure 4.3. Daily active power output curve of 3 GW solar PV plant in Karapınar in winter

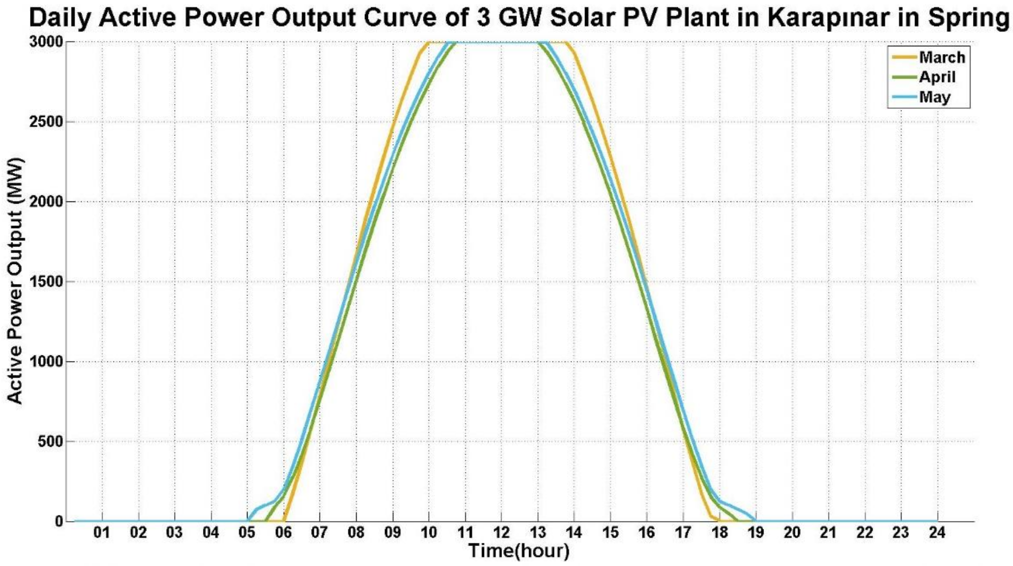

Figure 4.4. Daily active power output curve of 3 GW solar PV plant in Karapınar in spring

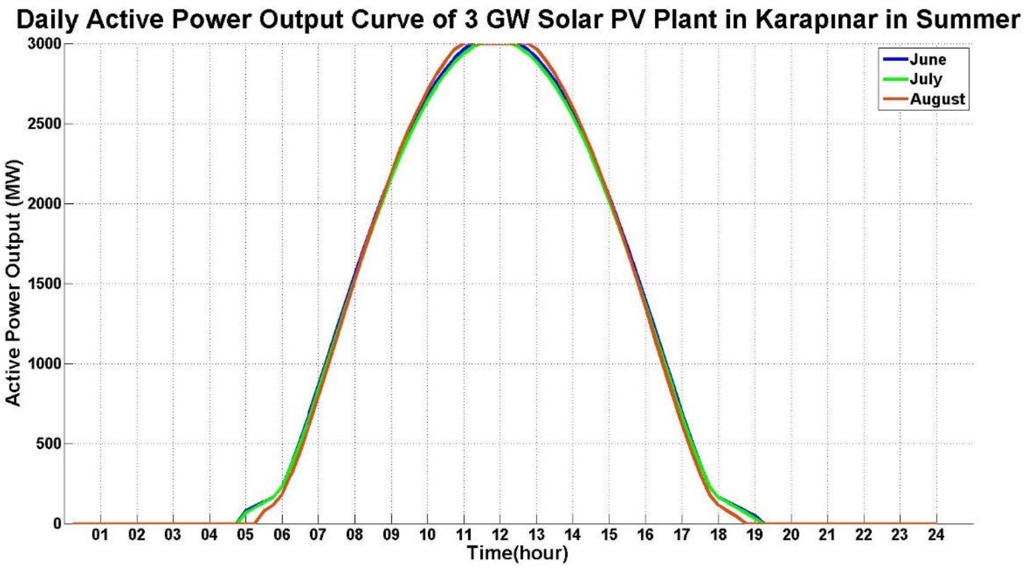

Figure 4.5. Daily active power output curve of 3 GW solar PV plant in Karapınar in summer

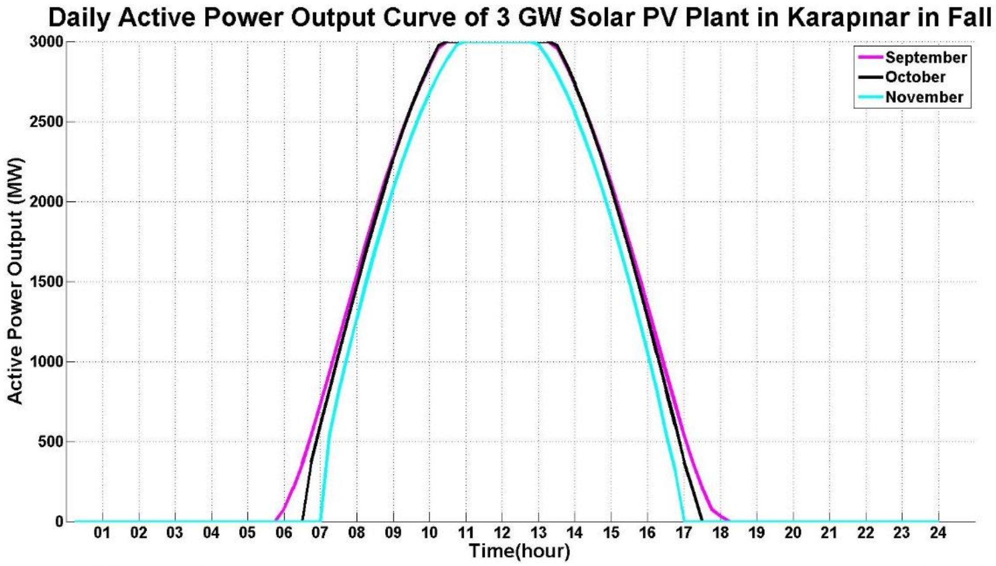

Figure 4.6. Daily active power output curve of 3 GW solar PV plant in Karapınar in fall

As can be seen in the above figures, 3 GW PV power plant active power output increases rapidly in the morning hours and decreases rapidly in the evening hours. PV plant electricity generation hours are increasing in summer and decreasing in winter. Another point is that the time to reach the maximum of the active output power.

PV power plant active power output remains at its maximum in spring and fall. Especially in March and October, it is observed that the active power output is at the maximum level between 10 and 14 hours. When summer and winter months are compared, it is observed that the sunshine durations in summer are increased, but the periods of maximum power of the active power output do not change. In this topic, generation profile for March and October are shown in Figure 4.7, and for December and June are shown in Figure 4.7.

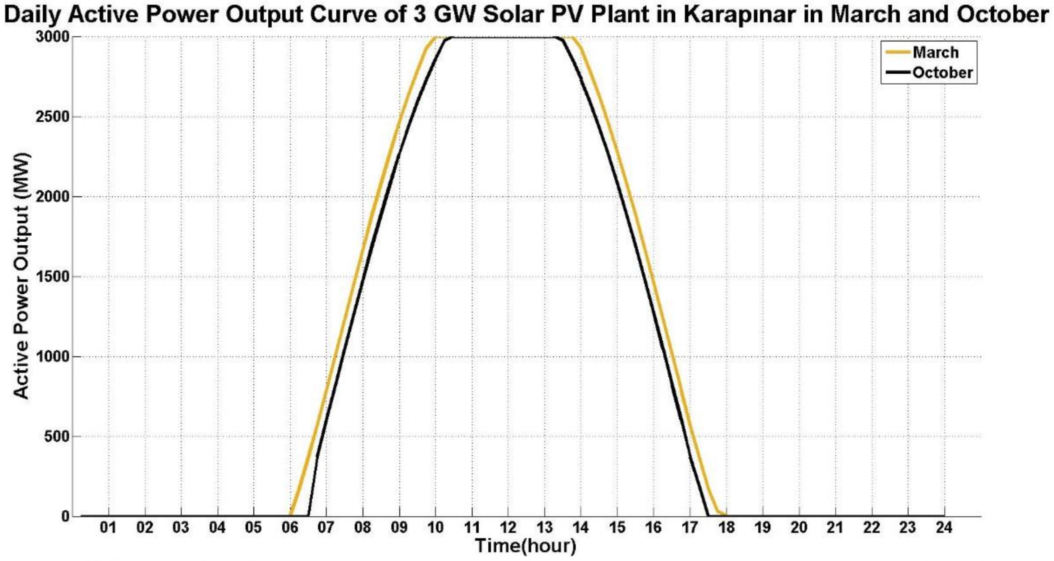

Figure 4.7. Karapınar solar PV plant active power generation profile in March and October

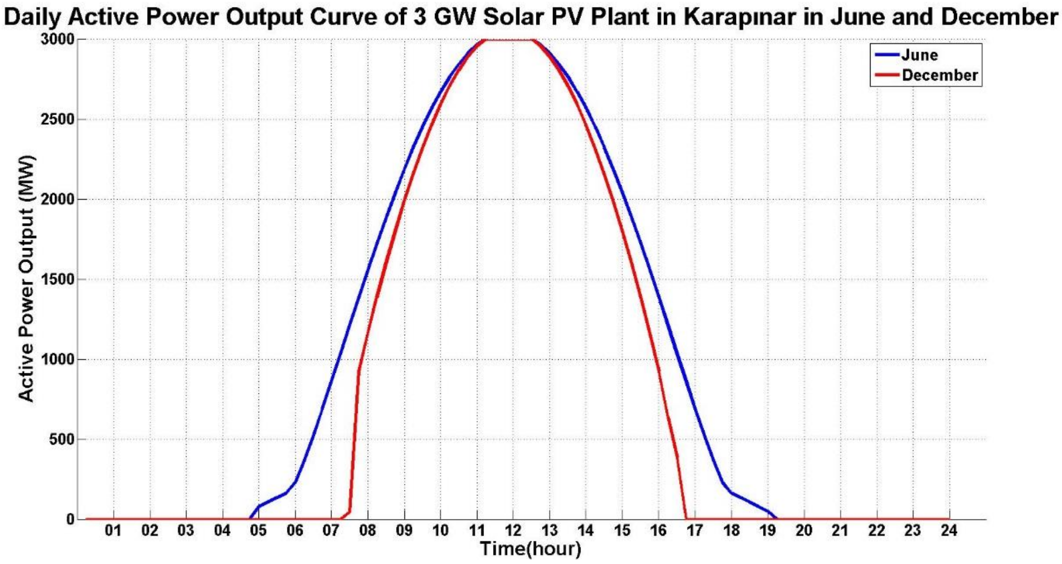

Figure 4.8. Karapınar solar PV plant active power generation profile in June and December

5. IMPACT OF SOLAR POWER PLANT IN KARAPINAR ON SECONDARY FREQUENCY CONTROL

The importance of assessing the changes in the active output power of the solar power plants is the speed of the changes in the active output power. As is known, a rapid change in the active power output power is compensated by the frequency control reserves in the first stage. It is necessary to balance a generation demand imbalance to be experienced by the secondary frequency control within 15 minutes at the latest [18]. For this reason, it is necessary to consider the changes that can be experienced in minute periods in the solar power plant's active power output.

In order to evaluate the effects of 3 GW Karapınar solar PV plant on secondary frequency control, it is necessary to examine the day-to-day variation of active power output of the plant and daily generation curve together. The daily load curves for sample day of each month of the year 2015 are derived from YTBS. The investments to be made in the Karapınar are planned to be completed in 2025. Therefore the daily load curves obtained from the YTBS are scaled in the direction of the 2025 consumption. These curves also be thought as the daily generation curves.

In this context, when the effect of solar power plant to be installed in Karapınar to secondary frequency control are examined and two important topics came to the forefront. First one is the daily solar radiation variance and the second one is the clouding over power plant area which cause the changing in the active power output level. The effects of these changes on the secondary frequency control is examined in the fallowing topics.

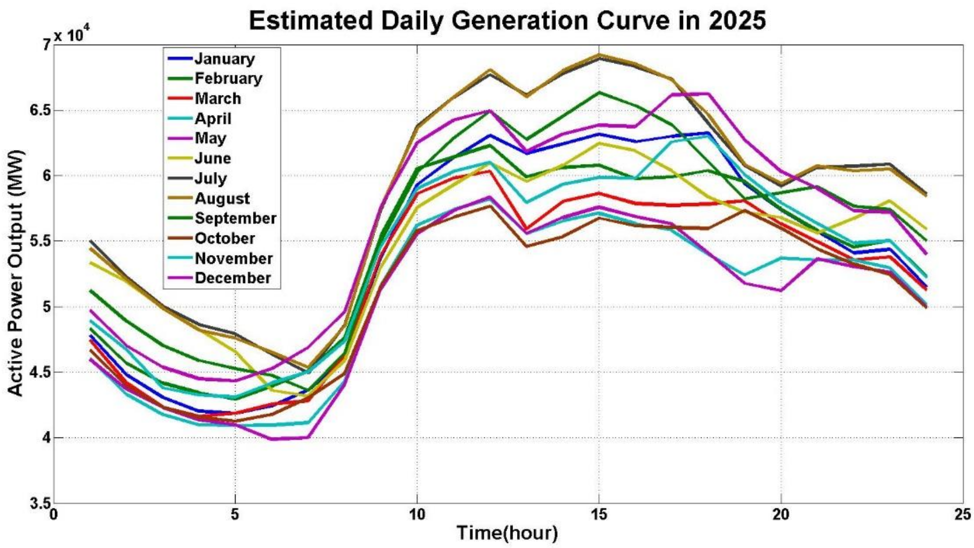

Figure 5.1. Estimated daily generation curves in 2025

5.1. Daily Active Power Changes due to Solar Radiation Variation

The daily generation profiles of solar PV plant in Karapınar for each month are shown in the previous sections. However, in secondary frequency control mechanism, active output power of the solar power is gaining importance. In this context, the rates of active power change in Karapınar solar PV plant are shown in Figure 5.2.

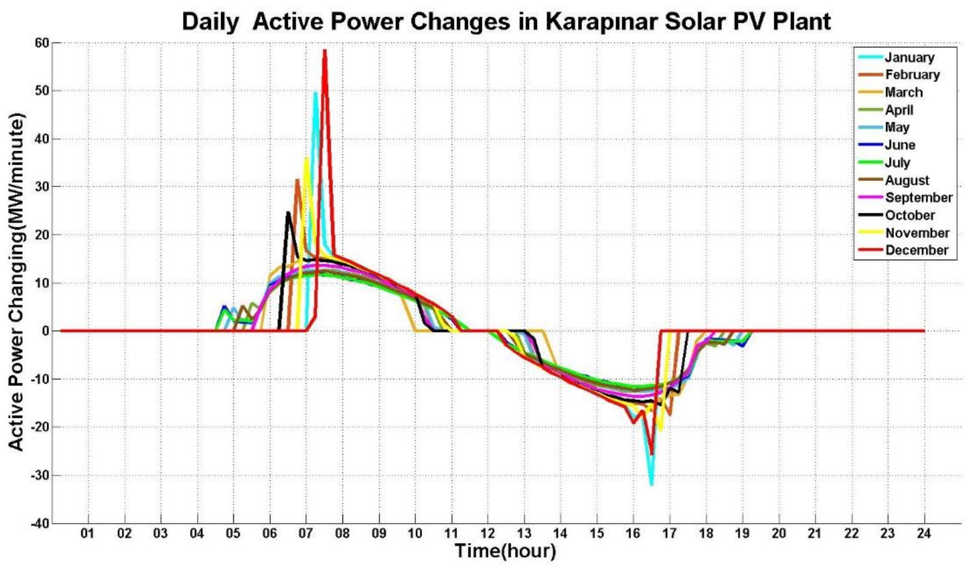

Figure 5.2. Daily active power changing rate in Karapınar solar PV plant

As can be seen in the Figure 5.2, the rate of increase in active power output of the solar power plant in the morning can reach up to 60 MW/min. On the other hand, the rate of decrease in active power output of the solar power plant in the evening can reach up to 30 MW/min. These rates are gaining more importance when considering 15 minute time scale.

Daily generation curves of Karapınar solar plant in Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6 are compared with the estimated daily generation curves of 2025 and the effects of 3 GW Karapınar solar PV plant on estimated daily generation curves in 2025 are shown in between Figure 5.3 and Figure 5.14.

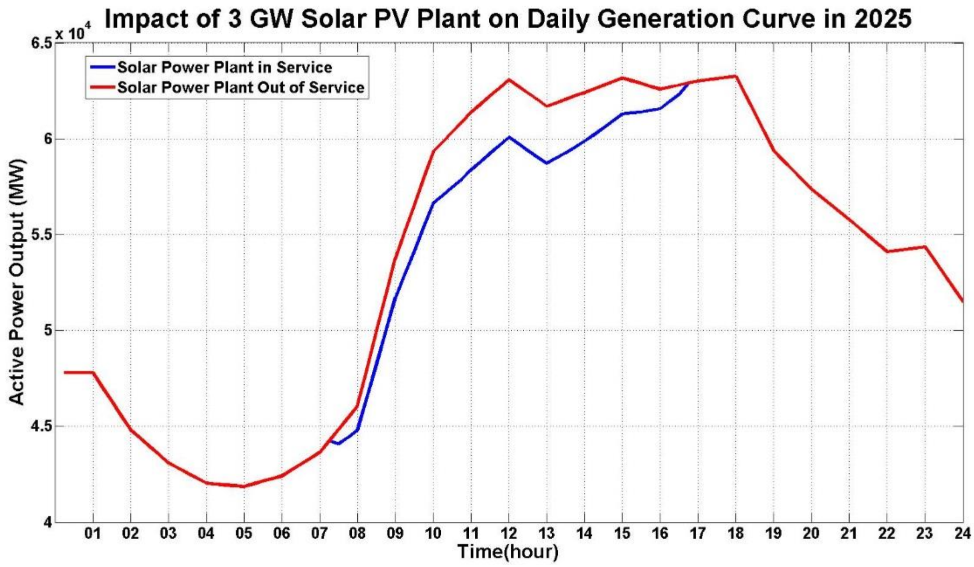

Figure 5.3. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (January)

When the daily generation curve for January is analyzed, it is observed that the active power of solar plant increases with the consumption in the morning hours. On the other hand, while the consumption increases, the active power of solar plant decreases in the evening hours. For this reason, it can be said that the solar plant has positive effect in the morning hours and the negative effect in the evening hours on daily generation in January.

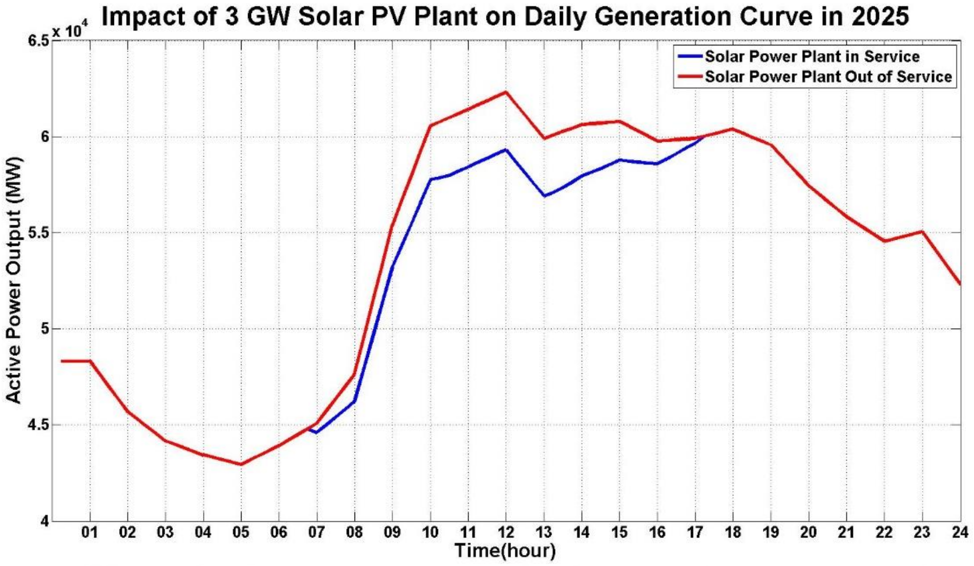

Figure 5.4. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (February)

When the daily generation curve for February is analyzed, it is observed that the active power of solar plant increases with the consumption in the morning hours. On the other hand, while the consumption increases, the active power of solar plant decreases in the evening hours. For this reason, it can be said that the solar plant has positive effect in the morning hours and the negative effect in the evening hours on daily generation curve in February.

