

## Impacts of 1 MW Solar Power Plants Connected to the Medium Voltage Distribution Network of Ayrancı, Karaman

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### Abstract

Turkey Solar Energy Potential Map shows that in the southern side of Turkey within a few years, different size of solar power plants may be integrated to distribution network; but distributed generation and its requirements is not a literally well-known issue in Turkey. National legislation standards were published by the authorities and as a result of arising applications, distribution companies have started to integrate renewable power plants in their network as a micro-model (wind, solar, biogas, etc.) of the traditional power plants. Generation type, line size, state of the load and the distance are very important for voltage profile. This paper presents an overview of the 8 MW solar plant integrations and analyzes the impacts of them to Ayrancı network using load flow and short circuit analysis methods with Sincal software and geographical coordinates. Through these analyses, the overloading of the bar, the line and the transformer can be observed when there is a variable load status in the plant connected to system, and also the strength of the distribution element boundaries can be observed. After all commissioning, the solar plants can undertake the supply of local energy and it is possible to reduce investment needs for distribution companies.

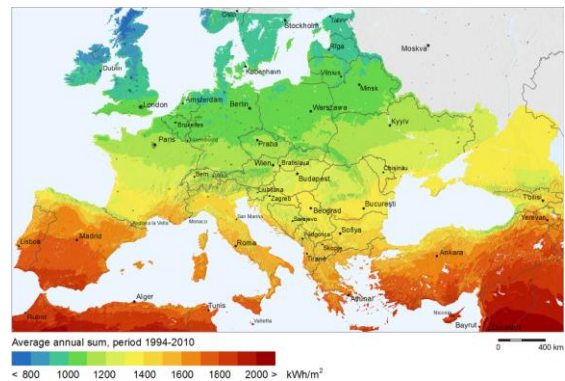
**Keyword:** Distributed Generation, Impact of Distributed Generation, Interconnection of Distributed Generation, Analysis Methods for Distributed Generation, PSS Sincal Software.

## INTRODUCTION

In recent years, there is a reform in energy sector. Traditional generators lost its importance no longer and technological developments have proved that it is possible to generate energy by using renewable energy sources at a lower cost. Today, almost all countries in the world support the sustainable power system of the future and create new laws/legislations for distributed generation (DG) and its integration. In this context, some of European Union countries as like Germany, Denmark and Spain have the largest renewable generation capacities. In these countries, the percentage of electrical energy produced by distributed generation (including wind, solar, combined heat and power, biogas and the others) are rather high [1].

The main reasons for this can be explained as high engineering standards and government policies that aim energy saving. They developed different policies to achieve this purpose, including market rules, regulation, prices and technical issues for connection to distributed generation [1].

On the other hand, in recent years there is a great interest to this topic also in Turkey. Every year, huge numbers of electrical power plants based on the renewable energy sources are integrated our transmission or distribution system. Thus, variety of energy sources is increasing year by year. When we consider the maps of global horizontal irradiation for European countries we can see clearly that due to its advantageous geographical position, Turkey has a respectable solar power capacity for new generations (Figure 1).



**Figure 1.** Global horizontal irradiation (GHI) of Europe

Unfortunately compared with European countries there are not enough solar power plants currently in Turkey. As shown in Table 1, electricity generations by coal and natural gases have still the largest shares compared with other electrical generating types in energy market of Turkey [2].

Since 2008, Turkish government took important actions to use its native resources and raise the share of the renewable energies in the electricity generation in order to decrease carbon dioxide emissions for the implementation of Kyoto protocol and decrease its energy dependencies on foreign countries [3]. To create a more liberal, secure, transparent and competitive energy sector and to increase energy production ratio from renewable resources, Turkey

has made some legislative changes in its energy market. For instance, according to the decisions taken by the High Planning Council, the share of renewable energy sources in electricity generation is intended to be at least %30 by 2023 [4]. Besides, the last legislations published by EPDK (Energy Market Regulatory Authority) also made it possible for unlicensed production owners of small solar plants to sell their surplus to the distribution company [5-6].

**Table 1.** Electricity generation and shares by energy resources in Turkey

Year	Total (GWh)	Liquid fuels					Renewable Energy
		Coal	Natural Gas	Hydro	(%)		
1970	8623	32.8	30.2	-	35.2	1.9	
1980	23275	25.6	25.1	-	48.8	0.6	
1990	57543	35.1	6.9	17.7	40.2	0.1	
2000	124922	30.6	7.5	37.0	24.7	0.3	
2003	140581	22.9	6.5	45.2	25.1	0.2	
2004	150698	22.9	5.1	41.3	30.6	0.2	
2005	161956	26.7	3.4	45.3	24.4	0.2	
2006	176300	26.5	2.5	45.8	25.1	0.2	
2007	191558	27.9	3.4	49.6	18.7	0.4	
2008	198418	29.1	3.8	49.7	16.8	0.6	
2009	194813	28.6	2.5	49.3	18.5	1.2	
2010	211208	26.1	1.0	46.5	24.5	1.9	
2011	229395	28.9	0.4	45.4	22.8	2.6	
2012	239497	28.4	0.7	43.6	24.2	3.1	
2013	240154	26.6	0.7	43.8	24.7	4.2	

