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Effect of PV Plants Connected to the Electrical Distribution System on the Grid Voltage

Hatice AYDIN [a,*], Muciz ÖZCAN [b]

[a-b] Department of Electrical-Electronics Engineering, Faculty of Engineering, Necmettin Erbakan University, Konya, Turkiye
* Corresponding author’s e-mail address: 23821113001@ogr.erbakan.edu.tr

Abstract
With the Paris Climate Agreement, incentives and demand for distributed generation are increasing day by day to reduce the carbon footprint, increase sustainability, and fight energy crises. However, since the current structure of the EDS is designed to be a one-way energy flow, the traditional grid evolves into a completely different structure with the connection to the distributed generation system. It is known that at the point where the distributed generation is connected to the system, it can have positive contributions to the grid as well as negative contributions. In this study, the effects of the generation-consumption relationship in the integration of PV power plants on the voltage on busbars, lines and transformers between the substation and the end user are investigated. Load flow analysis is performed with MatlabSimulink for two different generation-consumption cases and voltage variations are analyzed within the limits specified in the standards. The results of the analysis show that with the correct integration of PV plants, the grid voltage increases from 30.89 kV to 31.5 kV, which is the nominal voltage level, while with incorrect integration, it increased to 32.56 kV, an increase above the standards.

Keywords: *Distributed generation (DG), Electricity distribution system (EDS), Load flow analysis, PV penetration, Voltage variation*

Elektrik Dağıtım Sistemine Bağlı FV Santrallerin Şebeke Gerilimi Üzerindeki Etkisi

Özet
Paris İklim Anlaşması ile karbon ayak izini azaltmak, sürdürülebilirliği artırmak ve enerji krizleriyle mücadele etmek amacıyla dağıtık üretime yönelik teşvikler ve talep her geçen gün artmaktadır. Ancak elektrik dağıtım sisteminin mevcut yapısı tek yönlü enerji akışı olacak şekilde tasarlandığından, dağıtık üretim sistemine bağlantı ile geleneksel şebeke tamamen farklı bir yapıya evrilmektedir. Dağıtık üretimin sisteme bağlandığı noktada şebekeye olumlu katkıları olabileceği gibi olumsuz katkılarının da olabileceği bilinmektedir. Bu makalede, FV santrallerin entegrasyonunda üretim-tüketim ilişkisinin trafo merkezi ile son kullanıcı arasındaki bara, hat ve trafolar üzerindeki gerilim üzerindeki etkileri incelenmiştir. İki farklı üretim-tüketim durumu için MatlabSimulink ile yük akış analizi gerçekleştirilmiş ve gerilim değişimleri standartlarda belirtilen sınırlar dahilinde analiz edilmiştir. Analiz sonuçları, FV santrallerin doğru entegrasyonu ile şebeke geriliminin 30,89 kV' dan nominal gerilim seviyesi olan 31,5 kV' a yükseldiğini, hatalı bir entegrasyon ile ise standartların üzerinde bir artışla 32,56 kV' a yükseldiğini göstermektedir.

Anahtar kelimeler: *Dağıtık üretim (DÜ), Elektrik dağıtım sistemi (EDS), FV penetrasyonu, Gerilim değişimi, Yük akış analizi*

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1. Introduction

The fact that global climate change, population growth and the increase in per capita energy consumption have increasingly negative effects on modern distribution networks has led to the need to find alternative and clean energy sources and therefore to include more photovoltaic (PV) sources in the grid. The "distributed generation" method, which is called the electricity generation system, where electricity is aimed to be produced at or near the point where it is consumed, has gained increasing importance in recent years due to its great advantages in environmental and efficiency compared to the old "centralized generation" structure [1].

An extensive array of policy measures and technological advancements are necessary to accomplish a swift decrease in carbon dioxide emissions during the next thirty years, as per the special report released by the International Energy Agency (IEA). Energy efficiency, behavioral modifications, electrification, renewable energy sources, hydrogen and hydrogen-based fuels, and bioenergy are the primary subjects of the global energy system's decarbonization. It is planned that 88% of the world's electrical energy needs, obtained from renewable sources, will consist of PV power plants and wind power plants until 2050. This requires high diffusion of “decentralized” renewable energy generation within net zero carbon emission scenarios, which is a challenge for the current operation of electricity grids [2].

Renewable energy (RE) resources characterized by great resource potential and environmental benefits - especially wind and solar photovoltaic resources - will reshape the global energy sector in 2040 according to the sustainable development scenario, and their installed capacity will reach 7059 GW, accounting for 49.21% of the total [3].

Photovoltaic power generation is considered one of the most capable methods of generating electricity from solar energy, except in its different forms. With an annual growth rate of 25-35% in the last decade, solar PV is one of the fastest growing energy sources worldwide. Initially, the solar PV market was used for initial applications, pumping water, solar lighting, etc. In the last decade, there has been a transition from off-grid to grid-connected applications. The installation of grid-tied PV systems is increasing all over the world. The main reasons for this increase on a global scale are the efficiency of PV systems and inverters, incentives, tax breaks, subsidies for the initial cost of the system, feed-in tariff etc. and low costs due to different government supports [4].

Distribution systems, whether radial type systems located in rural residential areas or ring-type systems located in urban areas, are generally designed to operate without any generation in the distribution system [5]. It tends to be radial with mostly unidirectional power flows and "passive" operation [6]. Their primary role is energy distribution to end users. Today, the world is shifting towards the growth of DG consisting of several alternative energy sources that are sustainable, as this traditional method of distribution, which tends to depend on limited fossil fuel energy sources, has proven unsustainable. Until now, the existence of DG has not significantly affected the operation of the electricity distribution system as the number of installed units is small. However, as the number of generation sources increases, it will significantly affect the power flow and voltage conditions for consumers and service equipment. These effects may manifest themselves as positive or negative depending on the operating characteristics of the electricity distribution system and the DG characteristics.

