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SOLAR POWER PLANT IN KARAPINAR EFFECT ON SECONDARY FREQUENCY CONTROL

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Abstract- This article discusses the effect of 3 GW solar power plant which is planned to be completed in 2025 in Turkey in Karapinar on secondary frequency control performance. There are two main reasons of the active power fluctuations of a solar plant which are solar irradiance and clouding. The former yields comparably slow increase and decrease in the active power output in the morning and evening hours and the latter yields sudden active power changes. The main purpose of this paper is evaluation of secondary frequency control performance in 2025 system with a solar power plant which has 3 GW installed capacity.

Keywords: PV Power Plant, Frequency Control, Secondary Frequency.

I. INTRODUCTION

Green energy becomes more popular in many countries. Governments in these countries are aware that carbon emissions from other sources cause to climate change. In recent years, many developed countries are channeling their money to renewable energy sources such as solar, wind and geothermal energy. Especially China and US are the main countries that use renewable energy in the world [1]. Germany, Russia and Brazil are the other countries that invest in renewable energy.

Solar energy is a major renewable energy source with the potential to meet many of the necessities about power generation and economical return. Solar power plant is increasing in popularity because it is versatile with many benefits to the environment. On the other hand, solar power plant industries provide new job opportunities.

In Turkey, the establishment of generation facilities based on renewable energy sources, especially solar and wind power plants, is encouraged by the government. Turkey has large wind and solar energy potential. Western part of Turkey has enormous wind energy potential, while the middle parts of Turkey have huge solar energy potential.

In this context, it is planned to establish a 3 GW solar power plant in Karapinar in 2025 by Turkish government [2]. This plant which is planned to be installed on a 60 km^2 area, is under consideration since it would have a considerable effect on the Turkish power system. Especially, sudden active power changes of the solar power plant would have serious effects on the secondary frequency control performance.

Frequency control of an interconnected system takes place on 4 stages: primary frequency, secondary frequency, tertiary frequency and time control [3]. Primary frequency and secondary frequency control are controlled automatically and primary control reserves are replaced via secondary control reserves hence, sudden active power changes in 3 GW solar power plant will most likely force the secondary control performance [10].

In this paper, study of evaluation of secondary frequency control performance in 2025 system with a solar power plant which has 3 GW installed capacity is presented. Meanwhile, 3 GW solar power plants daily generation profile is investigated by monthly and clouding effect over the solar power plant area is examined.

The effects of the 3 GW solar power plant on the secondary frequency control are examined with nine different scenarios which are simulated in the DIgSILENT.

In section II, information is given about Turkish power system in 2025. The analysis methodology is described in section III. The simulation results are given in section IV. Finally, in section V, the summary of this article is given.

II. TURKISH POWER SYSTEM IN 2025

The operation of the Turkish power transmission system is managed by Turkish Electricity Transmission Company (TEIAS). Considering the investments to be made by TEIAS and the growth rates in the power system up to 2025, it is expected to have about 70 GW peak demand. It is also expected that the installed power capacity in the Turkish power system will be 125 GW. The daily load curves obtained from Load Dispatch Information System (YTBS) are scaled in the direction of 2025-year consumption forecast and the estimated load curves for each month of 2025 are calculated. Estimated daily load curves for 2025 are given in Figure 1.

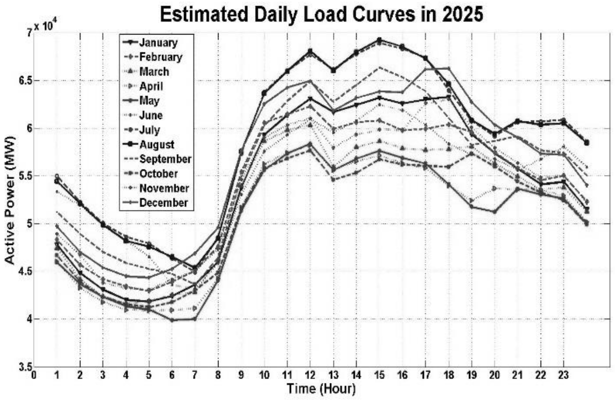

Figure 1. Estimated daily load curves in 2025

In this study, the daily active output power changes of the solar power plant in Karapinar have been studied together with the estimated daily load curve in 2025 to see how it will affect the daily load curve.