With the government incentives, a great number of the unlicensed solar power plants application increased in southern side of Turkey, especially through on countryside in order to high infrastructure costs and large area requirements for installations. In Central Anatolia electricity distribution network, there are a large number of distributed generation plant applications have different sources as like solar, wind, biogas and etc. But most distributed generation systems, in especial solar plants, are not owned by Distribution Company and the locations of them are decided by the customers [7]. The company can only assess the applications within the framework of existing regulations and sign the connection and use of system agreement with unlicensed production owner after that, distributed generation owners pay charges for connection to the network (paid once) and for use of system (paid on repeated periods) [8]. These distributed generation sources are expected to create some effects to the distribution network. Because the direction of the load flow will completely change with distributed generation plants like as inverter based systems or other induction, synchronous and asynchronous generators.

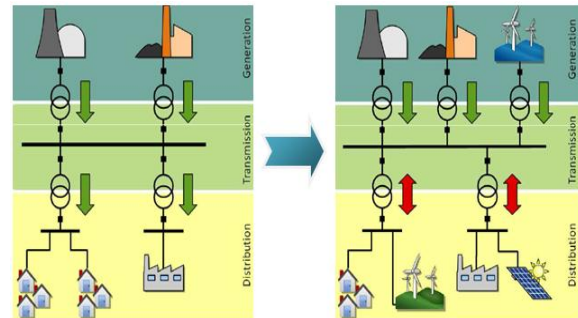
In this study, at the outset, the distributed generation term was described. Then, on the distribution region of Ayrancı-Karaman, the impacts of 1 MW solar power plants connected to the network were examined.

The effects of this two-way power flow were observed on the virtual network with real data. Connection of the 8 solar power plants was modeled to Karaman distribution network. The distributed generation grid was simulated for different locations and different size in PSS Sincal power system analyzer software. Thereafter, the changes of short-circuit current and voltage profile with or without DG were examined using power-flow analysis and short-circuit analyses.

**Distributed Generation and Its Major Benefits**

Distributed generation term has different definitions and there is no consensus on how it should be defined [1]. IEEE defines distributed generation as the electric generation facilities includes both generators and energy storage technologies are connected to distribution system not to the transmission system directly [9]. On the other hand, distributed generation can be defined as small generations on customer side connect to the main distribution network [10].

Actually, we can describe the distribution generation, except for existing generating stations, any scale of power generation systems in our network to operate as a primary energy source and to connect at any point of distribution or transmission grid. It is more important to be an additional generating plant in the electricity network rather than it is licensed or not. Both of these conditions will change the direction of load flows and the security and coordination levels at the each side of the existing network. Because today’s power generation systems include the centralized and distributed generation have multi-directional and bottom-up power flow in contrast to the traditional grid based on top-down and one-way power flow (Figure 2).



**Figure 2.** Traditional and future power system energy flow structure

The main reason for distributed generation is to ensure the local power supply. Distributed generation systems can also be used as a backup generation to compensate for operational failures on the customer side. In addition to that, distributed generation reduces the environmental pollutions caused by the techniques of traditional power generation and decreases the transmission and distribution costs by shortening the power lines [8].

For distributed generation integration it has an important role to analyze the existing system and planning electricity network for a distribution company before developing a road map. Thus, the distribution network planners will have provided a more intelligible view on the grid and network capabilities to detect difference between today’s situations and future aims [11].

Year by year, as a result of the growth of population and the development of technology, most of distribution companies need more capacity investments to protect reliability, fulfill growth, and/or provide operational flexibility for distribution system. In addition to that, distribution companies are inevitable upgrading the lines and the transformers or replacing aging equipments [12]. Whereas, distributed generation systems can delay the required investments and/or supply the local load to reduce losses [12].

The total amounts of the energy losses on transmission and distribution lines are important for charges. As a solution to this matter, solar power plants are feasible to

locating capacitor banks to minimize losses are similar to locating distributed generation units near to consumption areas to decrease losses [7]. Regulations on this point are different within some European countries. For instance in Italy, the distributed generation owners connected on the transmission level are paid by the network operator for the loss prevention [8]. On the other hand, in France, the system operator encourages distributed generators to enter the market whilst it pays for the losses through the purchase of electricity from a distributed generation [8]. In this way, network operator will have an income and reduce the amount cost of losses [8].

