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Voltage Level Managements of Multilevel Inverter Based on Renewable Energy Sources and Environment Conditions

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Anahtar Kelimeler

Bağımsız, PV, rüzgar türbini, hibrit yenilenebilir enerji, çok seviyeli invertör

Graphical/Tabular Abstract (Grafik Özet)

This study presents a hybrid multilevel inverter (MLI) design that minimizes switching devices while utilizing multiple renewable energy sources, achieving flexible output levels. The system demonstrates effective performance, with total harmonic distortion (THD) ranging from 3.1% to 1.04%, in compliance with IEEE Standard 519-2022. /Bu çalışma, birden fazla yenilenebilir enerji kaynağını kullanarak anahtarlama elemanlarını en aza indiren bir hibrit çok seviyeli inverter (MLI) tasarımını sunmaktadır ve esnek çıkış seviyeleri sağlamaktadır. Sistem, IEEE Standardı 519-2022 ile uyumlu olarak toplam harmonik distorsiyon (THD) değerinin %3.1'den %1.04'e kadar değiştiğini göstermektedir.

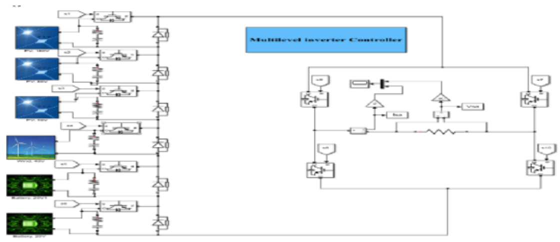

Figure A. *The proposed MLI(Önerilen MLI)*

Highlights (Önemli noktalar)

- *Innovative Design / Yenilikçi Tasarım.*
- *Utilization of Renewable Energy Sources / Yenilenebilir Enerji Kaynaklarının Kullanımı.*
- *Flexibility in Output Levels / Çıkış Seviyelerinde Esneklik.*
- *Performance Improvement / Performans İyileştirmesi.*

Aim (Amaç): *A hybrid multilevel inverter design that uses fewer switching elements and multiple renewable energy sources to produce high-quality AC output while optimizing performance by reducing total harmonic distortion (THD). / Daha az anahtarlama elemanı ve birden fazla yenilenebilir enerji kaynağı kullanarak yüksek kaliteli AC çıkışı üreten bir hibrit çok seviyeli inverter tasarımı, toplam harmonik distorsiyonu (THD) azaltarak performansı optimize etmektedir.*

Originality (Özgünlük): *This study presents a novel hybrid multilevel inverter (MLI) design that minimizes the number of switching devices while utilizing a modulation technique for various renewable energy sources. This innovative approach enhances flexibility in generating different output levels and effectively addresses harmonic distortion, ensuring high-quality voltage and current waveforms. / Bu çalışma, çeşitli yenilenebilir enerji kaynakları için modülasyon tekniği kullanarak anahtarlama elemanlarının sayısını en aza indiren yenilikçi bir hibrit çok seviyeli inverter (MLI) tasarımını sunmaktadır. Bu yenilikçi yaklaşım, farklı çıkış seviyeleri üretme esnekliğini artırırken harmonik bozulmayı etkili bir şekilde ele almakta ve yüksek kaliteli gerilim ve akım dalga formlarını sağlamaktadır.*

Results (Bulgular): *the system achieves a (THD) of 1.04% with a 37-level output when all sources are operational. and 1.19% with 33-level output and 0.99% at 35-level output . Finally the output voltage remains at 31 levels, demonstrating effective voltage and THD management. / Sistem, tüm kaynaklar çalışırken 37 seviye çıkışta %1.04 toplam harmonik distorsiyon (THD) elde etmektedir. 33 seviye çıkışta %1.19 ve 35 seviye çıkışta %0.99 THD ile çalışmaktadır. Son olarak, çıkış gerilimi 31 seviyede kalmakta ve bu da gerilim ile THD yönetiminin etkinliğini göstermektedir.*