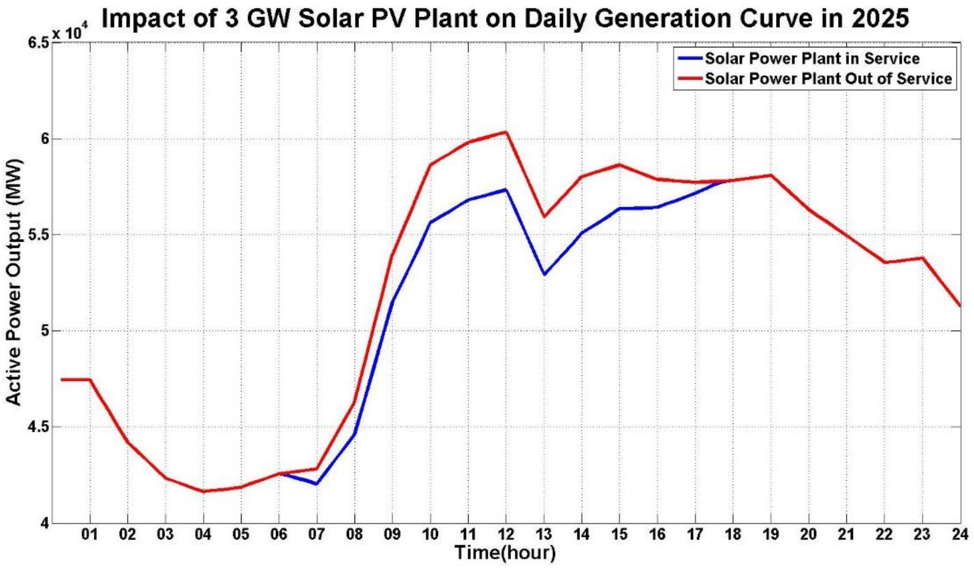

Figure 5.5. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (March)

When the daily generation curve for March is analyzed, it is observed that the active power of solar plant decreases when the consumption increases in the morning and evening hours. For this reason, it can be said that the solar plant has negative effect in the morning and the evening hours on daily generation curve in March.

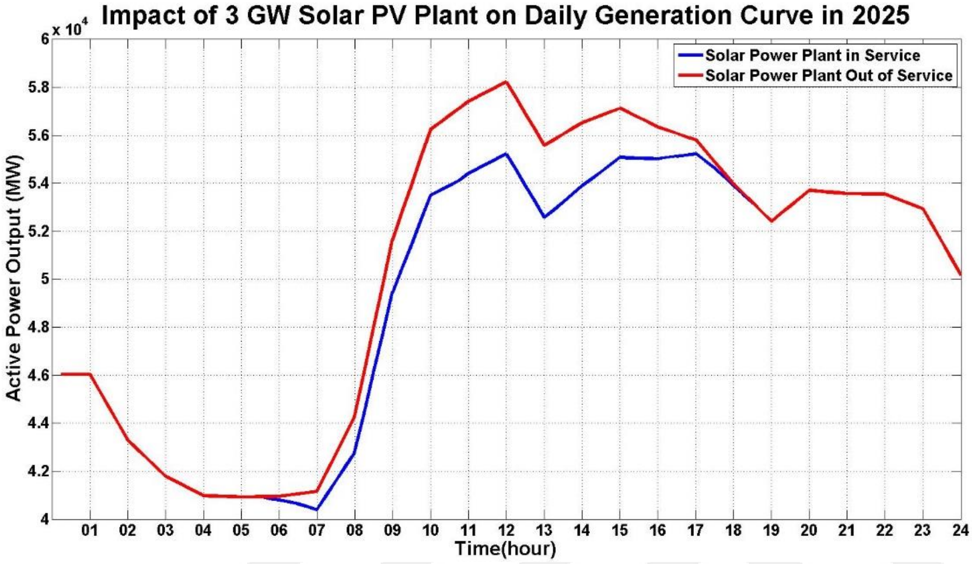

Figure 5.6. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (April)

When the daily generation curve for April is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in April.

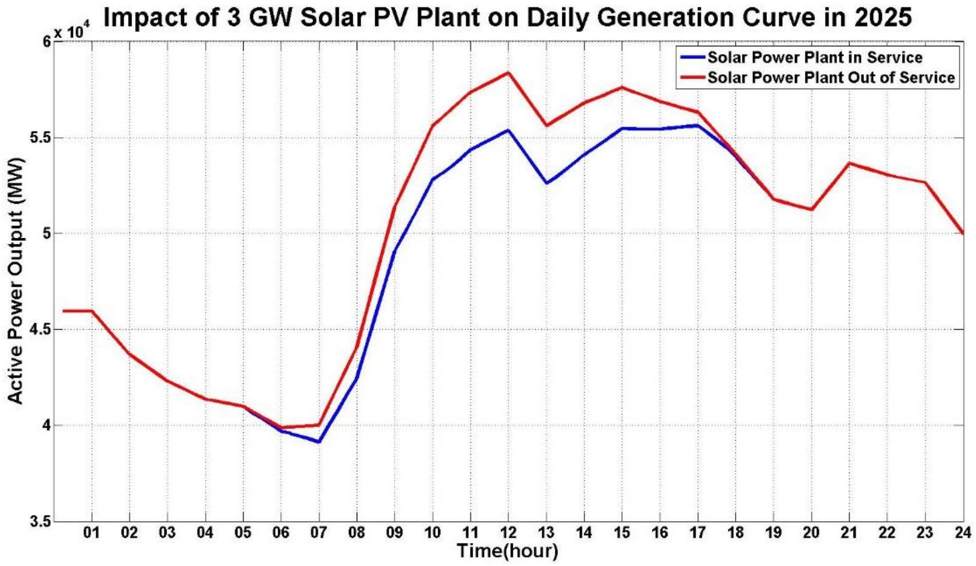

Figure 5.7. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (May)

When the daily generation curve for May is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in May.

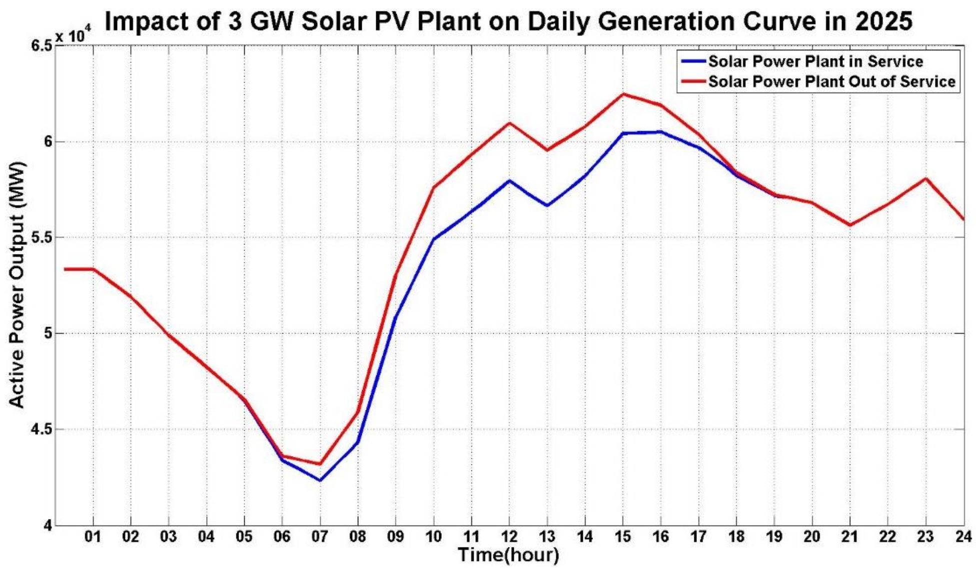

Figure 5.8. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (June)

When the daily generation curve for June is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in June.

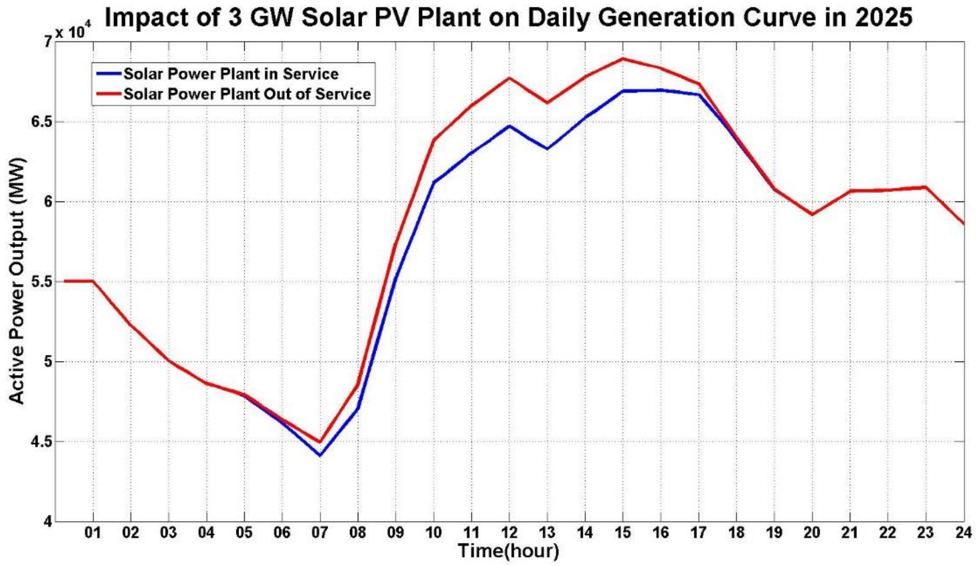

Figure 5.9. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (July)

When the daily generation curve for July is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in July.

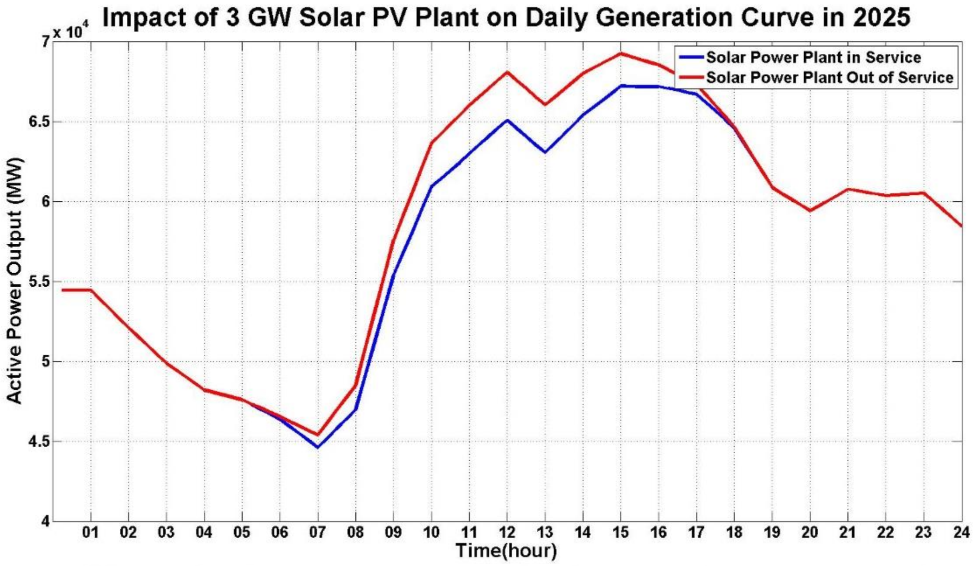

Figure 5.10. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (August)

When the daily generation curve for August is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in August.

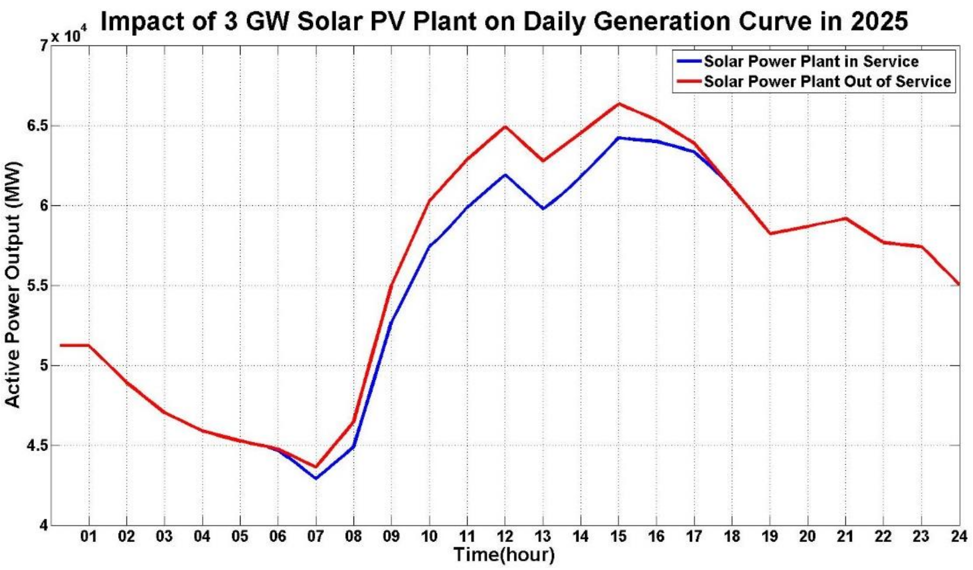

Figure 5.11. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (September)

When the daily generation curve for September is analyzed, it is observed that the active power of solar plant decreases with the consumption in the evening hours. On the other hand, the active power of solar plant increases more than the consumption in the morning hours. For this reason, it can be said that the solar plant has negative effect in the morning hours and the positive effect in the evening hours on daily generation curve in September.

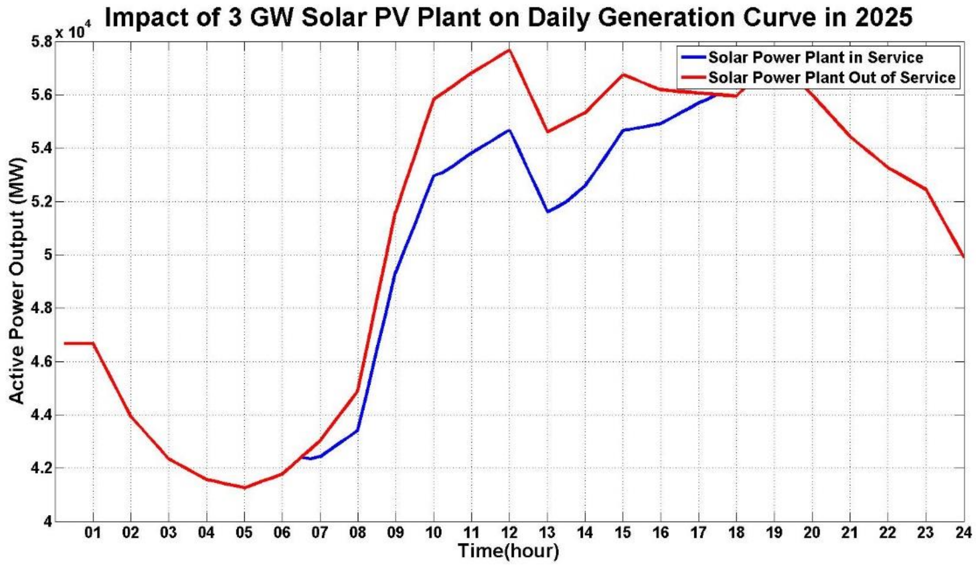

Figure 5.12. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (October)

When the daily generation curve for October is analyzed, it is observed that the active power of solar plant increases with the consumption in the morning hours. On the other hand, while the consumption decreases, the active power of solar plant did not change too much in the evening hours. For this reason, it can be said that the solar plant has positive effect in the morning hours and the negative effect in the evening hours on daily generation curve in October.

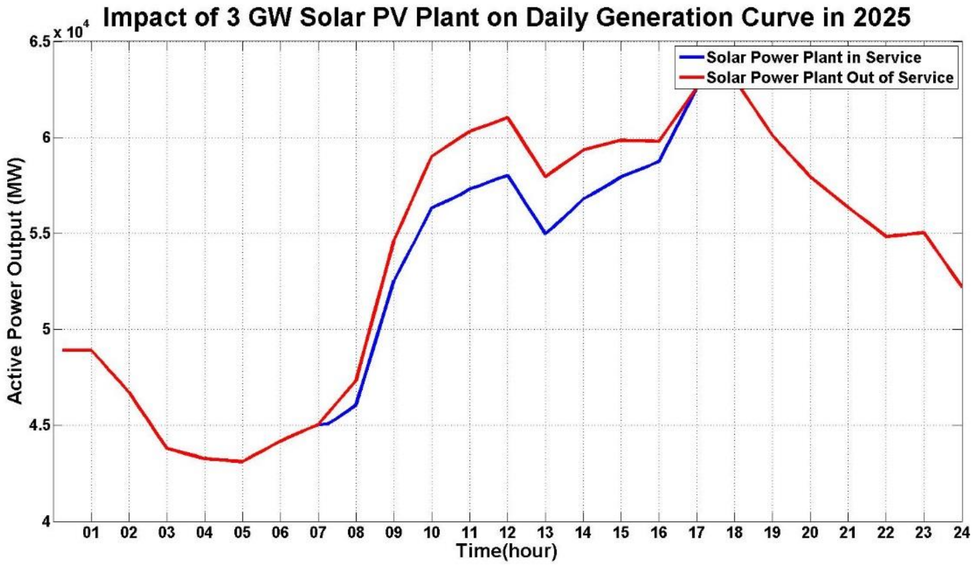

Figure 5.13. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (November)

When the daily generation curve for November is analyzed, it is observed that the active power of solar plant increases with the consumption in the morning hours. On the other hand, while the consumption increases, the active power of solar plant decreases in the evening hours. For this reason, it can be said that the solar plant has positive effect in the morning hours and the negative effect in the evening hours on daily generation curve in November.

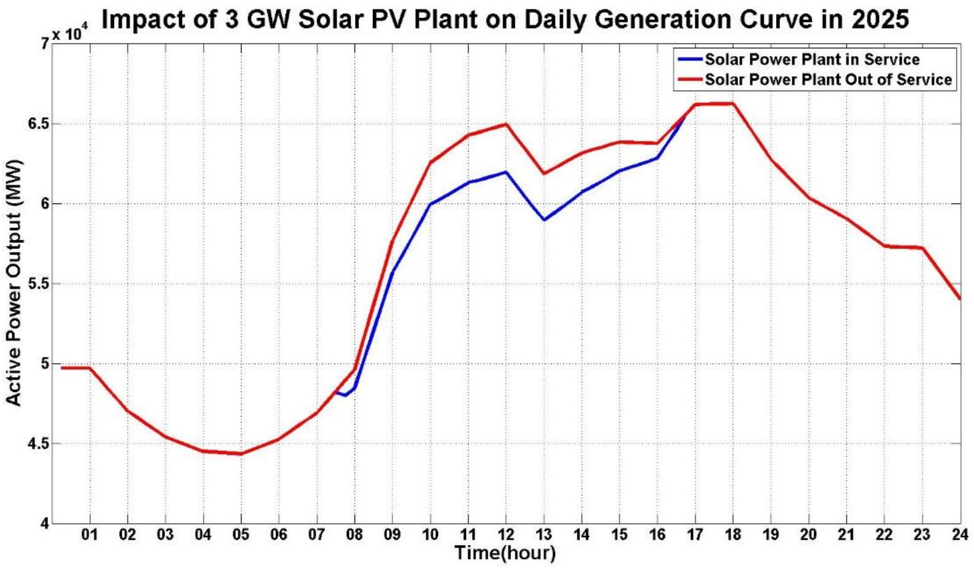

Figure 5.14. Effect of 3 GW solar PV plant in Karapınar on daily generation curve (December)

When the daily generation curve for December is analyzed, it is observed that the active power of solar plant increases with the consumption in the morning hours. On the other hand, while the consumption increases, the active power of solar plant decreases in the evening hours. For this reason, it can be said that the solar plant has positive effect in the morning hours and the negative effect in the evening hours on daily generation curve in December.

When the effects of the 3 GW solar PV plant in Karapınar active power output changing on the daily generation curve are assessed in general, it is seen that there are different effects according to the months. It is observed that there are negative effects both in the morning and in the evening in March. Between October and February there are positive effects in the morning and the negative effects in the evening. For remaining months there are negative effects in the morning and the positive effects in the evening.

