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DESIGN AND PERFORMANCE ANALYSIS OF FLOATING SOLAR PHOTOVOLTAIC SYSTEMS

M.Sc. Thesis by

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DESIGN AND PERFORMANCE ANALYSIS OF FLOATING SOLAR PHOTOVOLTAIC SYSTEMS

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M.Sc. THESIS EXAMINATION RESULT FORM

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DESIGN AND PERFORMANCE ANALYSIS OF FLOATING SOLAR PHOTOVOLTAIC SYSTEMS

ABSTRACT

The floating solar photovoltaic system is a new trend in the world. This system is suitable for hybrid solutions with hydropower plants. There are a lot of advantages of the floating solar photovoltaic systems. Solar energy is an intermittent energy source so with a hybrid solution of floating solar and hydroelectric power plant can balance each other's energy generation. It can be said that this hybrid solution can increase the capacity factor of the hydropower plant. Turkey has the second greatest hydropower installed capacity in Europe with about 31.493 MW so the floating solar photovoltaic and hydropower hybrid solutions will be very beneficial to Turkey's solar installed capacity growth without using land areas. In this respect Gursogut-1 HEPP with 38.08 MW installed capacity which is located in Ankara was chosen for the hybrid solution in this study.

During the literature survey period it was seen that there aren't a lot of academic studies about floating solar and hydropower plant hybrid systems' performance analysis. The aim of this study is to investigate the performance analysis of the floating solar photovoltaic and hydropower plant hybrid system. In this study the gain in the energy yield when a floating solar photovoltaic system mounted on this hydropower water reservoir has been analyzed. The performance analysis has been carried out on PVsyst software according to the system's key parameters including meteorological data, available installation area, photovoltaic module properties and inverter features. Results obtained for system's total energy production, performance ratio and specific energy are discussed.

Keywords: Renewable energy, solar photovoltaic, floating solar photovoltaic, PV, FPV.

DESIGN AND PERFORMANCE ANALYSIS OF FLOATING SOLAR PHOTOVOLTAIC SYSTEMS

ÖZ

Yüzer güneş enerjisi sistemi dünyada yeni bir akımdır. Bu sistem hidroelektrik santrallarla hibrit çözümler için uygundur. Yüzer güneş enerjisi sistemlerinin birçok faydası vardır. Güneş enerjisi kesintili bir enerji kaynağıdır bu yüzden yüzer güneş enerjisi ve hidroelektrik santralin hibrit çözümüyle her iki santral birbirinin enerji üretimini dengeleyebilir. Bu hibrit çözümün hidroelektrik santralin kapasite faktörünü yükselteceği söylenebilir.Türkiye Avrupa hidroelektrik santal kurulu gücü sıralamasında 31493 MW ile ikinci sırada olduğu için yüzer güneş enerjisi santrali ile hidroelektrik enerji santral hibrit çözümleri Türkiye'nin güneş enerjisi kurulu gücünün karasal alanlar kullanılmadan artırılması için çok yararlı olur. Bu çerçevede bu çalışma için Ankara ilinde bulunan 38.08 MW kurulu gücündeki Gürsöğüt-1 Hidroelektrik Santralı hibrit çözüm amacıyla seçilmiştir.

Literatür araştırması aşamasında yüzer güneş enerjisi ve hidroelektrik santral hibrit sistemlerinin performans analiziyle ilgili çok fazla akademik çalışma olmadığı görülmüştür. Bu çalışmanın amacı yüzer güneş enerjis ve hidroelektrik santral hibrit sisteminin performans analizini araştırmaktır. Bu çalışmada yüzer güneş enerjisi santralının hidroelektrik santralın baraj gölüne kurulduğundaki enerji getirisindeki artış analizi yapılmıştır. Performans analizleri meteorolojik veriler, uygun montaj alanı, fotovoltaik modül ve inverter özellikleri gibi systemin ana parametrelerine göre PVsyst programında gerçekleştirilmiştir. Sistemin toplam enerji üretimi, performans oranı ve spesifik enerji sonuçları elde edilmiş ve tartışılmıştır.

Anahtar kelimeler: Yenilenebilir enerji, solar fotovoltaik, yüzer güneş enerjisi, PV, FPV

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NOMENCLATURE

Roman Letter Symbols

A	Ampere
E	Energy
P	Power
T	Temperature
V	Voltage

Acronyms

AC	Alternative Current
FPV	Floating Photovoltaic
HEPP	Hydroelectric Power Plant
N/A	Not available
$Glob_{inc}$	Global Incident Irradiation
$Glob_{hor}$	Global Horizontal Irradiation
Pnom	Nominal Power
PR	Performance Ratio
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
STC	Standard Conditions
T_Amb	Ambient Temperature
TMY	Typical Meteorological Year

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CHAPTER 1

INTRODUCTION

Renewable energy sources are very important for the world. Unlike generating electricity from fossil energy sources, generating electricity from renewable energy sources such as hydropower, solar and wind emits low carbon to the atmosphere. Generating electricity from renewable energy sources are increasing worldwide. Almost 39% of generated electricity in the world came from low carbon sources in 2020 [1]. Low carbon sources are nuclear and renewable energy sources. Reducing carbon dioxide (CO_2) emissions is at the heart of the world's accelerating shift from climate-damaging fossil fuels towards clean, renewable forms of energy [2].

In 2020 world total installed capacity of renewable energy power plants was 2,799.094 GW. World solar power plant installed capacity was 713,970 MW in 2020 [3]. Almost 99% of the solar energy capacity is solar photovoltaics. Solar energy has a huge potential in the world.

Using new renewable energy technologies are becoming popular all around the world. Floating solar photovoltaic system is a new trend in the world. Floating solar photovoltaics are installed on unused areas of water. Floating solar photovoltaics does not occupy land areas. Approximately 75% of the world's surface consists of water [4]. It means there is a huge potential of floating solar photovoltaics in the world. The floating solar photovoltaics can also be suitable for the locations near the shores and for the islands. Deployment of floating solar photovoltaic is accelerating with global installed capacity up from below 1 MW in 2007 to 1,314 MW in 2018 and is expected to reach approximately 13,000 MW by 2022 [5].

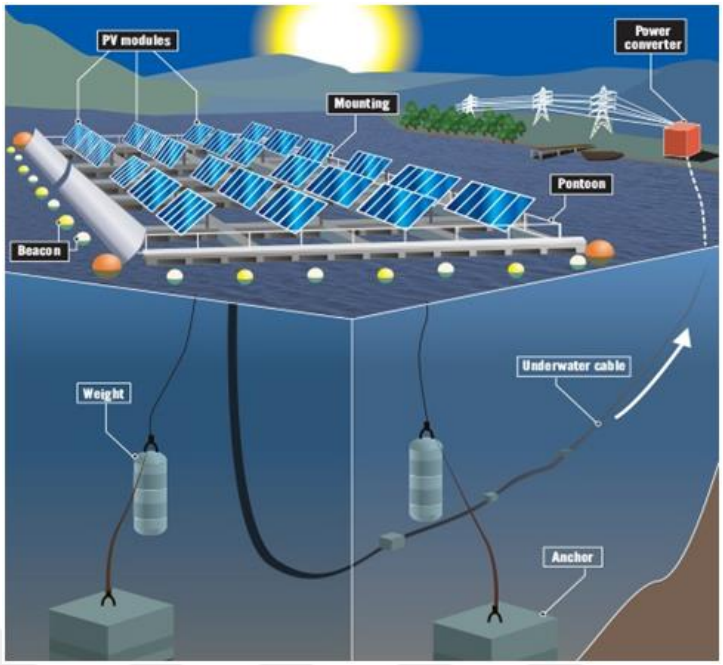


Figure 1.1 An Illustration of a Floating Solar Photovoltaic System [6]

Hybrid renewable energy technologies are also a new trend in the world. Several benefits can be achieved with some hybrid renewable energy technologies. All the renewable energy power plants have different capacity factors. Capacity factor is the total electricity generation of a power plant for a given period like a year divided by the total installed capacity of a power plant times 365 days times 24 hours. Capacity factors of the power plants that are generating electricity from fossil energy sources are usually higher than the power plants that are generating electricity from renewable energy sources.

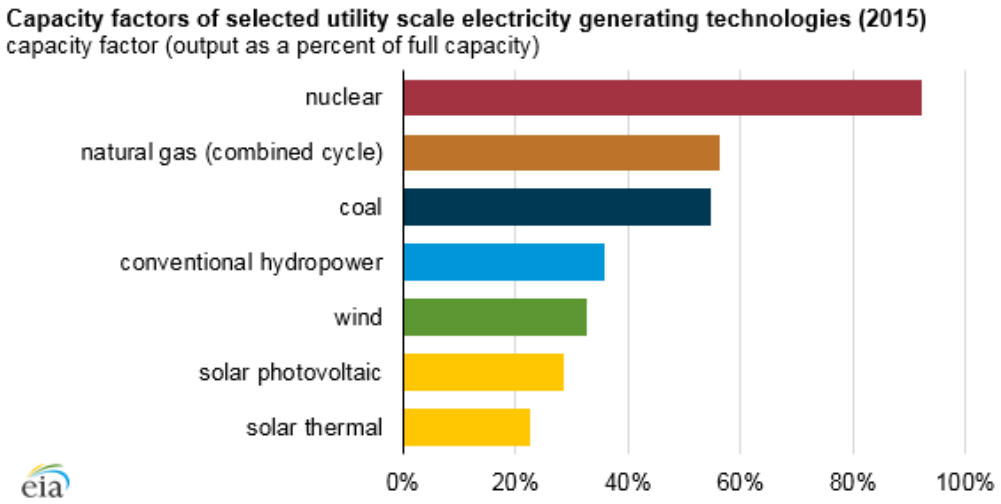


Figure 1.2 Capacity Factors of Power Plants [7]

As can be seen from Figure 1.2 conventional hydropower plants have a capacity factor about 35%, wind energy powerplants have a capacity factor about 30% and solar photovoltaic power plants have a capacity factor about 25% in United States in 2015. Capacity factors can change for the other regions in the world but it will be about minus and plus 5% from United States' power plant capacity factor values. In a year there are 8760 hours. This table means that a hydropower plant generates electricity with full capacity in a year about 3066 hours and a solar photovoltaic power plant generates electricity with full capacity in a year about 2190 hours. Hydropower-onshore wind, hydropower-offshore wind, hydropower-onshore solar or hydropower-floating solar photovoltaic technologies can increase the total system's capacity factor and also efficiency.

1.1. Working Principles of Hybrid Floating Solar Photovoltaic and Hydroelectric Power Plant Systems

There are mainly five types of solar photovoltaic systems. These are ground mounted/conventional land based, roof top, canal top, offshore and floating solar photovoltaic systems. The conventional land based solar photovoltaic systems are held in place by racks or frames that are attached to ground based mounting supports [8]. The solar photovoltaics directly convert solar energy into electricity. When certain materials are exposed to light, they absorb photons and release free electrons. This

phenomenon is called as the photoelectric effect. Photovoltaic effect is a method of producing direct current electricity based on the principle of the photoelectric effect. Based on the principle of photovoltaic effect, solar cells or photovoltaic cells are made. A number of photovoltaic cells are mounted on a supporting frame and are electrically connected to each other to form a photovoltaic module or solar panel. According to the requirement of power, multiple photovoltaic modules are electrically connected together to form a photovoltaic array and to achieve more power.

Floating solar photovoltaic systems have solar panels on the floating platform. The photovoltaic modules are generally the same as those deployed in land-based systems; however, floating solar photovoltaic systems are mounted on floating platforms constructed with plastic and stainless (or galvanized) steel, instead of fixed racks utilized for land-based system [9]. The main components of a floating solar photovoltaic system can be seen from the below figure (Figure 1.3). The main component of the system is the photovoltaic modules. Mostly crystalline solar PV modules have been used for the floating solar systems [10]. There are two different types of crystalline silicon solar PV modules; monocrystalline and multi crystalline [11].

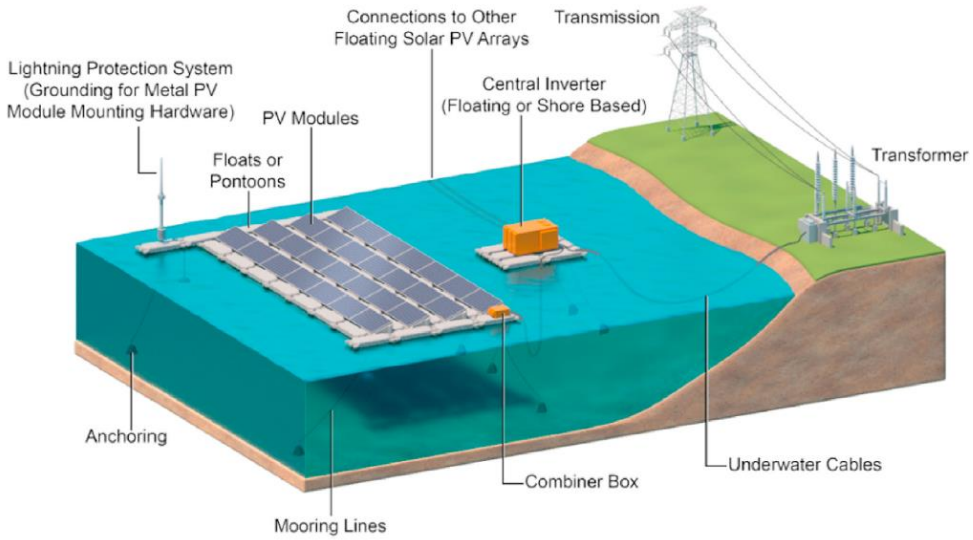


Figure 1.3 Schematic of a typical stand-alone large-scale FPV system and key components [9]

The photovoltaic modules are mounted on the floats or pontoons. The floats are anchored to the bottom of the water reservoir via mooring lines. The mooring lines

provide the system's stability, with these lines the floating system is secured. The design of the anchoring and mooring systems- which are used to keep in place the floating platforms, will depend on a wide range of factors such as water level and its variability, bathymetry, soil conditions, float type, and wind load [10]. There are a lot of floats which are connected to each other. There are pathways on the floats for operation and maintenance works. The floats have to be designed to carry the photovoltaic modules. The floats' components are main float which was designated as 1 in the below figure (Figure 1.4) and is for supporting the photovoltaic module, secondary float was designated as 2 in the below figure, connection pin which was designated as 3 in the below figure, rail to fix the module on the float that was designated as 4 in the below figure. The photovoltaic module was designated as 5 in the below figure.

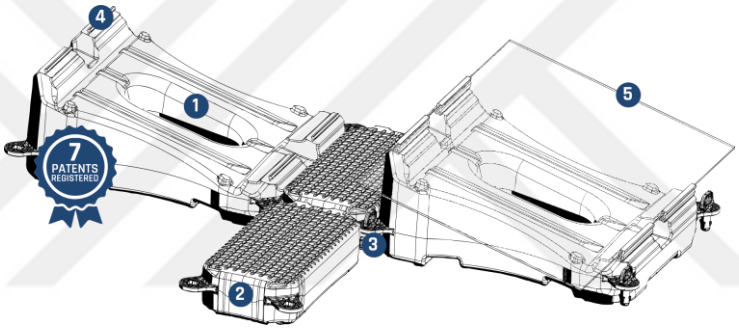


Figure 1.4 A Float Design for the Floating Solar Photovoltaic System [12]

The floats are made from recyclable HDPE (high density polyethylene). The floats are lego type, they are assembled into rows. The floats have to withstand against wind, rain, snow and other environmental hazards. The float is a flotation device with buoyancy enough to float by itself as well as with a heavy load [8].

The system is connected to main electrical equipment. There is a combiner box in the system which is located on the floating platform combines the output of several solar strings into one output. The combiner box is connected to the central inverter that can be located on a floating platform or on the land. The inverter is a device that converts DC voltage to AC voltage. In the system there has to be an inverter because the electricity transmission is done with high voltage electricity transmission lines. The input DC voltage is usually lower than the AC voltage. The inverter is connected to the transformer. A transformer is a device that transfers electrical energy from one

circuit to another through the process of electromagnetic induction. The transformer is used for increasing the AC voltage from the output of the inverter because the transmission of the electricity with high voltage is cheaper and there are less losses with high voltage. The transformer is located on the shore. The transformer is connected to transmission lines. There is also a lightning protection system on the floats for grounding the metal photovoltaic equipment. There are underwater cables for electrical connections. High temperature resistance, waterproof and robust cables are to be used to provide a long service [8].

There will be heat transfer between the photovoltaic modules and the pontoons, there will also be heat transfer from the pontoons to the reservoir. The warming of the solar photovoltaic modules reduces their efficiency. It can be said that the water reservoir can cool the photovoltaic modules which effects the performance of the modules positively. There are a lot of advantages of the floating photovoltaics system, decreasing evaporation from the water reservoir is one of the advantages. The conventional type of the solar photovoltaic systems is mounted on the natural lands. The floating solar photovoltaics don’t occupy land areas, these systems are mounted on the unused water surfaces. These surfaces can be a hydropower reservoir, a lake, a sea or an irrigation reservoir.

There are four main types of hydropower systems. First type is run-of-river hydropower a facility that channels flowing water from a river through a canal or penstock to spin a turbine [13]. Generally, run-of-river hydropower systems have little or no water storage capacity. It can be roughly said that these facilities can use only the water comes from upstream for generating electricity. Second type is storage hydropower that has a dam for water storage in a reservoir. Storage hydropower provides base load as well as the ability to be shut down and started up at short notice according the demands of the system (peak load) [13]. The other types are pumped storage hydropower and offshore hydropower. Hydropower installed capacity reached 1,330 gigawatts (GW) in 2020 as generation 4,370 terawatt hours (TWh) [14].