Conclusion (Sonuç): *These findings confirm the system's ability to maintain low THD across various operational scenarios. / Bu bulgular, sistemin farklı çalışma senaryolarında düşük toplam harmonik distorsiyon (THD) değerini koruma yeteneğini doğrulamaktadır.*

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Voltage Level Managements of Multilevel Inverter Based on Renewable Energy Sources and Environment Conditions

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Abstract

Due to its advantages in applications requiring high voltage, high power, and low harmonics, multilevel inverter (MLI) technology has attracted a lot of attention. Using multilevel inverter technology, one can expect to obtain output voltage and current waveforms of the highest quality. However, as the number of levels increases, so does the numbers of the switching devices and energy sources. This issue can be solved by creating the MLI using hybrid technology. This paper is devoted to designing a hybrid multilevel inverter with fewer switching elements and a modulation technique for multiple energy sources. In multilevel inverters, the most essential requirements are the evolution of the hybrid MLI model and a decrease of harmonic components in the output of the inverter voltage/current. This study proposes a system composed of four distinct renewable energy sources besides a backup battery. Three solar PV panel systems with voltages of (8:4:2)E are recommended, along with a wind turbine of 2E, a battery source of 1E, and a battery source of 1E. The sum of all DC sources was (8:4:2:2:1:1)E to generate a 37-level voltage on the output if all renewable energies are available. The system can also work to generate 35-level (without using batteries). Also, it can generate 33-level (without wind), 9-level (without PV systems), and 3-level (just using one of the battery systems). So, the system is flexible to generate different output levels according to what renewable energy sources are available. The system was created using the MATLAB software. The results proved that the designed hybrid multilevel has good THD responses for each level which ranges from 3.1% to 1.04% from level 3 to 37 of MLI regarding the IEEE Standard of 519-2022.

Yenilenebilir Enerji Kaynaklarına ve Ortam Koşullarına Göre Çok Seviyeli İnvertörün Gerilim Seviyesi Yönetimleri

Makale Bilgisi

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Öz

Yüksek gerilim, yüksek güç ve düşük harmonik gerektiren uygulamalardaki avantajları nedeniyle çok seviyeli invertör (MLI) teknolojisi büyük ilgi görmüştür. Çok seviyeli invertör teknolojisini kullanarak, en yüksek kalitede çıkış voltajı ve akım dalga formlarının elde edilmesi beklenebilir. Ancak seviye sayısı arttıkça anahtarlama cihazlarının ve enerji kaynaklarının sayısı da artar. Bu sorun, hibrit teknoloji kullanılarak MLI oluşturularak çözülebilir. Bu makale, daha az anahtarlama elemanına ve çoklu enerji kaynakları için bir modülasyon tekniğine sahip hibrit çok seviyeli bir invertörün tasarlanmasına ayrılmıştır. Çok seviyeli invertörlerde en temel gereksinimler, hibrit MLI modelinin geliştirilmesi ve invertör voltajı/akımının çıkışındaki harmonik bileşenlerin azaltılmasıdır. Bu çalışma, yedek bataryanın yanı sıra dört farklı yenilenebilir enerji kaynağından oluşan bir sistem önermektedir. Gerilimleri (8:4:2)E olan üç güneş PV paneli sisteminin yanı sıra 2E'lik bir rüzgar türbini, 1E'lik bir akü kaynağı ve 1E'lik bir akü kaynağı önerilir. Tüm yenilenebilir enerjilerin mevcut olması durumunda çıkışta 37 seviyeli bir voltaj oluşturmak için tüm DC kaynaklarının toplamı (8:4:2:2:1:1)E idi. Sistem ayrıca 35 seviyeli (pil kullanmadan) üretim yapabilecek şekilde de çalışabilmektedir. Ayrıca 33 seviyeli (rüzgarsız), 9 seviyeli (PV sistemsiz) ve 3 seviyeli (sadece akü sistemlerinden birini kullanarak) üretim yapabilmektedir. Dolayısıyla sistem, mevcut yenilenebilir enerji kaynaklarına göre farklı çıktı seviyeleri üretebilecek kadar esnektir. Sistem MATLAB yazılımı kullanılarak oluşturulmuştur. Sonuçlar, tasarlanan hibrit çoklu seviyenin, 519-2022 IEEE Standardına göre MLI'nın 3. seviyesinden 37. seviyesine kadar %3,1 ila %1,04 arasında değişen her seviye için iyi THD yanıtlarına sahip olduğunu kanıtladı.