III. METHODOLOGY

Two basic studies are carried out while analyzing the effects on the secondary frequency control mechanism of 3 GW solar power plant expected to be established in Turkey in 2025. The first one is the change in the active output power of the solar power plant, which is due to the daily solar radiation change. The second one is the rapid change in the active output power that will be created by the fast cloud passing over the power plant field.

Before examining these changes, necessary information about the power plant to be installed is given. Finally, in the last part of this chapter, scenarios will be formed to examine the effects of the solar power plant on the frequency control mechanism.

A. 3 GW Solar Power Plant in Karapınar

Until 2025, it is planned to establish 3 GW solar power plant in Karapinar, Konya. In accordance with the decisions of the government, it is planned to build this plant approximately 60 km^2 surface area. The total surface area of Karapinar is 3030 km^2 and the population of the city is about 50,000 [4].

The specified areas which have totally of approximately 60 km^2 is shown in Figure 2. These areas in the figure have been determined as suitable areas for solar power plant investment by the government [5].

When the previous investments are examined, it is expected that 3 GW solar power plants technology will be a fixed plane PV. Therefore, the results are evaluated in this direction.

B. Daily Active Power Changes due to Solar Radiation Variation

Solar radiation values of Karapinar region is obtained from the PV Geographical Information System (PV-GIS), which is prepared by the European Union Joint Research Center, has been used to examine Karapinar solar power plant generation profile [6]. These data are calculated with specific points' measurements [7].

Figure 2. Specified areas for 3 GW solar power plant investment in Karapinar [4]

The generation profile of the Karapinar solar power plant is obtained for each month after the solar radiation values of Karapinar are obtained from PV-GIS. In this context, the rates of active power change in solar power plant in Karapinar are examined.

The rate of increase in active power output of the solar 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 plant in the evening can reach up to 30 MW/min. These values are even more important when considering the 15-minute time frame.

Additional active power imbalances due to the solar power plant are given in Table 1 when solar power plant in Karapinar daily generation and 2025 estimated daily load 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 1. Additional 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

The graphs showing the effects of the Karapinar solar power plant generation to daily load curve in January and September are as shown in Figures 3 and 4.

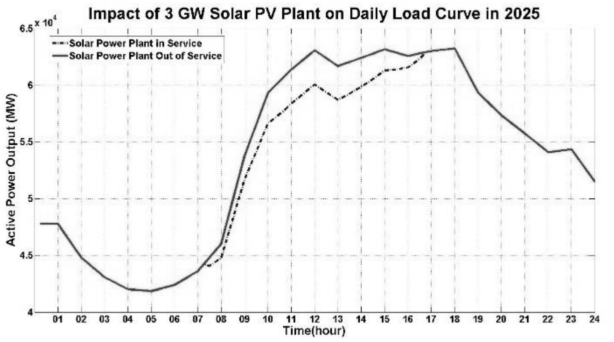

Figure 3. Effect of solar power plant in Karapinar on estimated daily load curve (January)

As can be seen in the Figure 3, the active power output of the solar plant decreases in the evening hours, while total power demand increases. Therefore, solar power plant has negative effect in the evening hours on daily load curve in January.

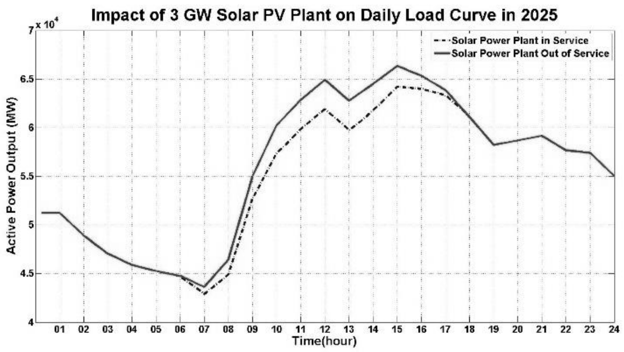

Figure 4. Effect of solar power plant in Karapinar on estimated daily load curve (September)

As can be seen in the Figure 4, the active power output of the solar power plant increases in the morning hours, while total power demand decreases. Therefore, solar power plant has negative effect in the morning on daily load curve in September.

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

Clouding over the PV panels causes a reduction in the active power level of the PV panel as it will reduce the amount of solar radiation. Therefore, clouding over the Karapinar solar power plant area may cause serious decrease in total active power.