Positive effects are frequently referred to as "system support benefits" and comprise the following; voltage support (voltage profile improvement and improved power quality), reduced line losses, reduced pollutant emissions, increased overall energy efficiency, enhanced system reliability and security, release of transmission and distribution capacity, postponing the investment need for new or improvement, improved auxiliary system reliability, enhanced productivity, lower operating costs and increased management lifetime, as it prevents power equipment from being exposed to excessive loads as the maximum demand is met for production, increased safety for critical loads, increasing the reliability of the power supply due to the redundancy of the power supplies, it is the possibility of using local non-renewable and renewable energy sources [5, 7].

Some of the negative effects of DG integration on EDS can be outlined as follows; the system's increased harmonic level as a result of the power electronic devices used to connect renewable distributed energy sources, over voltages, planning requirements, increased losses (occur when DG is not carefully dimensioned and placed), required protection system updates (capacity equipment both in settings and during upgrade), effects on voltage controller, in addition to altering the transient stability of the device and changing the short-circuit current in the EDS, adding more DG units necessitates recalculating the relay protection settings, the "duck curve," or mismatch in the supply and demand of energy in the grid, which might result from DG units' reliance on uncontrollable natural resources [7].

2. Materials and Method

Turkey is in a geographically excellent position with respect to solar energy potential. Turkey receives 1527 kWh/m2 of annual solar energy (average of 4.2 kWh/m2 per day) and has an annual solar radiation period of 2737 hours (7.5 hours on average per day), according to GEPA. With the current yearly solar radiation in Turkey, the country's potential for producing solar power has been calculated at 380 billion kWh per year [1, 8].

With the publication of the Unlicensed Electricity Generation Regulation in the Electricity Market in 2014, there has been a significant increase in the number of PV power plants connected to the distribution system, with the advantage of Turkey's geographical location. In this study, two separate situations that are currently working were examined.

In the first case, an EDS with high production and low consumption is examined, and in the second case, an EDS with low consumption and overproduction is examined.

In both cases, load flow analysis was performed with the MatlabSimulink program for the voltage changes in the busbars between the substation of the distribution system and the end user. According to the 12-month production and consumption information, the voltage information in the system when the power plant is connected and when it is not connected, is compared, and analyzed in both cases. In the analysis, calculations were made according to the maximum production and consumption values monthly.

2.1. Case A

A low consumption and high generation distribution system is shown in the single-line diagram in Figure 1 below.

The graph in Figure 2 shows the annual generation and consumption data of a feeder connected to the distribution system. In the distribution system, the consumption varies between 1.55 and 6.44 MVA, and the generation varies between 6.17 and 17.85 MVA. In the calculations made with the Photovoltaic geographical information system (PVGIS) program, the radiation duration of the region is 2034.39 kWh/m2 per year. Here, the generation facilities are connected to the system from a single electrical kiosk substation point (Figure 1). In accordance with the unlicensed electricity generation regulation in the electricity market, there are 18 (1x18 MVA) different meter circuits for generation facilities. As can be seen from the geographical image in Figure 3 below, it is a radial network, the consumer portfolio of the region is focused on agricultural irrigation use. Therefore, consumption is higher in the summer and lower in the winter. Considering the developments in the region and the population growth estimates, a significant increase in energy consumption supply is not expected.