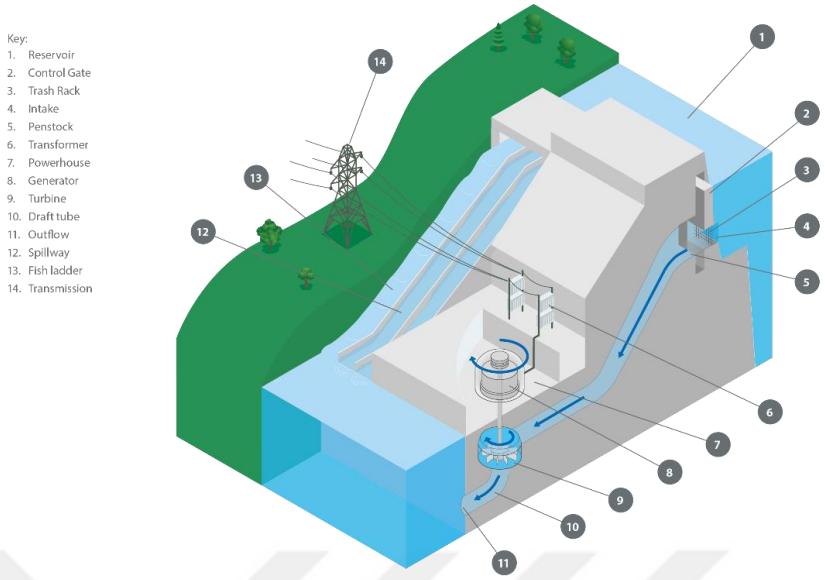


Figure 1.5 Hydropower Facility and Main Components [13]

Using hydropower reservoirs for mounting the floating solar photovoltaic modules is a hybrid solution which can provide benefits to each system. Putting solar farms on water has benefits, but coupling them with hydropower amps them up and could provide almost half of the world's electricity [14]. As mentioned in the first chapter with a good planning of energy generation hybrid floating solar power photovoltaic system and hydroelectric power plant can be very profitable for the owning company. If the hydroelectric power plant's type is storage it can be suitable for this hybrid solution. During nights hydroelectric power plant can generate electricity and floating solar photovoltaic system can stop electricity generation. During the convenient days floating solar photovoltaic system can generate electricity and hydropower plant can stop generating electricity during this period. The hydropower plant's transformer can be used also by the floating solar photovoltaic system for avoiding new investment costs. In summer the water flow rate that come to the dams usually lower than the water flow rate coming in March, April and May months that period is called as flood season. In summer months especially in July and August the electricity generation of the floating solar photovoltaic can support the system's cash flow very much. These months are dry season for the hydroelectric power plants but they can also be fruitful months for the floating solar photovoltaic systems' electricity generation. They

complement each other by being strong when the other is weak: solar for the dry season, hydro for the wet [15].

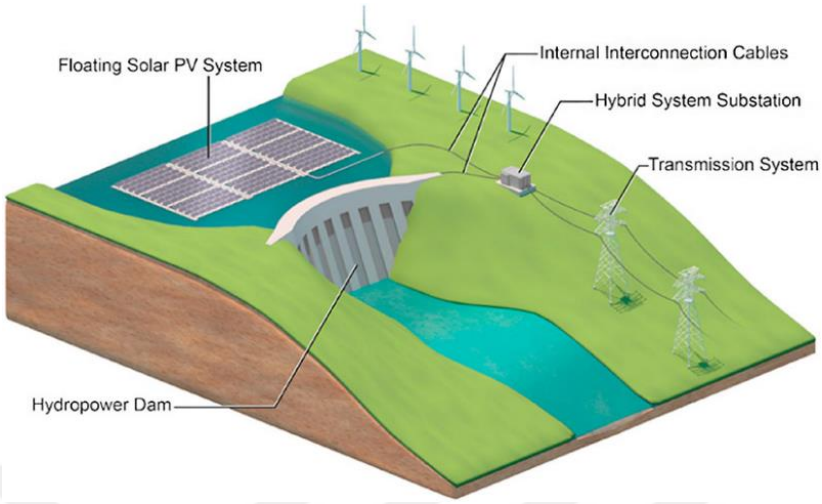


Figure 1.6 A Schematic of a Hybrid Floating Solar Photovoltaic and Hydropower System [9]

There are a lot of advantages of the floating solar photovoltaic system, decreasing evaporation from the water reservoir is one of the advantages. If the water reservoir of the dam is very big, the losses from evaporation will also very much. So, it is a big advantage for the big water reservoirs. In the hydroelectric power plant, the excess water capacity which is avoided from evaporation by the floating solar photovoltaic system can be used for electricity generation. In this hybrid system several benefits can be achieved. In general, hydro plants are easy to access and already grid-connected, thus the installation of PV panels requires less work and infrastructure [16]. If the hydropower type is pumped storage for this hybrid system, the electricity generated with the solar photovoltaic system can be used for pumping the water to the upper reservoir. The floating solar photovoltaics will have shading effect on the hydropower reservoir. This shading effect can reduce algae growth in the water reservoir so it can improve water quality. The large water reservoir can provide an area free of shading objects for the solar floating photovoltaic system which can improve photovoltaic generation with higher sunlight reflection.

1.2. Importance of the Floating Solar Photovoltaic System

There are three types of heat transfer mechanisms. First type is conduction which is the transfer of energy from more energetic particles of a substance to the adjacent, less energetic ones as a result of interactions between the particles. Second type is convection that is the mode of heat transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The last type of heat transfer mechanisms is radiation which is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules [17]. While analyzing the floating solar photovoltaics system all three types of heat transfer mechanisms have to be considered. Some examples for the heat transfer mechanisms occurring in the floating solar photovoltaics system were given. The heat will transfer from the sun to the photovoltaic modules with radiation. The photovoltaic modules are in contact with air. There will be heat transfer from the hot photovoltaic modules to air with convection. There will be heat transfer between the layers of the photovoltaic module with conduction. There will be heat transfer between the photovoltaic modules and the pontoons, there will also be heat transfer from the pontoons to the reservoir. The warming of the photovoltaics reduces their efficiency. It can be said that the reservoir can cool the photovoltaic modules which effects the performance of the modules positively.

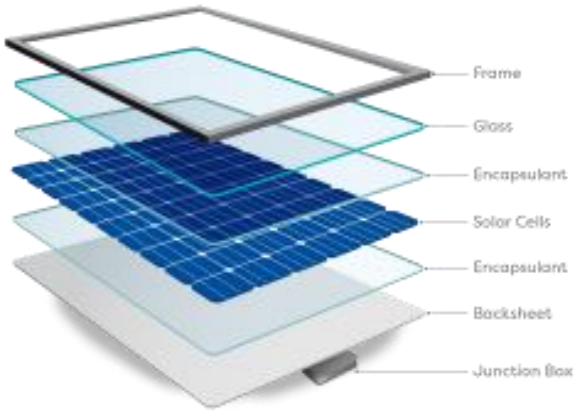


Figure 1.7 The Layers of a Photovoltaic Module [18]

From the water reservoir to the air there are always evaporation. Evaporation occurs at all temperature degrees. If the water reservoir is equipped with the floating solar photovoltaic system, evaporation from the water reservoir will decrease. If the water reservoir is very big, the losses from evaporation will also very much. So, it is a big advantage for the hydroelectric power plants with the big water reservoirs. The conventional type of the solar photovoltaic systems is mounted on the natural lands. The floating solar photovoltaics don't occupy land areas, these systems are mounted on the unused water surfaces. These surfaces can be a hydropower reservoir, a lake, a sea or an irrigation reservoir. Floating PV plants are more compact than land-based plants, their management is simpler and their construction and decommissioning straightforward. The main point is that no fixed structures exist, and the mooring of floating systems can be installed and removed in a totally reversible way, unlike the foundations used for a land-based plant which are far more intrusive and permanent [19]. If the floating solar photovoltaics and hydropower are combined with installing photovoltaic modules on the hydropower reservoirs both technologies can benefit. With reducing evaporation, the hydropower plant can generate more electricity. In this hybrid system several benefits can be achieved. If the hydropower type is pumped storage for this hybrid system, the electricity generated with the solar photovoltaic system can be used for pumping the water to the upper reservoir.

1.3. Global Floating Solar Photovoltaic Capacity

The floating solar photovoltaic systems are spreading worldwide. Deployment of floating solar photovoltaic is accelerating with global installed capacity up from below 1 MW in 2007 to 1,314 MW in 2018 and is expected to reach approximately 13,000 MW by 2022 [5]. Until the end of August 2020 the world total installed capacity of the floating solar photovoltaics was approximately 2.6 GW [20].

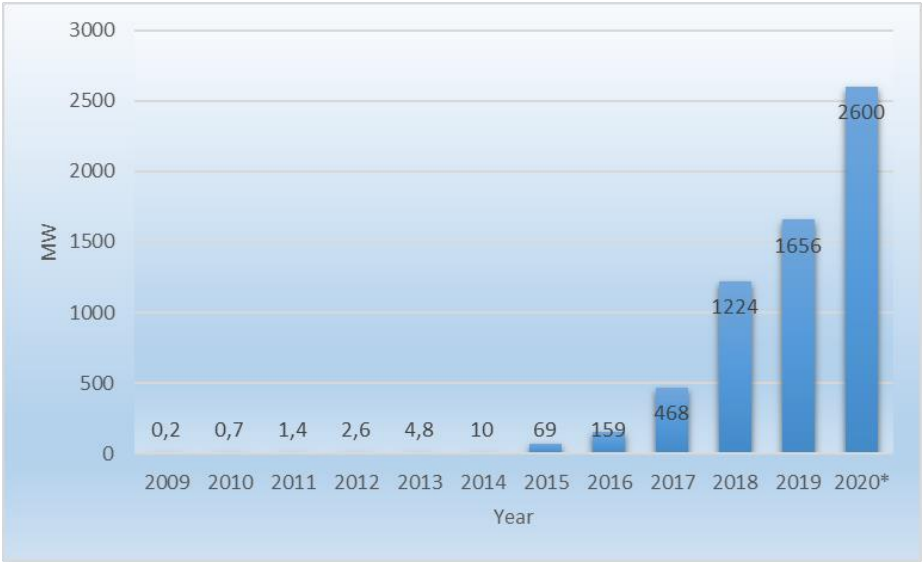


Figure 1.8 Global Installed Floating Solar Photovoltaic System Capacity (*The end of August 2020) [20,21]

The floating solar photovoltaics could well become the third pillar of the solar PV sector in future [20]. The floating solar photovoltaics is popular today in the world and it will be widespread in following years. As can be seen from the below map (Figure 1.9) these systems are being used especially in the Asia continent.



Figure 1.9 The Map of the Countries with Current Floating Solar Photovoltaic Installations [20]

China has the world's largest total installed capacity of the floating solar photovoltaics up to now. The first floating solar photovoltaics installation that was installed for research and development studies was in Aichi, Japan in 2007. The world's first commercial floating solar photovoltaics installation was in Far Niente Winery in Napa Valley, California in 2008 [20]. Its installed capacity was 175 kWp. The world's

largest floating solar photovoltaic system Dezhou Dingzhuang has been in operation in Shandong, China which has 320 MW installed capacity.

Dam/reservoir	Country	Reservoir size (km^2)	Hydropower (GW)	Percentage of reservoir area required for FPV to match dam's hydropower capacity (%)
Bakun Dam	Malaysia	690	2.4	3
Lake Volta	Ghana	8,500	1.0	<1
Guri Dam	Venezuela	4,250	10.2	2
Sobradinho "Lake"	Brazil	4,220	1.0	<1
Aswan Dam	Egypt	5,000	2.0	<1
Attaturk Lake and Dam	Turkey	820	2.4	3
Narmada Dam	India	375	1.5	4

Figure 1.10 Reservoir Size and Estimated Power Generation Capacity of Selected Hydropower Dams and Potential of Floating Solar Photovoltaic Systems to Match the Dams' Hydropower Capacity [5]

Ataturk Dam and Hydroelectric Power Plant is the biggest hydropower plant in Turkey with its 2.4 GW installed capacity and it has a large water reservoir with 820 km^2. It can be deduced from the above figure that with using 3% of Ataturk Dam and Hydroelectric Power Plant's water reservoir a floating solar photovoltaic system can be installed with 2.4 GW capacity. This capacity is almost equal to the world total installed capacity of floating solar photovoltaic systems until the end of August 2020 that was 2.6 GW.

1.4. A Review of Turkey's Floating Solar Photovoltaic Potential

Turkey's total installed capacity is 99820 MW as of the date of 1st of January 2022 according to Installed Capacity Report of Turkish Electricity Transmission Corporation [22]. Turkey's total hydropower installed capacity is 31493 MW and total solar power plant installed capacity is 7816 MW.

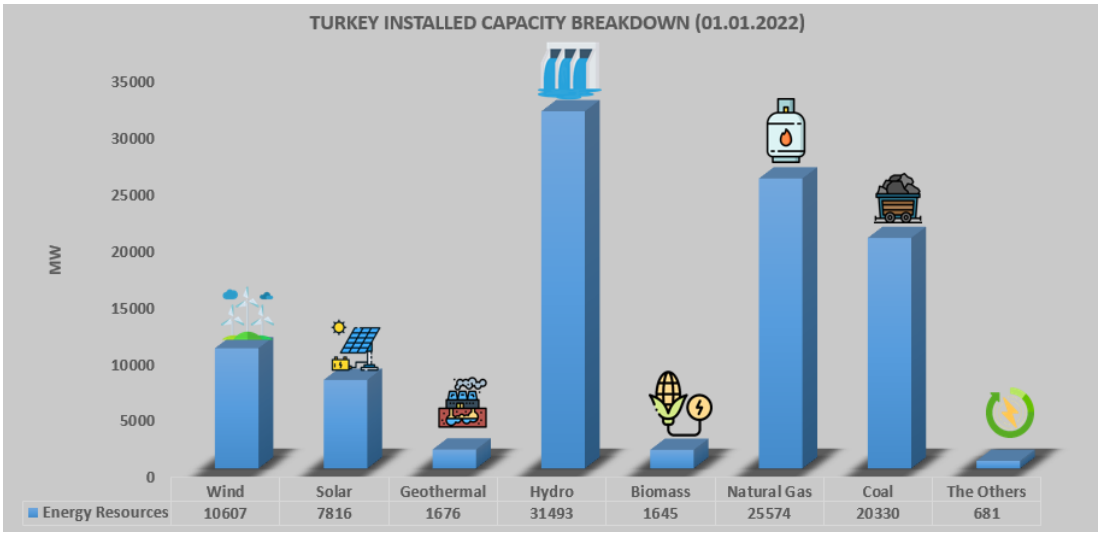


Figure 1.11 Turkey Installed Capacity Breakdown [22]

As it was shown in the above figure hydropower has the greatest installed capacity in Turkey. Turkey has 745 hydroelectric power plants, 604 of them are run-of river type and 141 of them are storage type hydroelectric power plants [22]. Storage type hydroelectric power plants have bigger water reservoir areas. Turkey has big potential for floating solar photovoltaic and hydroelectric power plant hybrid systems. In Turkey Ataturk Dam and HEPP has 2.4 GW installed capacity and 820 km^2 water reservoir area, Karakaya Dam and HEPP has 1800 MW installed capacity and 268 km^2 water reservoir area, Keban Dam and HEPP has 1330 MW installed capacity and 687 km^2 water reservoir area, Ilısu Dam and HEPP has 1208 MW installed capacity and 318 km^2 water reservoir area [23]. These are the top four greatest hydropower plants of Turkey with their installed capacities. According to the literature survey 1 MW floating solar photovoltaic system can be mounted on a hydropower water reservoir with about 9000 m^2. These four dams have total 2093 km^2 water reservoir area. If the floating solar photovoltaic systems are mounted on one tenth of these dams' water reservoir area, the total floating solar photovoltaic installed capacity will be approximately 41860 MW.

Ranking	Country	Capacity added (MW)
1	China	13,760
2	Turkey	2,480
3	India	478
4	Angola	401
5	Russia	380
6	Norway	324
7	Israel	300
8	Canada	275
9	Ethiopia	254
10	Indonesia	236

Figure 1.12 Top Ten Countries by New Hydropower Installed Capacity Added in 2020 [14]

Turkey added 2480 MW hydropower capacity in 2020 and became the second country about adding hydropower capacity in the world after China with 13760 MW added capacity [14]. In 2020 Turkey completed Ilısu HEPP with 1224 MW, Lower Kaleköy HEPP with 500 MW, Cetin HEPP with 429 MW capacities. Turkey has the second greatest hydropower installed capacity in Europe so the floating solar photovoltaic and hydropower hybrid solutions will be very beneficial to Turkey's solar installed capacity growth without using land areas.

CHAPTER 2

LITERATURE SURVEY

In the literature survey of this study, it was seen that there aren't a lot of published scientific papers about the performance analysis of floating solar photovoltaic and hydroelectric power plant hybrid systems. Below table shows the gain in the energy yield when a floating solar photovoltaic system used instead of a rooftop or an overland solar photovoltaic system and the weighted solar panel temperature decrease.

Table 2.1 The Performance Analysis Comparison Between The Overland and Floating Solar Photovoltaic Systems

Analysed Photovoltaic System Types	Location	Performance Analysis Type	Gain in Energy Yield	Weighted Solar Panel Tempeture Decrease (°C)	Referenced Scientific Paper
Overland and floating solar	South Korea (Hapcheon and Haman)	Empirical Data Analysis	%11 and more	N/A	K. Choi (2014) [30]
Floating, overland and rooftop solar	South-Holland (Netherlands) and	Empirical Data Analysis	3 %	Between 3.2 and 11.1 °C	M. Dörenkamper et al. (2020) [31]
Floating and rooftop solar	Tengeh Reservoir (Singapore)	Empirical Data Analysis	4-6 %	Between 9.9 and 14.5 °C	M. Dörenkamper et al. (2020) [31]
Overland and floating solar	N/A	Mathematical Model Simulation	12.96 %	N/A	S. Z. Golroodbari et al. (2020) [32]
Overland and floating solar	Peninsular Malaysia	Mathematical Model Simulation	15.5 %	10 °C	Z. A. A. Majid et al. (2014) [33]
Overland and floating solar	Marsh-Al Dalmach (Iraq)	Mathematical Model Simulation	9%	N/A	A.Z. Abass et al. (2020) [34]
Overland and floating solar	N/A	Mathematical Model Simulation	0.31-2.59 %	N/A	S. O. Pinto et al. (2020) [35]
Overland and floating solar	China	Mathematical Model Simulation	1.58-2 %	5 °C	L. Liu et al. (2017) [36]
Overland and floating solar	Kjeller (Norway)	Empirical Data Analysis	2-6 %	6-7 °C	Lereng (2018) [11]



Figure 2.1 Alto Rabagão Hybrid Floating Solar Photovoltaic and Hydroelectric Power Plant [24]

The first hybrid floating solar photovoltaic and hydropower system has been in operation since November, 2016. This system is located in Montalegre, Portugal and its installed capacity is 218 kWp. The hydroelectric dam's total water reservoir area is 22 km^2. There are 840 floating solar panels of 260 W modules on the floating platform. The total area of the floating solar photovoltaic is 2500 m^2 which is about 0,01% of the total water reservoir area. The floating platform was anchored at the bottom of the water reservoir. The anchoring system was designed to meet a maximum 60 m depth while dealing with 30 m water level variation [24].