1. INTRODUCTION (GİRİŞ)

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A multilevel inverter (MLI) is a power electronic device used to convert DC sources into AC type with multiple voltage levels. Unlike conventional two-level inverters, which can only generate two voltage levels (positive and negative), multilevel inverters can generate multiple different voltage levels, resulting in a smoother waveform, more sinusoidal AC waveform. This characteristic makes them attractive for high-power applications, especially in renewable energy systems, motor drives, and high-voltage transmission systems [1]. The basic principle of a multilevel inverter is to synthesize the required AC voltage waveform through the cascaded combination of multiple DC voltage sources. The number of voltage levels can affect the output waveform quality and other performance parameters such as switching losses and efficiency.

MLI technologies can be implemented to enhance power quality, increase stability, improve output voltage and current waveforms, decrease electromagnetic interference (EMI), decrease the altered size, and decrease the total harmonic distortion (THD). Reducing THD value is the primary advantage of MLIs over conventional inverters.

2. LITERATURE REVIEW (LITERATÜR TARAMASI)

Multilevel inverters are ideally suited for standalone applications requiring a few kilowatts or less [2]. The primary challenge that may confront renewable energy source (RES) is the production of electrical energy from unregulated DC or AC power sources, which must be converted into regulated DC or AC power [3]. There are numerous forms of RES, including solar energy, wind energy, geothermal energy, and others. The most prevalent RES applications are solar and wind energies [4]. RESs have increased in recent years due to their durability, eco-friendliness, and independence, which make them a viable replacement for conventional generation units. The primary issues with fossil fuels are that they require routine maintenance, are non-renewable, and contribute to global warming and ecological imbalance. These factors increase interest in the construction and advancement of RES-based electricity generation. Increasing burdens necessitate an increase in RES, which will become a viable option for system-supporting electrical technology applications [5]. Modified MLIs are viable alternatives for systems using solar PV and/or other renewable energy systems.

In 2018 [6], compared to fossil fuel units, renewable energy sources are suggested to dominate the scene of local power generation due to the highly efficient and minimal operating costs for independent networks. In 2021 [7], the characteristics of MLIs were summarized to highlight the significance of grid-tied PV systems, and novel converters were applied to enhance energy conversion in existing energy systems. In 2020 [8], the primary advantages of MLIs, which are focused on THD, EMI, and dV/dt switch stress were discussed. Utilizing MLI will decrease the number of power electronics components while simultaneously enhancing power quality and decreasing total cost. In 2019 [9], MATLAB Simulink was used to model an MLI fed by renewable energy sources (wind and solar energy) in a stand-alone system with varying wind speeds and solar irradiances. In 2018 [10], a study introduced a fresh perspective by investigating a novel 31-level asymmetric multilevel inverter using multi-carrier pulse width modulation (PWM). This approach, along with the utilization of an alternative phase opposition disposition PWM technique to achieve 3.75% THD and compliance with IEEE Standard 519, presents a unique contribution.