Additional active power imbalances due to the solar power plant are given in Table 5.1 when solar power plant in Karapinar daily generation and 2025 estimated daily generation curves are jointly evaluated in secondary frequency control. If the total power demand increases while the solar power plant active power output increases or if the total power demand decreases while the solar power plant active power output decreases, the additional secondary frequency reserve is not required since the power imbalance is decreased. Otherwise, it is investigated that additional secondary control reserves are required to balance the power imbalance in the Turkish power grid.

Table 5.1. Active power imbalance in the system in the scope of secondary frequency control

	Morning Hours	Evening Hours
January	-	+ 32,2 MW/min
February	-	+ 17,6 MW/min
March	-	+ 13,4 MW/min
April	-	+ 10,8 MW/min
May	- 5 MW/min	+ 10,4 MW/min
June	- 11,4 MW/min	+ 9,6 MW/min
July	- 11,2 MW/min	+ 9,8 MW/min
August	- 11,6 MW/min	+ 10,4 MW/min
September	- 12,8 MW/min	+ 11,4 MW/min
October	-	+ 12,2 MW/min
November	-	+ 20,8 MW/min
December	-	+ 25,8 MW/min

In the morning, PV plant electricity generation increases rapidly with the sunrise, causing the secondary frequency control reserves to be used as a load. On the other hand, PV plant generation decreases rapidly with the sunset, causing the secondary frequency control reserves to be used as a generator in the evening.

5.2. Clouding Effect on Solar Power Plant Active Power Output Level

The generation level of photovoltaic solar power plants is highly dependent on geographical conditions. Especially for large scale PV power plants, the clouding in the power plant region seriously affects the level of generation.

The change in generation level due to clouding differs due to the reasons such as cloud speed, density, height, etc. Level of change depends on PV plant area.

Total solar radiation value, which is determinant in the generation quantities of photovoltaic panels, consists of direct radiation and diffuse radiation. The clouding dramatically reduces the direct radiation value. Reduced direct radiation on the panel causes a decrease in total solar radiation and hence a decrease in the active power generation level.

The US National Renewable Energy Laboratory (NREL) is able to record the radiation values in these regions on a daily basis by placing certain point-of-day solar radiation measurement devices in the USA. Therefore, it is possible to reach real values for the measured points. In this respect, the measurements for the two different days obtained in the NREL study for the Los Angeles area are shown in Figure 5.15 [19].

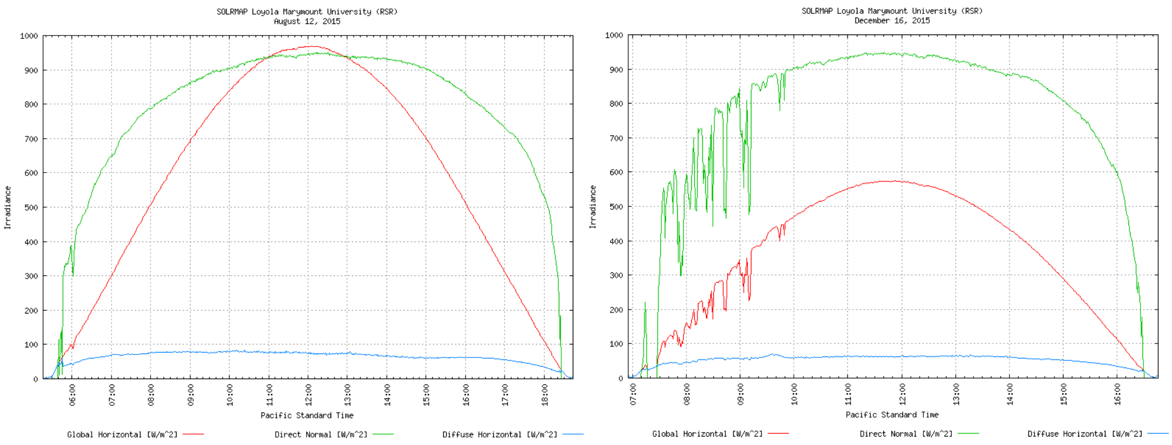

Figure 5.15. Radiation values for a sample days in August and December for the measuring point in Los Angeles area [19]

The values in August 12 when clouding has not occurred and there are no significant changes in direct radiation, so total solar radiation has smooth structure. However it is observed that there are significant changes in the direct radiation due to the clouding in December 16, this change causes the oscillations in the total amount of solar radiation.

It is observed that clouding at 09:15 in the morning in December, caused the direct radiation value to decrease by approximately 300 W/m^2 for the sampling point which resulted in a decrease of approximately 40 % in total solar radiation value. In this direction, the change in the output power of a single panel is about 40%.

Clouding, which causes serious changes in radiation values, may occur in different types. There are basically three different types of clouding in photovoltaic studies. The visual state of these clouding is shown in Figure 5.16.

Figure 5.16. Left – Stratus Cloud, Middle – Shallow Cloud, Right – Dense Cloud

Another study on clouding is the study of the "Observed Impacts of Transient Clouds on Utility-Scale PV Fields" for the Florida region [20]. The results obtained in this study are shown in Figure 5.17, Figure 5.18 and Figure 5.19.

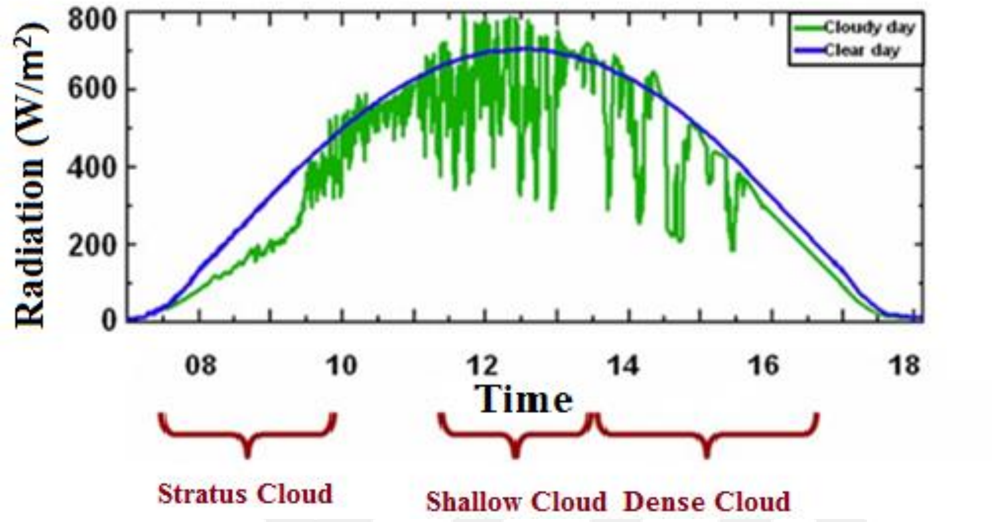

Figure 5.17. Changes in radiation values for photovoltaic power plant in Florida region according to the type of clouding [20]

As shown in Figure 5.18, there is some reduction in the level of radiation in the stratus cloud and no oscillation is observed. However, in the case of dense cloud, it is observed that the level of radiation is decreasing severely and the oscillations become more frequent.

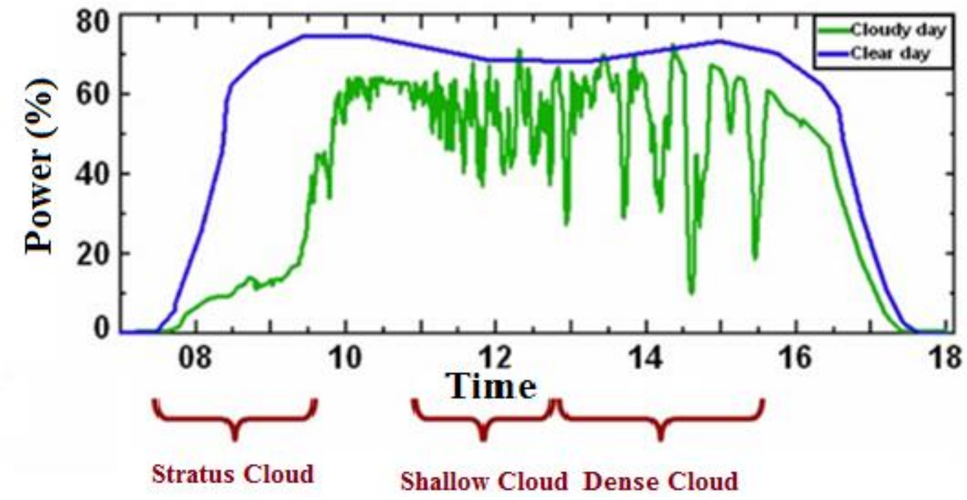

Figure 5.18. Percentage of photovoltaic power plant generation established on 730 000 m^2 and located in Florida by changing radiation value [20]

As shown in Figure 5.19, the generation level is reduced by up to 80% when exposed to the effect of a dense cloud.

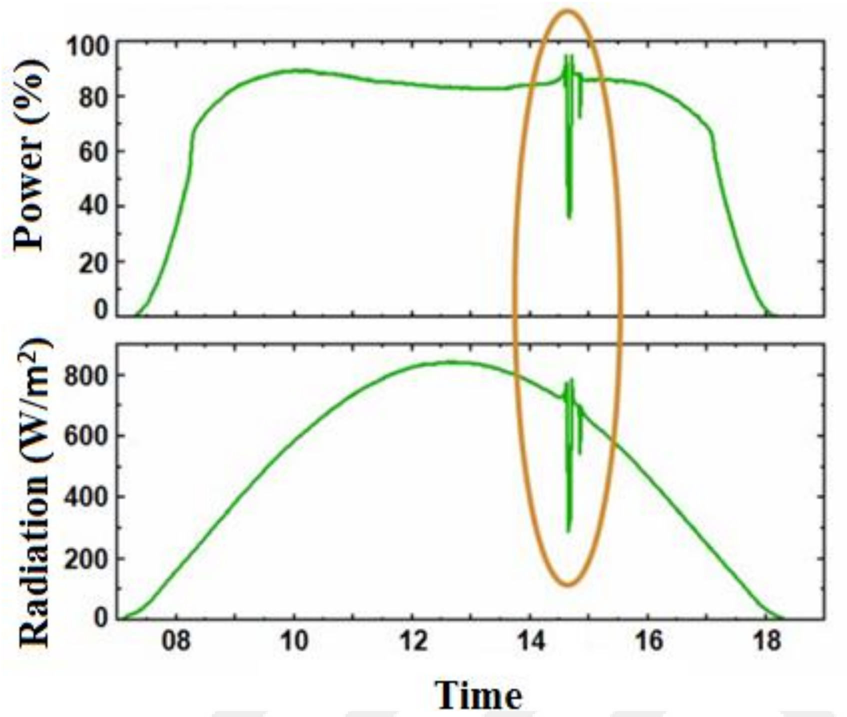

Figure 5.19. The impact of fast cloud transition on daily generation of photovoltaic solar power plant located in Florida established on 730 000 m^2 [20]

In addition to affecting the daily generation profile of clouding, a very sudden cloud crossing over the PV plant on a sunny day also dramatically reduces the generation level instantaneously. The change in radiation caused by a fast and dense cloud passing over the PV plant installed on 730 000 m^2 and the oscillation at the generation level caused by this change is shown in Figure 5.19. It is seen that the instantaneous cloud transition caused a drop of close to 60% within 3 minutes of the generation level.

In addition, for the South Africa region, the study of "Cloud Cover Impact on Photovoltaic Power Production in South Africa" is investigated [21]. The results obtained in this study are shown in Figure 5.20 and Table 5.2.

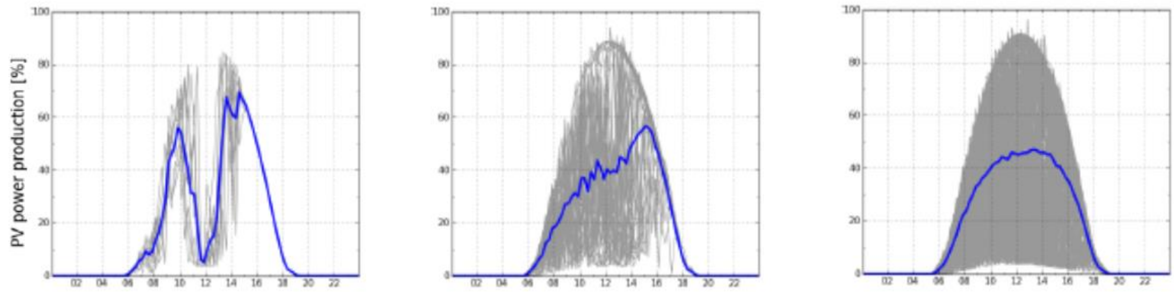

Figure 5.20. Daily generation curves of three PV plants in the same zone (50 km^2 on the left, 250 km^2 on the Middle, 500 km^2 on the Right) [21]

The effect of radiation due to clouding on the generation level may vary depending on the size of the PV plant area. As the area of the generation facility grows, the percentage of active power changes level decreases. As can be seen in Figure 5.20, as the area grows, the daily generation profile has a smoother structure and sudden changes are less likely to disappear.

Considering the 15-minute changes in the generation level, as seen in Table 5.2, it is observed that the photovoltaic power plant installed on a 50 km^2 area is observed 24% loss of generation level at the time of clouding, and this oscillation decreases as the area grows. It is observed to loss of generation level fall down to 6% for the larger area.

Table 5.2. Percentage of active power changes that occur due to the clouding according to plant area [21]

PV Plant Area [km^2]	15 Minutes Change Interval [% Nominal DC Power]
5	± 15 - ±40
50	± 8 - ±24
250	± 3 - ±10
500	± 2 - ±6

In the direction of these studies, 3 GW Karapınar solar PV plant is planned to be built on 60 km^2, active power output may change to ±25% (±750 MW) of the installed power of PV plant during clouding within 15 minutes.

6. SIMULATION AND RESULTS

9 different scenarios are constructed for examining the effects of the 3 GW Karapınar solar power plant on the secondary frequency control performance. In this context, the scenarios are simulated in the DIgSILENT PowerFactory program and the results are analyzed in the MATLAB program.

The following topics inform the simulation model, scenario information and results of the simulation.

6.1. Simulation Model in DIgSILENT PowerFactory

After synchronizing the Turkish electricity system with the ENTSO-E system, the secondary frequency control performance has gain more importance than before. In order to be able to make the evaluations of the secondary frequency control properly, it is necessary to verify the model of the automatic generation control (AGC) and the relevant generators created in the DIgSILENT PowerFactory program.

The AGC simulation model calculates the total secondary reserve amount to be used by measuring the measured frequency data and difference between the power flow values on the ENSO-E lines and the scheduled power flow values. Then the calculated secondary reserve is shared among the power plants with secondary frequency control obligations according to reserve capacity of the plants.

In this context, the block diagram of the AGC system modeled on DIgSILENT PowerFactory is as shown in Figure 6.1.

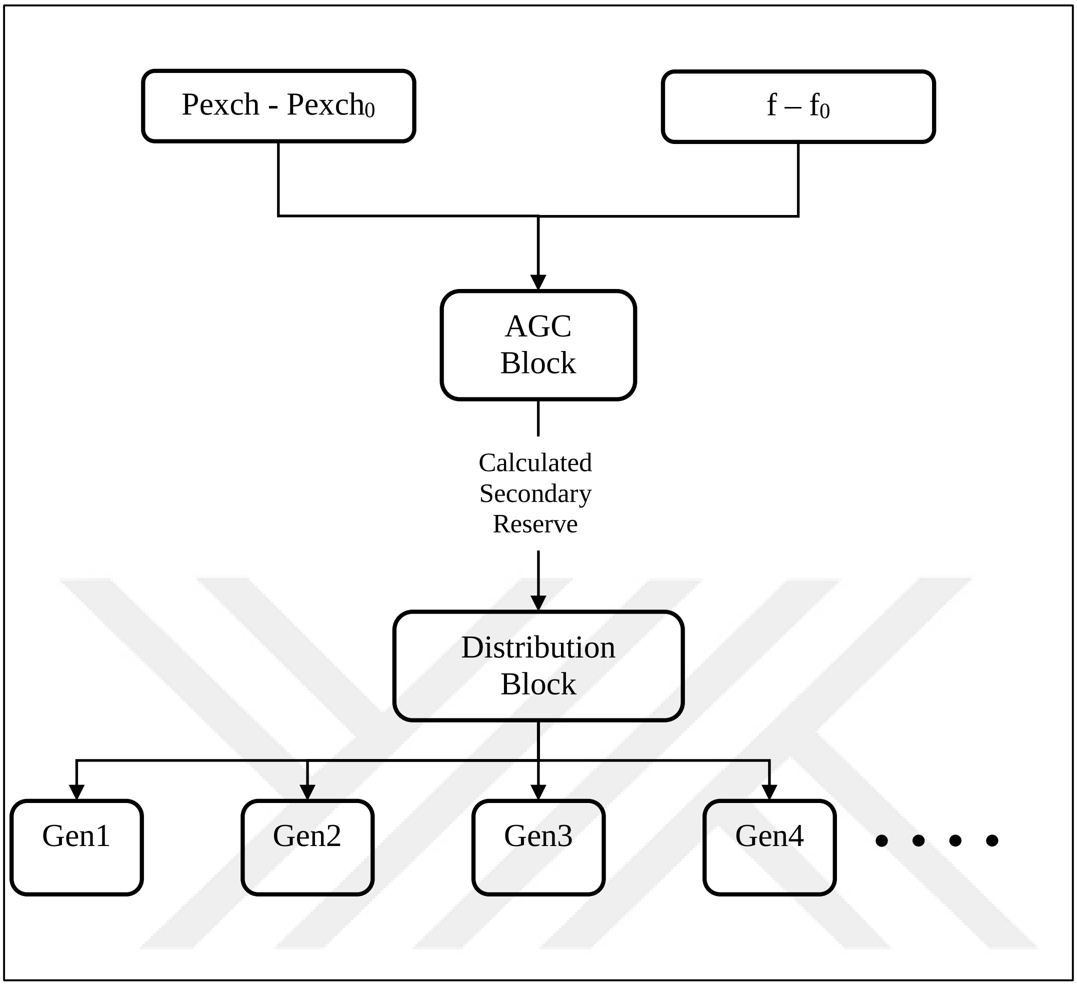

Figure 6.1. Block diagram of modeled AGC system in DIgSILENT PowerFactory

Parameters used in Figure 6.1 are explained as follows:

Pexch: Power flow values on the ENTSO-E connection lines

$Pexch_0$: Planned power flow values on the ENTSO-E connection lines

f: System frequency in Hz

f_0: Nominal frequency (50 Hz in Turkey)

Gen1, Gen2, Gen3 and Gen4: Generators with secondary frequency control obligation

The AGC model used in DIgSILENT PowerFactory is shown in Figure 6.2.

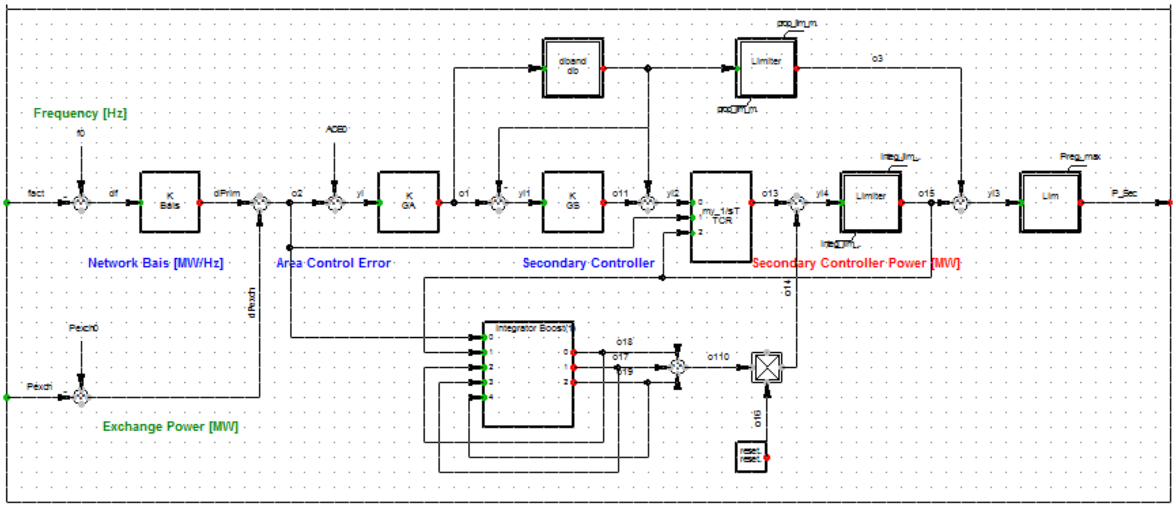

Figure 6.2. Secondary frequency control model in DIgSILENT PowerFactory

Calculation of ACE as shown in below:

$$ACE = \Delta P + K\Delta f \qquad (6.1)$$

Where;

ΔP: Difference of power flow in ENTSO-E connection lines from planned

K: Network frequency bias value

Δf: Frequency difference

With the secondary frequency controller model, the ACE is calculated by looking frequency and ENTSO-E connection lines. After PI controllers and limiters total setpoints to be sent to the generators is determined. Distribution blocks are used to distribute the total setpoints to the generators with secondary frequency control obligation.