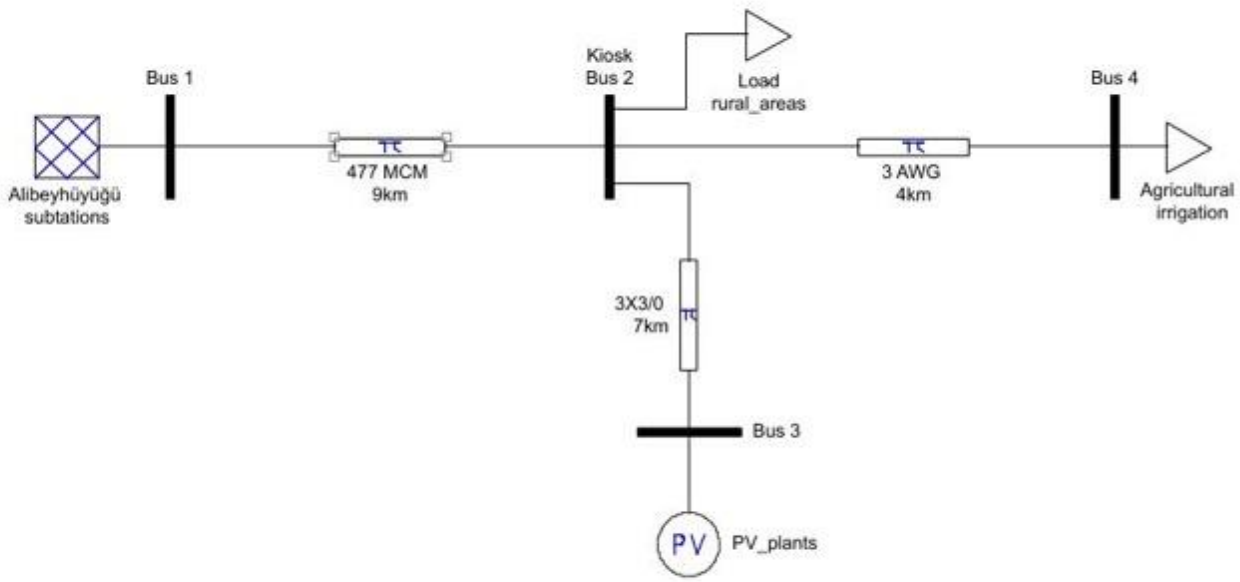

Figure 1. Single-line diagram of the electrical distribution system of case A

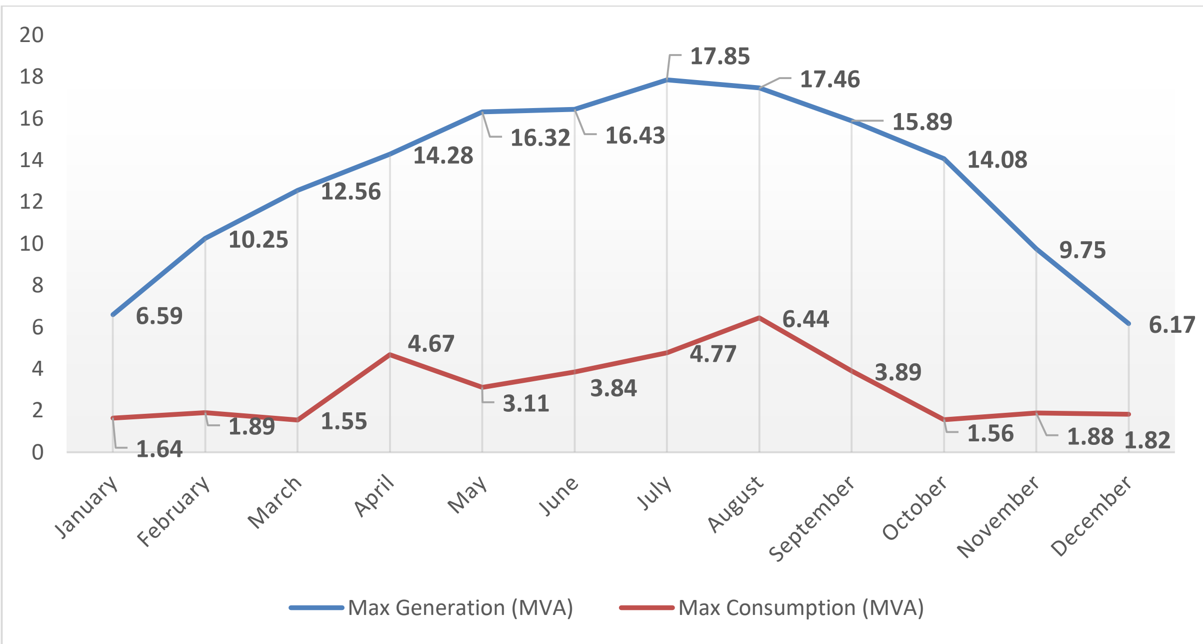

Figure 2. Graph of generation-consumption (MVA) by month of Case A

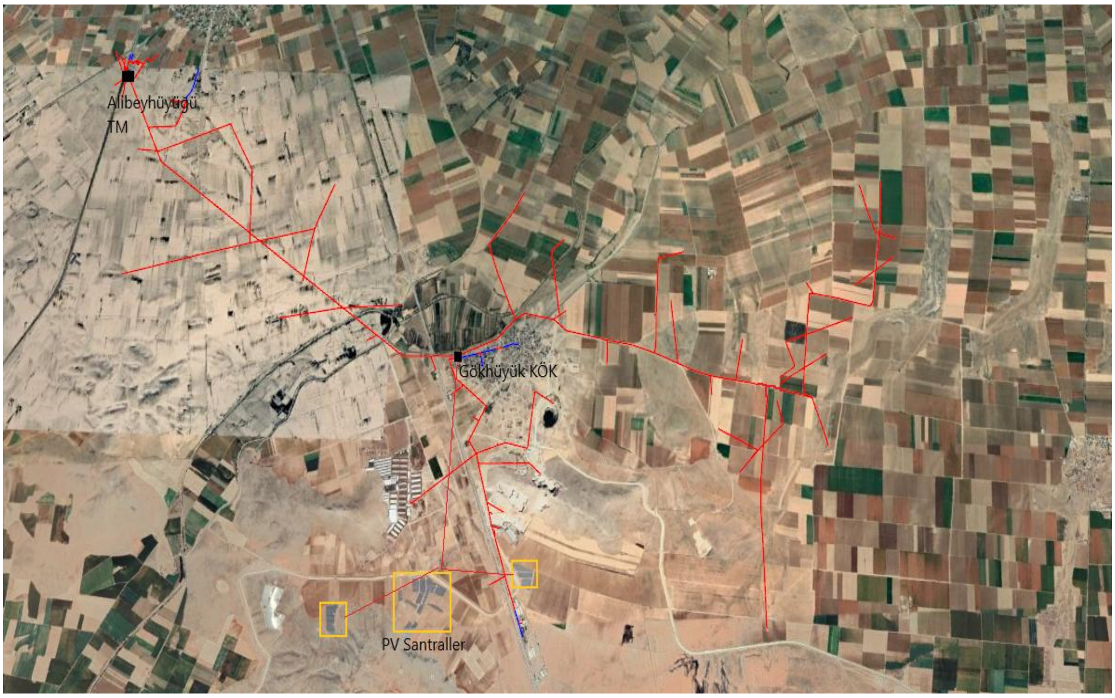

Figure 3. Geographical view of case A and current distribution system

Table 1. Load flow analysis results

2023	Max Generation (MVA)	Max Consumption (MVA)	Without PV Power Plant (kV)			With PV Power Plant (kV)			
			TM	BUS_2	BUS_4	TM	BUS_2	BUS_4	PV
January	6.59	1.64	31.5	31.44	31.43	31.5	31.64	31.63	31.91
February	10.25	1.89	31.5	31.44	31.42	31.5	31.74	31.72	32.15
March	12.56	1.55	31.5	31.45	31.43	31.5	31.82	31.81	32.32
April	14.28	4.67	31.5	31.34	31.30	31.5	31.76	31.72	32.33
May	16.32	3.11	31.5	31.40	31.37	31.5	31.87	31.85	32.51
June	16.43	3.84	31.5	31.37	31.34	31.5	31.85	31.82	32.50
July	17.85	4.77	31.5	31.34	31.30	31.5	31.86	31.82	32.56
August	17.46	6.44	31.5	31.28	31.23	31.5	31.86	31.82	32.56
September	15.89	3.89	31.5	31.28	31.23	31.5	31.79	31.74	32.48
October	14.08	1.56	31.5	31.45	31.43	31.5	31.86	31.85	32.,42
November	9.75	1.88	31.5	31.44	31.42	31.5	31.73	31.71	32.11
December	6.17	1.82	31.5	31.44	31.42	31.5	31.62	31.61	31.87

While performing load flow analysis with MatlabSimulink program [9], [10], [11]; There is a 154/31.5 kV – 100 MVA transformer. MV short-circuit busbar power is 540 MVA, X: 0.703 Ω, R: 0.202 Ω. The rated operating voltage of the distribution system is 31.5 kV.

2.2. Case B

A high consumption and low generation distribution system is shown in the single-line diagram in Figure 4 below.