The percentage of active power changes that occur due to the clouding varies according to the size of the power plant area. As the area of the solar power plant increases, the percentage of the active power changes decreases in case of sudden cloud transient [8].

Table 2 shows the decrease in active power output for 15 minute intervals during cloud passes. As seen in Table 2, the photovoltaic power plant installed on a 500 km^2 area is observed 6% loss of generation level at the time of clouding, and the decrease in the active power output increases as the area size decreases. It has been observed that decrease in active power output can reach up to 40% for the smaller areas.

Since the area of Karapinar solar power plant is 60 km^2 in, it can be concluded that the decrease in the active power output of the solar plant will be approximately 25 % of the active power output. If the clouding occurs when the active power output is maximum, the decrease in the active power output will be 750 MW.

Table 2. Percentage of the decrease in the active power output of the solar plant according to PV plant area size during clouding [8]

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

D. Scenarios

The 9 different scenarios are constructed to observe the effects of the Karapinar solar power plant with 3 GW installed power on the secondary frequency control.

According to secondary frequency control regulations, it is necessary to annihilate area control error, which consists of frequency error and power mismatch between the measured and scheduled power flows of interconnection lines, by the secondary frequency control mechanism within 15 minutes [9]. 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 area control error.

There are two main reasons for changes in active power output of Karapinar solar power plant: daily active power variations due to solar radiation variation and clouding effect on solar power plant active power output level. The maximum active power changes, as shown in the Table 1, caused by daily changes are identified as +32.2 MW/min and -12.8 MW/min, respectively in January and September. Considering the 15 minutes time interval, these values are reached up to +483 MW/15 min and -192 MW/15 min. On the other hand, it is observed that the solar power plant can experience 750 MW active power changes in 15 minutes time interval during clouding.

The main purpose of secondary frequency control is to keep power flow in the interconnection lines at the scheduled levels and the frequency at the nominal value. Within this scope, different scenarios are constructed in order to examine the effects of Karapinar solar power plant on the secondary frequency control performance. While these scenarios are formed the arc furnaces changes are taken into consideration as well since the effect of the arc furnaces are critical in secondary frequency control performance. 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.

For scenarios to be applied over a 1-hour period, the cases where the changes occur in the arc furnace are high, medium and low will be simulated separately. Therefore 9 different scenarios are created by simulating 3 different situations in which the secondary frequency control could be faced due to Karapinar solar power plant, respectively, in cases where arc furnace power demand change is low, medium and high. These scenarios are shown in Table 3.

Table 3. Scenarios for examination of the effects of Karapinar solar power plant on secondary frequency control

Scenario	Scenario Description
S-1	clouding & low case EAF (±750 MW / 15 min)
S-2	clouding & moderate case EAF (±750 MW / 15 min)
S-3	clouding & high case EAF (±750 MW / 15 min)
S-4	Positive active power change & low case EAF (+483 MW / 15 min)
S-5	Positive active power change & moderate case EAF (+483 MW / 15 min)
S-6	Positive active power change & high case EAF (+483 mw MW / 15 min)
S-7	Negative active power change & low case EAF (-192 MW / 15 min)
S-8	Negative active power change & moderate case EAF (-192 MW / 15 min)
S-9	Negative active power change & high case EAF (-192 MW / 15 min)

The DIgSILENT program is used to simulate the scenarios and the model is verified by modeling the secondary frequency control structure. It is known that the secondary frequency reserve capacity is approximately 1000 MW in the real system. In this direction, 990 MW reserves are provided from 20 different power plants during 9 scenarios and results are evaluated in this direction.

The secondary frequency control mechanism block diagram on DIgSILENT PowerFactory is as shown in Figure 5. With the secondary frequency controller model, the Area Control Error (ACE) is calculated by looking power flow on ENTSO-E connection lines and system frequency. After PI controllers and limiters total set points to be sent to the generators is determined. Distribution blocks are used to distribute the total set points to the generators with secondary frequency control obligation.

It is necessary to sweep electricity load generation imbalances by the secondary frequency control mechanism within 15 minutes. 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. In this context, the events applied during 1 hour simulation are shown in Figure 6.

The ACE performance criteria plays an important role for evaluating these scenarios. This criterion 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 [3].