Verification of the AGC model in DIgSILENT PowerFactory was performed with real data from SCADA. After analyzing two model, it is seen that the model used in DIgSILENT PowerFactory has perform similar performance with real AGC model.

In Turkey, the secondary control frequency capacity is about 1000 MW. Therefore in the simulation model 990 MW secondary reserve is used.

Modeled generators with secondary frequency control obligation and its reserve capacity is shown in Table 6.1.

Table 6.1. Generators with secondary frequency control obligation and its reserve capacity in DIgSILENT PowerFactory model

Generator	Source	Secondary frequency reserve capacity (MW)
Generator-A	Natural Gas	45
Generator-B	Natural Gas	38
Generator-C	Natural Gas	10
Generator-D	Natural Gas	30
Generator-E	Natural Gas	56
Generator-F	Natural Gas	29
Generator-G	Hydro	135
Generator-H	Natural Gas	30
Generator-I	Natural Gas	50
Generator-J	Natural Gas	95
Generator-K	Natural Gas	38
Generator-L	Natural Gas	38
Generator-M	Natural Gas	37
Generator-N	Natural Gas	37
Generator-O	Natural Gas	33
Generator-P	Natural Gas	71
Generator-Q	Hydro	15
Generator-R	Natural Gas	36
Generator-S	Hydro	7
Generator-T	Natural Gas	160

For the active power changes that occur at the generation level of Karapınar solar power plant, “load event” is defined during simulation in DIgSILENT PowerFactory. Thus, active power changes in Karapınar solar power plant can be applied in the simulation model with this load event. The details of the simulation model are presented in the appendix.

In the simulation, ACE performance will be examined as described in chapter 3.2. After simulation whether the current secondary frequency performance is evaluated during the active power changes in the solar power plant.

It is necessary to sweep electricity generation demand imbalance by the secondary frequency control within 15 minutes [18]. Therefore, active power changes that the solar power plant can occur in 15 minutes will be taken into consideration, since the power imbalance due to the solar power plant yields to an increase in the magnitude of the ACE.

Simulation time is set to 1 hour to evaluate the criteria described in chapter 3.2. In this context, the events applied during 1 hour simulation are shown in Figure 6.3.

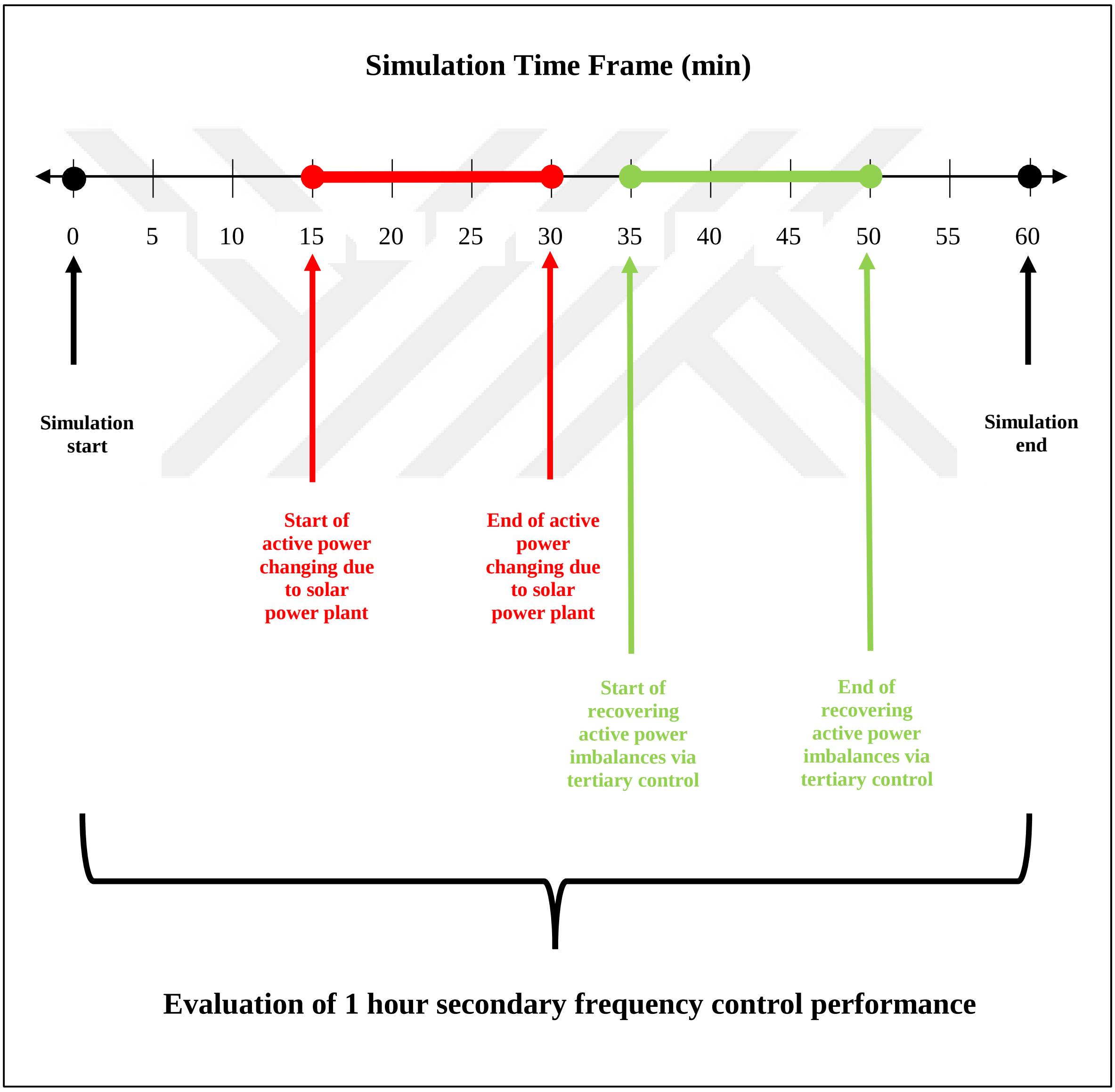

Figure 6.3. Simulation time frame of simulation

6.2. Simulation and Results

The main purpose secondary frequency control is to keep the frequency at the nominal value and power flow in the interconnection lines at the scheduled levels. Within this scope, different scenarios are created in order to examine the effects of Karapınar solar plant on the power grid. While these scenarios are created the arc furnaces changes is taken into consideration.

The iron-steel industry causes unwanted sudden load changes. This constantly changes the amount of power flow in the ENTSO-E lines. Therefore the active power changes in the solar power plant are considered together with changes in the active power demand of the arc furnaces to ensure the reality of the scenarios.

The active power variations of arc furnaces loads in the iron and steel industry are shown in Table 6.2. The normal load shown in the table shows the unchanging part of the consumption and the impact load shows the sudden changes in the active power consumption of the arc furnaces.

Table 6.2. Active power demand of arc furnaces

Arc Furnace	Normal Load (MW)	Impact Load (MW)
Arc Furnace-A	119	410
Arc Furnace-B	55	277
Arc Furnace-C	100	178
Arc Furnace-D	480	175
Arc Furnace-E	40	155
Arc Furnace-F	50	150
Arc Furnace-G	19	135
Arc Furnace-H	40	134
Arc Furnace-I	30	120
Arc Furnace-J	30	105
Arc Furnace-K	0	90
Arc Furnace-L	40	90
Arc Furnace-M	0	72
Arc Furnace-N	15	70
Arc Furnace-O	16	64
Arc Furnace-P	60	58

The active power changes that occur in the arc furnace loads are examined in three different scenarios. For scenarios to be applied over a 1-hour period, it is simulated that the active power changes occurring in the arc furnace as high, moderate and low.

The load curves of the low, moderate and high arc load variations are shown in Figure 6.4, Figure 6.5 and Figure 6.6.

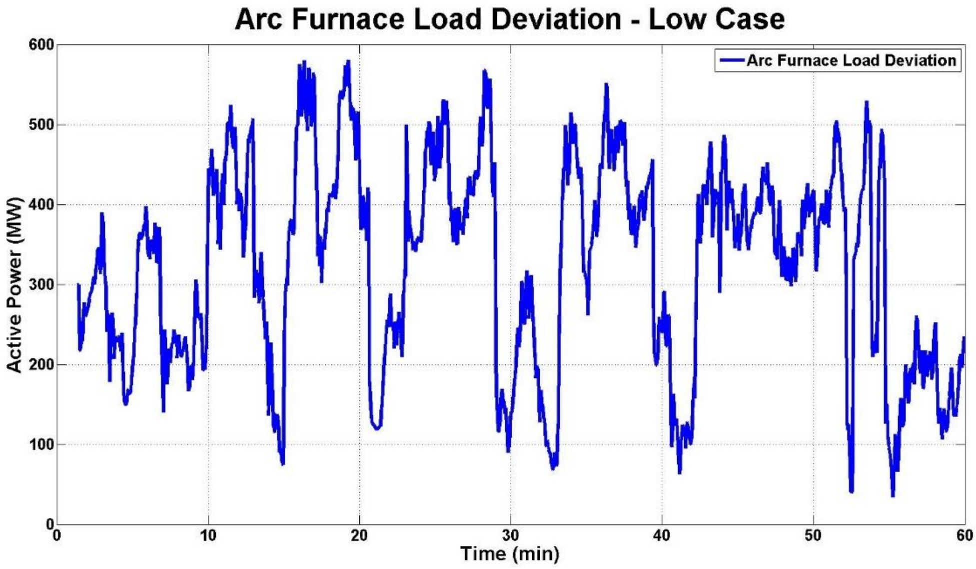

Figure 6.4. Arc furnace load deviation - low case

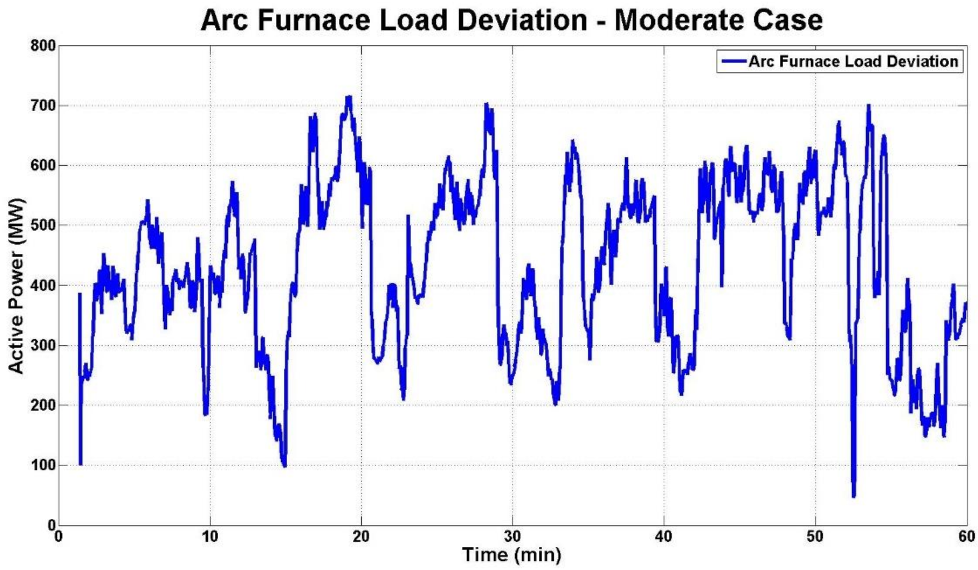

Figure 6.5. Arc furnace load deviation - moderate case

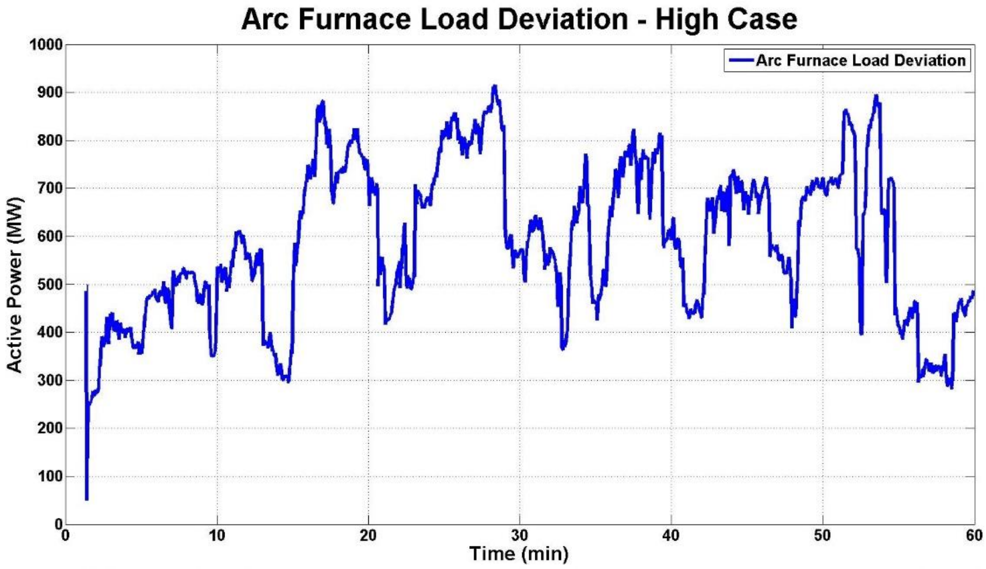

Figure 6.6. Arc furnace load deviation - high case

6.2.1. Simulation scenarios

First of all clouding is considered as a scenario. As mentioned in 5.2, there is ±750 MW change in solar power plant in Karapınar due to clouding. In the scenario of clouding, the active power level of Karapınar solar power plant decreases 750 MW in 7,5 minutes and then increases 750 MW in 7,5 minutes. Totally, 750 MW total active power change in 15 minutes duration. The clouding scenarios are examined for 3 different situations as low, moderate and high deviations of arc furnace.

On the other hand, active power changing because of sunrise and sinking are determined as scenarios. The biggest active power changes are +32,2 MW/min and -12,8 MW/min as shown in Table 5.1. When considering 15 minutes time interval, +483 MW /15 min and -192 MW/15 min changes are observed. These changes are considered with low, moderate and high deviations of arc furnace.

As a result, 9 different scenarios are constructed. Active power changing in solar power plant is considered with arc furnace. These scenarios are represented in Table 6.3.

Table 6.3. Scenarios for examining the effects of Karapınar solar power plant on secondary frequency control

Scenario	Scenario Description
Scenario 1	Clouding & Low Case Arc Furnace (± 750 MW /15 min)
Scenario 2	Clouding & Moderate Case Arc Furnace (± 750 MW /15 min)
Scenario 3	Clouding & High Case Arc Furnace (± 750 MW /15 min)
Scenario 4	Active Power Positively Change & Low Case Arc Furnace (+ 483 MW /15 min)
Scenario 5	Active Power Positively Change & Moderate Case Arc Furnace (+ 483 MW /15 min)
Scenario 6	Active Power Positively Change & High Case Arc Furnace (+ 483 MW /15 min)
Scenario 7	Active Power Negatively Change & Low Case Arc Furnace (- 192 MW /15 min)
Scenario 8	Active Power Negatively Change & Moderate Case Arc Furnace (- 192 MW /15 min)
Scenario 9	Active Power Negatively Change & High Case Arc Furnace (- 192 MW /15 min)

9 different scenarios are simulated and the results are evaluated. The evaluations generally take into account active power change in the ENTSO-E lines, frequency oscillation, changes in the generation levels of the power plants participating in the secondary reserve and changes in the ACE signal.

6.2.2. Results

In this part of the thesis, it is examined whether the active power imbalance in the system which is formed as a result of the 9 scenarios can be met by the seconder frequency control system. In this context, it is examined whether the ACE signal conforms to the performance criteria described in 3.2 and whether the maximum and minimum active power changes can be met by the secondary frequency reserve.

The minimum and maximum active power changes in the demand, which is the change in generation levels of 9 different scenarios because of arc furnaces and Karapınar solar plant, are shown in Table 6.4.

Table 6.4. Maximum and minimum active power changes in the scenarios

Scenario Name	Maximum Active Power Change in Total Load (MW)	Minimum Active Power Change in Total Load (MW)
Scenario 1	988	-162
Scenario 2	1060	-150
Scenario 3	1271	111
Scenario 4	868	-280
Scenario 5	1016	-364
Scenario 6	1251	-200
Scenario 7	415	-317
Scenario 8	528	-342
Scenario 9	738	-178

Scenario 1 results

In scenario 1, clouding over the 3 GW solar power plant and low case arc furnace changing is considered together. There is 750 MW active power changing within 15 minutes because of sudden cloud transition over the solar power plant area. The solar power plant active power generation during Scenario 1 is shown in Figure 6.7. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 1 is shown in Figure 6.8.

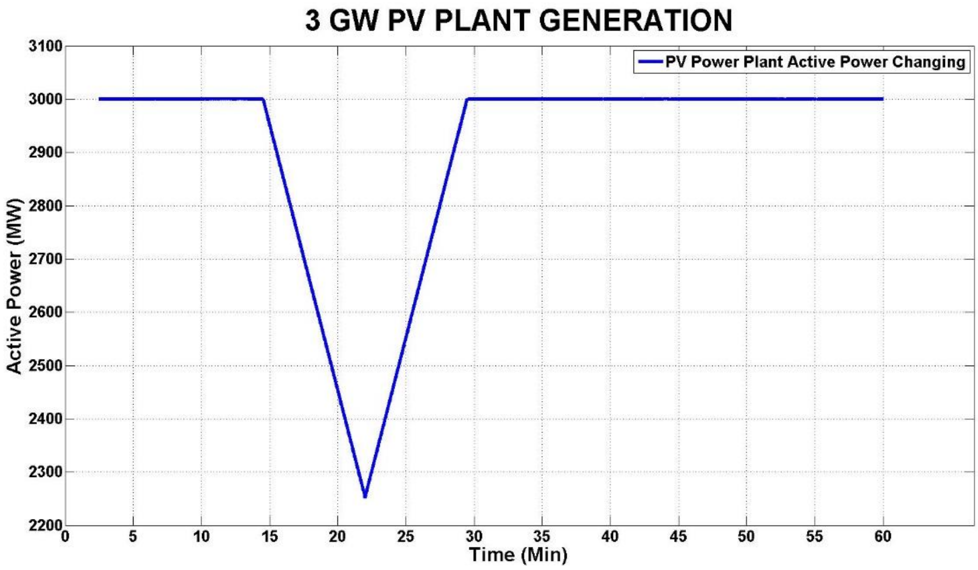

Figure 6.7. Solar power plant generation profile during Scenario 1

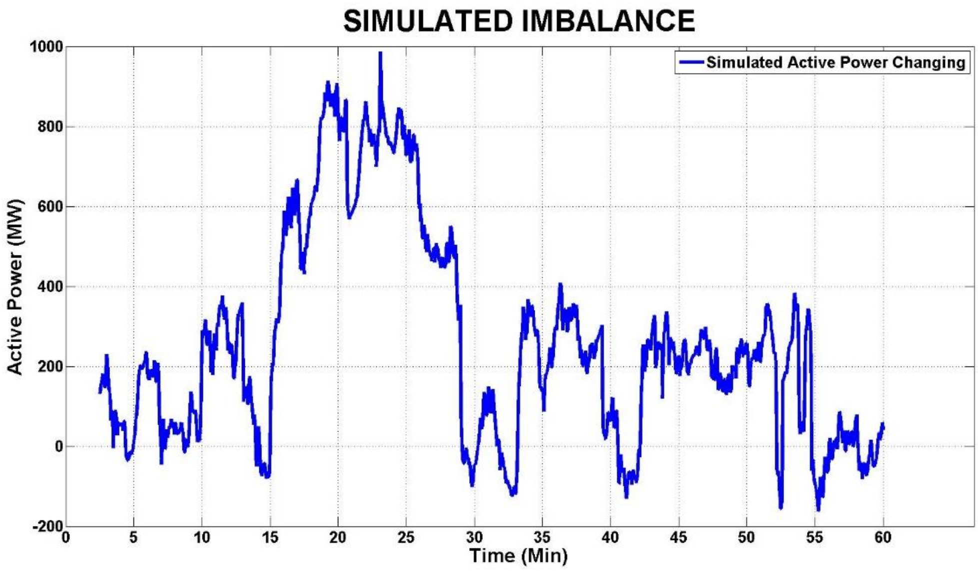

Figure 6.8. Scenario 1 simulated imbalance

After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.9 and the results summary of Scenario 1 is shown in Table 6.5.