Figure 2.2 Azmak 2 HEPP Floating Solar Photovoltaics System [25]

Azmak 2 Floating Solar Photovoltaic System is located in Mersin, Turkey. It is the first floating solar photovoltaics system in Turkey. It was installed in 2014. Its installed capacity is 10 kWp. It was a prototype installation [25].



Figure 2.3 Büyükçekmece Lake Floating Solar Photovoltaics System [26]

Büyükçekmece Lake Floating Solar Photovoltaics System is located in Istanbul, Turkey. The system consists of 960 floating solar panels each of them has 260 W capacity. The total installed capacity of the system is 249.6 kWp. This system was installed in 2017. The plant is expected to prevent 210 tons of carbon dioxide emission every year [26].



Figure 2.4 Floating Solar Photovoltaic System Installation in Walden, Colorado, USA [27]

The Walden Pond floating solar photovoltaic system was installed on a water treatment reservoir in Walden, Colorado, USA. The water reservoir area is 1,320 m^2. There are 208 solar panels of 355 W capacity modules on the floating platform. The floating solar photovoltaic system is occupying 52% of the water reservoir area. The system has been in operation since October, 2018 [24].



Figure 2.5 Hanaoka Ike Floating Solar Photovoltaics System [24]

Hanaoka Ike floating solar photovoltaics system is located in Hyogo, Japan. Its installed capacity is 2,290 kWp. It was built on an irrigation reservoir with an area of 44,027 m^2. The tolta structure covers the %47 of the water surface. There are 6,107 floating solar panels of 72 cells (375 W modules) on the floating platform. The floating platform anchored at the bottom of the pond with 6.45 m depth. The Hanaoka Ike has been in operation since March 2020 [24].



Figure 2.6 Anhui CECEP Floating Solar Photovoltaics System [24]

Anhui CECEP Floating Solar Photovoltaics System was installed on a mine lake, it is located in Bengbu in the province of Anhui, China. Its installed capacity is 70,005 kWp. The total floating structure occupy more than 600,000 m^2 on the lake. There are 194,731 floating solar panels of 60 cells (335 W and 360 W solar modules) on the

floating platform. The floating platfrom anchored at the bottom of the pond, which has a depth of 14 m. The level variation on the lake is 3.9 m. This floating solar plant has been in operation since March 2019 [24]. It is one of the largest floating solar plants in the world.



Figure 2.7 Sobradinho Floating Solar Photovoltaics System [24]

Sobradinho Floating Solar Photovoltaics System was installed on a hydropower reservoir in Bahia, Brazil. Its installed capacity is 1,005 kWp. This hydropower's reservoir area is 421.400.000 m^2. The floating platform carries 3,792 floating solar panels of 60 cells (256 W solar modules). The floating platform was anchored to the bottom of the reservoir that has 29.3 m depth. There is 13 m water level variation, the floating system was adapted with this level variation. This dam's floating solar plant has been operational since August 2019 [24].

Lereng has a study about the cooling effect for floating PV modules in thermal contact with water and the potential for modelling floating PV. He estimated the cooling effect by analyzing the experimental data which was collected from the test site at IFE. The floating photovoltaic module's temperature and power output values were measured at this test site. These measured values were compared with reference module's data. Lereng also developed a thermal model for estimating the temperature and power output of a floating solar photovoltaic module. PVsyst and TRNSYS programs were also used for simulating the floating solar photovoltaic modules and their simulation abilities were compared [11].

A.P. Sukarso and K. N. Kim has a study about the cooling Effect on the floating solar PV: performance and economic analysis on the case of West Java province in

Indonesia. They used remote sensing devices to predict floating solar photovoltaic system's efficiency and measure energy yield from the system. They also compared the floating solar photovoltaic and ground based solar photovoltaic systems. The important results from this study are as follows; they found that lake is cooler than the ground with about 8 ^{o}C annually. They predicted the floating solar photovoltaic systems' efficiency about 0.61 % higher than ground mounted photovoltaic system's efficiency [29].

N. Lee et al. have a study about hybrid floating solar photovoltaics-hydropower systems: benefits and global assessment of technical potential. They described global potential globally of hybrid floating solar photovoltaic and hydropower systems ranging from 3.0 TW to 7.6 TW (4,251 TWh to 10,616 TWh annual generation). This global potential was based on their assumptions. They gave some details about benefits in operation with these hybrid solutions for future modeling and/or analyses of existing or planned hybrid systems [9].

K. Choi from K-water (Korea Water Resources Corporation) published a scientific paper with the subject of a study on power generation analysis of floating photovoltaic system considering environmental impact in 2014. K-water's 99.36 kW and 496.8 kW floating solar photovoltaic systems with 33° tilt angle and a near overland photovoltaic project with 935.9 kW installed capacity and 30° tilt angle were used in their studies [30].

M. Dörenkamper and his friends published a scientific paper about the cooling effect of floating PV in two different climate zones: a comparison of field test data from the Netherlands and Singapore. They compared a ground mounted solar photovoltaic system and floating solar photovoltaic systems' irradiance weighted average temperatures in two different climate zones [31].

S. Z. Goldbaari and her friends have a study about Simulation of performance differences between offshore and land-based photovoltaic systems. The purpose of this study is to model, simulate, and compare the performance of a photovoltaics system on land and at sea. They considered sea waves, wind speed and relative humidity in modelling. They modelled sea waves in the frequency domain with a wave spectrum. The temperature estimations were done for both floating and ground mounted solar photovoltaic systems. Energy generations were calculated for different weather

conditions. The results show that the relative annual average output energy is about 12.96% higher at sea compared with land [32].

Z. A. A. Majid and his friends have a study about Performance of 80 Watt Floating Panel. In this study, they did an experiment for two hours in a pond simulator and they found that the energy generation of floating solar photovoltaic system increased up to 15.5 % than a normal solar photovoltaic system [33].

A. Z. Abass and D. A. Pavlyuchenko have a study about The Use of Floating Solar Panels in Hot Regions Such as Iraq to Benefit in Cooling the Panels and Increasing Their Efficiency. For the purpose of their study, they chose Marsh Al-Dalmach in Iraq where the solar radiation is 2150 kWh/m^2 annually. They conducted a survey around this area and they collected data for using in the softwares for example Homer and Matlab. According to their study results the temperature of the solar panels reduced and the efficiency of the solar panels increased from 15 to 24 % [34].

S. O. Pinto and J. Stokkermans have a study about Assessment of the potential of different floating solar technologies –Overview and analysis of different case studies. They did numerical simulations in PVsyst for energy production of floating solar photovoltaic systems. According to their results the increase in energy production of a floating solar photovoltaic system is about 0.31 to 2.59 % depending on the floating solar technology. They emphasized that the technology of the floating solar photovoltaic system and the location are important parameters for higher performance of the system [35].

L. Liu and his friends have a study about Power Generation Efficiency and Prospects of Floating Photovoltaic Systems. They discussed the development of photovoltaic technology. Then they worked on the efficiency of floating solar photovoltaic systems. Finally, they analyzed the advantages and potential of floating solar photovoltaic systems in China [36].

R. Gonzalez Sanchez and his friends have a study about Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa. In this study they analyzed the potential floating solar photovoltaic system installations on the largest 146 hydropower water reservoirs in Africa with the contribution of highly accurate water surface data. In addition to the electricity production, evaporation savings and the potential extra hydroelectricity generated by these water savings are also estimated

at reservoir level for four different cases and two types of floating structures. Their results indicate that with using less than 1 % of these hydropower reservoirs for installing floating solar photovoltaic systems, the hybrid system installed capacity can double the existing hydropower installed capacity. The electricity generation can be increased by 58 % with 46.06 TWh extra electricity generation. [37].

Huzaifa Rauf and his friends have a study about Integrating Floating Solar PV with Hydroelectric Power Plant: Analysis of Ghazi Barotha Reservoir in Pakistan. In this study they analyzed hybrid hydropower floating solar photovoltaic system on a small dam which is located in Pakistan. Their results show that floating solar photovoltaic system can support the hydroelectric power plant's electricity generation and the both systems can generate electricity together [38].

Uri Stiubiener and his friends have a study about PV power generation on hydro dam's reservoirs in Brazil: A way to improve operational flexibility. According to the results of this paper they found that with using less than 10 % of the hydropower water reservoirs in Brazil for mounting floating solar photovoltaic systems the hybrid hydropower floating solar photovoltaic system can generate electricity without harming each other's energy generation plan. Floating solar photovoltaic system can generate electricity during peak irradiation hours and hydropower plant can generate electricity during low or no irradiation times. This sequence can improve operational flexibility [39].

Parisa Ranjbaran and his friends have a study about A review on floating photovoltaic (FPV) power generation units. In this paper, an analytical analysis was carried out for energy generation of floating solar photovoltaic systems. They compared the ground mounted and floating solar photovoltaic systems [40].

N. M. Silverio and his friends have a study about Use of floating PV plants for coordinated operation with hydropower plants: Case study of the hydroelectric plants of the São Francisco River basin. Hybrid floating solar photovoltaic and hydropower plant operation's technical and economical sizing procedure was presented in this paper. São Francisco River basin has intense droughts. The case study focused on hydropower plants located on this river.

Their paper results show that the floating solar photovoltaic system with 3° solar panel tilt angle can generate electricity at the lowest cost. The energy generation gain by the

hydropower plant after adding floating solar photovoltaic system on the hydropower water reservoir was 76 % and the capacity factor the power plant increased by 17.3 % on average [41].

Luyao Liu and his friends have a study about Evaluating the benefits of Integrating Floating Photovoltaic and Pumped Storage Power System. The system would help to save 20.16 km^2 land with mounting the solar photovoltaic system on the water reservoir and 19.06 million m^3 water a year due to the reduction in evaporation loss from the water reservoir [42].

Huzaifa Rauf and his friends have a study about Complementing hydroelectric power with floating solar PV for daytime peak electricity demand. The hybrid floating solar photovoltaic with 200 MWp installed capacity and hydropower plant generates more than 3.5 % additional electricity together with respect to the electricity generation of hydropower plant alone. Floating solar photovoltaic system can generate electricity with the daily mid-day peak load and can work a peak power plant for the grid [43].

CHAPTER 3

MATERIAL AND METHOD

In this chapter performance analysis of hybrid floating solar photovoltaic and hydropower plant is clarified. Gursogut-1 Dam and HEPP was selected as the hydropower plant for this paper and a floating solar photovoltaic system will be integrated to this power plant's actual operation period. Gursogut Dam and HEPP is located in Ankara-Eskişehir in Turkey. Gursogut Dam and HEPP is located on Sakarya River. Gursogut HEPP's total installed capacity is 58,17 MWm / 55,8 MWe. Its total reservoir area is 6,37 km^2. Gursogut HEPP is in operation with its total installed capacity since 25.06.2021. Its annual electricity generation is 302.475.000 kWh according to the water inflow values on Sakarya River for many years. Gursogut HEPP is seperated as Gursogut-1 HEPP and Gursogut-2 HEPP. Gursogut-1 HEPP's total installed capacity is 39,63 MWm / 38,08 MWe. Gursogut-1 HEPP's maximum water level is 649 m and minimum water level is 642 m above from sea level. It means Gursogut-1 HEPP's operating water level variation is 7 m. Gursogut-1 HEPP river bed level is 600 m. Annual average water flow rate coming from the Sakarya Lake to the dam is 47 m^3/s. It is a storage type dam. The dam's maximum water storage capacity is 56,529 hm^3, minimum water storage volume is 34,68 hm^3. Its active water storage volume is 21,849 hm^3.

Gürsögüt-1 Barajı		
Kot	**Alan**	**Hacim**
(m)	(km^2)	(hm^3)
595.00	0.000	0.000
600.00	0.190	0.500
610.00	0.440	3.800
620.00	0.860	10.400
630.00	1.360	21.500
640.00	2.440	40.500
650.00	5.630	80.900

Figure 3.1 Gursogut-1 Dam and HEPP Elevation-Area-Volume Diagram

From the above figure it can be calculated with interpolation that at 649 m water level the water reservoir area is about 5.311 km^2. The water reservoir area at 642 m water level is about 3.078 km^2. Gursogut-1 HEPP's annual electricity generation is

206.069.868 kWh. It has two big units with 17,63 MWm / 16,96 MWe capacity, 32,7 m^3/s turbine discharge and one small unit with 4,37 MWm / 4,16 MWe capacity, 10 m^3/s turbine discharge. The total turbine discharge of the hydroelectric power plant is 75,4 m^3/s. Gursogut-1 HEPP two big units' turbine type is vertical francis and the small unit's turbine type is horizontal francis. Generally, the power capacities under 10 MW of a francis turbine unit can be chosen as horizontal francis turbine.

There are generally two hydro turbine types. These are impulse and reaction turbines. Impulse turbine type is divided into pelton, turgo and cross flow. Reaction turbine type is divided into bulb, francis and kaplan. The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. An impulse turbine is generally suitable for high head, low flow applications. A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines. The most used hydro turbine types are francis, kaplan and pelton worldwide.

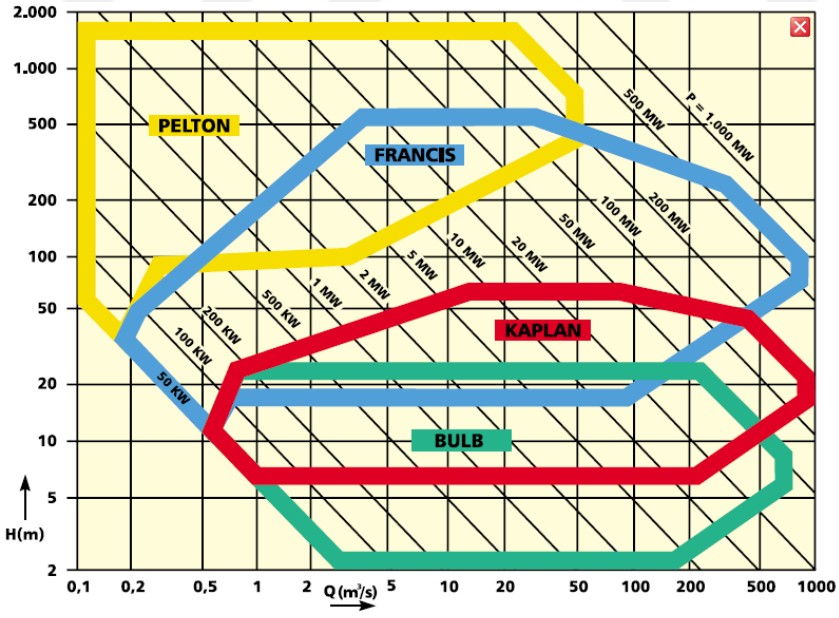


Figure 3.2 Hydro Turbine Selection Chart [44]

It is a graph for selecting the turbine type. Generally, for the net heads between 7 m and 40 m kaplan turbine can be chosen. For the hydropower plants with the net heads

bigger than 10 m and lower than 350 m the Francis turbine can be suitable. For the projects that have higher heads and lower flows choosing pelton turbine can be appropriate.

TURBINE TYPE	NET HEAD
KAPLAN	7 m<H<40 m
FRANCIS	10 m<H<350 m
PELTON	50 m<H<1300 m

Figure 3.3 Hydro Turbine Type-Net Head Diagram

For the Francis turbines cavitation is a big problem. If the pressure of a liquid in course of its flow becomes equal to its vapor pressure at the existing temperature, then the liquid starts boiling and the pockets of vapors are formed which create vapor locks to the flow and the flow is stopped. The phenomenon is known as cavitation [45]. Reaction turbines like Francis and Kaplan are more prone to cavitation as pressure of water flow varies inside the turbines [46]. Francis turbines' water discharge shouldn't be reduced under 45 % of their nominal water flow rates and their power output shouldn't be reduced under 50 % of their nominal power output. It is important for the Francis turbines' proper and trouble-free working at higher efficiency values. It means that with working at higher operating water levels the turbine can work with higher efficiency values and it can also avoid the turbine from cavitation damages. Below figure is an example of how cavitation can cause catastrophic damage on a francis turbine runner.

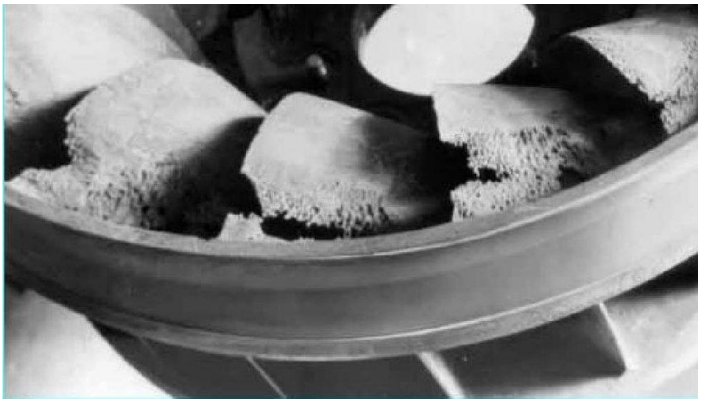


Figure 3.4 Cavitation Damage on a Francis Turbine Runner [47]

As can be seen from the below figure at higher net heads and at full load turbine outputs and turbine efficiencies are higher. Today turbine efficiencies can be higher than 94 % with proper design of the turbine runner and other turbine equipment. Gursogut-1 HEPP's weighted average turbine efficiency is 91.82 %.