In 2020 [11], research utilizes a reference sinusoidal signal and a triangle carrier signal for pulse width modulation in multilevel inverters. The research investigates the effects of carrier signal level shifting on a hybrid PV-based multilevel inverter, emphasizing the utilization of harmonics to enhance voltage quality and minimize losses. In 2019 [12], a concept for a hybrid electric boat power system has been introduced. This system incorporates diverse renewable energy sources including wind turbines, solar PV panels, and polymer electrolyte membrane fuel cells. The hybrid power system efficiently drives the boat's electric motor. Energy distribution between these sources is controlled using circuit breakers, depending on wind speed conditions. The proposed three-component system was simulated using SIMULINK. Simulation results demonstrate the electric boat's continuous operation even in varying weather conditions such as solar irradiance and wind speed fluctuations. In 2021 [13], this research highlights the advantages of multilevel inverters: high output voltage with low distortion. It presents a 15-level inverter design using modified sinusoidal pulse width modulation for reduced harmonic distortion and variable output voltage. Simulation shows that non-zero-level (NZL) inverters achieve lower distortion compared to zero-level (ZL). Results confirm the effectiveness of the power circuit and modified absolute sinusoidal PWM controller in achieving the desired voltage with reduced THD.

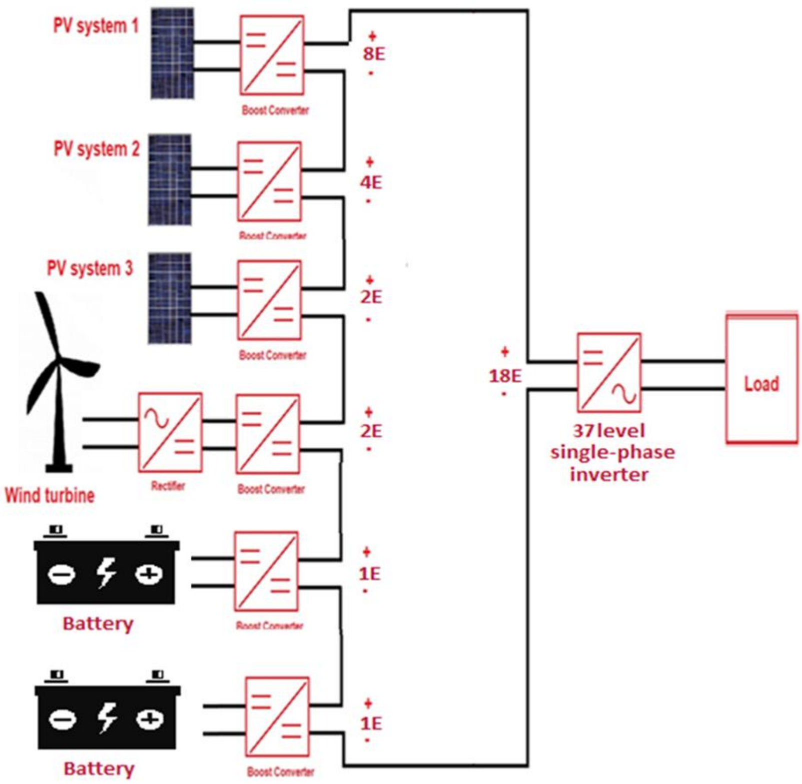
In this study, single-phase cascade MLIs are designed and implemented for stand-alone RES (PV, wind turbine, batteries). By defining E as 20 Volts, the configuration of the power supplies is (1:1:2:2:4:8)E to generate a different 37 voltage level. Compared to conventional types, the designed system reduces switching losses, THD, price, and size, and improves output waveforms. A test bench including six feed sources was built in MATLAB/Simulink, as shown in Fig. 1, and the performance of the suggested MLIs was examined in terms of the power quality in detail. The results proved that the designed hybrid multilevel has good THD responses for each level of MLI regarding the IEEE Standard of 519-2022.