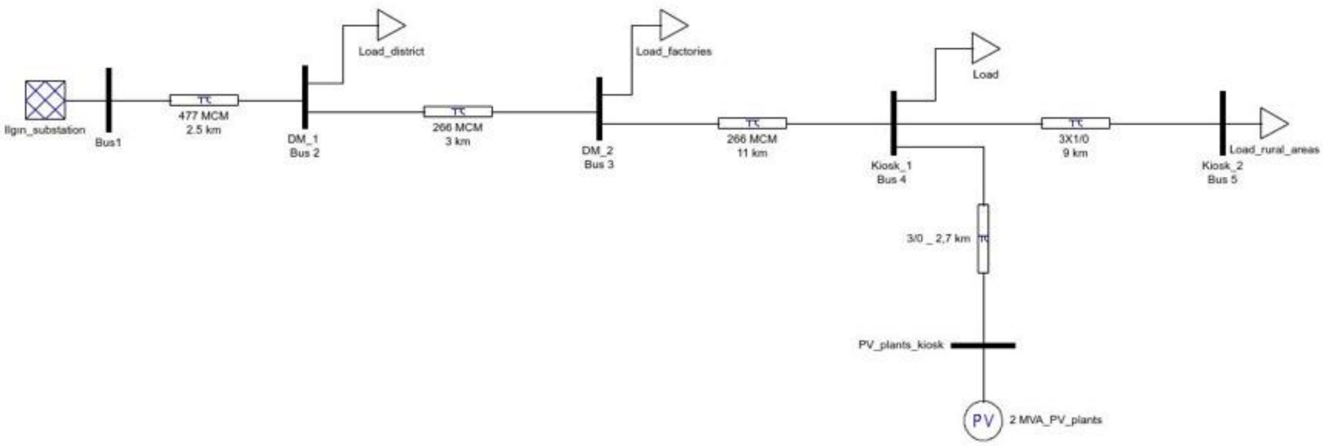

Figure 4. Single-line diagram of the electrical distribution system of case B

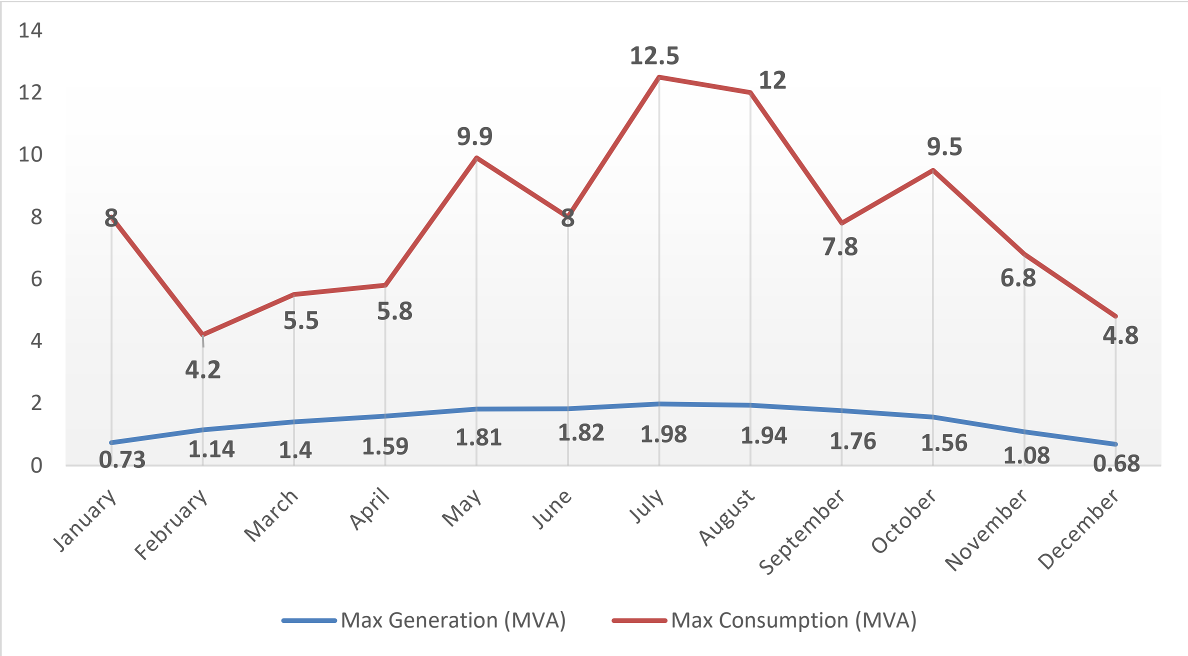

Figure 5. Generation-consumption (MVA) graph by month for case B

The graph in Figure 5 shows the annual generation and consumption data of a feeder connected to the electricity distribution system. It has been observed that consumption in the distribution system varies between 4.2 and 12.5 MVA, and the generation varies between 0.73 and 1.98 MVA. In the calculations made with the PVGIS program, the radiation duration of the region is 1891.42 kWh/m2 per year. Here, the generation facilities are connected to the system from a single point via a pole. In accordance with the unlicensed electricity generation regulation in the electricity market, there are 2 (1x2 MVA) different meter circuits for generation facilities. As can be seen from the geographical view in Figure 6, it is a radial network, the consumer portfolio of the region consists of villages and agricultural irrigation. In Figure 5, the consumption is higher between May and October. In other months, the data of the villages with regular consumption can be seen.

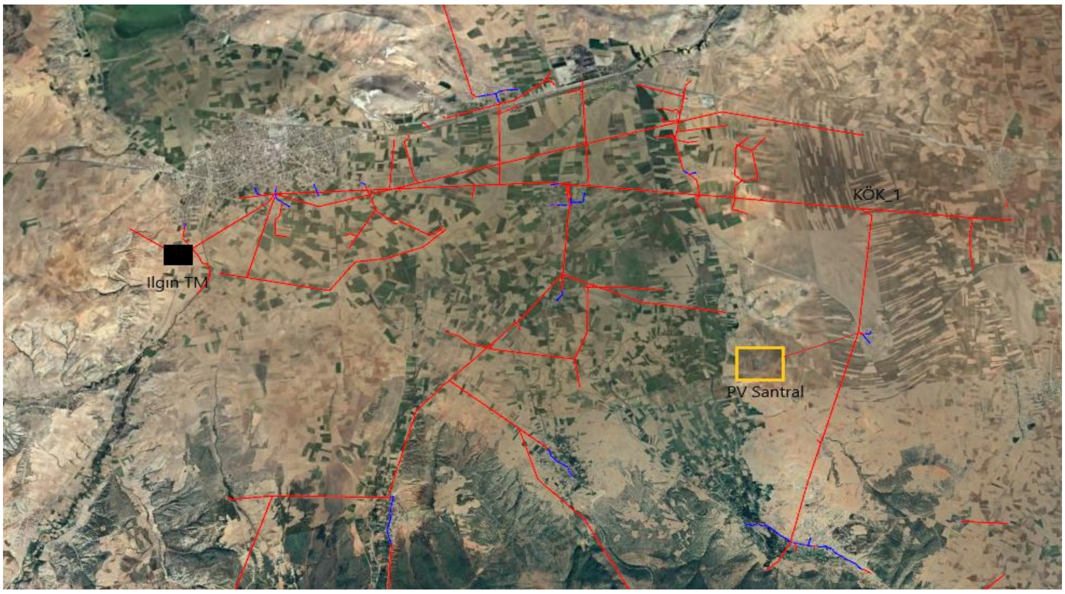

Figure 6. Geographical view of case B and current distribution system

Table 2. Load flow analysis results