Net Head (m.)	Turbine Output (%)	100	80	60	40
	Weighting factor	*5*	*2.9*	*1.5*	*0.6*
Maximum Net	Turbine Output (MW)	**17.63**	**14.13**	**10.04**	**5.59**
Head	Efficiency (%)	**95.00**	**92.66**	**87.79**	**73.39**
59.52 m.	Turbine Discharge (m^3/s)	**31.8**	**26.16**	**19.62**	**13.08**
	Weighting factor	*10*	*5.8*	*3*	*1.2*
Rated Net	Turbine Output (MW)	**17.63**	**13.76**	**9.82**	**5.45**
Head	Efficiency (%)	**94.87**	**92.57**	**88.08**	**73.35**
58.05 m.	Turbine Discharge (m^3/s)	**32.70**	**26.16**	**19.62**	**13.08**
	Weighting factor	*30*	*17.4*	*9*	*3.6*
Weighted Net	Turbine Output (MW)	**17.46**	**13.63**	**9.74**	**5.40**
Head	Efficiency (%)	**94.84**	**92.54**	**88.16**	**73.28**
57,49 m.	Turbine Discharge (m^3/s)	**32.70**	**26.16**	**19.62**	**13.08**
	Weighting factor	*5*	*2.9*	*1.5*	*0.6*
Minimum Net	Turbine Output (MW)	**15.40**	**11.99**	**8.63**	**4.65**
Head	Efficiency (%)	**94.23**	**91.69**	**87.98**	**71.09**
51.05 m.	Turbine Discharge (m^3/s)	**32.70**	**26.16**	**19.62**	**13.08**
Guaranteed Weighted Average Efficiency		**91.82 %**			

Figure 3.5 Gursogut-1 HEPP Turbine Data Diagram

As can be seen from the above figure Gursogut-1 HEPP's big turbine units can work with 95 % turbine efficiency at maximum net head which is 59.52 m with 31.8 m3/s turbine discharge and 17.63 MW mechanical turbine output. The turbines can also generate 17.63 MW turbine output at 58.05 m nominal net head with 32.7 m3/s turbine discharge and 94.87 % turbine efficiency.

Table 3.1 Gursogut-1 HEPP Average Water Inflow Values for Many Years (hm^3)

YIL	EKİ	KAS	ARA	OCA	ŞUB	MAR	NİS	MAY	HAZ	TEM	AĞU	EYL	TOPLAM
1974	103.176	99.456	100.035	90.052	82.053	113.207	88.336	101.007	78.821	52.744	59.127	83.776	1051.790
1975	105.601	110.644	97.659	103.525	93.640	138.579	133.870	243.473	122.337	68.615	71.471	82.254	1371.668
1976	106.385	115.741	109.892	111.919	125.072	204.618	203.425	148.598	112.126	74.427	75.298	98.891	1486.393
1977	128.131	125.389	136.770	118.922	163.810	150.168	137.362	108.989	65.255	61.173	64.123	118.024	1378.116
1978	136.689	110.382	107.442	127.356	237.963	183.447	221.841	137.056	93.509	71.583	65.702	111.329	1604.299
1979	146.950	162.849	195.982	294.209	296.420	181.539	139.968	156.614	164.636	87.223	85.893	131.953	2044.235
1980	187.914	183.610	166.944	177.681	182.780	267.723	252.459	225.663	116.965	82.552	96.639	150.147	2091.078
1981	178.882	154.981	152.532	198.455	187.091	393.312	230.208	199.096	124.192	108.824	98.521	143.476	2169.570
1982	181.217	188.650	249.642	208.836	148.962	167.229	214.444	168.856	141.025	84.799	85.053	106.976	1945.688
1983	137.527	136.526	123.294	125.288	115.044	182.089	187.639	105.991	127.461	92.828	83.716	92.643	1510.045
1984	109.416	138.260	177.340	159.932	179.628	247.199	347.938	357.251	132.767	138.415	138.738	132.914	2259.797
1985	151.738	154.136	145.174	160.558	147.730	221.869	224.641	118.901	116.415	91.061	89.470	102.082	1723.774
1986	129.689	142.793	131.746	174.339	189.235	168.325	91.619	100.838	114.969	71.015	70.965	94.570	1480.104
1987	111.407	112.526	117.486	190.471	184.359	178.213	241.441	169.205	110.593	71.323	68.839	81.642	1637.504
1988	118.103	131.509	141.594	130.080	108.166	196.817	217.460	145.733	130.823	76.916	72.394	97.332	1566.926
1989	136.617	157.717	152.256	130.368	109.216	117.262	71.697	86.339	77.835	57.143	59.060	73.426	1228.936
1990	118.926	119.051	140.138	126.259	111.512	129.432	137.842	131.657	81.968	58.486	53.142	86.539	1294.951
1991	105.627	111.525	125.867	113.678	115.160	118.992	123.357	116.033	86.437	39.655	43.887	76.900	1177.117
1992	110.803	108.409	110.862	105.496	90.740	157.432	209.025	70.711	69.696	73.805	48.903	60.928	1216.810
1993	94.673	105.621	116.209	113.269	123.193	184.310	136.762	147.887	79.788	34.313	34.602	59.687	1230.315
1994	85.592	91.254	100.820	110.254	92.238	108.011	84.696	79.739	35.734	24.235	33.334	52.006	897.913
1995	78.873	96.081	93.971	119.590	90.044	128.140	152.990	84.197	47.837	56.073	41.423	66.846	1056.066
1996	88.927	116.362	107.739	118.804	123.252	174.066	206.436	111.356	84.148	40.516	45.671	79.967	1297.243
1997	114.761	104.502	121.716	139.613	106.151	103.929	193.310	174.301	125.651	48.619	71.146	83.900	1387.598
1998	134.445	144.758	174.163	151.469	177.974	166.174	237.736	248.082	200.573	53.768	43.397	81.501	1814.040
1999	119.960	128.886	142.167	138.755	195.769	237.502	256.078	117.963	100.287	75.587	88.432	109.115	1710.501
2000	129.685	134.710	133.465	125.882	112.198	140.745	222.302	137.490	91.753	69.939	75.274	98.497	1471.939
2001	115.167	115.660	111.502	116.438	98.899	97.979	94.478	114.881	64.607	64.778	69.086	84.161	1147.636
2002	100.993	119.489	203.113	160.022	146.232	157.435	248.005	140.144	83.452	87.519	88.263	117.774	1652.439
2003	133.729	138.259	126.803	139.827	128.576	106.850	174.192	113.524	76.023	78.494	91.042	114.150	1421.470
2004	130.039	135.102	128.336	139.320	138.424	119.451	171.748	118.968	86.560	83.241	89.074	108.826	1449.088
2005	114.723	110.140	109.260	122.388	104.079	149.776	149.136	120.895	105.697	86.995	86.985	115.691	1375.766
2006	125.894	128.724	116.957	115.504	124.142	165.570	123.630	92.811	66.570	69.162	66.558	96.605	1292.127
2007	125.013	114.311	116.286	105.425	102.217	97.297	88.846	91.172	67.522	59.331	66.120	82.327	1115.868
2008	92.227	110.008	133.146	95.974	79.004	135.283	120.539	91.447	62.496	51.728	54.189	72.340	1098.381
2009	103.130	113.915	105.809	131.892	159.117	151.363	185.284	146.157	79.761	76.639	80.808	108.339	1442.215
2010	122.621	129.684	148.922	151.831	203.230	146.810	139.913	109.137	87.066	67.415	85.359	112.011	1504.000
2011	149.021	134.096	164.536	145.916	112.708	143.079	185.973	163.509	136.176	91.960	89.196	117.745	1633.914
2012	146.705	145.760	141.206	141.157	133.124	190.069	200.683	144.863	95.444	92.994	101.249	115.747	1649.000
ORT. (hm^3)	123.358	127.730	135.353	139.250	138.953	164.649	175.572	139.501	98.589	71.177	72.619	97.514	**1484.265**
	123.689												

The average monthly water inflow from Sakarya River to Gursogut-1 HEPP was 123.689 hm^3 according to the above table. The daily average water inflow can be calculated as 47.72 m^3/s for many years. This table was prepared for Gursogut HEPP project's feasibility report. The data in this table was deduced from the data which was

collected on the Sakarya River basin by Turkey's EIE and DSI (Directorate General of State Hydraulic Works) corporations for many years.

Table 3.2 Kargı HEPP Annual Total Water Inflow from Sakarya River 2018-2020

Kargı HEPP Annual Total Water Inflow from Sakarya River 2018-2020													
Year/Month	January	February	March	April	May	June	Jully	August	September	October	November	December	TOTAL
2018	108,24	92,18	120,71	55,66	73,05	72,51	30,14	41,12	44,73	71,68	79,35	104,68	894,05
2019	118,95	121,79	124,4	94,3	59,69	75,56	37,61	31,96	38,91	53,27	62,76	98,84	918,04
2020	104,9	117,48	122,37	82,78	62,34	69,74	21,71	21,81	29,6	0	61,3	70,98	765,01
Average Water Inflow for Many Years	139,25	138,953	164,649	175,57	139,501	98,589	71,177	72,619	97,514	123,358	127,73	135,353	1.484,27

Kargı HEPP is located at the downstream of the Gursogut HEPP on Sakarya River and it is in operation since 2017. On Table 3.2 annual total water inflow to Kargı HEPP between the years 2018-2020 and average water inflow for many years from Table 3.1 can be seen. It can be deduced from Table 3.2 that the water inflow from Sakarya River to Kargı Dam decreased about 38-48 % between the years 2018-2020 from the average water inflow for many years.

Table 3.3 Gursogut-1 HEPP 2021 Daily Average Water Flow Rate Coming from Sakarya River (m^3/s)

Gursogut-1 HEPP 2021 Average Daily Water Flow Rate Coming from Sakarya River (m3/s)												
Day/Month	January	February	March	April	May	June	Jully	August	September	October	November	December
1	29,34	37,64	30,30	37,63	8,85	13,19	1,45	2,69	8,87	13,09	13,78	38,34
2	29,69	36,14	27,76	49,51	9,14	12,50	9,65	4,81	12,32	13,22	16,06	32,03
3	33,40	33,99	38,55	39,24	9,08	13,76	6,84	4,47	11,18	10,89	15,61	26,75
4	34,25	31,03	35,18	40,86	7,73	10,57	8,00	3,79	9,47	14,58	17,72	24,58
5	32,10	36,19	38,60	39,13	7,91	9,54	6,85	4,59	10,50	12,04	14,41	24,57
6	37,16	33,99	30,74	35,31	8,18	9,78	6,06	5,95	10,16	13,07	13,41	27,03
7	42,43	31,83	38,27	35,41	10,76	9,85	5,60	5,13	10,04	14,23	13,45	26,05
8	35,70	32,79	31,32	39,70	9,69	10,69	6,00	9,36	9,70	14,21	13,61	27,66
9	31,30	33,29	40,60	35,20	6,41	12,45	7,05	7,65	9,70	13,46	14,02	29,39
10	31,66	33,29	35,02	36,36	8,39	15,09	6,31	10,04	9,58	9,99	15,29	28,48
11	32,12	33,69	33,08	36,36	7,41	16,48	4,85	6,29	9,93	16,18	19,69	24,63
12	30,40	35,95	31,69	37,05	8,98	21,89	5,27	6,29	10,27	13,60	15,61	25,76
13	33,78	31,10	31,36	37,17	10,57	23,52	5,77	5,61	9,93	14,56	17,03	28,72
14	41,93	26,85	33,36	34,86	10,08	57,42	4,43	6,29	12,02	14,73	16,08	27,10
15	46,14	34,12	32,14	31,51	7,54	6,02	4,31	5,95	15,71	13,96	17,69	33,32
16	36,25	34,01	36,44	30,75	8,33	35,07	4,54	5,72	24,95	12,56	15,19	48,53
17	36,23	33,97	42,21	32,53	7,87	23,07	2,97	5,60	13,91	17,39	16,60	33,86
18	36,18	33,97	40,52	29,00	9,66	21,22	3,27	6,40	16,43	13,19	15,33	31,25
19	33,51	39,23	38,23	33,34	9,13	15,07	3,70	5,72	14,60	13,03	16,81	30,83
20	34,84	26,24	36,17	24,85	8,33	16,13	4,12	5,49	16,22	15,22	18,19	31,36
21	29,28	27,25	39,09	24,56	9,81	22,35	5,50	6,85	14,53	15,65	19,46	31,60
22	31,41	29,53	46,63	23,80	10,48	22,36	3,08	9,01	14,11	14,36	19,77	27,56
23	32,94	35,46	41,32	17,14	11,89	27,21	2,67	6,29	14,42	12,71	20,22	28,33
24	33,52	30,46	46,51	13,05	12,37	20,07	2,67	7,89	13,57	13,53	23,05	25,40
25	30,50	30,41	55,62	12,62	11,03	20,00	1,31	7,16	13,88	12,08	27,22	28,76
26	36,46	37,20	49,28	17,73	8,59	18,44	3,92	5,44	13,03	15,06	24,83	27,60
27	33,55	40,60	43,97	13,90	10,00	27,10	4,18	7,89	13,89	12,40	22,96	27,65
28	31,51	26,98	42,58	12,70	10,00	15,26	3,19	7,77	13,89	13,04	28,19	26,90
29	39,77		40,97	11,67	13,66	12,39	3,02	7,89	14,35	11,71	29,13	30,26
30	28,87		40,86	11,14	11,71	10,77	3,42	8,61	14,00	11,92	24,41	23,62
31	35,98		40,86		10,85		3,64	9,56		12,69		26,63
Monthly Average Flow Rate (m3/s)	34,26	33,11	38,36	29,14	9,50	18,31	4,63	6,52	12,84	13,50	18,49	29,18
Monthly Total Water Inflow (hm3)	91,77	80,11	102,75	75,52	25,44	47,46	12,41	17,47	33,28	36,15	47,94	78,15

It can be seen from the above table the greatest daily water inflow rate from Sakarya River was 57.42 m^3/s on 14th of June 2021. Annual daily average water inflow rate

was 20.47 m^3/s in 2021. Total annual water inflow was 648.44 hm^3 in 2021. From 1974 to 2012 the average total water inflow in a year was 1484.265 hm^3 according to Table 3.1.

Table 3.4 Comparison Table of Gursogut-1 HEPP Average Water Inflow in 2021 and for Many Years from Sakarya River

Comparison Table of Gursogut-1 HEPP Average Water Inflow in 2021 and for Many Years from Sakarya River (hm3)													
Day/Month	January	February	March	April	May	June	Jully	August	September	October	November	December	TOTAL
Monthly Average Flow Rate (m3/s)	34,26	33,11	38,36	29,14	9,50	18,31	4,63	6,52	12,84	13,50	18,49	29,18	
Monthly Total Water Inflow (hm3)	91,77	80,11	102,75	75,52	25,44	47,46	12,41	17,47	33,28	36,15	47,94	78,15	648,44
Average Water Inflow for Many Years (hm3)	139,25	138,95	164,65	175,57	139,50	98,59	71,18	72,62	97,51	123,36	127,73	135,35	1484,27
Actual Decrease from Average Water Inflow for Many Years	34%	42%	38%	57%	82%	52%	83%	76%	66%	71%	62%	42%	56%

The total annual water inflow to Gursogut-1 HEPP in 2021 is about 44 % of the average annual total water inflow between the years 1974 and 2012. It means the water inflow on the Sakarya River Basin clearly decreased today. Such decrease in the water inflow in the river basin can occur big problems in the hydroelectric power plant projects' cash flows. In Gursogut-1 HEPP big units' turbine discharge is 32.7 m^3/s and the annual average daily water inflow was less than this value with 20.47 m^3/s. Because of the lack of water inflow, the turbine-generator units in Gursogut-1 HEPP can't reach the planned electricity generation capacity.

Specific water consumption is an efficient indicator for evaluating hydropower electricity generations. Specific water consumption is the water requirement for generating 1 kwh electricity with a turbine-generator unit. The lower values of specific water consumption mean the turbine-generator unit works efficiently and the water levels of the dam reservoir is kept higher. It can be calculated from dividing the total water amount used in the turbine by the total electricity generated.