3. ARCHITECTURE OF THE SUGGESTED SYSTEM (ÖNERILEN SISTEMIN MIMARISI)

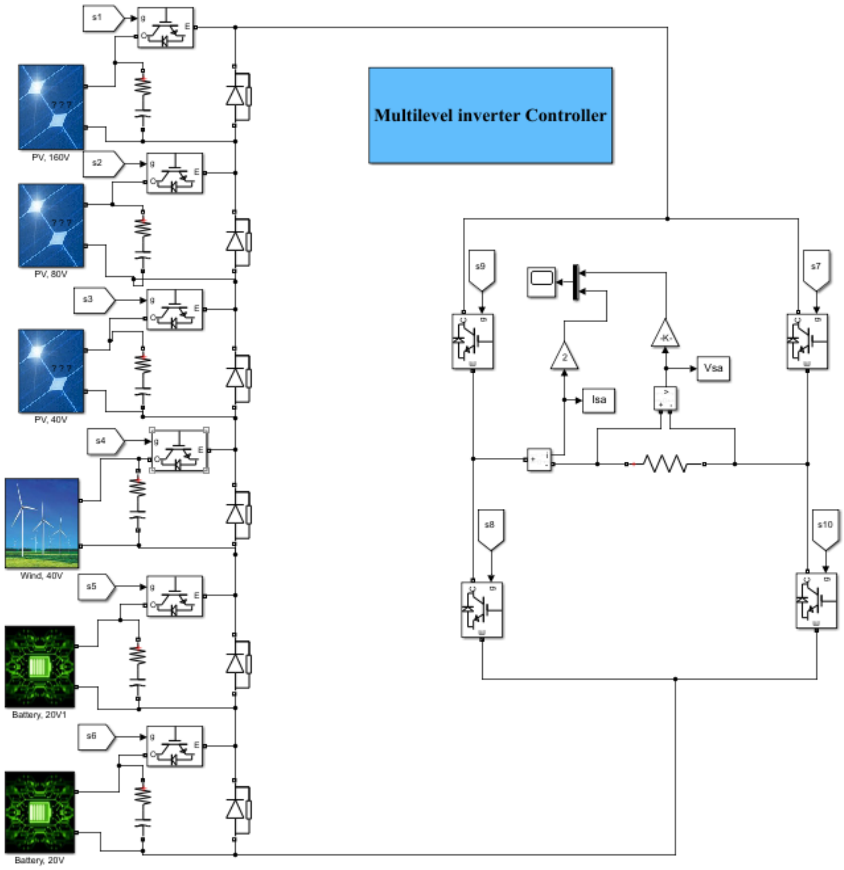
Different structures of asymmetrical multilevel inverters with fewer power electronics switches using a modified absolute sinusoidal PWM method have been done [14–15]. The total system in Fig. 1a consists of four separate RESs as one wind turbine energy system based on a PMSG type to produce 2E, and three photovoltaic systems with voltages of (2:4:8)E. Also, two battery systems each one producing 1E as a backup circuit for an emergency are used. The symbol (E) is the output voltage level of the boost circuit. The DC sources are set together in the form (8:4:2:2:1:1)E to get an output voltage of 37 levels (+18E to -18E). If the proposed circuit works with three PV systems and two batteries, the structure will be (8, 4, 2, 1, 1)E to produce an output voltage of 33-level. If one battery isn't working, the suggested circuit will work with three PV systems, a wind turbine, and a battery (8, 4, 2, 2, 1)E to produce 35-level. If both wind turbines and one battery are out of work, the system will produce 31-level. The system also can produce 9-level without PV systems and 5-level without battery systems.

3.1. DC-DC Boost Converter (Dc-Dc Yükseltici Dönüştürücü)

A step-up (boost) converter is one of the most used converters to increase and regulate the DC output voltage of the PV solar system, wind turbine system, and battery backup system, to meet the desired DC bus voltage. The circuit diagram of the boost converter is shown in Fig. 2.