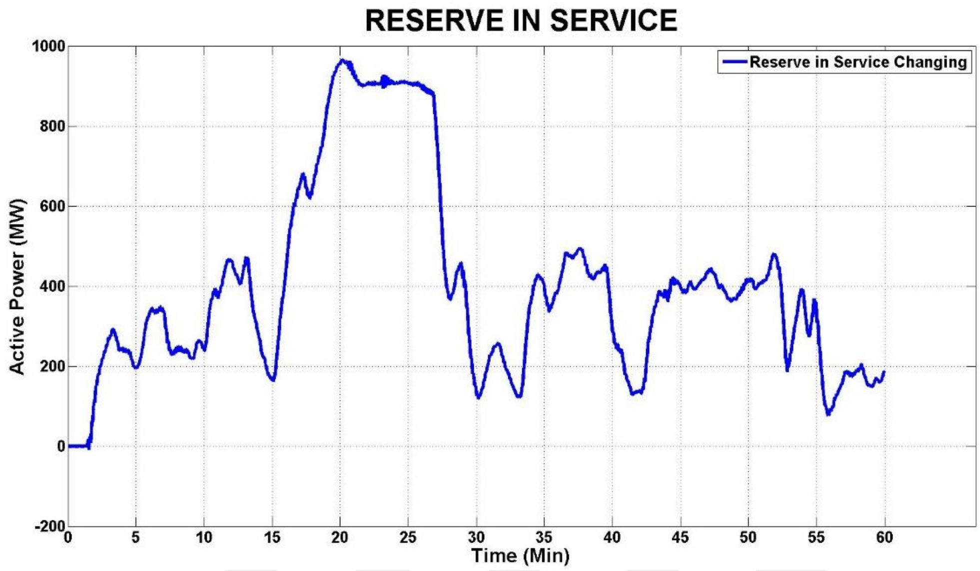

Figure 6.9. Secondary frequency reserve in service changing during Scenario 1

Table 6.5. Results summary of Scenario 1

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
988	13,6	30,7

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria exactly, although 990 MW reserve capacity meets the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

Scenario 2 results

In scenario 2, clouding over the 3 GW solar power plant and moderate case arc furnace changing is considered together. There is 750 MW active power changing within 15 minutes because of sudden cloud transition over the solar power plant area. The solar power plant active power generation during Scenario 2 is shown in Figure 6.10. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 2 is shown in Figure 6.11.

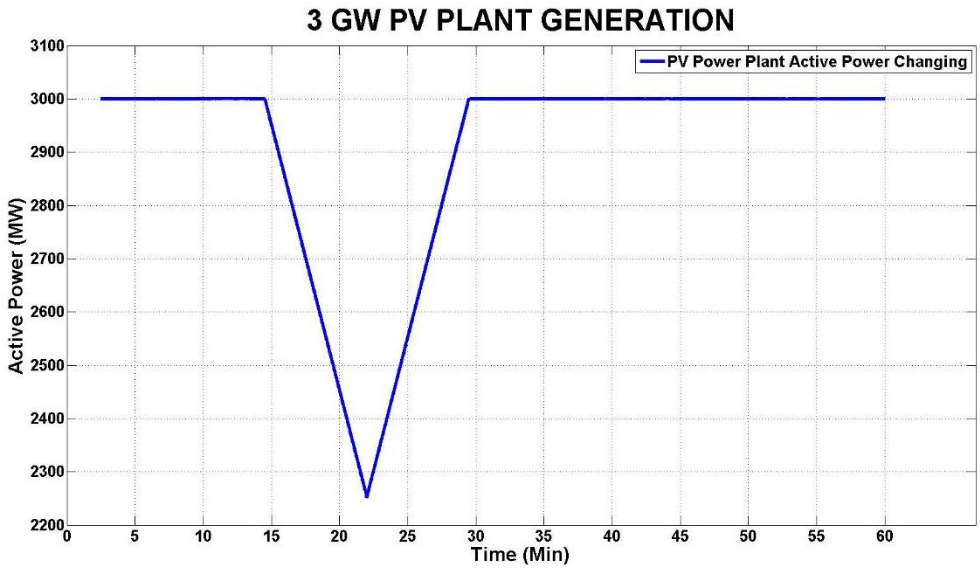

Figure 6.10. Solar power plant generation profile during Scenario 2

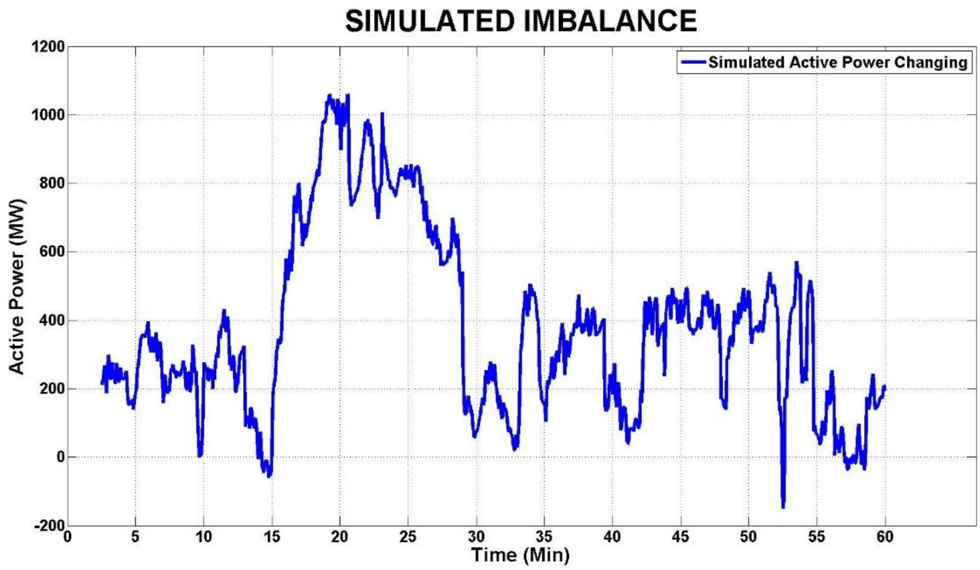

Figure 6.11. Scenario 2 simulated imbalance

After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.12 and the results summary of Scenario 2 is shown in Table 6.6.

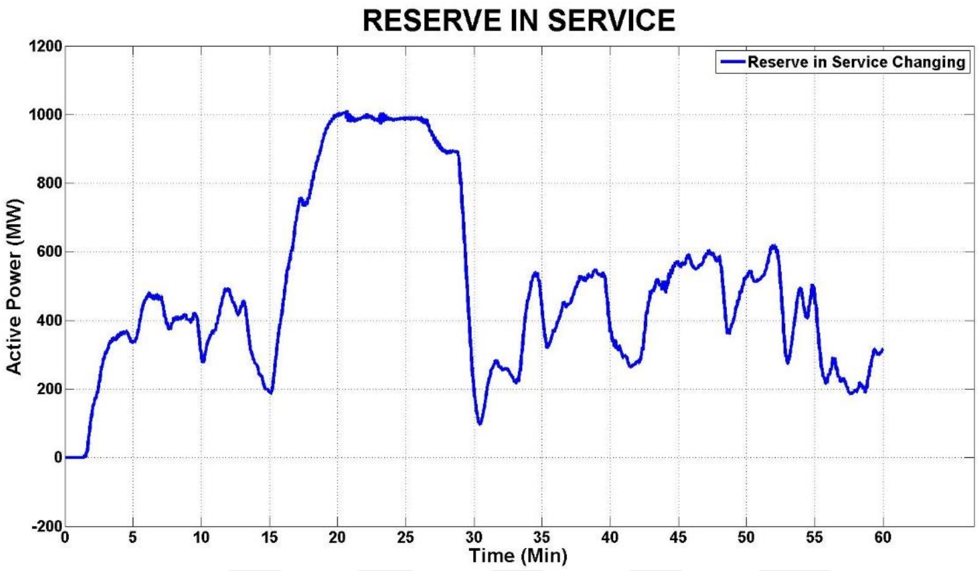

Figure 6.12. Secondary frequency reserve in service changing during Scenario 2

Table 6.6. Results summary of Scenario 2

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
1060	17,1	38,5

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria and 990 MW reserve capacity does not meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

<u>Scenario 3 results</u>

In scenario 3, clouding over the 3 GW solar power plant and high case arc furnace changing is considered together. There is 750 MW active power changing within 15 minutes because of sudden cloud transition over the solar power plant area. The solar power plant active power generation during Scenario 3 is shown in Figure 6.13. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 3 is shown in Figure 6.14.

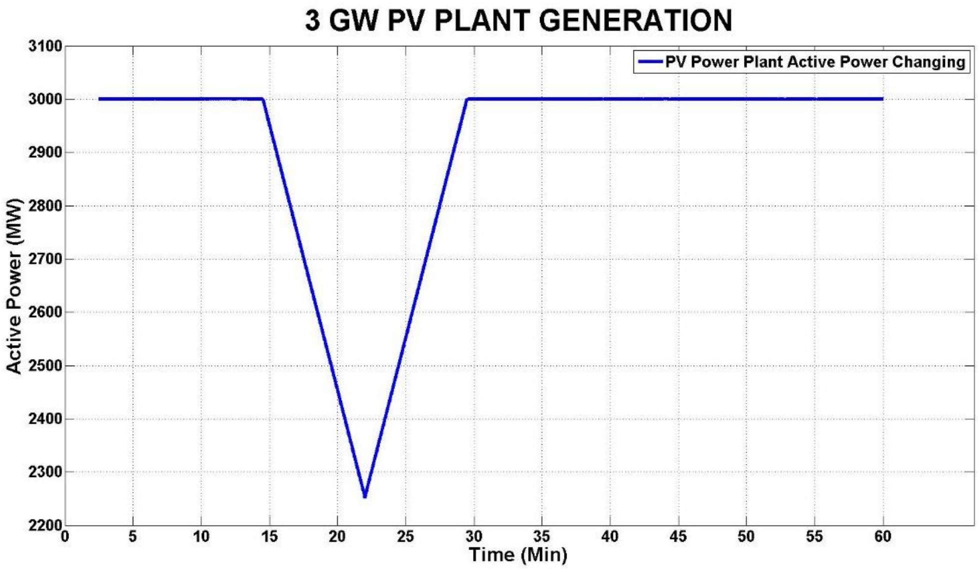

Figure 6.13. Solar power plant generation profile during Scenario 3

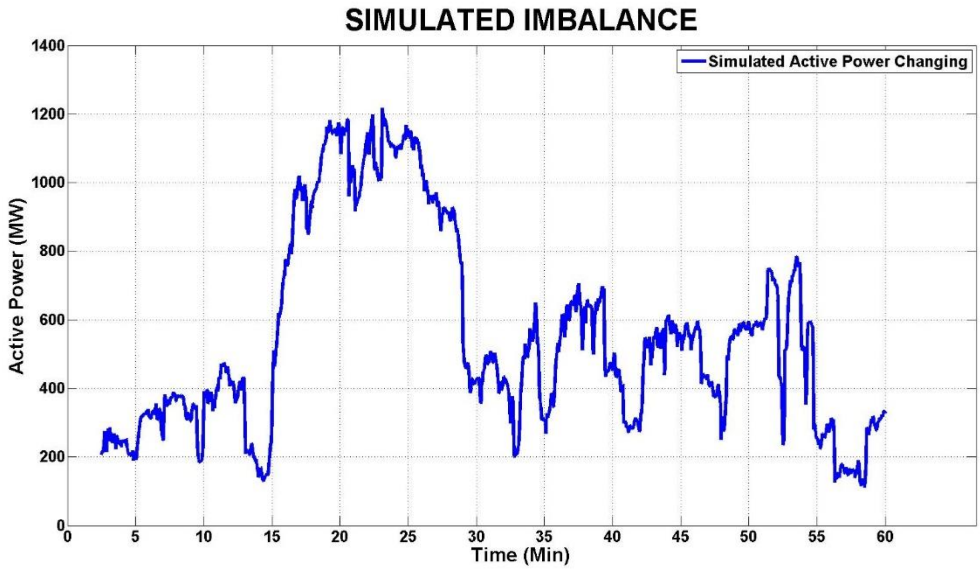

Figure 6.14. Scenario 3 simulated imbalance

After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.15 and the results summary of Scenario 3 is shown in Table 6.7.

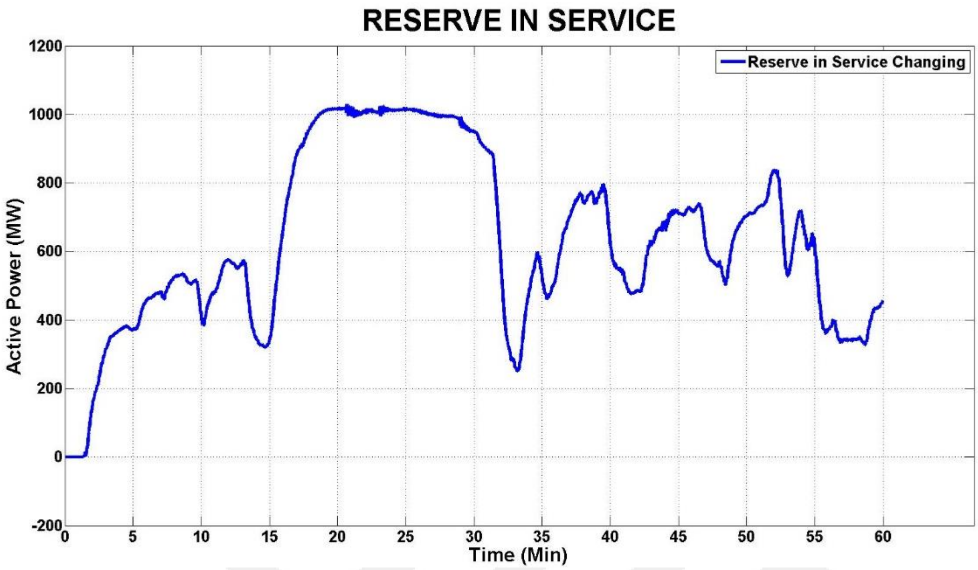

Figure 6.15. Secondary frequency reserve in service changing during Scenario 3

Table 6.7. Results summary of Scenario 3

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
1271	28,9	47,2

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria and 990 MW reserve capacity does not meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

Scenario 4 results

In scenario 4, active power changing because of sunset over the 3 GW solar power plant and low case arc furnace changing is considered together. There is 483 MW active power increasing within 15 minutes because of sunset in January evening in Karapınar region. The solar power plant active power generation during Scenario 4 is shown in Figure 6.16. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 4 is shown in Figure 6.17.

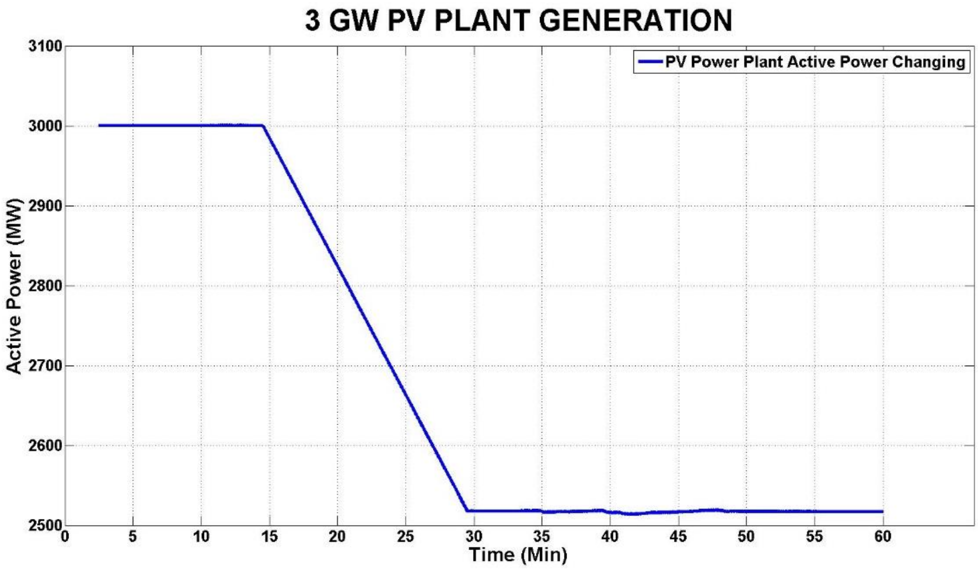

Figure 6.16. Solar power plant generation profile during Scenario 4

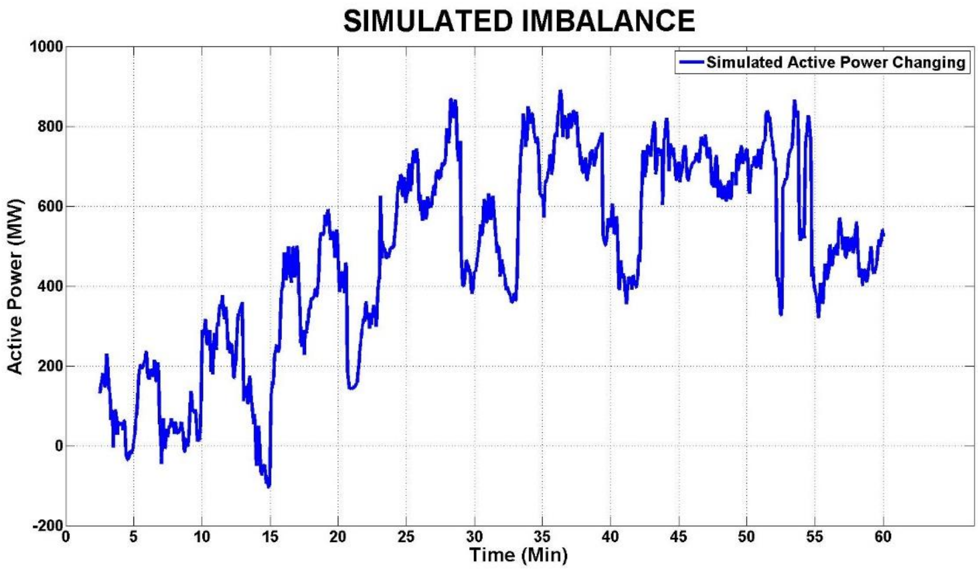

Figure 6.17. Scenario 4 simulated imbalance

From the 35th minute, 600 MW tertiary frequency control is activated within 15 minutes. After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.18 and the results summary of Scenario 4 is shown in Table 6.8.