**Connection Principles of Regulations**

Distribution Company is responsible for the quality of services offered to users in the area specified in its distribution license [13]. For the continuity of a distribution system, quality of the electricity is important. To provide the quality, there are four basic requirements. First of all, the energy must be continuous and uninterrupted. Afterwards, voltage level and frequency level must be in stable and defined limits. And finally, energy must be smooth and intact sinusoidal wave form. In this context, the integrations of distributed generations have some remarkable impacts on system quality. The following factors directly affect this issue [14].

- Size and location of DG on the connection point.
- Characteristics of the grid. (Radial, auto looped, mesh looped, etc.)
- Type of DG source (Wind, solar, combined heat and power, etc.)
- DG protection equipment settings
- Type of DG grounding and interface transformer
- Interaction with other DG(s) or load(s)

Hereof, existing legislations which named “Regulation relating to the unlicensed production of electricity in the electricity market” and “Notification on implementation of the regulations relating to unlicensed electricity production in electricity market” contain the technical specifications and the required limitations about DG integrations and application process.

According to this legislation, first of all, every power plant must be associated with a consumer. Producer and consumer have to be in same or different locations, but both of them should be in the same distribution area. For each of consumption, the limit for the unlicensed production can be 1 MW in total. Until the power allowed reaches 2 MW, connection capacities for each transformer station will be allocated by the distribution company. When 2 MW capacity limit is reached, the distribution company ask TEİAŞ (Turkish Electricity Transmission Company) for capacity approval. Even though, there are no power limitations for private transformer connections, the total production capacity of the plant and the amount of annual allocation are limited for low voltage connections [5]. This ratio is shown in Table 2.

**Table 2.** Annual transformer capacity

Transformer power (t.p.) (kVA)	Total connection capacity	Annual capacity (kWe)
t.p.<100	t.p.x0.3	7.5
100≤t.p.≤1000		t.p.x0.1
t.p.>1000		100 kWe

Using load flow analysis software, the optimum location for connection of DG can be acquired. For instance, adding smaller units to a feeder has high losses will have positive effect to the network, but on the contrary adding a large capacity of DGs will may overcome the feeder capacity boundaries [7].

The individual firm or incorporated firm own the distributed generation which are connected to the network at high voltage level or low voltage (LV) level, is responsible for the construction, commissioning, operation and work safety of the facility [5]. All through the process, there are some important points must complied [5]. Some of power quality and protection setting limits are shown in the following tables [6], (Tables 3,4).

**Table 3.** Protection setting limits to the level of production facilities connected to high voltage [6]

Clearing time (second)	Voltage range <sup>a</sup>
0.2	V≥120
1.0	110<V<120
2.0	50≤V<88
0.2	V<50

a) Voltage regulation is expressed as a percentage of the rated voltage.

**Table 4.** Current harmonics [6]

For phase current ≤ 16A with the connected LV facilities							
Harmonic number	2	3	5	7	9	11	13
Limit	1.08	2.3	1.14	0.77	0.4	0.33	0.21

In addition to that, for a safer operation in distribution utility and to protect the distributed generation unit and the customers from a fault or an injury, some conditions comprise interconnection relay class, configuration of the interconnecting transformer winding, current and voltage transformer requirements and islanding should also be analyzed [7]. For this case, especially the relay settings should be set in acceptable ranges and all protection coordination scenarios should be reviewed for each application of embedded generation.

**Analysis on Solar Power Plants**

In this paper, we use geographical information system which includes all the power network elements (e.i. transformers, lines and breaker) from substations to load and PSS@SINCAL (Siemens Network Calculation) for simulation and evaluation of the existing distribution system.

For this purpose, a total of 8 MW of solar plants were selected and these are represented in the table below where the project name, location name and capacity can be noted.

**Table 5.** Solar plant data

Project Name	Location	Capacity (MW)
Solar Plant 1	1	1
Solar Plant 2	1	1
Solar Plant 3	2	1
Solar Plant 4	2	1
Solar Plant 5	2	1
Solar Plant 6	3	1
Solar Plant 7	3	1
Solar Plant 8	3	1

Figure 3 represents a geographical location of this approach.

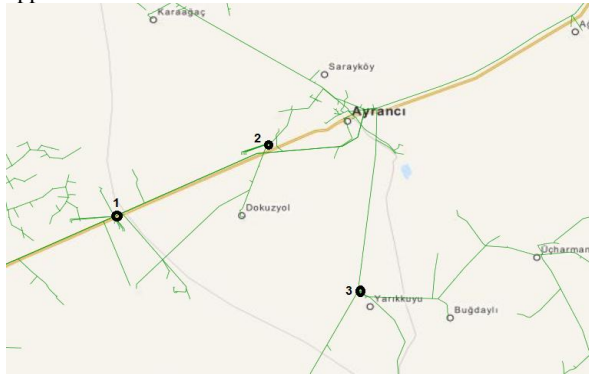


Figure 3. Solar plant locations in Ayrancı-Karaman

Single-line diagram for this distributed generation system approach is shown in Figure 4.