2023	Max Gen. (MVA)	Max Cons. (MVA)	Without PV Power Plant (kV)					With PV Power Plant (kV)					
			TM	BUS_2	BUS_3	BUS_4	BUS_5	TM	BUS_2	BUS_3	BUS_4	BUS_5	PV
January	0.73	8	31.5	31.42	31.33	31.17	31.11	31.5	31.43	31.34	31.23	31.17	31.44
February	1.14	4.2	31.5	31.46	31.41	31.33	31.30	31.5	31.47	31.44	31.41	31.38	31.43
March	1.40	5.5	31.5	31.45	31.38	31.27	31.23	31.5	31.46	31.41	31.38	31.34	31.42
April	1.59	5.8	31.5	31.45	31.37	31.26	31.22	31.5	31.46	31.42	31.40	31.36	31.43
May	1.81	9.9	31.5	31.41	31.29	31.09	31.02	31.5	31.42	31.33	31.23	31.16	31.50
June	1.82	8	31.5	31.42	31.33	31.17	31.11	31.5	31.44	31.37	31.31	31.25	31.50
July	1.98	12.5	31.5	31.38	31.23	30.99	30.89	31.5	31.40	31.27	31.14	31.04	31.50
August	1.94	12	31.5	31.39	31.24	31.01	30.91	31.5	31.40	31.28	31.16	31.06	31.49
Sept.	1.76	7.8	31.5	31.43	31.33	31.18	31.12	31.5	31.44	31.37	31.32	31.26	31.44
October	1.56	9.5	31.5	31.43	31.33	31.18	31.12	31.5	31.42	31.33	31.23	31.16	31.45
Nov.	1.08	6.8	31.5	31.44	31.35	31.22	31.17	31.5	31.45	31.38	31.30	31.25	31.42
Dec.	0.68	4.8	31.5	31.46	31.40	31.30	31.27	31.5	31.46	31.41	31.36	31.32	31.47

While performing load flow analysis with MatlabSimulink program [9], [10], [11]; There is a 154/31.5 kV – 50 MVA transformer. MV short-circuit busbar power is 271 MVA X: 1.486 Ω, R: 0.520 Ω. The rated operating voltage of the distribution system is 31.5 kV.