Table 3.5 Gursogut-1 HEPP Daily Average Specific Water Consumption Values in 2021

Gursogut-1 HEPP Daily Average Specific Water Consumption 2021 (m3/kWh)												
Day/Month	**January**	**February**	**March**	**April**	**May**	**June**	**Jully**	**August**	**September**	**October**	**November**	**December**
1	8,20	7,17	8,66	6,83	7,41	8,50	7,18	8,34	8,73	7,07	7,49	7,11
2	8,10	7,26	8,81	6,83	7,75	8,52	7,08	8,34	8,74	7,08	7,97	7,17
3	7,89	7,36	8,72	6,82	7,75	8,30	7,56	8,34	8,61	7,15	7,29	7,05
4	8,58	7,40	8,58	6,83	7,04	8,22	7,56	8,45	8,62	7,16	7,29	7,02
5	8,60	7,39	8,50	6,83	7,26	8,18	7,49	8,48	8,62	6,96	7,31	7,04
6	8,68	7,44	8,36	6,82	7,49	8,08	7,79	8,47	8,63	7,14	7,86	7,22
7	8,52	7,51	8,31	6,85	8,15	7,67	7,15	8,51	8,50	6,98	7,68	7,11
8	8,47	7,58	8,24	6,83	7,39	8,11	7,66	8,49	8,49	7,17	7,55	7,08
9	8,59	7,57	8,13	6,85	7,76	7,94	7,69	8,49	8,49	7,02	7,60	7,08
10	8,53	7,58	8,17	6,85	9,65	7,93	7,64	8,48	8,31	7,00	7,29	7,08
11	8,42	7,57	8,07	6,85	9,37	7,78	7,69	8,48	8,36	7,05	7,43	6,97
12	8,31	7,60	8,04	6,87	9,29	7,79	7,71	8,49	8,36	7,13	7,53	6,95
13	8,20	7,63	8,04	6,88	9,37	7,70	7,64	8,45	8,36	7,15	7,20	7,04
14	8,01	7,68	8,05	6,88	9,29	7,32	7,69	8,49	8,23	7,25	7,29	7,15
15	7,71	7,75	7,76	6,90	9,27	7,32	7,73	8,59	8,24	6,90	7,35	7,09
16	7,56	7,76	7,71	6,90	9,34	6,99	7,84	8,62	7,93	7,33	7,11	7,09
17	7,44	7,82	7,64	6,92	9,22	7,05	7,93	8,58	7,87	7,31	7,06	7,10
18	7,31	7,93	7,42	6,96	9,26	7,07	7,83	8,61	7,73	7,46	7,04	7,14
19	7,22	8,00	6,78	6,98	9,27	7,00	7,85	8,61	7,64	7,73	7,14	7,14
20	7,13	8,05	6,75	7,05	9,26	7,10	7,84	8,59	7,54	7,38	7,12	6,90
21	7,05	3,22	6,73	7,22	9,29	7,24	7,96	8,42	7,54	7,41	7,14	7,23
22	6,99	8,10	6,60	7,08	9,24	6,78	7,91	8,49	7,54	7,40	7,21	7,14
23	6,99	8,17	6,86	7,20	9,11	7,08	7,97	8,49	7,44	7,45	7,17	7,20
24	6,99	8,21	6,85	7,92	9,12	7,08	7,96	8,62	7,44	7,81	7,12	7,17
25	6,99	8,37	6,84	8,00	8,95	6,92	7,83	8,63	7,34	7,54	7,17	7,24
26	7,01	8,43	6,79	7,96	8,96	7,16	8,09	8,73	7,34	7,43	7,11	7,17
27	6,99	8,42	6,82	7,82	8,80	7,45	8,10	8,78	7,31	7,64	7,08	7,23
28	7,01	8,43	6,79	7,47	8,81	7,41	7,93	8,71	7,24	7,57	7,56	7,25
29	7,02		6,83	7,76	8,81	7,14	8,32	8,75	7,15	7,88	7,14	7,30
30	7,13		6,84	7,72	8,65	7,45	8,27	8,87		8,05	7,38	7,30
31	7,16		6,83		8,67		8,27	8,78		7,75		6,99
Monthly Average Specific Water Consumption	7,70	7,62	7,60	7,12	8,68	7,54	7,78	8,55	8,01	7,33	7,32	7,12

In 2021 annual average specific water consumption of Gursogut-1 HEPP was 7.70 m^3/kWh. Daily specific water consumption of Gursogut-1 HEPP in 2021 is shown in above Table 3.5. This value is directly related with turbine-generator efficiency and dam reservoir water level. In May and August monthly average specific water consumption values of Gursogut-1 HEPP were 8.68 and 8.55 m^3/kWh respectively. These values are relatively high from the specific water consumptions in the other months.

Table 3.6 Gursogut-1 HEPP Daily Water Reservoir Levels in 2021

Gursogut-1 HEPP Daily Water Reservoir Levels in 2021 (m)												
Day/Month	**January**	**February**	**March**	**April**	**May**	**June**	**Jully**	**August**	**September**	**October**	**November**	**December**
1	644,60	647,85	645,20	648,75	646,80	645,29	648,34	645,88	645,02	648,32	647,15	648,07
2	645,00	647,80	645,10	648,90	646,80	645,47	648,17	645,80	645,15	648,28	647,36	648,30
3	645,00	647,70	645,40	648,88	646,78	645,68	648,17	645,71	645,25	648,32	647,34	648,27
4	644,80	647,75	645,60	648,88	646,42	645,80	648,19	645,60	645,30	648,40	647,37	648,02
5	644,70	647,70	645,90	648,85	645,80	645,90	648,18	645,51	645,38	648,40	647,36	647,88
6	644,75	647,60	645,95	648,78	645,30	646,00	648,03	645,46	645,45	648,45	647,51	648,13
7	644,95	647,45	646,10	648,80	645,30	646,12	647,88	645,42	645,52	648,47	647,65	648,09
8	644,95	647,40	646,30	648,78	644,50	646,25	647,86	645,47	645,58	648,63	647,78	648,08
9	644,90	647,40	646,50	648,68	643,60	646,43	647,78	645,47	645,64	648,46	647,95	648,10
10	645,15	647,40	646,55	648,60	643,48	646,68	647,77	645,54	645,70	648,30	647,98	648,08
11	645,40	647,30	646,55	648,52	643,48	646,97	647,72	645,50	645,77	647,82	648,16	647,98
12	645,60	647,25	646,55	648,45	643,50	647,36	647,68	645,46	645,85	647,55	648,30	647,85
13	645,90	647,15	646,75	648,38	643,58	647,78	647,66	645,39	645,92	647,30	648,29	647,59
14	646,40	647,00	647,00	648,27	643,65	648,73	647,60	645,35	646,05	647,18	648,41	647,30
15	647,00	646,90	647,20	648,11	643,62	648,73	647,54	645,30	646,27	647,05	648,59	647,16
16	647,30	646,80	647,50	647,90	643,62	648,74	647,48	645,24	646,68	646,95	648,52	647,38
17	647,60	646,70	647,80	647,70	643,62	648,52	647,38	645,18	646,80	646,88	648,32	647,25
18	647,90	646,60	647,85	647,40	643,67	648,32	647,29	645,14	646,99	646,80	648,10	647,25
19	648,10	646,60	647,70	647,20	643,70	648,20	647,21	645,08	647,12	646,90	648,04	647,24
20	648,30	646,30	647,80	646,95	643,70	648,09	647,14	645,02	647,29	646,88	648,01	647,27
21	648,40	646,20	647,95	646,80	643,76	648,15	647,10	645,00	647,42	646,85	647,80	647,27
22	648,50	646,05	648,20	646,55	643,88	648,16	647,00	645,04	647,54	646,77	647,78	647,18
23	648,50	646,00	648,20	646,20	644,05	648,25	646,88	645,00	647,67	646,64	647,65	647,10
24	648,50	645,80	648,30	646,27	644,22	648,15	646,76	645,00	647,78	646,75	647,45	646,92
25	648,45	645,60	648,55	646,35	644,35	647,99	646,61	644,98	647,90	646,72	647,42	646,82
26	648,50	645,60	648,70	646,63	644,40	647,90	646,52	644,90	648,00	646,68	647,21	646,72
27	648,50	645,70	648,75	646,75	644,50	648,28	646,44	644,90	648,09	646,72	647,06	646,60
28	648,35	645,40	648,80	646,78	644,60	648,45	646,34	644,90	648,18	646,78	647,36	646,42
29	648,30		648,80	646,85	644,82	648,50	646,22	644,90	648,28	646,90	647,26	646,32
30	648,05		648,80	646,90	644,98	648,57	646,12	644,92		647,02	647,58	646,05
31	647,90		648,80		645,10		646,02	644,99		647,12		645,94
Monthly Average Water Level	646,78	646,82	647,26	647,76	644,50	647,45	647,33	645,26	646,54	647,43	647,76	647,38

It can be seen from the above Table 3.6 that the monthly average water levels in May and August were 644.50 and 645.26 m from seal level respectively. These water levels are less than the maximum operating water level 649 m with 4.5 m and 3.74 m respectively. Operating the dam and hydroelectric plant at lower water reservoir levels cause higher specific water consumption values while generating electricity. If the water reservoir levels were higher than the actual values in especially May and August, the specific water consumption values of the hydroelectric power plant could be lower and the power plant could generate more electricity with using less water.

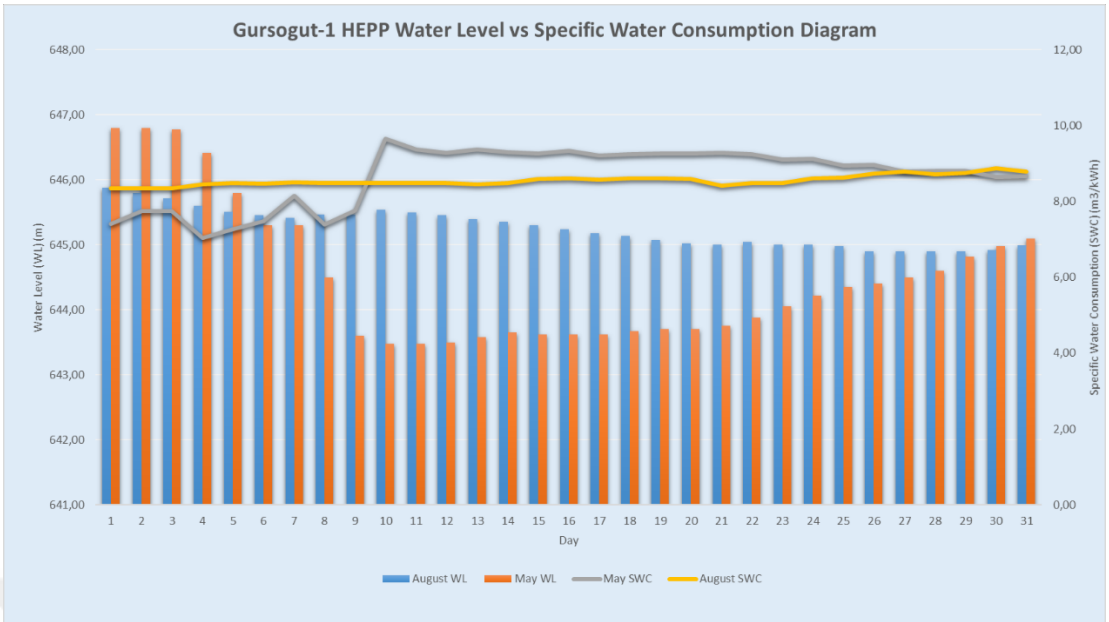


Figure 3.6 Gursogut-1 HEPP Water Level versus Specific Water Consumption Diagram

From the above diagram change in the specific water consumption values according to change in the water reservoir levels in May and August 2021 in Gursogut-1 HEPP can be seen.

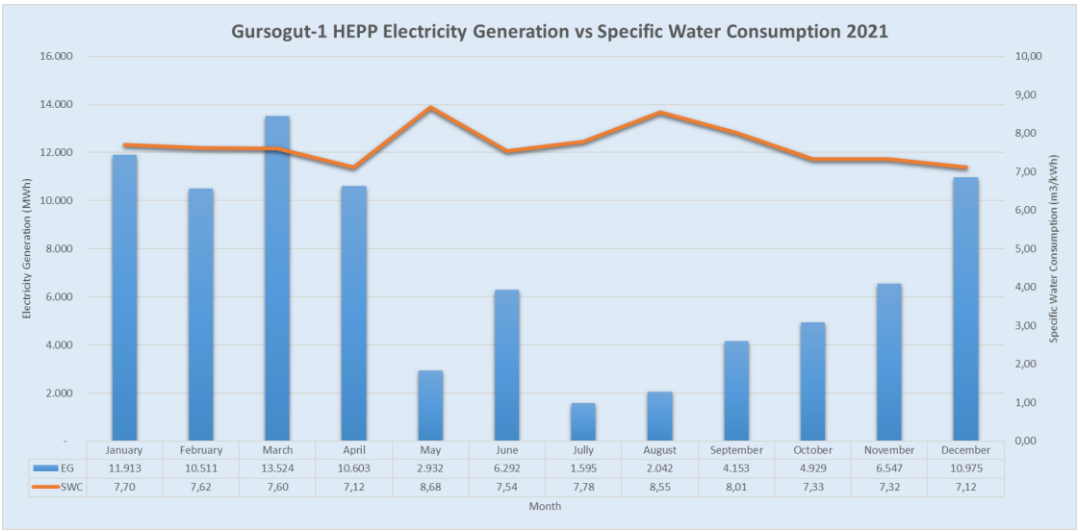


Figure 3.7 Gursogut-1 HEPP Electricity Generation vs Specific Water Consumption in 2021 Diagram

From Table 3.3 monthly total water inflow values were taken, from Table 3.5 monthly average water consumption values were taken and the electricity generation values for

each month were calculated in 2021 with an estimation of using the total inflow from Sakarya River for generating electricity without dropping any amount of water from dam's radial gates. For the calculation the monthly total inflow values divided by the average water consumption values for each month and the electricity generation values for each month were found. From the above diagram it can be deduced that Gursogut-1 HEPP total electricity generation could be 86017 MWh in 2021.

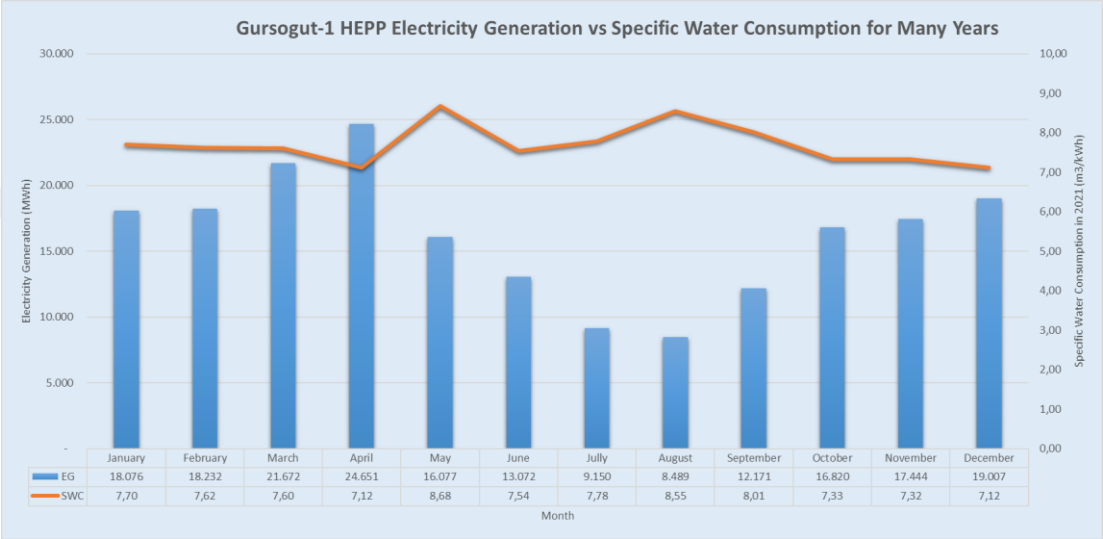


Figure 3.8 Gursogut-1 HEPP Electricity Generation vs Specific Water Consumption for Many Years Diagram

From Table 3.1 monthly total inflow values from Sakarya River for many years were taken,

from Table 3.5 monthly average water consumption values in 2021 were taken and the electricity generation values for each month were calculated with an estimation of using the total inflow from Sakarya River for generating electricity without dropping any amount of water from dam's radial gates. For the calculation the monthly total inflow values for many years divided by the average water consumption values in 2021 for each month and the electricity generation values for each month were found. According to this calculation Gursogut-1 HEPP total electricity generation in a year can be 194861 MWh.

Table 3.7 Gursogut-1 Dam and HEPP Evaporation Table

AYLAR	SICAKLIK		YAĞIŞ		Gürsöğüt Baraj Gölü Aylık Ortalama Buharlaşma 649	Serbest Su Yüzeyinden Buharlaşma	Net Buharlaşma
	Beypazarı (DMI)	Gürsöğüt Baraj Gölü	Beypazarı (DMI)	Gürsöğüt Baraj Gölü			
	Sıcaklıkları		Yağışları				
	682.00 1975 - 2010	649.00 1975 - 2010	682.00 1975 - 2010	649.00 1975 - 2010			
	(°C)		(mm)				
(1)	(2)	(3)=(2)-(1 325 - 650)x0.5/100	(4)	(5)	(6)=1.0706x(3)$^{1.6697}$	(7)=0.70 x (6)	(8)=(7)-(4)
EKİM	14.18	14.34	31.28	31.28	91.38	63.97	32.69
KASIM	7.57	7.74	37.30	37.30	32.61	22.82	0.00
ARALIK	3.08	3.24	53.62	53.62	7.62	5.34	0.00
OCAK	1.12	1.28	49.73	49.73	1.62	1.13	0.00
ŞUBAT	2.87	3.03	38.30	38.30	6.82	4.77	0.00
MART	7.21	7.38	34.83	34.83	30.11	21.07	0.00
NİSAN	12.49	12.65	47.06	47.06	74.13	51.89	4.83
MAYIS	17.44	17.60	39.82	39.82	128.63	90.04	50.22
HAZİRAN	21.77	21.93	29.21	29.21	185.70	129.99	100.78
TEMMUZ	25.02	25.18	13.44	13.44	233.89	163.73	150.28
AĞUSTOS	24.87	25.03	12.65	12.65	231.61	162.13	149.48
EYLÜL	20.03	20.19	16.32	16.32	161.76	113.23	96.91
ORT./AVR.	**13.14**	**13.30**	**403.56**	**403.56**	**1,185.88**	**830.12**	**585.19**

In hydropower reservoirs the existing water evaporates at all ambient temperatures. For the hydropower dam and power plants with big water reservoirs evaporation from the reservoir means loss of potential electricity generation. It was shown on the above Table 3.7 the net evaporation from Gursogut-1 HEPP water reservoir is 585.19 mm. This evaporation value was calculated according to the precipitation, temperature and evaporation data from Beypazarı meteorological observation station for many years. It can be deduced from the above Table 3.7 that from the maximum water level of the Gursogut-1 reservoir 585.19 mm water can evaporate annually. This evaporation can cause 2.94 hm^3 water loss from the reservoir. According to Table 3.5 annual average specific water consumption of Gursogut-1 HEPP was 7.70 m^3/kWh in 2021. If the 2.94 hm^3 water was used for electricity generation in Gursogut-1 HEPP, 318.8 MWh electricity could be generated in addition.

In the previous passages of this chapter various information about Gursogut-1 HEPP was discussed. From now on floating solar system will be integrated to this hydropower system. When selecting a solar panel there are some factors to consider. Solar panel type should be specified initially. There are generally three types of solar

panels. These are monocrystalline, polycrystalline and thin film. The advantages and disadvantages of solar panel types can be seen from the below figure.