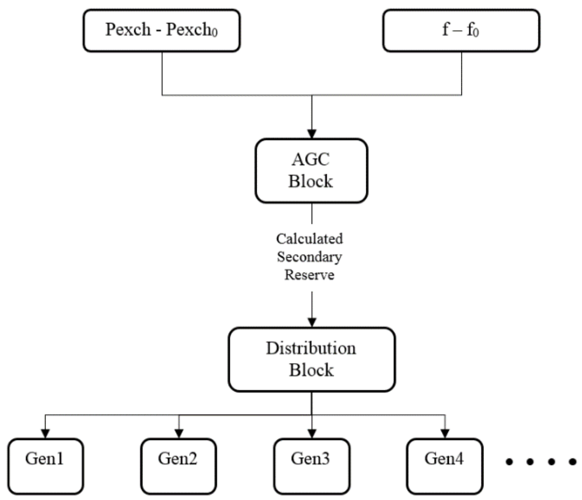

Figure 5. Block diagram of modeled AGC system in DIgSILENT PowerFactory

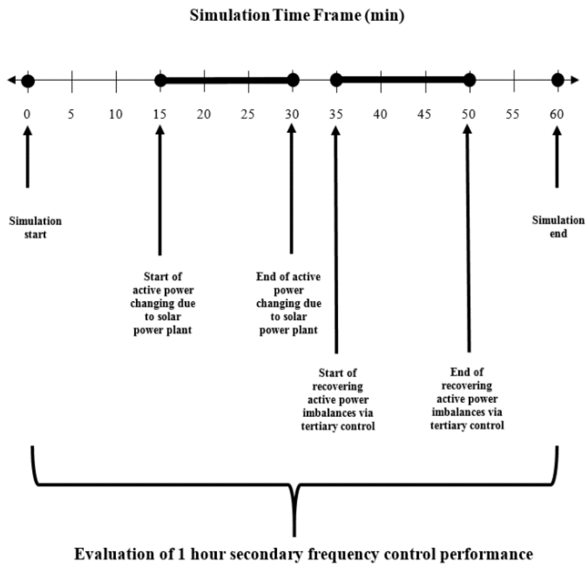

Figure 6. Simulation time frame

IV. SIMULATION RESULTS

When evaluating the 1-hour simulation, the following criteria are investigated:

• Is the secondary frequency reserve amount able to meet the maximum and minimum load requirement during the simulation?

• Does 1-hour simulation ACE signal meet the ENTSO-E criteria?

For those situations that fulfill these two requirements, the scenario is considered as successful, otherwise it is found to be unsuccessful. It is observed that the current amount of reserves cannot meet most of the possible load changes due to the active power changes of Karapinar solar power plants.

Only Scenario 7, Scenario 8 and Scenario 9, which the active power change due to the solar power plant is negative, could meet the maximum and minimum load requirements and these scenarios' ACE signal can meet the ENTSO-E criteria. The summary of the simulation results are shown in Table 4.

Table 4. Summary of simulation results

Scenario	Reserve Requirement	ACE Criteria
S-1	✓	✗
S-2	✗	✗
S-3	✗	✗
S-4	✗	✗
S-5	✗	✗
S-6	✗	✗
S-7	✓	✓
S-8	✓	✓
S-9	✓	✓

V. CONCLUSION

In this paper, the effect of the solar power plant with 3 GW installed power, which is planned to be built in Karapinar in the coming years, to the secondary frequency control has been investigated. In this context, active power fluctuations due to the daily solar radiation variation and clouding effect have been investigated. Nine different scenarios are developed to examine the effects of these changes on the secondary frequency control performance. While the scenarios are being developed, the arc furnaces that are critical for the Turkish power system have been taken into consideration.

After simulating these scenarios, the results are examined and evaluated. The assessments are based on the adequacy of secondary reserves and the ENTSO-E criteria.

The current secondary frequency control mechanism has been found to be successful for only three of nine scenarios, others has been found to be unsuccessful. Therefore, it is considered that the planned solar power plant will be risky in terms of the secondary frequency control mechanism. In this context, 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.

NOMENCLATURES

ENTSO-E: European Network of Transmission System Operators for Electricity
TEIAS: Turkish Electricity Transmission Company
YTBS: Load Dispatch Information System
PV-GIS: Photo-Voltaic Geographical Information System
ACE: Area Control Error
EAF: Electric Arc Field

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BIOGRAPHIES

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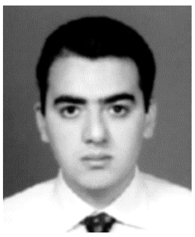

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