3. Results and Discussion

For two different electricity distribution systems made by load flow analysis [12], [13], [14], it is seen that the energy generated in Case A is 9 times more in October and 3 times more in August, according to the consumed energy. Under normal operating conditions (when generation facilities are not connected), the voltage drop for the end user is 0.87. It is seen that the energy supply is provided in accordance with the energy legislation in terms of the distance of the end user to the substation, line section and load. When PV power plants are connected, the voltage is constantly above 31.5 kV in all electrical equipment. In Table 1, the voltage in the electrical kiosk substation (BUS 2) to which the PV plants are connected is 1.18% higher than the operating voltage. At the output of the PV plant, it rises to 32.56 kV. In July, when the generation is the highest, there is a consumption of 4.77 MVA and a generation of 17.85 MVA in the distribution system. While 4.77 MVA of the generated energy is used by the consumption facilities, 13.08 MVA (line losses are not considered [15]) causes reverse energy flow towards the substation through the same distribution system. In Case A, it is seen that integrating PV plants into this grid causes disadvantages. The distribution transformers used in the system have the voltage levels specified in Table 3. However, in Case A, the grid voltage rises up to 32.56 kV as more generation plants are connected than the grid needs. At 32.56 kV, since the equipment connected to the system will be outside the nominal operating conditions, the transformers of the users connected to the grid should be increased from 31.5 kV to 33 kV. Since there is no system to prevent overvoltage spikes in the existing structure, faults such as short circuits and heating due to overvoltage will occur on the user side (loads) and pose a danger to the security of the system. Therefore, supply reliability and power quality issues will also arise.

To solve these problems, passive methods such as grid reinforcement can be utilized as well as control strategies. These control strategies include reducing the PV active power, controlling the reactive power generated by the PV system, and using transformer tap changers. Apart from these methods, an effective method recommended in academic studies is to integrate the storage system with an on-site generation source such as PV systems. When PV offers peak power generation and empty load, excess generation can be avoided by storing the electricity and preventing overvoltage. When there is no PV generation and the load rises to maximum values, the stored power is injected into the distribution grid to prevent or mitigate voltage drops [16].

In case B, generation is low, and consumption is high. According to the energy generated, it is seen that consumption is about 11 times in January and about 4 times in April. In Table 2, under normal operating conditions (when generation facilities are not connected), the voltage drop for the end user is 1.94%. It is seen that the energy supply is provided in accordance with the energy legislation in terms of the distance of the end user to the substation, line section and load. When PV plants are connected, it is observed that there is an improvement in the voltage profile at the levels of 0.05 and 0.16, where the voltage approaches the nominal operating voltage (31.5 kV) in the busbars (BUS 4 and BUS 5) close to the point where the plant is connected. All energy produced for 12 months is consumed by consumers connected to the distribution system. In Case B, PV plants connected to the system provide an advantage for the grid by increasing the voltage since there is a voltage drop in the existing grid. With the integration of generation facilities into the system, the operation approaches the nominal voltage values (31.5 kV) as shown in Table 2. With the inclusion of PV systems, the power quality of the system improves, technical losses are reduced and the lifetime of the grid due to heating is positively contributed. In addition, the grid operator will also benefit economically as it will not need to make a new investment due to voltage drop.

According to the data obtained from both cases, the characteristics of the grid to which PV systems will be connected are of great importance. PV plants have value when used effectively [17]. Excessive penetrations of PVs can lead to various power quality limit violations such as overvoltage, undervoltage, and high harmonic distortion. Hosting capacity is defined as the maximum amount of PV that can be safely deployed in a grid without causing any technical violations. PV hosting capacity is an important issue in PV planning [18]. If a generation facility is integrated into the grid by making adequate analyses, it provides significant advantages to the system. Integration without the necessary analysis brings additional negative effects to the grid by jeopardizing the security of the grid.

4. Voltage Level According to Standards

One of the most important negative effects of PVs on power quality is voltage imbalance. Voltage imbalance is the situation where the effective values of the three-phase voltages are not equal to each other and/or there is no 120-degree phase difference between them. Among the causes of unbalance in conventional power systems, lines that do not have equal impedance, failure to distribute single-phase loads to phases with equal power, and asymmetric power system failures can be counted [19].
When the voltage variation in the electricity distribution system is examined according to legislation and standards, no limit is specified for 36 kV and below voltage levels in Turkey. The limit values of the 36 kV transmission system are given.

4.1. Turkey, TEDAŞ MYD technical specification

According to the technical specifications, in Table 3 the values related to the voltage setting of the transformers to be used in the distribution system are given [20]. The normal operating voltage is 31.5 kV, if the voltage rises by 4.76%, the stage must be changed.

Table 3. Idle voltage adjustment of TEDAŞ MYD distribution transformer

Setting winding	On the MV side	
Setting class	Constant flux (TS EN 60076-1: CFVV)	
Voltage setting range Number of stages Idle spin rate NOTE: Values in bold are the main setting values	**6.3-10.5-15.8 kV** ± 2x%2.5 5 YG± 2x%2.5/0.4 kV	**33 kV** 28.5-30-31.5-**33**-34.5 kV 5 28.5-30-31.5-**33**-34.5/0.4 kV

4.2. Turkey, Electricity market distribution system legislation

Under normal operating conditions, the active power output of the unit should not be affected by voltage variations. In this case, the reactive power output of the unit should be fully available within ± 5% voltage variation range [21].