SOLAR PANEL TYPE	ADVANTAGES	DISADVANTAGES
Monocrystalline	High efficiency and performance	Higher costs
Polycrystalline	Lower costs	Lower efficiency and performance
Thin-film	Portable and flexible	Lower efficiency and performance

Figure 3.9 Advantages and Disadvantages of Solar Panel Types [48]

As it was shown in the above figure the most efficient type of the solar panels is monocrystalline. Monocrystalline solar panels' efficiency values are between 15-20 % and polycrystalline solar panels' efficiency values are between 15-17 % [48]. Monocrystalline solar panels have more power capacity than the other types. In this study monocrystalline solar panels were used in the hybrid system. This type of solar panels has higher costs from the other types but with higher efficiency and performance values this higher costs cannot be a problem in long term investment.

After choosing the solar panel type the first factor is solar panel cost. Solar panel cost can vary according to the power size, the physical size, the trademark, the quality of the solar panel materials and the durability. The second factor is solar panel quality. The manufacturing quality and the materials' quality which were used during the solar panel manufacturing are important. Today solar panel design companies are investing for research and development activities of solar panel design. When choosing the solar panel trademark, it is important to research about the company's reference projects. The third factor is energy efficiency. Energy efficiency is a significant factor for selecting a solar panel. More efficient solar panels can produce more electricity with less solar irradiation compared to the less efficient solar panels. The fourth factor is temperature coefficient. The solar panel temperature can directly effect the electricity generation of the solar panel. This impact can be expressed with temperature coefficient. Solar panel efficiency tests are held at 25 ^{o}C. The temperature coefficient is expressed as the percentage decrease in output for every 1 ^{o}C increase in temperature

from 25 °C [49]. Some temperature coefficients of solar panel manufacturers were shown in below figure.

SOLAR MANUFACTURER	TEMPERATURE COEFFICIENT RANGE
Q CELLS	-0.42 to -0.37
Hyundai	-0.45 to -0.41
LG	-0.42 to -0.3
SunPower	-0.38 to -0.29
Panasonic	-0.3 to -0.29

Figure 3.10 Solar Panel Temperature Coefficients [49]

There are two main types of solar inverters. These are string inverter and micro inverter. String solar inverters are connected to a string of solar panels linked together in series [50]. String inverter is the most common used inverter type in the world. Micro inverters are very small solar inverters attached directly to individual solar panels [50].

On Gursogut-1 HEPP's water reservoir an area was chosen with 15137 m^2 for mounting the floating solar photovoltaic system. The suitable area for floating solar photovoltaic system was shown in the below figure via Google Earth. This area is about 0.3% of total water reservoir of Gursogut-1 HEPP.

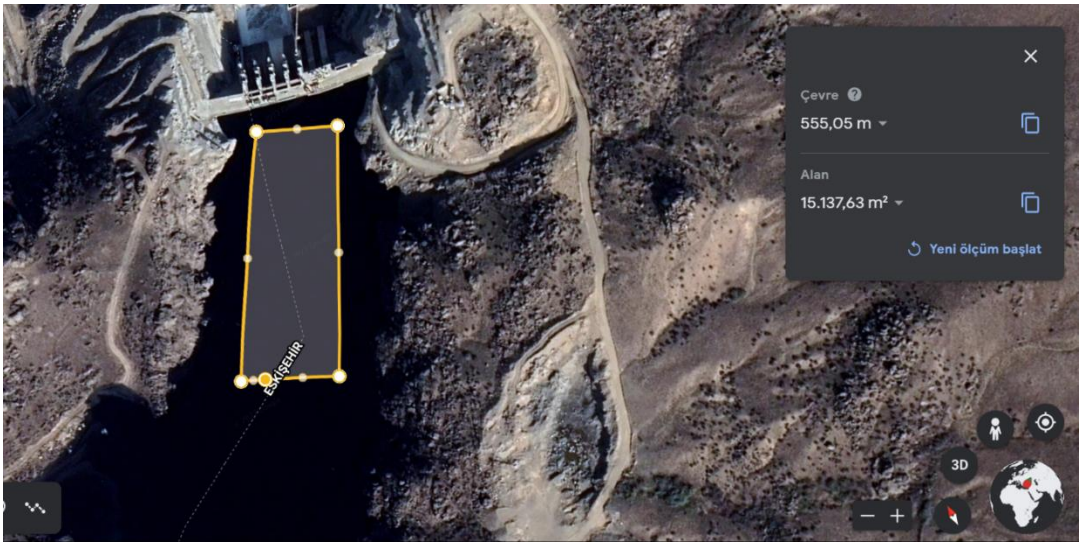


Figure 3.11 Gursogut-1 HEPP Suitable Floating Solar Photovoltaic Area

Gursogut-1 HEPP's geographical coordinates are 39°51'10''N 31°53'57''E. Gursogut-1 hydropower plant is located on 39.8528 north latitudes and 31.8992 east longitudes.

The performance analysis of the floating solar photovoltaic system was carried out with PVsyst. In this software it is possible to do system design, system sizing and energy generation simulations. At the system design period of the PVsyst software, desired power or available area for the solar photovoltaic system has to be specified. After that photovoltaic module and the inverter has to be chosen from the software's database. The simulation gives these main results; the total energy production (MWh/year), the performance ratio (%), the specific energy (kWh/kWp). PVsyst presents the results in the form of a full report with specific graphs and tables. PVsyst software is a useful software for analyzing photovoltaic solar systems' energy generation. First, the geographical coordinates of the floating solar photovoltaic system on Gursogut-1 HEPP water reservoir were added to the PVsyst software. In PVsyst there isn't any meteorological data for Ankara, some locations exist in the software from the world. The altitude of the floating solar photovoltaic system was chosen 649 m above from sea level which is the maximum water level of the Gursogut-1 hydropower water reservoir. Meteorological data was imported from Photovoltaic Geographical Information System Typical Meteorological Year (PVGIS TMY) to PVsyst. Typical meteorological year is a set of meteorological data with data values

for every hour in a year with the data are selected from hourly data in 10 years or more for a given geographical location [51]. According to the PVGIS TMY solar paths at Gursogut-1 HEPP Floating Solar Photovoltaic System were shown in the below figure.

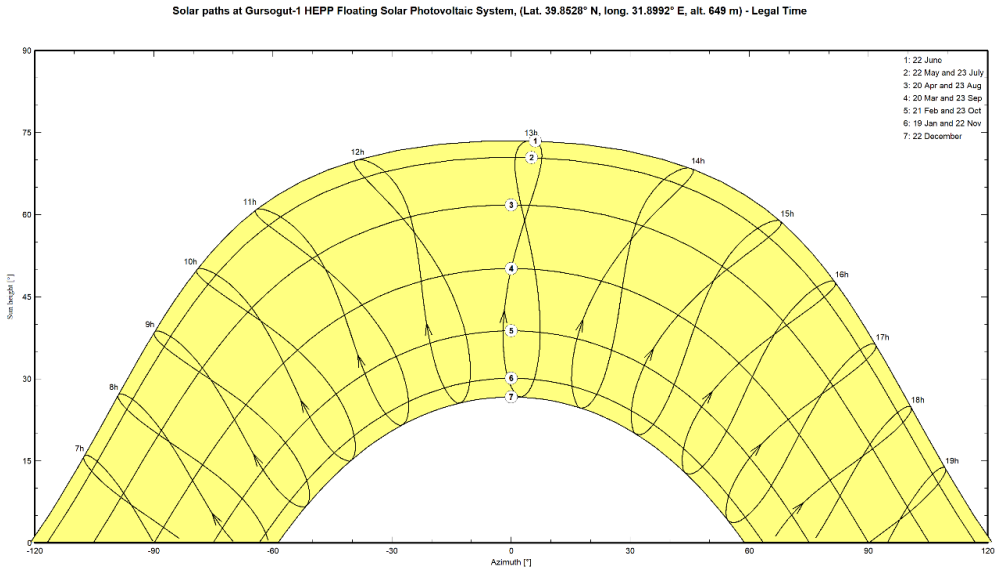


Figure 3.12 Solar Paths Diagram at Gursogut-1 HEPP Floating Solar Photovoltaic System

It can be seen from the above figure that the highest sun height in a day is at 13.00 with about 72° at the hybrid system area on 22th of June. It is one day after the equinox date 21th of June which is the longest day in a year in the northern hemisphere. Solar rays come with the lowest height at 13.00 with about 25° at this location.

Table 3.8 Gursogut-1 HEPP Floating Solar Photovoltaic System Monthly Meteorological Data

Monthly Meteo Values

Source PVGIS TMY: SARAH, COSMO or NSRDB

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	54.0	95.5	130.7	165.1	174.9	235.0	242.3	216.9	164.5	116.7	83.1	49.5	1728.1	kWh/m²
Horizontal diffuse	29.5	34.2	53.0	67.6	84.2	64.0	62.2	59.5	51.3	46.1	28.7	25.9	606.1	kWh/m²
Extraterrestrial	133.2	163.3	238.4	289.9	341.8	348.1	351.8	317.9	254.6	201.2	141.5	119.7	2901.4	kWh/m²
Clearness Index	0.405	0.585	0.548	0.569	0.512	0.675	0.689	0.682	0.646	0.580	0.587	0.413	0.596	ratio
Ambient Temper.	4.5	6.6	9.9	10.9	17.9	24.2	28.7	26.2	24.9	14.5	9.3	3.1	15.1	°C
Wind Velocity	1.4	1.5	2.2	2.6	3.0	3.0	2.7	2.7	1.7	2.5	1.6	2.3	2.3	m/s

According to PVGIS TMY annual average global horizontal irradiation is 1728.1 kWh/m^2 at the hybrid system location. The greatest monthly average global horizontal irradiation is 242.3 kWh/m^2 in July, the second greatest global horizontal irradiation

is 235 kWh/m^2 in June and the third greatest global horizontal irradiation is 216.9 kWh/m^2 in August. June, July and August months are in the dry season for Gursogut-1 HEPP. From Figure 25 it can be deduced that the electricity generation in June, July and August at Gursogut-1 HEPP is lower than the several other months. It is a big benefit for the hybrid system. The average temperature and the average wind velocity in a year is 15.1 ^oC and 2.3 m/s respectively at the hybrid system location. The net evaporation values from the Gursogut-1 HEPP reservoir are greater in June, July and August than the other months because of the higher ambient temperature values. The net evaporation values were shown in Table 3.7.

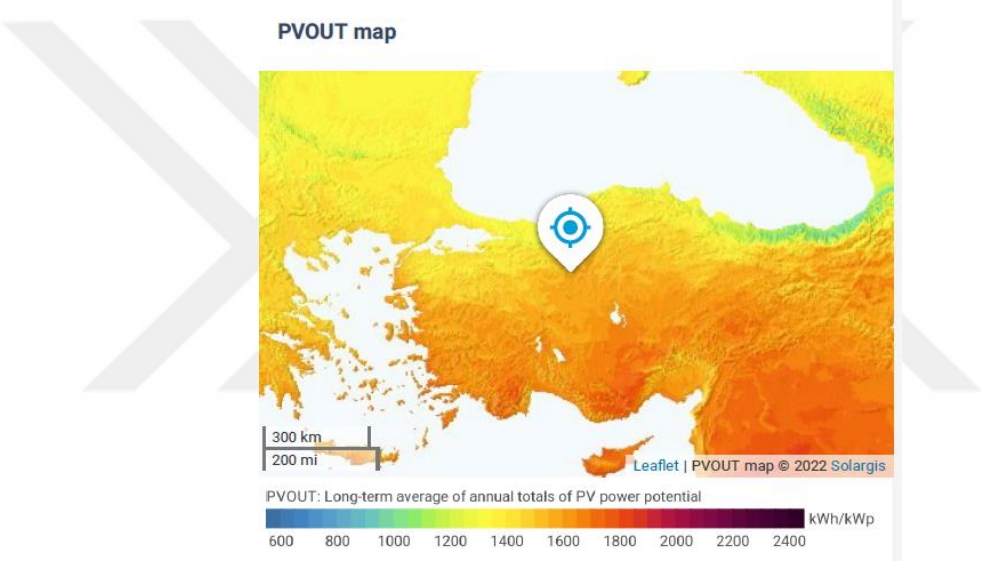


Figure 3.13 Turkey's Long Term Average Photovoltaic Power Potential Map [52]

In the above figure Gursogut-1 HEPP floating solar photovoltaic system was marked and the long-term average photovoltaic power potential was shown with color scale.

Table 3.9 Gursogut-1 HEPP Floating Solar Photovoltaic System Monthly Average Values

Meteo for Gursogut-1 HEPP Floating Solar Photovoltaic System - Typical Meteorological Year

Plane: tilt 10°, azimuth 0°, Albedo 0.20

Interval beginning	GlobHor kWh/m²/mth	GlobInc (Perez model) kWh/m²/mth	T_Amb °C	WindVel m/s
January	54.0	63.9	4.5	1.4
February	95.5	113.7	6.6	1.5
March	130.7	144.0	9.9	2.2
April	165.1	174.2	10.9	2.6
May	174.9	178.0	17.9	3.0
June	235.0	237.9	24.2	3.0
July	242.3	246.6	28.7	2.7
August	216.9	227.9	26.2	2.7
September	164.5	180.1	24.9	1.7
October	116.7	134.5	14.5	2.5
November	83.1	103.1	9.3	1.6
December	49.5	60.5	3.1	2.3
Year	1728.1	1864.4	15.1	2.3

If the tilt angle of the solar panels is chosen as 10°, the annual average global inclined irradiation will be 1864.4 kWh/m^2. CWT455-144PM was chosen as the photovoltaic module for the floating solar photovoltaic system.

Table 3.10 Photovoltaic Module Characteristics

PV Module	Reference Irradiation	Reference Temperature	Nominal Power at Standard Conditions	PV Module Technology
CWT455-144PM	1000 W/m^2	25 ^{o}C	455 Wp	Si-Mono Crystal

The photovoltaic module's nominal power at standard conditions (25 ^{o}C, 1000 W/m^2) is 455 Wp. The photovoltaic module's open circuit voltage is 49.4 V and maximum power voltage is 41.6 V at standard conditions (at 25 ^{o}C and 1000 W/m^2 solar irradiation). This photovoltaic module has 144 cells per module. The module's weight is 24.5 kg. Panel dimensions are 2095 x 1039 x 40 mm. The module area is 2.117 m^2. The area of 144 cells of a module is 1.973 m^2. Temperature coefficient of Pmax is -0.360 %/^{o}C. The module efficiency is 20.9 % [53]. In the hybrid system there are 6954 photovoltaic modules. The module area is 15137 m^2. The total installed capacity is 3164 kWp. Huawei SUN2000-100KTL-M1-480Vac was chosen as the inverter for the

hybrid system. 25 inverters were used in the system. The nominal inverter power is 2500 kWAC. The technical specifications of the inverter were shown in below Table.

Table 3.11 Inverter Technical Specifications [54]

Efficiency	
Max. Efficiency	98.8% @480 V, 98.6% @380 V / 400 V
European Efficiency	98.6% @480 V, 98.4% @380 V / 400 V
Input	
Max. Input Voltage	1,100 V
Max. Current per MPPT	26 A
Max. Short Circuit Current per MPPT	40 A
Start Voltage	200 V
MPPT Operating Voltage Range	200 V ~ 1,000 V
Nominal Input Voltage	720 V @480 Vac, 600 V @400 Vac, 570 V @380 Vac
Number of Inputs	20
Number of MPP Trackers	10
Output	
Nominal AC Active Power	100,000 W
Max. AC Apparent Power	110,000 VA
Max. AC Active Power (cosϕ=1)	110,000 W
Nominal Output Voltage	480 V/ 400 V/ 380 V, 3W+(N)+PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Nominal Output Current	120.3 A @480 V, 144.4 A @400 V, 152.0 A @380 V
Max. Output Current	133.7 A @480 V, 160.4 A @400 V, 168.8 A @380 V
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%

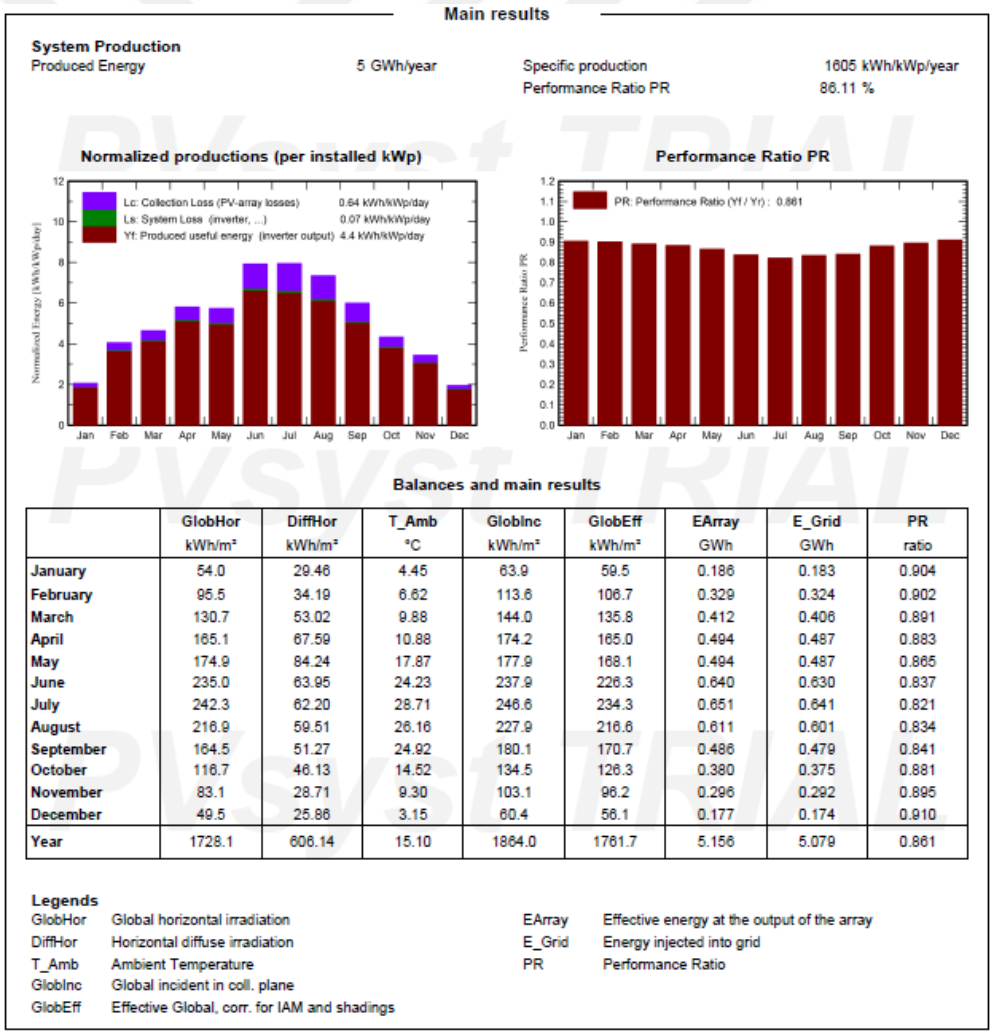
The maximum efficiency of the inverter is 98.8 % at 480 V grid voltage. The nominal AC power of the inverter is 100 kW. The Pnom ratio of the photovoltaic system is 1.266. The Pnom ratio is the ratio of the installed nominal photovoltaic power at standard conditions with respect to the nominal ac power of the inverter [55].