(a)



(b)

Figure 1. The proposed MLI with different RESs; (a) structure, and (b) model circuits.
(Şekil 1. Farklı RES'lerle önerilen MLI; (a) yapı ve (b) model devreleri)

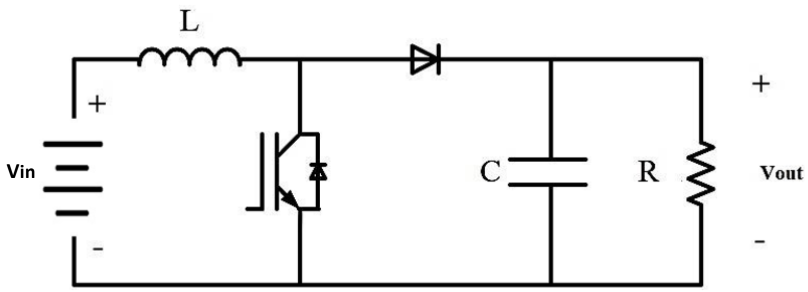


Figure 2. Circuit diagram of DC-DC step-up converter
(Şekil 2. DC-DC yükseltici dönüştürücünün devre şeması)

The boost converter's duty cycle (D) is determined as [16]:

$$D = 1 - \frac{V_{in}}{V_{out}} \quad (1)$$

where V_{in} and V_{out} are the input and output voltages of the converter. The boost converter's inductor and output capacitor values can be calculated as [16]:

$$L_{min} = \frac{D\ (1-D)^2\ R}{2\ f} \quad (2)$$

$$C = \frac{D}{R\left(\frac{\Delta V_o}{V_o}\right)f} \tag{3}$$

where $\left(\frac{\Delta V_o}{V_o}\right)$ outputs voltage ripple is 1%, "R" is output resistance, and "f" is the frequency.

3.2. PV Solar Power System (Pv Güneş Enerjisi Sistemi)

By utilizing the PV effect, the PV system transforms sunlight into a DC power source. Several solar cells can be coupled in parallel and/or series as a module to generate adequate voltage and power [8]. To satisfy the intended DC transit voltage. Figure 3 depicts the PV cell's circuit diagram. Figure 4 depicts the (V-I) and (P-V) characteristics curves of the suggested PV systems.

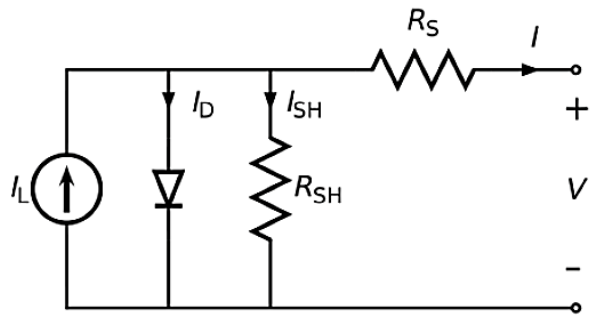
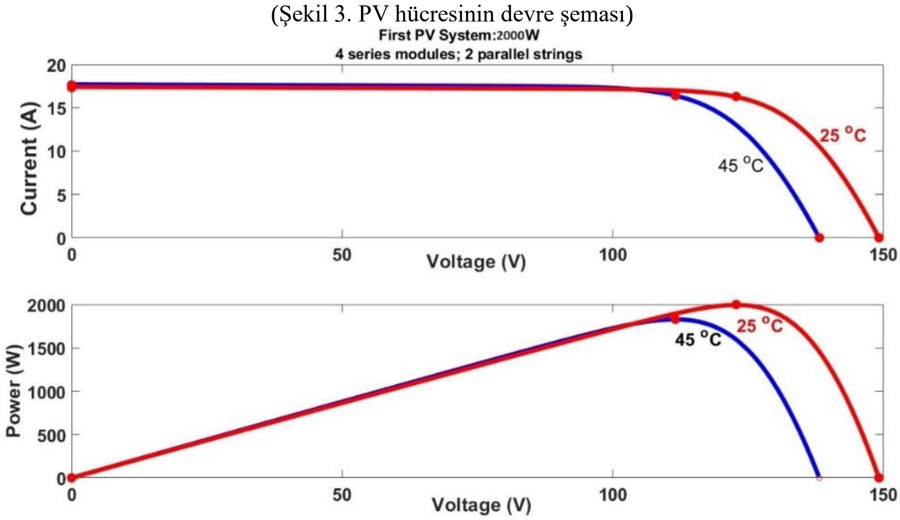
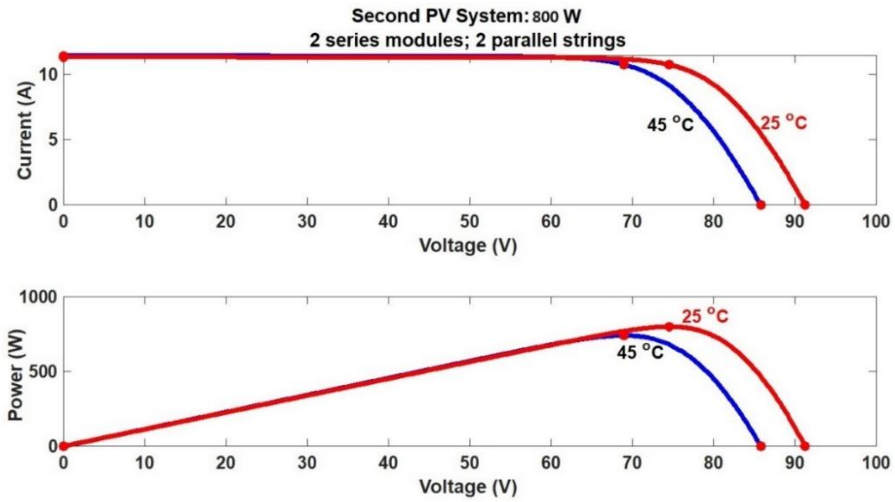