4.3. Turkey, Electricity market grid legislation

The nominal frequency of the system, which is 50 Hertz (Hz), is controlled by TEIAS in the range of 49.8-50.2 Hz.

System voltage and variation limits:
The rated voltages of the transmission system are 400 kV, 154 kV and 66 kV. Under normal operating conditions, the 400 kV transmission system is operated between 340 kV and 420 kV, and the 154 kV transmission system is operated between 140 kV and 170 kV. For a transmission system of 66 kV and below, the voltage variation is ±10% [22].

4.4. IEEE 1547-2008 standard

It is recommended that the total DG value in a system should not be more than 2% of the system load. The following Table 4 shows the voltage variation according to the power of the DGs to be connected to the EDS.

Table 4. IEEE 1547 synchronization parameter limits

Aggregate rating of DG units (kVA)	**Frequency difference (Δf, Hz)**	**Voltage difference (ΔV, %)**	**Phase angle difference (ΔΦ, °)**
0–500	0.3	10	20
>500–1500	0.2	5	15
>1500–10 000	0.1	3	10

In addition, according to IEEE 1547, the stiffness ratio of the system should be calculated when connecting DG. The capacity of a power system to withstand variations in load or voltage fluctuations caused by DG is known as its durability [23].

$$stiffness\ ratio\ = \frac{SC\ kVA\ (area\ EDS) + SC\ \ kVA(D\ddot{U})}{SC\ kVA\ (D\ddot{U})} = \frac{SC\ kVA\ (area\ EDS) + 1}{SC\ kVA\ (D\ddot{U})} \tag{1}$$

SC kVA (EDS) = Short-circuit contribution of the EDS field in kVA (including all other sources)
SC kVA (DG) = Short circuit contribution of evaluated DG in kVA

$$stiffness\ ratio = \frac{sc + 1}{sc} \tag{2}$$

In cases where this ratio is high (>200), voltage flicker shows that it will not pose a problem in terms of steady-state voltage regulation and harmonics. The fact that this ratio is small (<50) indicates that the problems increase significantly [24].

4.5. Germany, BDEW

The amount of voltage fluctuations brought about by all generation facilities on medium voltage network connection points should not, under typical network operating conditions, surpass 2% of the voltage at any one of the network's connection points. (without a connected generating plant)

Under normal operating conditions, the maximum voltage variation that the generation plants will create at the medium voltage connection point should not be more than 2% compared to the network structure they are not located in.

The voltage change that occurs because of the generators being disabled at a single connection point should not be greater than 5% [25].

4.6. AS/NZ 4777.1

It has limited the voltage rise to 2%. The numbers listed in Table 5 below correspond to the frequency and voltage restrictions as stated in Standards Australia clause 5.3. The disconnect device for passive anti-island protection will activate in two seconds if this range is crossed. It also suggests that the inverter capacity shouldn't be exceeded by the protection device settings.

Table 5. Voltage and frequency limits according to Australian Standards

Voltage	Single phase system	Three phase system
V_{min}	200 – 230 V	350 – 400 V
V_{max}	230 – 270 V	400 – 470 V

Frequency	Range
F_{min}	45 – 50 Hz
F_{max}	50 – 55 Hz

4.7. NER (National Electricity Rules), Australia/Queensland

Magnitude of power frequency voltage, which is during credible contingency events, supply voltages should not rise above its normal voltage. The Regulations/Rules are further defined in Table 6.

Table 6. Allowed changes in Australia/Queensland nominal voltage.

Voltage level	Electrical legislation	NER
Low voltage (>1 kV)	+10 /-6 %	±10 %
Medium voltage (1kv – 22 kV)	±5 %	±10 %
High voltage (22 kV – 132 kV)	As agreed,	±10 %

4.8. Japan

Distribution firms are required to maintain the three-phase LV distribution voltage at 202+/-10 V and the single-phase voltage at 101+/-6 V. The PV output is limited if the voltage increases above the previously mentioned thresholds.

For low voltage, from the supply point to the inverter AC the total voltage rise at the terminals (main interactive connection point) must not exceed 2% of the rated voltage at the supply point [4].

4.9. New York

In general terms, the maximum DG connected to the distribution system is 10 MW at the distribution feeder and 20 MW per grid substation.

Furthermore, it is prohibited to link synchronous generators to the low voltage secondary grid since doing so could result in the grid's network protectors opening. This is because DGs connected to the low voltage secondary grid may cause problems. On an individual basis, small induction and inverter-based power plants are allowed [26].

4.10. European standard EN-50160

The cases where the nominal rms voltage between phase-phase does not exceed 1000 V are expressed as low voltage, and cases where the nominal rms value between phase-phase is between 1 kV and 35 kV are expressed as medium voltage.

It has been stated that, under normal operating conditions, excluding voltage interruptions, 95% of the 10-minute average rms values of the supply voltage should be in the range of Uc ± 10% in one-week periods [27].

4.11. Poland

In Poland, the electrical energy distribution rules are set by the government supply voltage; it is applied as -10% and +5% of the 15-minute rms value for low voltage and medium voltage [28].

4.12. Hungary

Table 7. Limits for grid voltage variation

Period	Time	Limit	Voltage level
10 min	95%	±7.5% of Un	LV
10 min	100%	±10 % of Un	LV
1 min	100%	±15 %/-20% of Un	LV
10 min	100%	±10 % of Un	MV

The required supply voltage variation levels mentioned Table 7 above are set out in the Hungarian regulation as a Guaranteed Standard [29].

4.13. ANSI c84.1 (American national standard for electric power systems and equipment)

The MV voltage variation in the distribution network is between +5% and -5% for the system operating at 600 V and below under nominal operating conditions. For systems operating above 600V, this range is +5% to -2.5%.