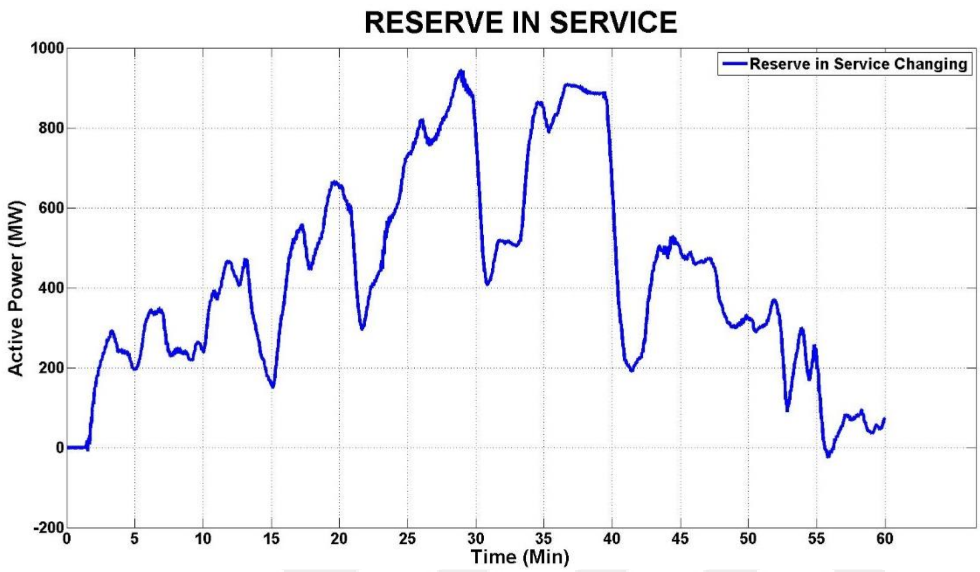

Figure 6.18. Secondary frequency reserve in service changing during Scenario 4

Table 6.8. Results summary of Scenario 4

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
868	16,1	38,4

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria while 990 MW reserve capacity can meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

Scenario 5 results

In scenario 5, active power changing because of sunset over the 3 GW solar power plant and moderate case arc furnace changing is considered together. There is 483 MW active power increasing within 15 minutes because of sunset in January evening in Karapınar region. The solar power plant active power generation during Scenario 5 is shown in Figure 6.19. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 5 is shown in Figure 6.20.

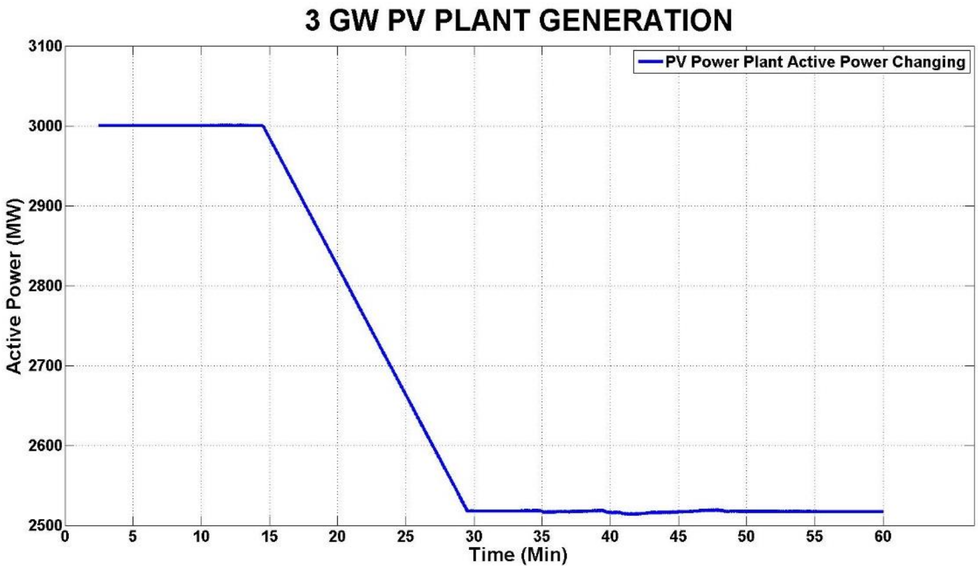

Figure 6.19. Solar power plant generation profile during Scenario 5

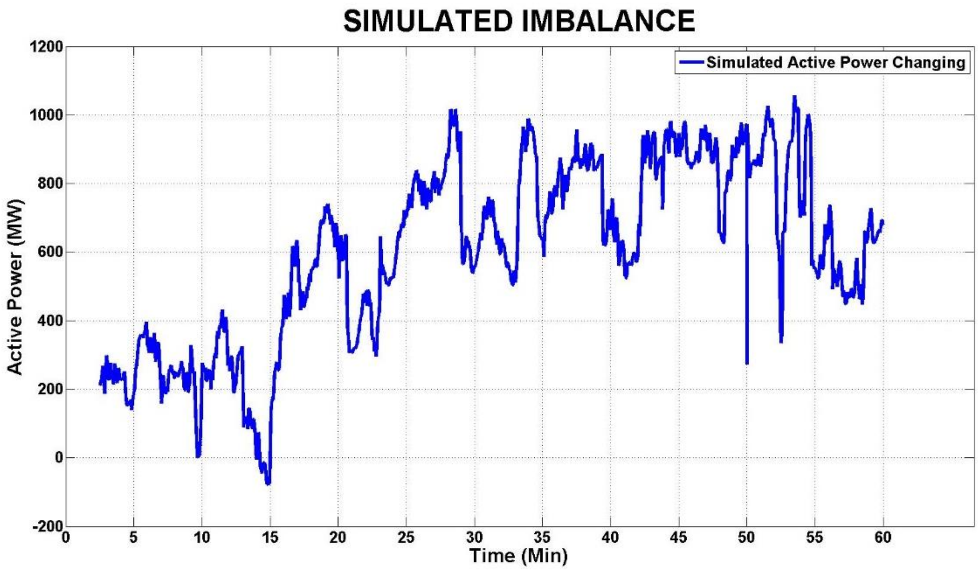

Figure 6.20. Scenario 5 simulated imbalance

From the 35th minute, 700 MW tertiary frequency control is activated within 15 minutes. After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.21 and the results summary of Scenario 5 is shown in Table 6.9.

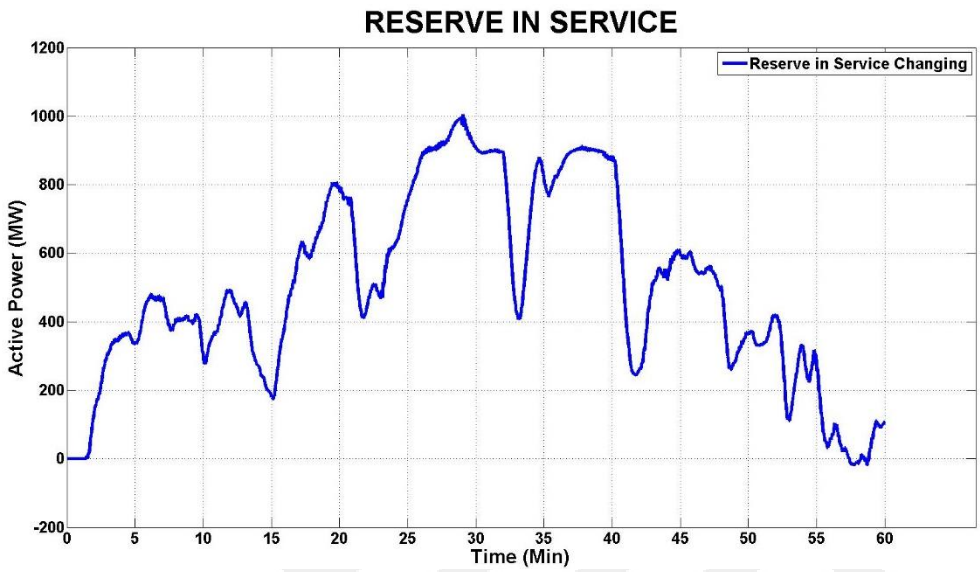

Figure 6.21. Secondary frequency reserve in service changing during Scenario 5

Table 6.9. Results summary of Scenario 5

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
1016	19	39,8

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria and 990 MW reserve capacity does not meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

Scenario 6 results

In scenario 6, active power changing because of sunset over the 3 GW solar power plant and high case arc furnace changing is considered together. There is 483 MW active power increasing within 15 minutes because of sunset in January evening in Karapınar region. The solar power plant active power generation during Scenario 6 is shown in Figure 6.22. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 6 is shown in Figure 6.23.

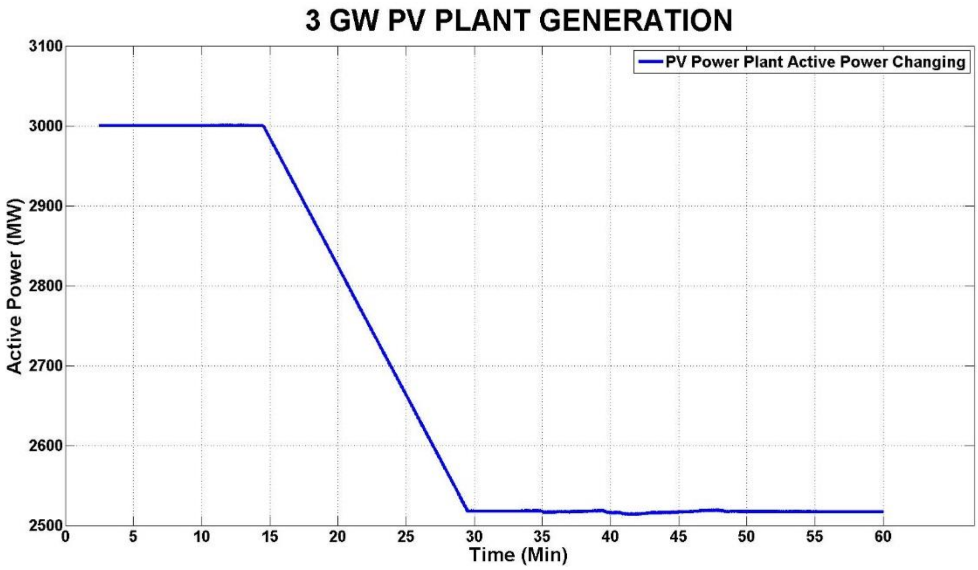

Figure 6.22. Solar power plant generation profile during Scenario 6

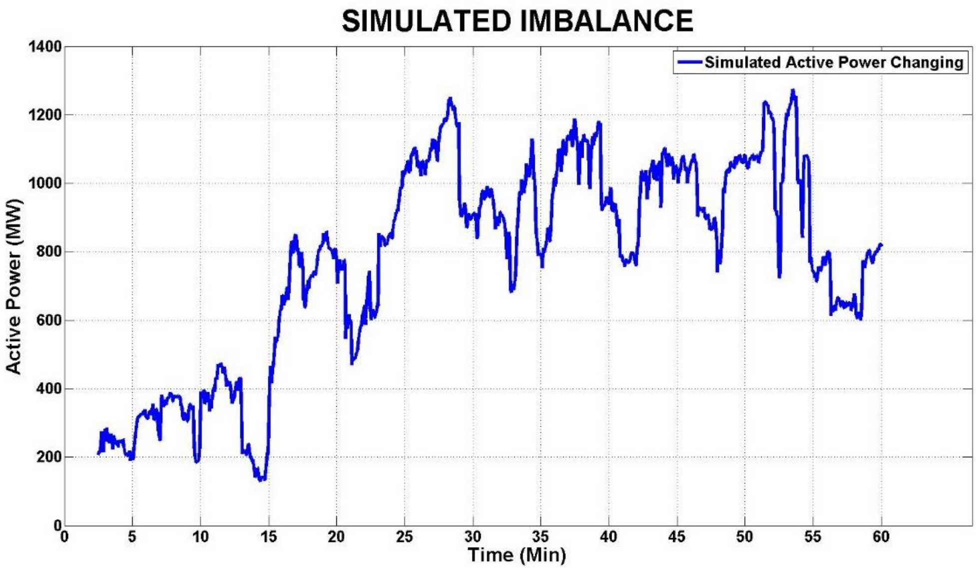

Figure 6.23. Scenario 6 simulated imbalance

From the 35th minute, 800 MW tertiary frequency control is activated within 15 minutes. After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.24 and the results summary of Scenario 6 is shown in Table 6.10.

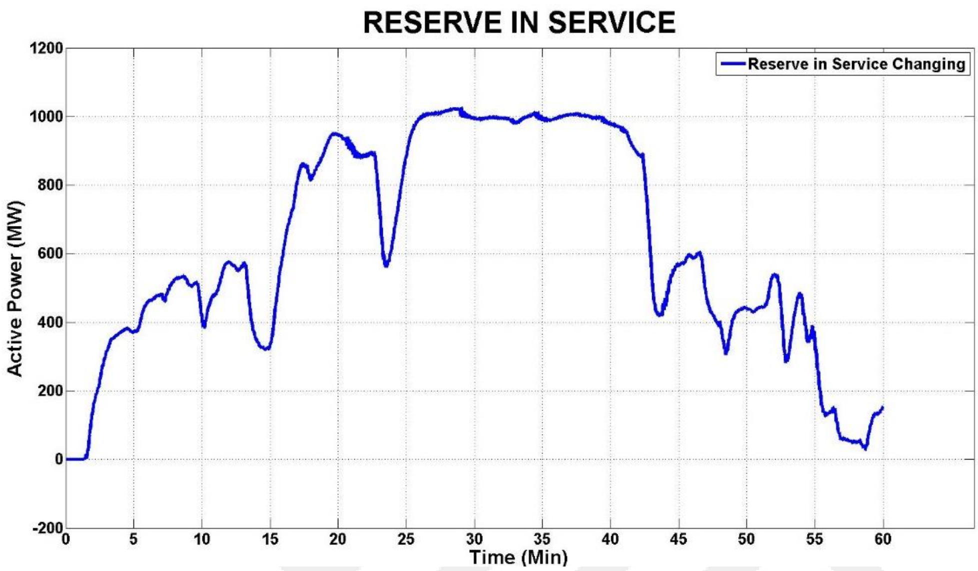

Figure 6.24. Secondary frequency reserve in service changing during Scenario 6

Table 6.10. Results summary of Scenario 6

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>175 MW
1251	26,6	46,9

After 1 hour simulation it is seen that secondary frequency control mechanism does not meet the ACE performance criteria and 990 MW reserve capacity does not meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be insufficient for this scenario.

Scenario 7 results

In scenario 7, active power changing because of sunrise over the 3 GW solar power plant and low case arc furnace changing is considered together. There is 192 MW active power decreasing within 15 minutes because of sunrise in September morning in Karapınar region. The solar power plant active power generation during Scenario 7 is shown in Figure 6.25. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 7 is shown in Figure 6.26.

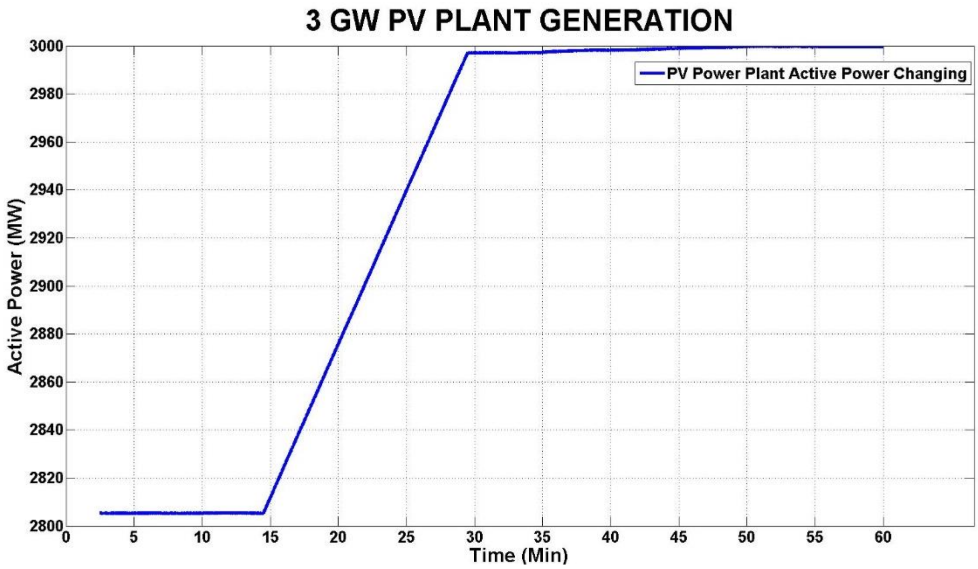

Figure 6.25. Solar power plant generation profile during Scenario 7

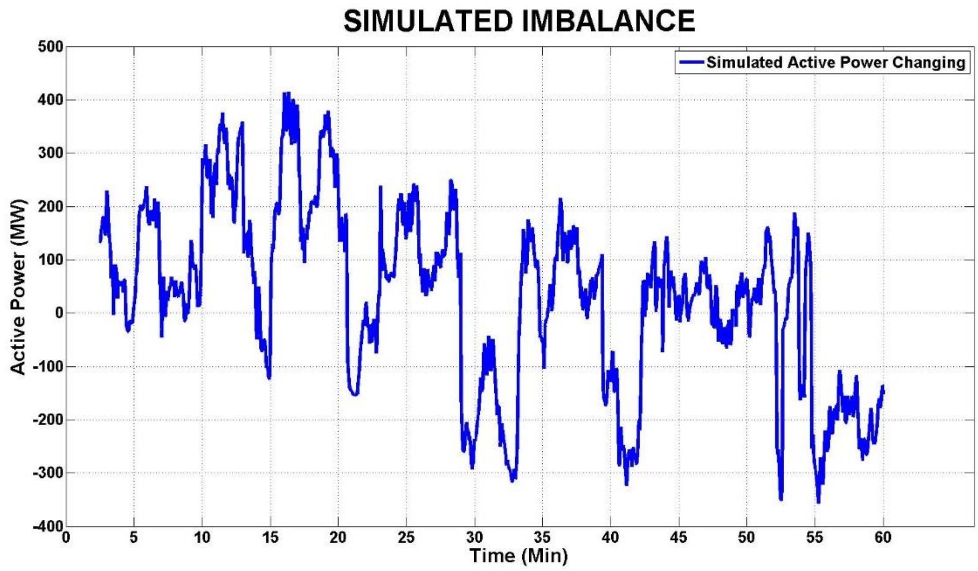

Figure 6.26. Scenario 7 simulated imbalance

From the 35th minute, 100 MW tertiary frequency control is activated within 15 minutes. After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.27 and the results summary of Scenario 7 is shown in Table 6.11.

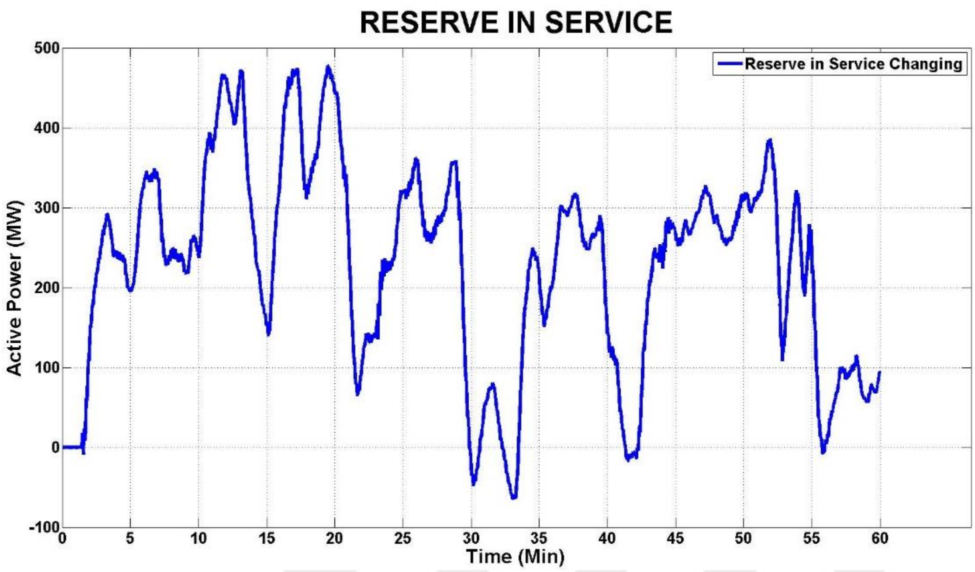

Figure 6.27. Secondary frequency reserve in service changing during Scenario 7

Table 6.11. Results summary of Scenario 7

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>175 MW
477	8,3	25,2

After 1 hour simulation it is seen that secondary frequency control mechanism can meet the ACE performance criteria and 990 MW reserve capacity can meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be sufficient for this scenario.

Scenario 8 results

In scenario 8, active power changing because of sunrise over the 3 GW solar power plant and moderate case arc furnace changing is considered together. There is 192 MW active power decreasing within 15 minutes because of sunrise in September morning in Karapınar region. The solar power plant active power generation during Scenario 8 is shown in Figure 6.28. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 8 is shown in Figure 6.29.