CHAPTER 4

RESULTS AND DISCUSSION

The simulation was done on the PVsyst. According to this simulation the system production was calculated as 5079 MWh/year. Specific production was calculated as 1605 kWh/kWp/year. The performance ratio of the system was calculated as 0.861. The performance ratio is the ratio of the energy effectively produced with respect to the energy which would be produced if the system was continuously working at its nominal standard conditions efficiency [55].

In the below figure the simulation results were shown.



Main results

System Production

Produced Energy 5 GWh/year

Specific production 1605 kWh/kWp/year

Performance Ratio PR 86.11 %

Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	54.0	29.46	4.45	63.9	59.5	0.186	0.183	0.904
February	95.5	34.19	6.62	113.6	106.7	0.329	0.324	0.902
March	130.7	53.02	9.88	144.0	135.8	0.412	0.406	0.891
April	165.1	67.59	10.88	174.2	165.0	0.494	0.487	0.883
May	174.9	84.24	17.87	177.9	168.1	0.494	0.487	0.865
June	235.0	63.95	24.23	237.9	226.3	0.640	0.630	0.837
July	242.3	62.20	28.71	246.6	234.3	0.651	0.641	0.821
August	216.9	59.51	26.16	227.9	216.6	0.611	0.601	0.834
September	164.5	51.27	24.92	180.1	170.7	0.486	0.479	0.841
October	116.7	46.13	14.52	134.5	126.3	0.380	0.375	0.881
November	83.1	28.71	9.30	103.1	96.2	0.296	0.292	0.895
December	49.5	25.86	3.15	60.4	56.1	0.177	0.174	0.910
Year	1728.1	606.14	15.10	1864.0	1761.7	5.156	5.079	0.861

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 4.1 Gursogut-1 HEPP Floating Solar Photovoltaic System PVsyst Results Table

About 37% of the annual electricity generation of the solar photovoltaic system can be generated in June, July and August months. December and January are the least electricity generated months of the year with 174 MWh and 183 MWh respectively.

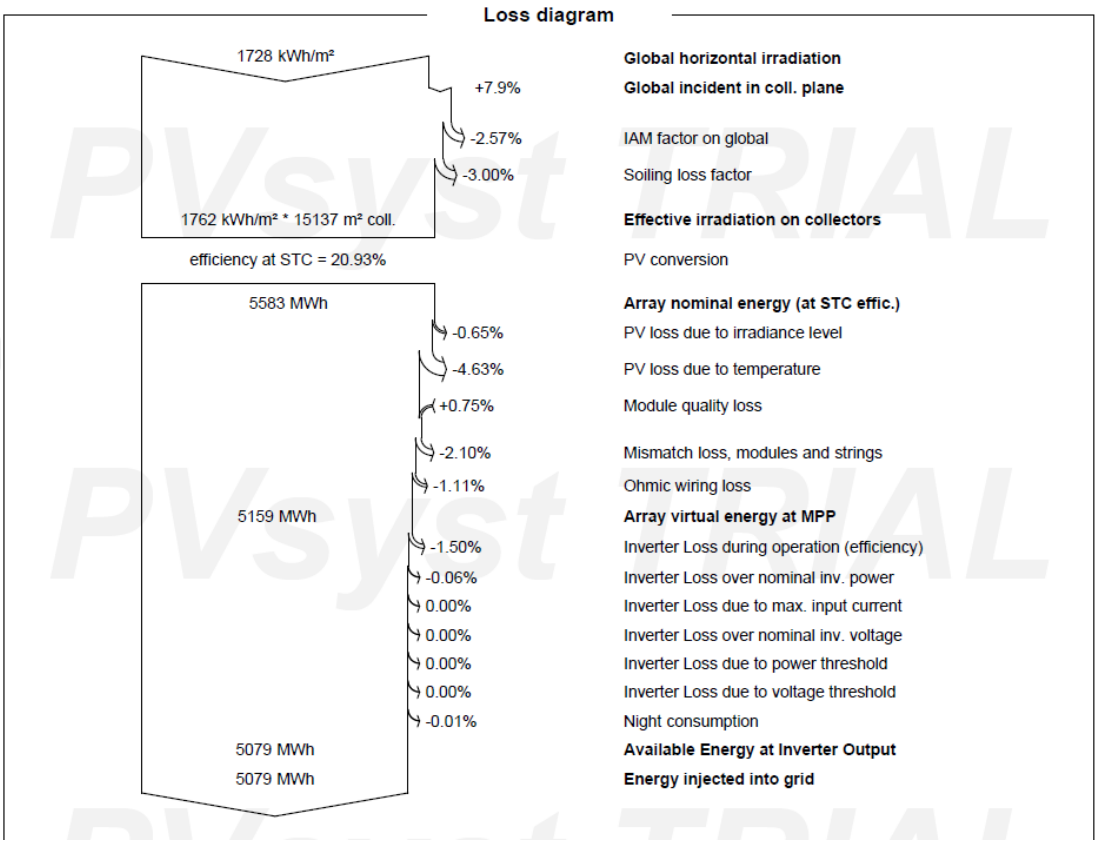


Figure 4.2 Gursogut-1 HEPP Floating Solar Photovoltaic System PVsyst Loss Diagram

In the above figure Gursogut-1 HEPP floating solar photovoltaic system's losses were shown. The total loss is about 9 % from the nominal energy that is 5583 MWh because of the irradiance level, temperature, mismatch loss, ohmic wiring loss and inverter losses.

In the below table solar photovoltaic systems' monthly hourly electricity generation sums were shown.

Table 4.1 Gursogut-1 HEPP Floating Solar Photovoltaic System Monthly Hourly Electricity Generation Sums

Monthly Hourly sums for E_Grid [MWh]

	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.03	14.78	25.33	28.81	31.03	31.03	24.52	15.98	5.35	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	15.84	30.44	41.76	47.78	52.88	49.67	41.22	29.10	13.53	0.87	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.22	27.28	43.10	51.37	55.50	54.35	54.62	46.93	34.88	20.04	6.55	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.38	19.38	37.11	52.78	61.55	64.15	58.81	60.13	51.31	39.86	24.51	12.29	0.70	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.84	9.95	23.00	38.95	52.19	55.75	55.56	60.20	54.66	47.05	39.22	29.53	16.11	4.06	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00	2.00	13.95	33.14	50.81	63.07	73.05	77.14	76.68	71.18	63.29	46.97	33.08	19.68	5.92	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	1.13	12.65	31.90	50.29	61.33	72.75	76.47	76.20	72.73	64.32	54.63	38.15	21.93	6.37	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	0.01	7.42	25.83	45.77	62.11	71.87	78.50	77.54	72.26	62.22	48.01	32.45	14.86	2.60	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.52	17.04	36.15	49.95	62.14	67.30	66.31	60.59	50.39	37.99	22.29	6.30	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	12.48	28.83	41.91	52.04	56.33	55.23	48.44	38.38	29.72	11.41	0.06	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.68	19.30	33.68	43.89	48.25	47.74	43.92	30.31	18.18	3.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.70	17.20	24.64	30.40	30.27	30.28	22.00	10.23	0.32	0.00	0.00	0.00	0.00	0.00	0.00
Year	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	3.97	50.88	178.73	365.05	522.54	638.13	686.21	687.24	649.51	541.92	404.77	233.65	98.63	19.63	-0.03	-0.03	-0.03	-0.03

The specific production of the solar photovoltaic system is 1605 kWh/kWp/year. From Figure 24 it can be deduced that Gursogut-1 HEPP's electricity generation could be 86017 MWh. If this value is divided to the Gursogut-1 HEPP's installed capacity 38.08 Mwe, 2259 hours can be found. This means Gursogut-1 HEPP can produce electricity with its total installed for 2259 hours in a year. The floating solar photovoltaic system's peak power is 3164 kW. If the annual electricity generation of the solar photovoltaic system which is 5.079.000 kWh divided by 3164 kW, 1605 hours can be found. The capacity factor of the floating solar system was calculated as dividing 1605 hour by 8760 hours and it was found about 18 %. The capacity factor of the Gursogut-1 HEPP was calculated was dividing 2259 hours by 8760 hours and it was found about 26 %.

Table 4.2 Floating Solar Photovoltaic System Energy Yield Gain

Analysed Photovoltaic System Types	Location	Performance Analysis Type	Gain in Energy Yield	Weighted Solar Panel Tempeture Decrease (^{o}C)	Referenced Scientific Paper	Gain From 5079 MWh (MWh)	
Overland and floating solar	South Korea (Hapcheon and Haman)	Empirical Data Analysis	%11 and more	N/A	K. Choi (2014) [30]	5637,69 (11%)	
Floating, overland and rooftop solar	South-Holland (Netherlands) and	Empirical Data Analysis	3%	Between 3.2 and 11.1 ^{o}C	M. Dörenkamper et al. (2020) [31]	5231,37 (3%)	
Floating and rooftop solar	Tengeh Reservoir (Singapore)	Empirical Data Analysis	4-6 %	Between 9.9 and 14.5 ^{o}C	M. Dörenkamper et al. (2020) [31]	5282,16 (4%)	5383,74 (6%)
Overland and floating solar	N/A	Mathematical Model Simulation	12.96 %	N/A	S. Z. Golroodbari et al. (2020) [32]	5737,24 (12.96 %)	
Overland and floating solar	Peninsular Malaysia	Mathematical Model Simulation	15.5 %	10 ^{o}C	Z. A. A. Majid et al. (2014) [33]	5866,25 (15.5 %)	
Overland and floating solar	Marsh-Al Dalmach (Iraq)	Mathematical Model Simulation	9%	N/A	A.Z. Abass et al. (2020) [34]	5536,11 (9 %)	
Overland and floating solar	N/A	Mathematical Model Simulation	0.31-2.59 %	N/A	S. O. Pinto et al. (2020) [35]	5094,75 (0.31 %)	5210,55 (2.59 %)
Overland and floating solar	China	Mathematical Model Simulation	1.58-2 %	5 ^{o}C	L. Liu et al. (2017) [36]	5159,25 (1.58 %)	5180,58 (2%)
Overland and floating solar	Kjeller (Norway)	Empirical Data Analysis	2-6 %	6-7 ^{o}C	Lereng (2018) [11]	5180,58 (2%)	5383,74 (6%)

In PVsyst the solar photovoltaic system simulation was carried out as the system is located in land but in Gursogut-1 hybrid system the solar photovoltaic system is located in Gursogut-1 HEPP's water reservoir. During the literature survey from the various scientific papers gain in the energy yields when the solar photovoltaic system is located in a water reservoir instead of land areas were taken and these values were shown in above table. In some of the studies mathematical model simulations were used, in some of the studies empirical data analysis was used for calculating the gain in the energy generation. The gain in the energy yield is resulted from the solar panel temperature decrease because of the water reservoir's cooling effect. Annual electricity generation of the Gursogut-1 solar photovoltaic system was calculated as 5079 MWh in PVsyst. In the above table annual electricity generation of Gursogut-1 solar photovoltaic system was increased by the scientific papers' gain in energy yield values and the new results were added as a new column in the table. The average gain

in energy yield from the scientific papers is 5.8 %. The annual electricity generation of the Gursogut-1 floating solar photovoltaic system can be 5375.69 MWh with 5.8 % gain. 5375.69 MWh divided by 3164 kW peak power of the solar photovoltaic system 1699 hours can be found. It can also be said that the specific production of the solar photovoltaic system can increase to 1699 kWh/kWp/year from 1605 kWh/kWp/year. If the 1699 hours divided by 8760 hours, 19.4 can be found. This value is the new capacity factor of the floating solar photovoltaic system which is 19.4 %. Gursogut-1 HEPP has 21.849 hm^3 active water storage capacity. Gursogut-1 HEPP and floating solar photovoltaic system can produce electricity at their nominal capacities with a good electricity generation planning. Gursogut-1 HEPP's active water storage capacity can play a good role in this electricity generation plan. As can be seen from Table 4.1 floating solar photovoltaic system can't produce electricity between the hours 19 and 5 in a day because of the lack of the solar irradiation. It means the floating solar photovoltaic system can't produce electricity in 10 hours of 24 hours in a day. 10 hours times 365 days is 3650 hours in a year. It means Gursogut-1 HEPP can produce electricity 2259 hours of this 3650 hours in a year.

The installed floating solar photovoltaic module area is 15137 m^2. The total evaporation loss from the Gursogut-1 HEPP reservoir is 2.94 hm^3. The total water reservoir area is 5.311 km^2. The floating solar photovoltaic module area occupy about 0.3 % of total water reservoir area. It means if the floating solar photovoltaic system isn't installed on the water surface the annual total water loss with evaporation from the 15137 m^2 area will be about 8379 m^3. Gursogut-1 hydroelectric power plant can generate about 1.088 MWh additional electricity with this 8379 m^3 water with 7.7 m^3/kWh average specific water consumption. The gained water from avoiding the evaporation with floating solar photovoltaic system is about 553.5 l/m^2.

Table 4.3 Gursogut-1 HEPP Floating Solar Photovoltaic System Electricity Generation Gain from Avoiding Evaporation Loss

Floating Solar Area (m2)	Percentage of Total Water Reservoir (%)	Annual Water Loss with Evaporation (m3)	Gain in Electricity Generation (MWh)	Installed Photovoltaic Power (kWp)
15137	0,30%	8379	1,1	3164
265541	5,00%	146995	19,1	55506
531094	10,00%	293997	38,2	111015

If the floating solar photovoltaic system is mounted on 5 or 10 % of the total water reservoir area, the gain on electricity generation can be 19.1 and 38.2 MWh annually respectively.

Table 4.4 Gursogut-1 HEPP Floating Solar Photovoltaic System Energy Generation Plan

GURSOGUT-1 HEPP FLOATING SOLAR PHOTOVOLTAIC SYSTEM ENERGY GENERATION (MWh)																								
Month/Hour	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	794,2	794,2	794,2	794,2	794,2	794,2	794,2	794,2	794,2	6,4	15,6	26,8	30,5	32,8	32,8	25,9	16,9	5,7	794,2	794,2	794,2	794,2	794,2	794,2
February	808,6	808,6	808,6	808,6	808,6	808,6	808,6	808,6	1,1	16,8	32,2	44,2	50,6	56,0	52,6	43,6	30,8	14,3	0,9	808,6	808,6	808,6	808,6	808,6
March	1040,3	1040,3	1040,3	1040,3	1040,3	1040,3	1040,3	1040,3	11,9	28,9	45,6	54,4	58,7	57,5	57,8	49,7	36,9	21,2	6,9	1040,3	1040,3	1040,3	1040,3	1040,3
April	963,9	963,9	963,9	963,9	963,9	963,9	963,9	4,6	20,5	39,3	55,8	65,1	67,9	62,2	63,6	54,3	42,2	25,9	13,0	0,7	963,9	963,9	963,9	963,9
May	293,2	293,2	293,2	293,2	293,2	293,2	0,9	10,5	24,3	41,2	55,2	59,0	58,8	63,7	57,8	49,8	41,5	31,2	17,0	4,3	293,2	293,2	293,2	293,2
June	629,2	629,2	629,2	629,2	629,2	629,2	2,1	14,8	35,1	53,8	66,7	77,3	81,6	81,1	75,3	67,0	49,7	35,0	20,8	6,3	629,2	629,2	629,2	629,2
July	159,5	159,5	159,5	159,5	159,5	159,5	1,2	13,4	33,8	53,2	64,9	77,0	80,9	80,6	77,0	68,1	57,8	40,4	23,2	6,7	159,5	159,5	159,5	159,5
August	204,2	204,2	204,2	204,2	204,2	204,2	0,0	7,9	27,5	48,6	65,9	76,2	83,2	82,2	76,6	66,0	50,9	34,5	15,7	2,8	204,2	204,2	204,2	204,2
September	346,1	346,1	346,1	346,1	346,1	346,1	346,1	2,7	18,0	38,3	52,9	65,8	71,2	70,2	64,1	53,3	40,2	23,6	6,7	346,1	346,1	346,1	346,1	346,1
October	410,7	410,7	410,7	410,7	410,7	410,7	410,7	0,0	13,2	30,5	44,3	55,1	59,6	58,4	51,3	40,6	31,4	12,1	0,1	410,7	410,7	410,7	410,7	410,7
November	467,6	467,6	467,6	467,6	467,6	467,6	467,6	467,6	3,9	20,4	35,6	46,4	51,1	50,5	46,5	32,1	19,2	3,2	467,6	467,6	467,6	467,6	467,6	467,6
December	731,7	731,7	731,7	731,7	731,7	731,7	731,7	731,7	731,7	9,2	18,2	26,1	32,2	32,0	32,0	23,3	10,8	0,3	731,7	731,7	731,7	731,7	731,7	731,7

In the above table the annual electricity generation plan of Gursogut-1 HEPP floating solar photovoltaic system was shown. The yellow labeled values are electricity generation of floating solar photovoltaic system. The blue labeled values are electricity generation of hydropower plant. The hydropower and solar photovoltaic system can generate electricity without harming the other system's electricity generation plan as can be seen from the above table. The hydropower plant can generate electricity minimum 10 hours in a day when the solar photovoltaic system doesn't work. Gursogut-1 HEPP floating solar photovoltaic systems' annual electricity generation can be about 91392.7 MWh. The floating solar photovoltaic system can support the hydropower plant's electricity generation with additional 5375.69 MWh. The hybrid system can generate electricity 7 days 24 hours in a year with this energy generation plan.