4.14. Canadian standards association CSA

Preferred voltage levels for AC systems in Canada are up to 50.000 V. The acceptable voltage variation is Un ± 6% of the rated voltage.

The Figure 7 below shows the voltage variation limits according to the standards. Nominal voltage (operating voltage in Turkey) 31.5 kV is taken as a reference.

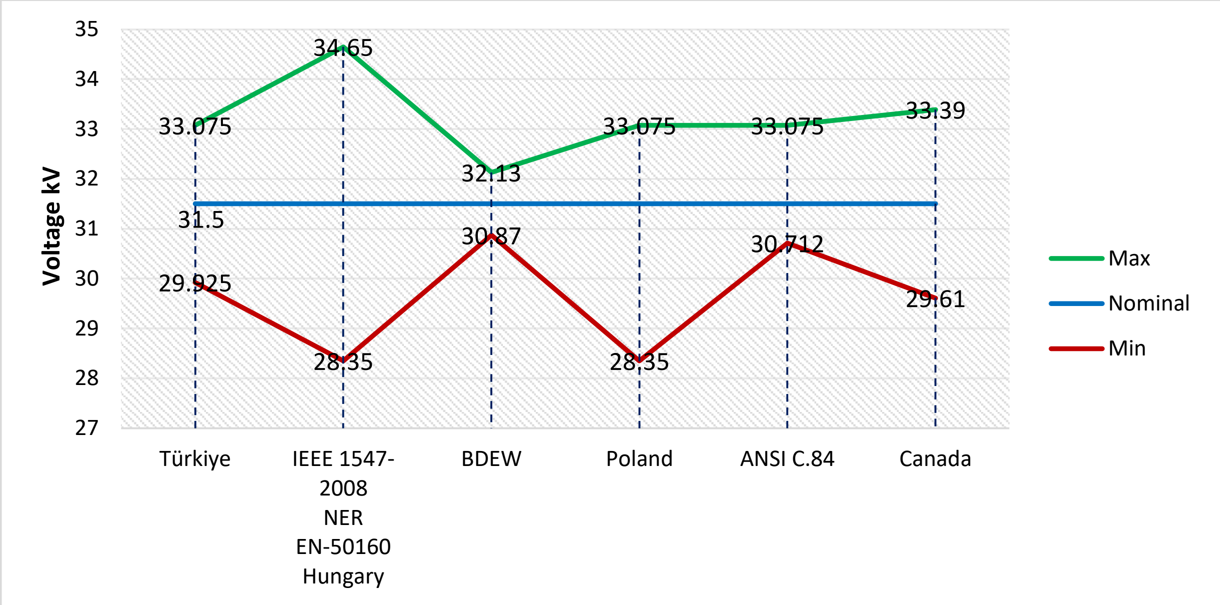

Figure 7. Max and min voltage variation according to standards

5. Conclusion

In the not-too-distant future, traditional centralized grid infrastructure will be replaced by distributed energy grids. Thus, the final consumption points and electricity generation plants will approach each other geographically and in numbers [30].

In the integration of grid-connected PV plants, it is expected to support the grid by providing some of the required main power and improving the system power quality by improving the system voltage profile, reducing power losses, and improving the grid connection to sell electrical energy.
However, obtaining the above benefits is often much more difficult in practice. PV generation sources must be reliable, dispatchable, of appropriate size, and in suitable locations. They must also meet various other (ancillary) employment criteria. Since PV plants will not be owned by the distribution company and are a variable energy source, there is no guarantee that these conditions will be met, and full system support benefits will be realized [5].

In addition, when electricity consumption in Turkey is analyzed on a tariff basis, it has 24/7 unstable load profiles, as in the examples we examined in the article. Due to the geographical location of the country, some regions consume in the summer due to summer tourism, while consumption increases in the winter months in some regions. In the regions where agricultural irrigation is made, energy consumption varies according to the cultivated crops, and they do not have a stable consumption curve. Therefore, when connecting a PV generation source to the system, it is essential to make detailed analyses for four different situations. These four different situations; 1) max load, max generation; 2) max load, min generation; 3) min load, max generation; 4) min load, min generation [6].

If the analyses are not done well, the generation facility will not be able to operate at the desired efficiency, since voltage increases may occur in the network [6]. In order to solve the voltage rise problem, distribution companies will either have to make additional investments or the power plant will not be allowed to transfer the surplus to the system.

In addition, distribution companies may face reactive penalties for the energy transferred to the transmission via the distribution system. Currently, reactive power support for PV plants on the grid

[23, 31] is not in practice. However, by developing a model for switching on such a system in the future, the voltage rise on the network will be reduced. With the use of reactive power control and storage systems, higher PV capacity will be obtained, and its positive effects will be increased over the grid.

List of Symbols

AC	Alternative current
EDS	Electricity distribution systems
DG	Distributed generated
PV	Photovoltaic
PVGIS	Photovoltaic geographical information system
RE	Renewable energy

Declarations and Ethical Standards

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Author Contribution

Author 1 conceived of the presented idea. Author 1 developed the theory, performed the computations and carried out the experiments. Author 2 supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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About the Authors

 Hatice Aydın	Hatice Aydın completed his undergraduate studies in Electrical and Electronics Engineering at Selçuk University. He pursued his master's and doctoral degrees in Electrical and Electronics Engineering at Necmettin Erbakan University.
 Muciz Özcan	Prof. Dr. Muciz Özcan completed their undergraduate studies in Electrical and Electronics Engineering at Anadolu University. They earned their master's and doctoral degrees in Electrical and Electronics Engineering at Selçuk University.