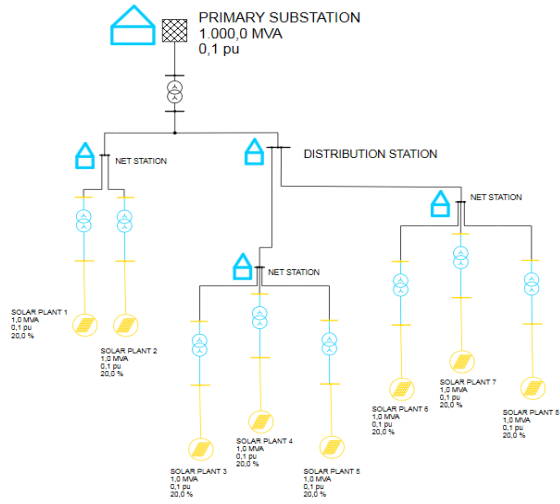


Figure 4. Distribution system in single-line drawings

For this medium voltage network, 3 phase load-flow and short-circuit analysis were applied. Load-flow analysis shows the results in the case where the system is completely unloaded and loaded. Following voltage range results based on places which are close to the location 1, 2 and 3 which include primary substation (TM), distribution stations (DM), net stations (KÖK) and transformers (TR).

Compared with traditional power plants, this effect is quite small for power plants include converter units like wind power plants and solar power plants, as seen as from the Table 7. They create a 1.1 times short-circuit contribution of the nominal current by themselves. For this reason, normally these types of power plants are not exceeding the value of short circuit resistance of bus-bars.

On the other hand, load flow analysis result shows that, the power plant can make the voltage profile better in a loaded system. Due to the capacitive effect, voltage is very high while there is no load on the system and the plant is out of service. In this case, it must be sure not to exceed to the upper voltage limit. Because, this effect leads to an increase of the voltage ripple and flicker effects.

Table 6. Results for loaded and unloaded conditions

Location Name	System with load (pu)		System without load (pu)	
	Before Integration	After Integration	Before Integration	After Integration
TM	1.00574	1.00702	1.03554	1.02964
DM1	0.99127	0.99537	1.03993	1.02885
DM2	1.01452	1.01464	1.08473	1.08293
KÖK1	0.99060	0.99540	1.03992	1.02839
KÖK2	1.00641	1.00742	1.05755	1.05286
KÖK3	0.98704	0.99825	1.04172	1.02613
TR1	0.98589	1.00233	1.03993	1.02391
TR2	0.98681	0.99802	1.04178	1.02619
TR3	0.98449	1.00095	1.03994	1.02392
TR4	0.98374	0.99501	1.04261	1.02700
TR5	1.00618	1.00719	1.05754	1.05286
TR6	1.01250	1.01279	1.07857	1.07611
TR7	0.99397	0.99409	1.08742	1.08562
TR8	1.00819	1.00881	1.06839	1.06486
TR9	0.98684	1.00326	1.03993	1.02391

Table 7. Short-circuit analysis results

Location Number	Before Integration (kA)	After Integration (kA)
TM	5.110	5.476
DM1	3.093	3.509
DM2	4.624	4.675
KÖK1	2.888	3.277
KÖK2	3.790	3.924
KÖK3	1.703	1.965
TR1	1.071	1.181
TR2	1.623	1.862
TR3	0.757	0.812
TR4	0.928	1.003
TR5	2.929	3.002
TR6	4.010	4.066
TR7	0.974	0.976
TR8	2.334	2.361
TR9	1.483	1.687

## RESULTS AND DISCUSSION

In summary, this paper shows that the power system of the future will be quite variable. In the following years, we could say that, the share of solar power plants will increase, especially in the southern parts of Turkey because of its solar radiation potential. For this reason, the analyses have a really critical importance during the review of distribution companies to determine the allowable applications.

In addition to that short circuit calculations are required for assessing the correct ratings for the network (maximum fault currents) and also for protection coordination (minimum fault currents). Besides using the load flow analysis, we could monitor the flow of power through the electric grid and observe the loading rates on lines, cables, busbars or transformers. In this way, the network planners through this analysis can decide optimal connection point for distributed generations.

Consequently, if distributed generations are planned based on these analyses; due to increased production diversity, the distance between the source and load, transformer load will be reduced. Furthermore energy sources do also not have to be away from generation to consumption. Thus, the network outages will decrease while the life of system equipments increases. This will allow Distribution Company the ability for fine operation conditions on a large scale.

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