Table 4.5 Gursogut-1 HEPP Floating Solar Photovoltaic System Daily Energy Generation Hours

GURSOGUT-1 HEPP FLOATING SOLAR PHOTOVOLTAIC SYSTEM ENERGY GENERATION HOURS IN A DAY		
MONTH	HYDRO	FLOATING SOLAR
January	15	9
February	13	11
March	13	11
April	11	13
May	10	14
June	10	14
July	10	14
August	10	14
September	12	12
October	12	12
November	14	10
December	15	9

In the above table planned daily electricity generation hours for hybrid Gursogut-1 hydropower plant and floating solar photovoltaic system was shown. As can be seen from this table in May, June, July and August months Gursogut-1 hydroelectric power plant can generate electricity for 10 hours in a day and floating solar photovoltaic system can generate electricity for 14 hours in a day. Gursogut-1 hydroelectric power plant can generate electricity for 13 hours in a day in February and March, for 14 hours in November and 15 hours in December and January.

Table 4.6 Gursogut-1 HEPP Floating Solar Photovoltaic System Monthly Electricity Generation

GURSOGUT-1 HEPP FLOATING SOLAR PHOTOVOLTAIC SYSTEM ENERGY GENERATION (MWh)		
MONTH	HYDRO	FLOATING SOLAR
January	11913,2	193,5
February	10511,4	343,0
March	13524,4	429,4
April	10603,2	515,3
May	2931,7	515,4
June	6292,1	666,6
July	1595,2	678,1
August	2042,1	637,8
September	4153,4	506,8
October	4928,6	396,6
November	6546,6	308,9
December	10975,1	184,2
TOTAL	86017,1	5375,7
GRAND TOTAL	91392,7	

In the above table Gursogut-1 hybrid system's hydropower and floating solar photovoltaic system monthly total electricity generations were shown. The greatest electricity generation of floating solar photovoltaic system in a month is in July with

about 678 MWh then June and August months come with about 667 and 638 MWh respectively.

CHAPTER 5

CONCLUDING REMARKS

Gursogut-1 HEPP with 38.08 MW installed capacity which is located in Ankara was chosen for the hybrid solution with floating solar photovoltaic system in this study. The performance analysis of the floating solar system and hydropower plant hybrid system was carried out during the study. Gursogut-1 HEPP's actual operational data was used in the analysis. The floating solar photovoltaic system was planned to be mounted at 649 m above sea level on the Gursogut-1 hydropower water reservoir. At 649 m elevation the water reservoir area is 5.311 km^2. The average water inflow values for many years (1974-2020) to Gursogut-1 HEPP from Sakarya River, Kargı HEPP water inflow values from Sakarya River between 2018 and 2020 which is located at the downstream of the Gursogut-1 HEPP, Gursogut-1 HEPP average daily water inflow values from Sakarya River in 2021, Gursogut-1 HEPP daily average specific water consumption values in 2021, Gursogut-1 HEPP daily water reservoir levels in 2021 were used in the calculations, analysis and discussions. Total annual water inflow was 649.56 hm^3 in 2021. From 1974 to 2012 the average total water inflow in a year was 1484.265 hm^3. The total annual water inflow to Gursogut-1 HEPP in 2021 is about 44 % of the average annual total water inflow between the years 1974 and 2012.

In 2021 annual average specific water consumption of Gursogut-1 HEPP was 7.70 m3/kWh. This value was used in the Gursogut-1 HEPP electricity generation calculations in this study. The electricity generation in Gursogut-1 HEPP in 2021 could be 86017 MWh according to the calculations with respect to monthly average water consumption values and monthly average water inflow to Gursogut-1 HEPP in 2021. The capacity factor of this hydropower plant was calculated about 26 %.

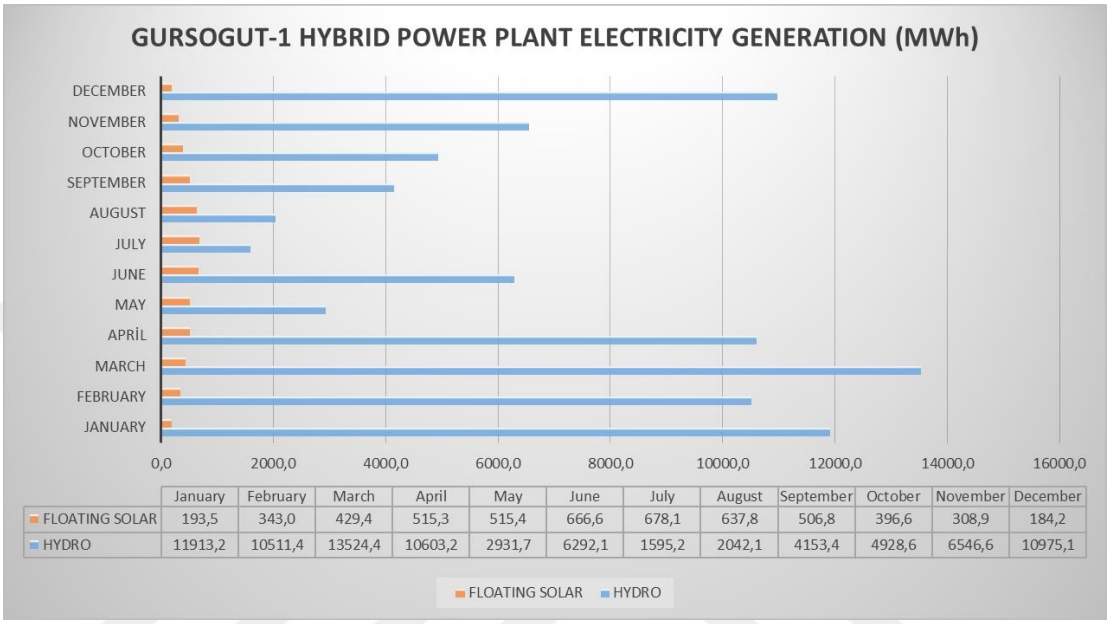
The performance analysis has been carried out on PVsyst software according to the system's key parameters including meteorological data, available installation area, photovoltaic module properties and inverter features. On Gursogut-1 HEPP's water reservoir an area was chosen with 15137 m^2 for mounting the floating solar photovoltaic system. Selected location's coordinates were used for importing meteorological data and values related with solar energy generation. According to

PVGIS TMY annual average global horizontal irradiation is 1728.1 kWh/m^2 at the hybrid system location. In this study monocrystalline solar panels were used. The tilt angle of the solar photovoltaic panels was chosen as 10°. The average global inclined irradiation was calculated in PVsyst with 10° solar panel tilt angle as 1864.4 kWh/m^2. CWT455-144PM was chosen as the photovoltaic module for the floating solar photovoltaic system. The photovoltaic module's nominal power at standard conditions (25 ^{o}C, 1000 W/m^2) is 455 Wp. The module efficiency is 20.9 %. In the hybrid system there are 6954 photovoltaic modules. The total installed capacity is 3164 kWp. Huawei SUN2000-100KTL-M1-480Vac was chosen as the inverter for the hybrid system. 25 inverters were used in the system. The nominal inverter power is 2500 kWAC. The maximum efficiency of the inverter is 98.8 % at 480 V grid voltage. The nominal AC power of the inverter is 100 kW. The solar photovoltaic system's ac power is 2500 kW. The Pnom ratio of the photovoltaic system is 1.266.

Results obtained for system's total energy production, performance ratio and specific energy are discussed. According to the PVsyst simulation the solar photovoltaic system production was calculated as 5079 MWh/year. Specific production was calculated as 1605 kWh/kWp/year. These calculations were done in PVsyst as the solar photovoltaic system is ground mounted. The performance ratio of the system was calculated as 0.861. The total loss is about 9 % from the nominal energy that is 5583 MWh because of the irradiance level, temperature, mismatch loss, ohmic wiring loss and inverter losses. The solar photovoltaic system's inverter ac power is 2500 kW.

In this study the gain in the energy yield when a floating solar photovoltaic system mounted on this hydropower water reservoir was analyzed. There would be gain in the energy generation in floating solar photovoltaic system with respect to a ground mounted solar photovoltaic system. During the literature survey percentage gains in the electricity generation of a floating solar photovoltaic system from the various scientific papers were collected. In some of the studies mathematical model simulations were used, in some of the studies empirical data analysis was used for calculating the gain in the energy generation. The gain in the energy generation is resulted from the solar panel temperature decrease because of the water reservoir's cooling effect which increases the solar panel efficiency. The average gain in energy generation from the surveyed scientific papers is 5.8 %. The annual electricity generation of the Gursogut-1 floating solar photovoltaic system can be 5375.69 MWh

with 5.8 % gain. It can also be said that the specific production of the solar photovoltaic system can increase to 1699 kWh/kWp/year from 1605 kWh/kWp/year. The capacity factor of the solar photovoltaic system can increase from 18 % to 19.4 % with mounting the system on a water reservoir.

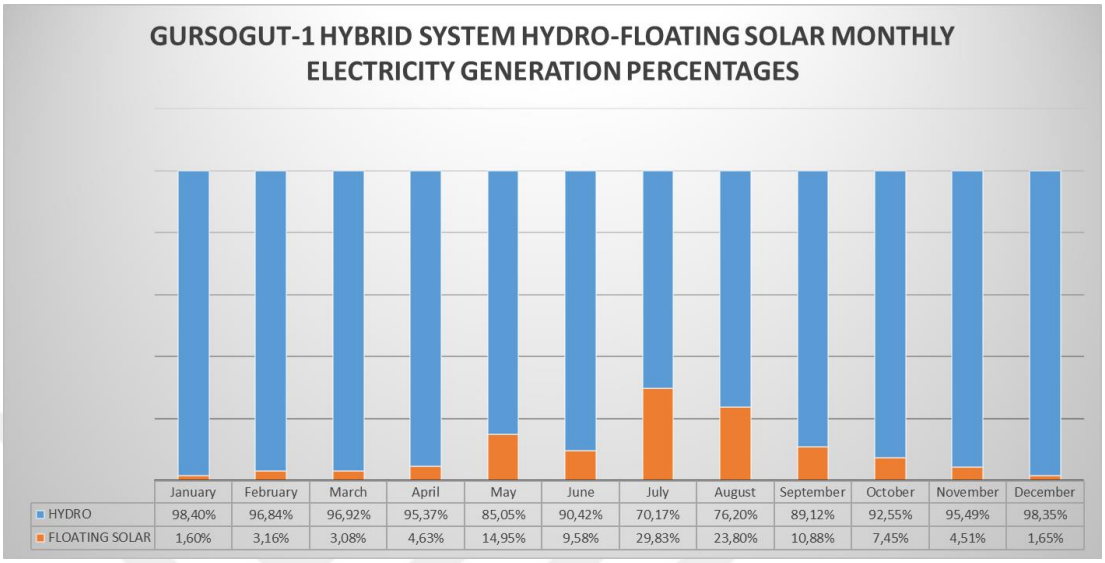


	January	February	March	April	May	June	July	August	September	October	November	December
FLOATING SOLAR	193,5	343,0	429,4	515,3	515,4	666,6	678,1	637,8	506,8	396,6	308,9	184,2
HYDRO	11913,2	10511,4	13524,4	10603,2	2931,7	6292,1	1595,2	2042,1	4153,4	4928,6	6546,6	10975,1

Figure 5.1 Gursogut-1 Hybrid Electricity Generation Plan

The hybrid electricity generation program of Gursogut-1 HEPP and floating solar photovoltaic system was created according to PVsyst simulation electricity generation and specific production results, solar photovoltaic system's monthly hourly annual electricity generation that is a PVsyst simulation output, energy generation gain calculations of floating solar photovoltaic system from a ground mounted solar photovoltaic system with respect to the average gain from the related scientific papers, Gursogut-1 HEPP average daily water inflow values from Sakarya River in 2021 and Gursogut-1 HEPP daily average specific water consumption values in 2021. The floating solar photovoltaic system's 37 % of annual electricity generation was in June, July and August months. The least electricity generation of the floating solar photovoltaic is in November, December and January. The floating solar photovoltaic system can't produce electricity in 10 hours of 24 hours in a day and 3650 hours in a year. It means Gursogut-1 HEPP can produce electricity for minimum 10 hours in a

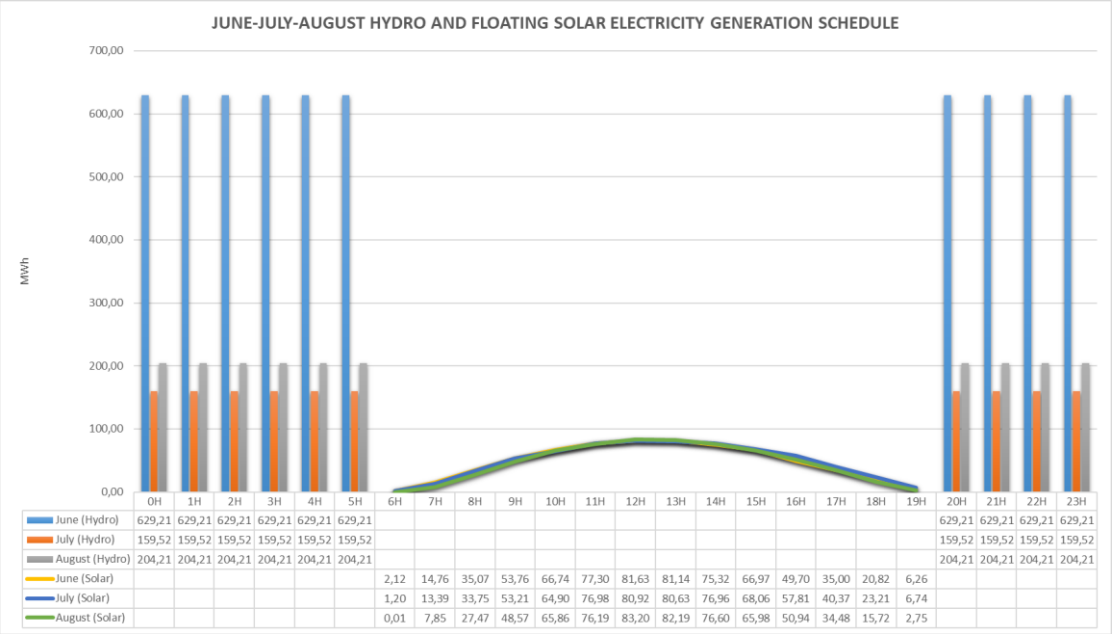
day. Gursogut-1 HEPP floating solar photovoltaic systems' annual electricity generation can be about 91392.7 MWh.



	January	February	March	April	May	June	July	August	September	October	November	December
HYDRO	98,40%	96,84%	96,92%	95,37%	85,05%	90,42%	70,17%	76,20%	89,12%	92,55%	95,49%	98,35%
FLOATING SOLAR	1,60%	3,16%	3,08%	4,63%	14,95%	9,58%	29,83%	23,80%	10,88%	7,45%	4,51%	1,65%

Figure 5.2 Gursogut-1 Hybrid System Monthly Electricity Generation Percentages

As it was shown in the above figure in July and August the floating solar photovoltaic system's electricity generation is about 30 % and 24 % of hybrid system's total electricity generation respectively. It means in July and August months the floating solar photovoltaic system can support the hydropower plant very much. The floating solar photovoltaic system's installed capacity is 3164 kWp which corresponds 8 % of Gursogut-1 hydropower plant installed capacity. Floating solar photovoltaic system's energy generation percentage can be higher with higher installed capacities than 3164 kWp.



	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
June (Hydro)	629,21	629,21	629,21	629,21	629,21	629,21															629,21	629,21	629,21	629,21
July (Hydro)	159,52	159,52	159,52	159,52	159,52	159,52															159,52	159,52	159,52	159,52
August (Hydro)	204,21	204,21	204,21	204,21	204,21	204,21															204,21	204,21	204,21	204,21
June (Solar)							2,12	14,76	35,07	53,76	66,74	77,30	81,63	81,14	75,32	66,97	49,70	35,00	20,82	6,26				
July (Solar)							1,20	13,39	33,75	53,21	64,90	76,98	80,92	80,63	76,96	68,06	57,81	40,37	23,21	6,74				
August (Solar)							0,01	7,85	27,47	48,57	65,86	76,19	83,20	82,19	76,60	65,98	50,94	34,48	15,72	2,75				

Figure 5.3 Gursogut-1 Hybrid System June-July-August Electricity Generation Schedule

Gursogut-1 hybrid system's electricity generation schedule in June, July and August was shown on above figure in MWh. As it can be seen from the above figure the floating solar photovoltaic system can generate electricity between 6 and 20 a.m. in a day and Gursogut-1 hydroelectric power plant can generate electricity for the rest of the hours in a day.

The gain in electricity generation by hydropower plant from avoiding water loss with evaporation from hydropower water reservoir by the existence of floating solar photovoltaic system on water surface was calculated. Net evaporation value from Gursogut-1 HEPP water reservoir was calculated as 585.19 mm at 649 m water level during Gursogut-1 HEPP feasibility study period. This evaporation can cause 2.94 hm^3 water loss from the reservoir. The floating solar photovoltaic system occupies 15137 m^2 and this area is about 0.3 % of the total water reservoir. If the floating solar photovoltaic system isn't installed on the water surface the annual total water loss with evaporation from the 15137 m^2 area will be about 8379 m^3. Gursogut-1 hydroelectric power plant can generate about 1.088 MWh additional electricity with this 8379 m^3 water with 7.7 m^3/kWh average specific water consumption. The gained water from avoiding the evaporation with floating solar photovoltaic system is about 553.5 l/m^2. If the floating solar photovoltaic system is mounted on 5 or 10 % of the total water

reservoir area, the gain on electricity generation can be 19.1 and 38.2 MWh annually respectively.

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