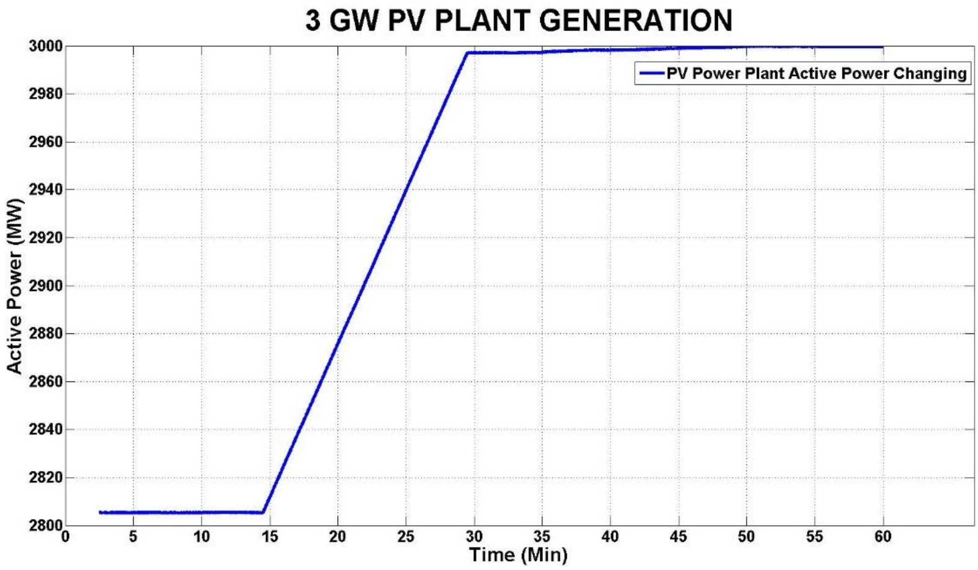

Figure 6.28. Solar power plant generation profile during Scenario 8

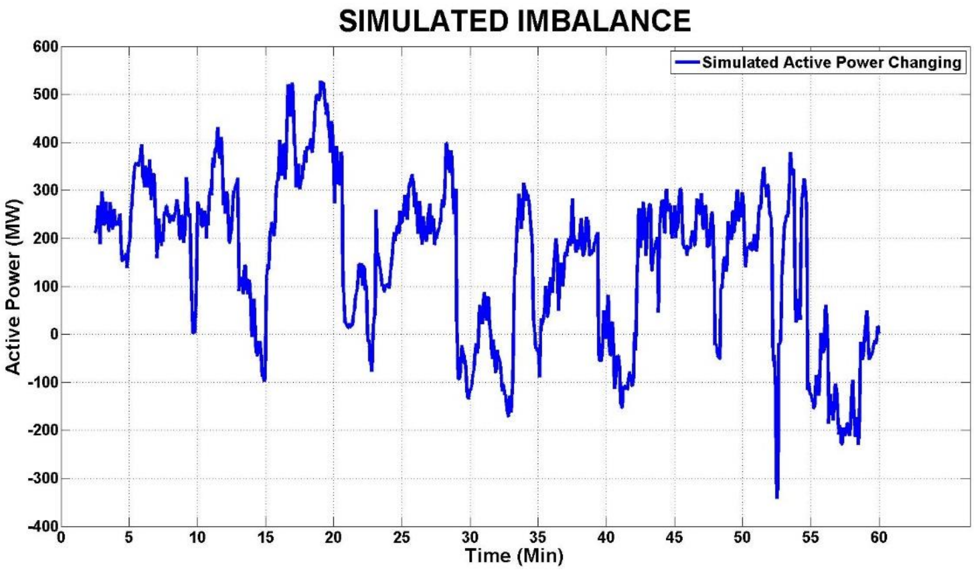

Figure 6.29. Scenario 8 simulated imbalance

After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.30 and the results summary of Scenario 8 is shown in Table 6.12.

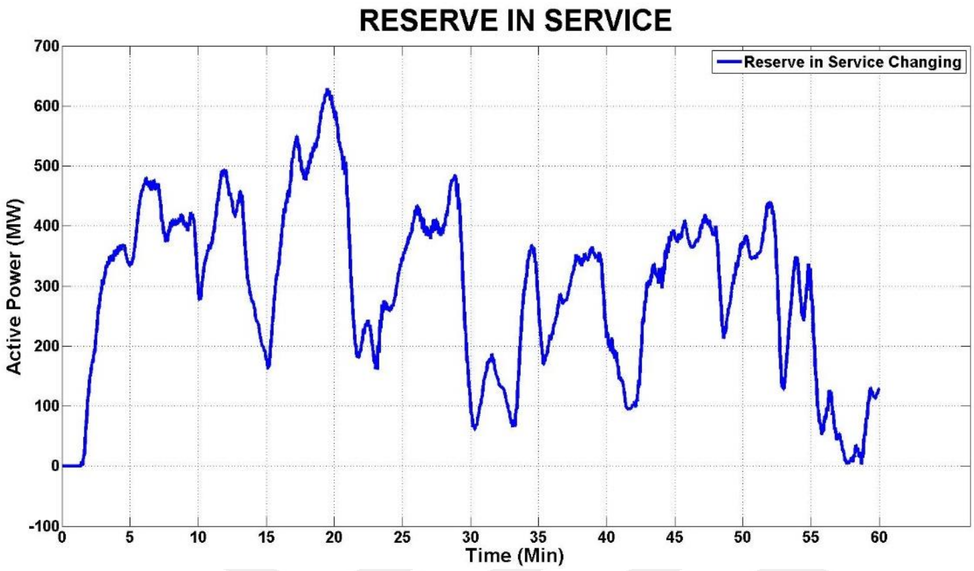

Figure 6.30. Secondary frequency reserve in service changing during Scenario 8

Table 6.12. Results summary of Scenario 8

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>175 MW
628	10,2	28,5

After 1 hour simulation it is seen that secondary frequency control mechanism can meet the ACE performance criteria and 990 MW reserve capacity can meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be sufficient for this scenario.

Scenario 9 results

In scenario 9, active power changing because of sunrise over the 3 GW solar power plant and high case arc furnace changing is considered together. There is 192 MW active power decreasing within 15 minutes because of sunrise in September morning in Karapınar region. The solar power plant active power generation during Scenario 9 is shown in Figure 6.31. In this respect, the active power imbalances because of solar power plant generation and arc furnaces loads changing during Scenario 9 is shown in Figure 6.32.

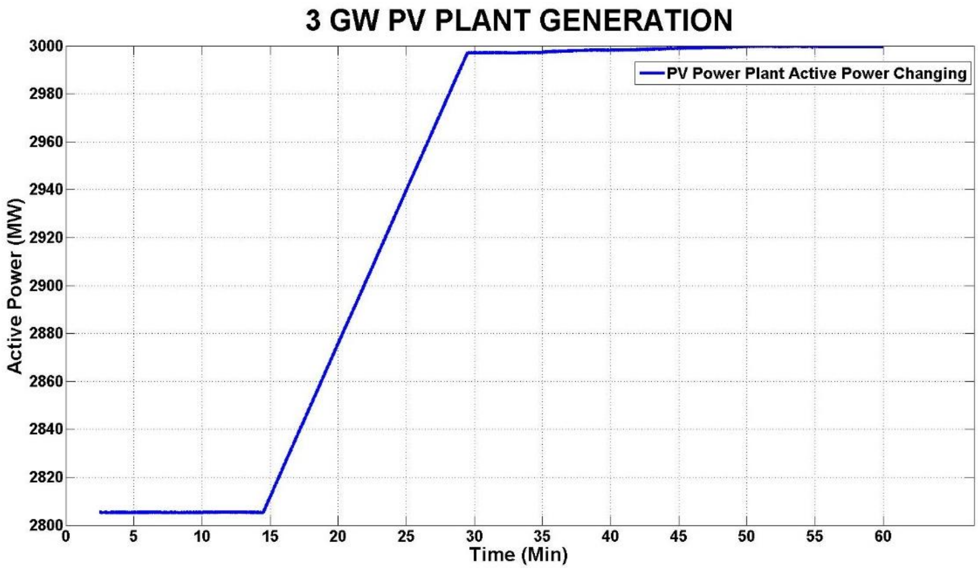

Figure 6.31. Solar power plant generation profile during Scenario 9

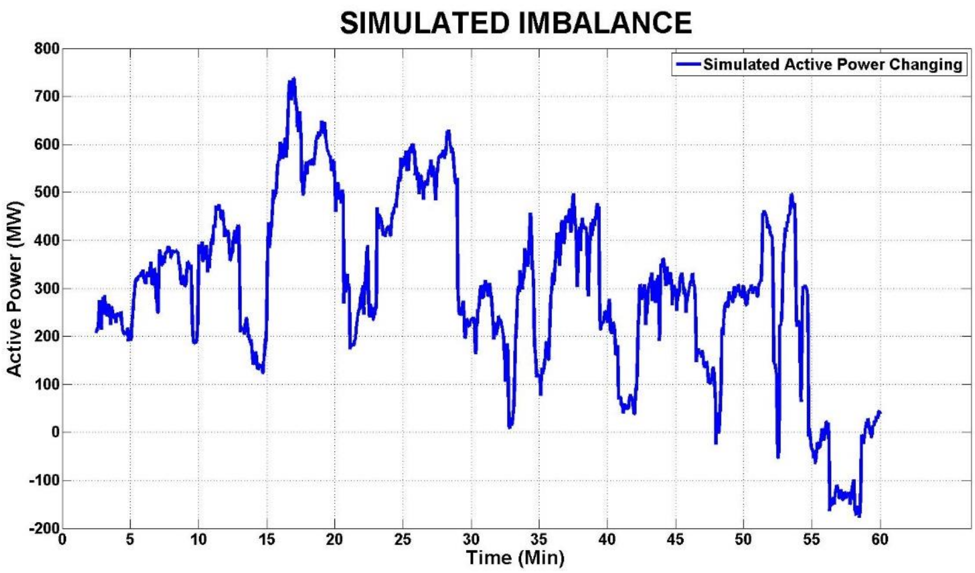

Figure 6.32. Scenario 9 simulated imbalance

From the 35th minute, 100 MW tertiary frequency control is activated within 15 minutes. After 1 hour simulation, secondary frequency reserve in service changing is shown in Figure 6.33 and the results summary of Scenario 9 is shown in Table 6.13.

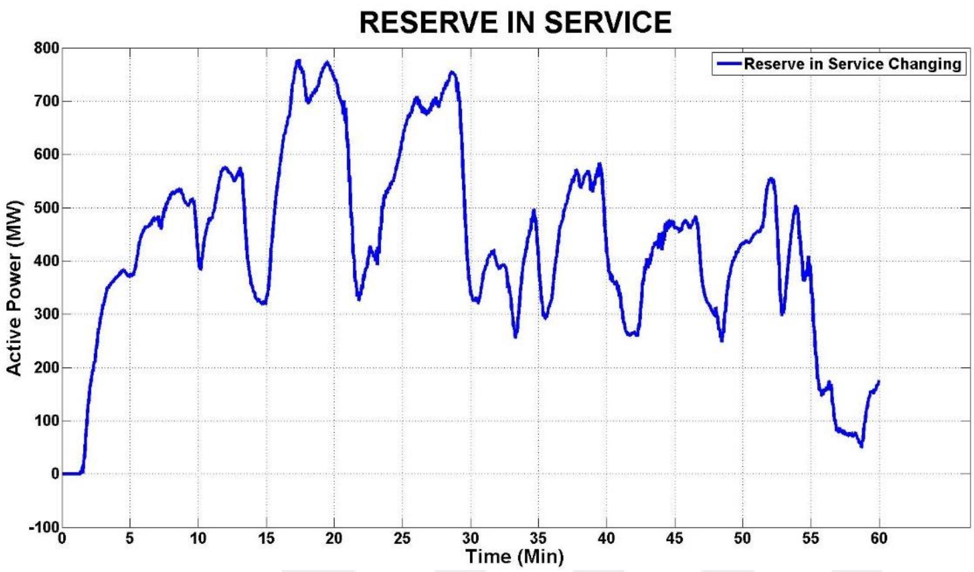

Figure 6.33. Secondary frequency reserve in service changing during Scenario 9

Table 6.13. Results summary of Scenario 9

Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>175 MW
738	8,8	29,3

After 1 hour simulation it is seen that secondary frequency control mechanism can meet the ACE performance criteria and 990 MW reserve capacity can meet the maximum reserve requirement needed.

As a result, the existing secondary frequency control performance is found to be sufficient for this scenario.

6.3. General Evaluation of Scenarios

The scenarios are examined which have 990 MW secondary frequency reserve capacity provided by 20 power plants within the scope of existing network system conditions. In this direction, 9 different scenarios are constructed according to the possible situations that the current system may encounter.

In this context, active power changes due to changes in solar radiation values during the day, as well as sudden changes in active power generation level during clouding, are examined.

At the end of the simulations it is determined whether the maximum secondary reserve requirement during the simulation have met and whether the ACE signal met the ENTSO-E criteria (described in 3.2). Then the current secondary frequency performance is evaluated.

In this context, the summary table of the simulation results is shown in Table 6.14. In the direction of the results, the current secondary frequency performance is sufficient for only 3 of 9 different scenarios.

Table 6.14. Summary table of simulation results

Scenario	Maximum Reserve Requirement	% of abs(ACE)>175 MW	% of abs(ACE)>100 MW
Scenario 1	✓	✗	✓
Scenario 2	✗	✗	✗
Scenario 3	✗	✗	✗
Scenario 4	✓	✗	✗
Scenario 5	✗	✗	✗
Scenario 6	✗	✗	✗
Scenario 7	✓	✓	✓
Scenario 8	✓	✓	✓
Scenario 9	✓	✓	✓

7. CONCLUSION

In this thesis study, the potential of solar power plant in Turkey is determined and the effects of the solar power plant planned to be established in the coming years on the secondary frequency control performance is investigated.

Firstly, in accordance with the information obtained from SEPA, suitable areas for the installation of solar energy power plant in Turkey are determined and solar radiation values of these areas are obtained. Then, an economic analysis is carried out according to the radiation values and the solar energy potential of Turkey is obtained.

In the next section, the frequency control mechanism in Turkey is explained. In this context, primary, secondary, tertiary and time frequency control issues are detailed. It is thought that the solar power plant planned to be established in Karapınar in the following years would have an effect especially on the secondary frequency control performance. Therefore, the ACE performance evaluation, which is the ENTSO-E evaluation criterion under the secondary frequency control, is described.

In Chapter 4, the properties of the solar power plant to be installed in Karapınar are mentioned. Within this scope, the installed power of the power plant, the area to be installed and the radiation values of this area are examined. The annual generation profile is investigated with the radiation values obtained.

In Chapter 5, the effects of active power changes caused by the solar power plant on the secondary frequency control are investigated. In this context, active power changes are examined in two main categories. The first one is how the solar power plant generation profile affects the daily generation curves for each month. The other effect of the solar power plant to the secondary frequency control is the active power changes due to clouding on the power plant area. In this direction, it is determined that there are +483 MW / 15 min and -192 MW / 15 min changes in the active power change due to the radiation values, and +/-750 MW / 15 min changes due to clouding.

In the next chapter, 9 different scenarios are constructed in order to evaluate the effects of these changes on the secondary frequency control performance. Active power changes identified in Chapter 5 are considered together with the electric arc furnace that are already a problem for the Turkish power system. Each change is combined with the low, medium and high variations of the arc furnace loads and 9 scenarios are constructed and their results are determined.

As a result of the evaluations, 3 successful results are obtained with 990 MW secondary frequency control reserve of 9 analysis scenarios. In this context, it is considered that the integration of the solar power plant to the electrical system at a single point at 3 GW levels is risky for the secondary frequency control system.

Within this scope, two different suggestions are presented. The first one is that reduction of the installed capacity of the planned solar power plant, and the second one is to increase the current secondary frequency control reserve amount.

In order to use the solar power potential in Turkey more efficiently, necessary precautions must be taken in advance. If necessary measures are taken, Turkey will improve further with this solar potential.

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APPENDICES

APPENDIX-1. Karapınar specialized industrial area map information (first area)

KARAPINAR ENERJİ İHTİSAS ENDÜSTRİ BÖLGESİ (I. KISIM)

Nokta No	X	Y	Nokta No	X	Y	Nokta No	X	Y
EB_1	555025,72	4187475,44	EB_58	548782,75	4176686,21	EB_115	552849,35	4187506,00
EB_2	555408,14	4187065,71	EB_59	548797,56	4176746,23	EB_116	552968,58	4187684,82
EB_3	554752,57	4186191,62	EB_60	548807,15	4176794,76	EB_117	552993,87	4187724,22
EB_4	554151,63	4185563,36	EB_61	548821,69	4176860,42	EB_118	553024,76	4187767,48
EB_5	553578,01	4184798,53	EB_62	548862,50	4177044,77	EB_119	553068,15	4187846,02
EB_6	552964,82	4183986,47	EB_63	548946,71	4177431,90	EB_120	553140,84	4187943,99
EB_7	552959,95	4183980,03	EB_64	549034,38	4177835,94	EB_121	553320,54	4188149,83
EB_8	552567,34	4183460,08	EB_65	549133,41	4178292,09	EB_122	553327,80	4188156,36
EB_9	551747,87	4181903,10	EB_66	549162,11	4178407,47	EB_123	553543,06	4188391,27
EB_10	551737,56	4181822,71	EB_67	549196,42	4178566,06	EB_124	553637,22	4188487,16
EB_11	551736,65	4181815,58	EB_68	549271,73	4178898,43	EB_125	553694,44	4188549,07
EB_12	551474,72	4179772,50	EB_69	549354,03	4179261,82	EB_126	553729,04	4188577,86
EB_13	551884,45	4178761,82	EB_70	549435,19	4179620,85	EB_127	553751,65	4188600,72
EB_14	552048,34	4177996,99	EB_71	549489,99	4179866,34	EB_128	553823,94	4188641,26
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EB_17	551889,49	4176887,67	EB_74	549588,42	4180308,43	EB_131	554032,03	4188748,76
EB_18	551874,41	4176878,18	EB_75	549643,80	4180562,56	EB_132	554200,09	4188828,71
EB_19	551794,79	4176855,69	EB_76	549675,31	4180700,84	EB_133	554428,57	4188918,06
EB_20	551673,75	4176822,94	EB_77	549692,66	4180782,40	EB_134	554555,36	4188971,19
EB_21	551642,58	4176815,55	EB_78	549737,85	4180981,69	EB_135	554579,21	4188978,36
EB_22	551579,72	4176798,65	EB_79	549752,80	4181053,64	EB_136	554669,91	4189006,29
EB_23	551515,56	4176780,83	EB_80	549757,68	4181074,42	EB_137	554767,78	4189030,38
EB_24	551465,74	4176766,96	EB_81	549773,85	4181130,94	EB_138	554821,41	4189041,38
EB_25	551413,09	4176753,35	EB_82	549842,63	4181438,26	EB_139	554992,86	4189113,78
EB_26	551296,76	4176722,54	EB_83	549910,88	4181742,96	EB_140	555002,53	4189121,48
EB_27	551253,10	4176711,49	EB_84	550002,40	4182151,37	EB_141	555009,92	4189125,62
EB_28	551200,45	4176697,37	EB_85	550009,52	4182156,15	EB_142	554988,87	4189086,79
EB_29	551166,04	4176688,67	EB_86	550017,50	4182195,79	EB_143	554966,32	4189048,50
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EB_32	551100,55	4176670,88	EB_89	550119,31	4182368,38	EB_146	554855,22	4188895,57
EB_33	551079,46	4176665,01	EB_90	550278,92	4182644,31	EB_147	554800,01	4188824,91
EB_34	551057,44	4176659,32	EB_91	550447,87	4182935,25	EB_148	554704,22	4188688,82
EB_35	551008,65	4176645,57	EB_92	550597,93	4183194,89	EB_149	554624,03	4188581,71
EB_36	550946,56	4176628,59	EB_93	550623,53	4183240,86	EB_150	554605,95	4188561,98
EB_37	550911,36	4176619,42	EB_94	550976,31	4183851,95	EB_151	554582,07	4188525,40
EB_38	550870,61	4176608,65	EB_95	551078,31	4184040,60	EB_152	554547,29	4188485,37
EB_39	550772,10	4176582,14	EB_96	551096,61	4184073,76	EB_153	554526,73	4188456,11
EB_40	550740,26	4176572,78	EB_97	551270,34	4184411,18	EB_154	554481,04	4188392,62
EB_41	550591,09	4176541,04	EB_98	551444,81	4184749,40	EB_155	554383,74	4188267,44
EB_42	550563,93	4176540,28	EB_99	551449,71	4184755,97	EB_156	554362,02	4188238,58
EB_43	550469,10	4176508,31	EB_100	551574,39	4185006,27	EB_157	554284,30	4188130,96
EB_44	550123,90	4176414,52	EB_101	551712,53	4185283,34	EB_158	554225,68	4188053,67
EB_45	549696,06	4176298,20	EB_102	551847,58	4185554,13	EB_159	554177,85	4187986,33
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EB_48	549008,09	4176206,98	EB_105	552281,05	4186432,05			
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EB_52	548661,63	4176086,88	EB_109	552371,07	4186635,47			
EB_53	548652,45	4176097,14	EB_110	552405,10	4186742,04			
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EB_55	548712,78	4176371,17	EB_112	552488,27	4187336,74			
EB_56	548720,14	4176400,14	EB_113	552801,04	4187432,79			
EB_57	548757,46	4176571,21	EB_114	552833,46	4187472,56			

Harita Bilgileri
Projeksiyon: UTM (6 Derece)
Datum: EUROPEAN 1950
Ölçek:1/50.000

APPENDIX-2. Karapınar specialized industrial area map information (second area)

KARAPINAR ENERJİ İHTİSAS ENDÜSTRİ BÖLGESİ (II. KISIM)

Nokta No	X	Y	Nokta No	X	Y	Nokta No	X	Y
EB_1	543475,64	4197510,64	EB_58	546370,90	4197792,78	EB_115	548124,06	4198932,39
EB_2	543829,54	4197751,37	EB_59	546363,14	4198093,33	EB_116	548146,22	4198917,21
EB_3	543851,95	4197352,35	EB_60	546354,48	4198209,04	EB_117	548221,09	4198875,68
EB_4	543867,31	4197305,21	EB_61	546358,96	4198365,21	EB_118	548265,94	4198854,91
EB_5	543874,82	4197237,51	EB_62	546367,32	4198423,44	EB_119	548315,50	4198828,03
EB_6	543888,66	4197146,01	EB_63	546380,60	4198481,52	EB_120	548335,39	4198820,01
EB_7	543893,28	4197085,06	EB_64	546387,62	4198506,30	EB_121	548378,15	4198797,77
EB_8	543921,32	4196958,52	EB_65	546397,92	4198574,72	EB_122	548464,11	4198746,80
EB_9	543941,47	4196862,91	EB_66	546418,23	4198670,39	EB_123	548499,15	4198721,55
EB_10	544007,18	4196853,11	EB_67	546424,50	4198716,52	EB_124	548505,36	4198720,91
EB_11	544008,85	4196809,47	EB_68	546427,79	4198764,00	EB_125	548747,44	4198557,02
EB_12	544015,17	4196733,84	EB_69	546438,68	4198823,57	EB_126	548847,27	4198495,54
EB_13	544017,24	4196716,17	EB_70	546442,57	4198926,89	EB_127	548915,21	4198441,36
EB_14	544018,84	4196706,31	EB_71	546450,63	4198958,84	EB_128	549022,29	4198346,86
EB_15	544021,83	4196699,20	EB_72	546503,49	4199052,91	EB_129	549058,71	4198318,80
EB_16	544070,92	4196676,26	EB_73	546533,60	4199111,12	EB_130	549117,84	4198280,24
EB_17	544077,34	4196670,07	EB_74	546620,43	4199264,06	EB_131	549177,18	4198234,82
EB_18	544104,09	4196588,06	EB_75	546649,51	4199325,34	EB_132	549249,16	4198190,48
EB_19	544108,52	4196568,97	EB_76	546658,29	4199349,33	EB_133	549283,65	4198166,27
EB_20	544117,15	4196544,92	EB_77	546666,28	4199363,84	EB_134	549507,95	4197985,46
EB_21	544127,08	4196526,10	EB_78	546672,31	4199384,86	EB_135	549525,73	4197969,61
EB_22	544130,74	4196518,52	EB_79	546699,59	4199442,45	EB_136	549584,85	4197911,13
EB_23	544132,05	4196506,50	EB_80	546712,18	4199475,41	EB_137	549627,70	4197861,64
EB_24	544631,81	4196472,82	EB_81	546772,45	4199626,74	EB_138	549669,90	4197796,08
EB_25	544646,07	4196483,25	EB_82	546779,58	4199643,26	EB_139	549814,72	4197629,20
EB_26	544684,03	4196484,22	EB_83	546796,82	4199623,37	EB_140	549832,93	4197610,99
EB_27	544819,65	4196448,69	EB_84	546813,85	4199584,42	EB_141	549860,78	4197593,64
EB_28	544857,34	4196436,87	EB_85	546864,22	4199503,35	EB_142	549988,24	4197534,30
EB_29	544933,75	4196402,84	EB_86	546872,17	4199493,56	EB_143	549999,81	4197525,94
EB_30	545038,67	4196361,62	EB_87	546880,43	4199485,81	EB_144	550047,16	4197494,67
EB_31	545048,77	4196362,61	EB_88	546897,91	4199473,55	EB_145	550054,44	4197488,02
EB_32	545109,45	4196402,20	EB_89	546927,44	4199461,95	EB_146	550079,08	4197446,46
EB_33	545123,57	4196407,56	EB_90	546991,99	4199464,81	EB_147	550116,78	4197402,76
EB_34	545263,71	4196385,29	EB_91	547011,77	4199464,40	EB_148	550136,96	4197389,34
EB_35	545330,64	4196377,54	EB_92	547034,10	4199462,97	EB_149	550244,62	4197340,47
EB_36	545343,86	4196374,80	EB_93	547046,03	4199461,54	EB_150	550342,15	4197286,86
EB_37	545367,78	4196366,76	EB_94	547107,11	4199444,11	EB_151	550403,85	4197229,67
EB_38	545406,47	4196367,47	EB_95	547143,72	4199442,68	EB_152	550413,49	4197222,60
EB_39	545442,46	4196361,95	EB_96	547178,08	4199448,08	EB_153	550421,63	4197218,95
EB_40	545528,79	4196341,43	EB_97	547187,57	4199450,94	EB_154	550451,88	4197213,59
EB_41	545567,94	4196335,59	EB_98	547226,22	4199449,00	EB_155	550481,20	4197204,20
EB_42	545769,49	4196329,91	EB_99	547248,75	4199441,25	EB_156	550487,07	4197196,88
EB_43	545799,75	4196336,19	EB_100	547288,21	4199415,25	EB_157	550455,67	4197168,26
EB_44	545984,35	4196513,15	EB_101	547327,68	4199377,96	EB_158	550435,18	4197145,41
EB_45	546003,22	4196762,43	EB_102	547361,45	4199349,82	EB_159	550411,90	4197111,41
EB_46	546527,71	4196762,43	EB_103	547407,17	4199314,57	EB_160	550359,48	4197063,11
EB_47	546503,78	4196839,02	EB_104	547482,73	4199231,68	EB_161	550274,45	4196993,41
EB_48	546461,83	4196956,67	EB_105	547532,82	4199191,54	EB_162	550201,47	4196938,85
EB_49	546449,88	4197000,87	EB_106	547558,66	4199179,28	EB_163	550147,93	4196902,39
EB_50	546429,13	4197152,71	EB_107	547592,15	4199171,65	EB_164	550076,40	4196847,29
EB_51	546421,96	4197235,12	EB_108	547646,95	4199159,43	EB_165	550028,01	4196792,43
EB_52	546412,91	4197297,37	EB_109	547694,94	4199143,55	EB_166	549987,83	4196753,48
EB_53	546378,96	4197412,20	EB_110	547771,90	4199111,62	EB_167	549938,91	4196709,35
EB_54	546373,59	4197436,24	EB_111	547918,31	4199040,07	EB_168	549895,36	4196720,92
EB_55	546370,90	4197556,88	EB_112	547953,39	4199018,95	EB_169	549809,37	4196734,90
EB_56	546372,39	4197569,57	EB_113	548038,38	4198979,16	EB_170	549695,26	4196760,04
EB_57	546374,04	4197611,97	EB_114	548093,52	4198950,54	EB_171	549602,98	4196788,49

APPENDIX-2. (Continued) Karapınar specialized industrial area map information (second area)

KARAPINAR ENERJİ İHTİSAS ENDÜSTRİ BÖLGESİ (II. KISIM)

Nokta No	X	Y	Nokta No	X	Y	Nokta No	X	Y
EB_172	549467,69	4196815,42	EB_229	546842,24	4193916,17	EB_286	545493,20	4192602,93
EB_173	549438,34	4196815,65	EB_230	546832,35	4193861,89	EB_287	545420,81	4192642,13
EB_174	549433,13	4196810,91	EB_231	546833,91	4193806,76	EB_288	545420,81	4193292,13
EB_175	549429,08	4196802,81	EB_232	546838,45	4193767,02	EB_289	544477,34	4193292,13
EB_176	549426,43	4196791,45	EB_233	546839,21	4193711,55	EB_290	544444,12	4193336,65
EB_177	549423,94	4196775,41	EB_234	546837,37	4193670,14	EB_291	544389,37	4193381,82
EB_178	549415,07	4196690,72	EB_235	546834,67	4193647,00	EB_292	544366,10	4193395,78
EB_179	549401,98	4196606,93	EB_236	546484,03	4193638,83	EB_293	544306,51	4193443,74
EB_180	549060,08	4196580,61	EB_237	546475,59	4193635,58	EB_294	544231,42	4193512,94
EB_181	549058,82	4196600,66	EB_238	546470,92	4193635,45	EB_295	544186,79	4193546,89
EB_182	549043,95	4196818,03	EB_239	546445,59	4193645,58	EB_296	544186,79	4194647,88
EB_183	548959,68	4196818,84	EB_240	546434,42	4193647,53	EB_297	543735,87	4194647,88
EB_184	548593,72	4196820,84	EB_241	546360,13	4193654,06	EB_298	542972,98	4194652,64
EB_185	548589,31	4196662,74	EB_242	546281,18	4193650,35	EB_299	542943,66	4194676,87
EB_186	548684,21	4196666,15	EB_243	546224,77	4193640,52	EB_300	542824,56	4194762,04
EB_187	548703,99	4196565,88	EB_244	546193,35	4193631,58	EB_301	542775,01	4194806,74
EB_188	548708,96	4196545,21	EB_245	546159,27	4193617,65	EB_302	542730,56	4194852,02
EB_189	548446,56	4196498,66	EB_246	546147,42	4193604,76	EB_303	542635,18	4194931,29
EB_190	548489,81	4195991,98	EB_247	546128,30	4193555,30	EB_304	542544,88	4195011,19
EB_191	548417,42	4195733,37	EB_248	546116,66	4193494,40	EB_305	542498,08	4195046,07
EB_192	548381,26	4195731,67	EB_249	546111,05	4193431,63	EB_306	542479,15	4195064,63
EB_193	548150,80	4195714,54	EB_250	546108,55	4193385,28	EB_307	542470,02	4195056,19
EB_194	548161,70	4195659,54	EB_251	546110,63	4193367,40	EB_308	542462,26	4195049,98
EB_195	548187,14	4195547,21	EB_252	545921,57	4193351,38	EB_309	542456,32	4195045,22
EB_196	548197,05	4195501,62	EB_253	545899,67	4193163,71	EB_310	542261,87	4194906,18
EB_197	548204,65	4195454,38	EB_254	545940,41	4192960,65	EB_311	542247,63	4194895,99
EB_198	548223,32	4195357,09	EB_255	545960,15	4192961,90	EB_312	542246,31	4194890,11
EB_199	548279,19	4195092,24	EB_256	546040,59	4192580,50	EB_313	541617,65	4194724,42
EB_200	548226,26	4195062,09	EB_257	546078,42	4192580,50	EB_314	541610,17	4194721,25
EB_201	548174,19	4195037,09	EB_258	546110,22	4192588,61	EB_315	541289,18	4194625,99
EB_202	548124,67	4195017,11	EB_259	546143,26	4192593,18	EB_316	541280,55	4194625,57
EB_203	548107,77	4195008,92	EB_260	546148,78	4192465,84	EB_317	541068,71	4194585,17
EB_204	548026,16	4194971,83	EB_261	546153,17	4192416,29	EB_318	541034,97	4194665,55
EB_205	547947,44	4194931,57	EB_262	546013,66	4192384,48	EB_319	540648,27	4195558,26
EB_206	547719,74	4195376,72	EB_263	546042,41	4192113,90	EB_320	540559,92	4195758,29
EB_207	546656,26	4194986,04	EB_264	546074,60	4192119,65	EB_321	540393,63	4196138,03
EB_208	546649,48	4194984,23	EB_265	546128,64	4192138,81	EB_322	540208,57	4196560,87
EB_209	546652,84	4194973,91	EB_266	546140,52	4191995,09	EB_323	540038,08	4196938,96
EB_210	546665,14	4194924,74	EB_267	546064,64	4191923,04	EB_324	539919,21	4197201,39
EB_211	546674,53	4194846,37	EB_268	546059,27	4191872,83	EB_325	539910,29	4197226,20
EB_212	546683,92	4194799,92	EB_269	545927,05	4191890,08	EB_326	539908,59	4197232,64
EB_213	546690,30	4194783,69	EB_270	545951,96	4191914,60	EB_327	539887,88	4197273,86
EB_214	546710,56	4194713,87	EB_271	545958,09	4191923,80	EB_328	539869,22	4197318,59
EB_215	546719,81	4194656,77	EB_272	545961,54	4191943,73	EB_329	539843,16	4197378,39
EB_216	546768,99	4194472,76	EB_273	545960,01	4192033,03	EB_330	539801,54	4197474,82
EB_217	546783,76	4194390,09	EB_274	545962,31	4192076,34	EB_331	539782,50	4197515,34
EB_218	546825,34	4194348,38	EB_275	545945,83	4192299,39	EB_332	539787,87	4197565,99
EB_219	546814,63	4194339,77	EB_276	545940,46	4192305,14	EB_333	539782,87	4197622,38
EB_220	546800,43	4194328,17	EB_277	545905,20	4192306,29	EB_334	539769,93	4197671,81
EB_221	546796,88	4194327,70	EB_278	545765,31	4192289,04	EB_335	539749,30	4197720,02
EB_222	546769,77	4194280,35	EB_279	545863,04	4192314,72	EB_336	539744,39	4197738,46
EB_223	546772,17	4194267,61	EB_280	545856,53	4192317,79	EB_337	539700,24	4197840,25
EB_224	546813,77	4194270,74	EB_281	545740,78	4192287,13	EB_338	539650,44	4197964,01
EB_225	546831,22	4194235,86	EB_282	545657,62	4192489,87	EB_339	539559,54	4198150,59
EB_226	546841,75	4194191,14	EB_283	545645,35	4192502,90	EB_340	539507,00	4198300,02
EB_227	546859,41	4194059,89	EB_284	545621,11	4192516,72	EB_341	539496,65	4198323,96
EB_228	546859,74	4194009,66	EB_285	545561,16	4192560,37	EB_342	539483,26	4198349,69

APPENDIX-2. (Continued) Karapınar specialized industrial area map information (second area)

KARAPINAR ENERJİ İHTİSAS ENDÜSTRİ BÖLGESİ (II. KISIM)

Nokta No	X	Y	Nokta No	X	Y
EB_343	539460,45	4198382,93	EB_400	540154,61	4199440,27
EB_344	539413,53	4198435,08	EB_401	540172,05	4199431,83
EB_345	539378,67	4198468,25	EB_402	540226,25	4199407,83
EB_346	539283,52	4198550,66	EB_403	540258,13	4199392,64
EB_347	539249,55	4198562,37	EB_404	540313,45	4199364,14
EB_348	539209,80	4198595,40	EB_405	540332,01	4199351,76
EB_349	539203,75	4198689,66	EB_406	540351,37	4199333,87
EB_350	539198,07	4198730,35	EB_407	540383,05	4199311,83
EB_351	539190,42	4198760,78	EB_408	540429,99	4199279,59
EB_352	539189,01	4198785,19	EB_409	540517,57	4199211,40
EB_353	539194,07	4198881,64	EB_410	540590,08	4199148,77
EB_354	539202,42	4198908,07	EB_411	540637,27	4199114,56
EB_355	539188,34	4199166,83	EB_412	540699,77	4199062,80
EB_356	539186,60	4199196,57	EB_413	540727,32	4199042,91
EB_357	539187,37	4199327,95	EB_414	540769,68	4199010,55
EB_358	539180,97	4199383,34	EB_415	540811,06	4198986,22
EB_359	539177,17	4199401,17	EB_416	540851,78	4198973,99
EB_360	539177,33	4199448,06	EB_417	540867,17	4198967,94
EB_361	539179,31	4199463,09	EB_418	540948,97	4198924,88
EB_362	539187,07	4199496,44	EB_419	541021,60	4198891,50
EB_363	539230,57	4199500,12	EB_420	541072,27	4198861,75
EB_364	539250,15	4199506,35	EB_421	541134,87	4198839,10
EB_365	539250,81	4199513,61	EB_422	541186,75	4198833,91
EB_366	539257,06	4199513,86	EB_423	541205,77	4198830,11
EB_367	539325,47	4199516,53	EB_424	541233,96	4198818,87
EB_368	539330,89	4199513,12	EB_425	541264,40	4198809,88
EB_369	539338,26	4199517,50	EB_426	541289,99	4198799,67
EB_370	539341,03	4199522,60	EB_427	541357,78	4198757,48
EB_371	539381,85	4199537,10	EB_428	541428,24	4198687,75
EB_372	539393,71	4199536,96	EB_429	541434,50	4198682,42
EB_373	539407,99	4199558,64	EB_430	541454,22	4198667,75
EB_374	539414,27	4199562,98	EB_431	541550,81	4198403,28
EB_375	539418,27	4199565,61	EB_432	541696,25	4197928,14
EB_376	539413,94	4199576,35	EB_433	541772,09	4197616,09
EB_377	539420,10	4199589,18	EB_434	541876,53	4197287,87
EB_378	539434,56	4199589,45	EB_435	541904,95	4197191,14
EB_379	539536,56	4199568,57	EB_436	541908,54	4197138,14
EB_380	539774,47	4199524,03	EB_437	541916,17	4197140,70
EB_381	539832,16	4199512,04	EB_438	541939,30	4197181,27
EB_382	539941,71	4199487,40	EB_439	541972,60	4197220,09
EB_383	539942,40	4199494,25	EB_440	542003,57	4197246,91
EB_384	539943,70	4199509,21	EB_441	542333,76	4197280,04
EB_385	539942,40	4199518,52	EB_442	542334,84	4197276,80
EB_386	539948,70	4199516,22	EB_443	542849,74	4197382,30
EB_387	539959,39	4199512,85	EB_444	543462,94	4197526,69
EB_388	539965,58	4199512,10			
EB_389	539987,90	4199506,10			
EB_390	539995,77	4199506,47			
EB_391	540000,28	4199505,53			
EB_392	540008,90	4199504,60			
EB_393	540023,90	4199492,41			
EB_394	540037,22	4199484,72			
EB_395	540061,03	4199473,84			
EB_396	540076,22	4199470,28			
EB_397	540100,23	4199464,65			
EB_398	540109,60	4199461,46			
EB_399	540130,80	4199450,21			

Harita Bilgileri
Projeksiyon: UTM (6 Derece)
Datum: EUROPEAN 1950
Ölçek:1/50.000

APPENDIX-3. Load shedding rate of generators with secondary frequency control obligation in DIgSILENT PowerFactory model

Generator	Generator's ramp rates (MW/min)
Generator-A	10
Generator-B	30
Generator-C	72
Generator-D	20
Generator-E	50
Generator-F	21
Generator-G	160
Generator-H	40
Generator-I	96
Generator-J	60
Generator-K	30
Generator-L	30
Generator-M	30
Generator-N	30
Generator-O	56
Generator-P	42
Generator-Q	150
Generator-R	36
Generator-S	120
Generator-T	69

RESUME

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Education

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Experience

Year	**Company Name**	**Position**
2014-Current	TÜBİTAK MAM Energy Institute	Researcher

Languages

English

Publications

1. Eren, S., Küçük, D., Ünlüer, C., Demircioğlu, M., Yanık, Y., Arslan, Y., Özsoy, B., Güverçinci, A. H., Elma, İ., Özgür, T., Ölmez, Y. C., Sönmez, S. (2016). A Ubiquitous Web-based Dispatcher Information System for Effective Monitoring and Analysis of the Electricity Transmission Grid. *Electrical Power and Energy Systems*, 86(2017), 93-103

Hobbies

Football, Table Tennis, Cinema

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