Figure 3. Circuit diagram of PV-cell
(Şekil 3. PV hücresinin devre şeması)



(a)



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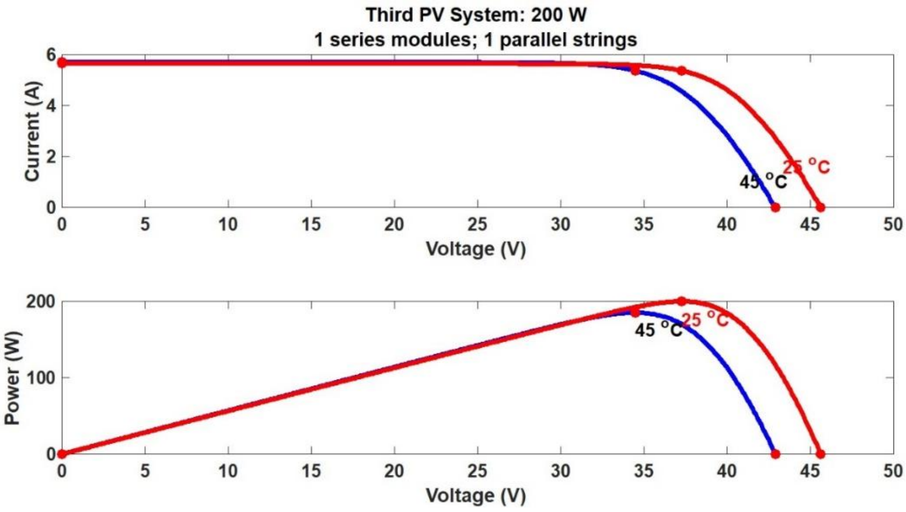


(c)

Figure 4. The (V-I) and (P-V) characteristics of (a) PV system 1 (b) PV system 2 (c) PV system 3
(Şekil 4. (V-I) ve (P-V) karakteristikleri (a) PV sistemi 1 (b) PV sistemi 2 (c) PV sistemi 3)

3.3. Wind Turbine (Rüzgar Türbini)

Wind turbines transfer wind energy to mechanical energy, and their kinetic energy can be estimated to calculate the required amount of power. PMSGs can serve as efficient and dependable generators in the wind energy sector [17]. A diode rectifier is used to convert the generated AC power into DC power. To boost the output DC voltage, another DC-DC converter circuit is required [18]. Figure 5 depicts a wind energy conversion system based on PMSG implemented in the MATLAB/Simulink environment.

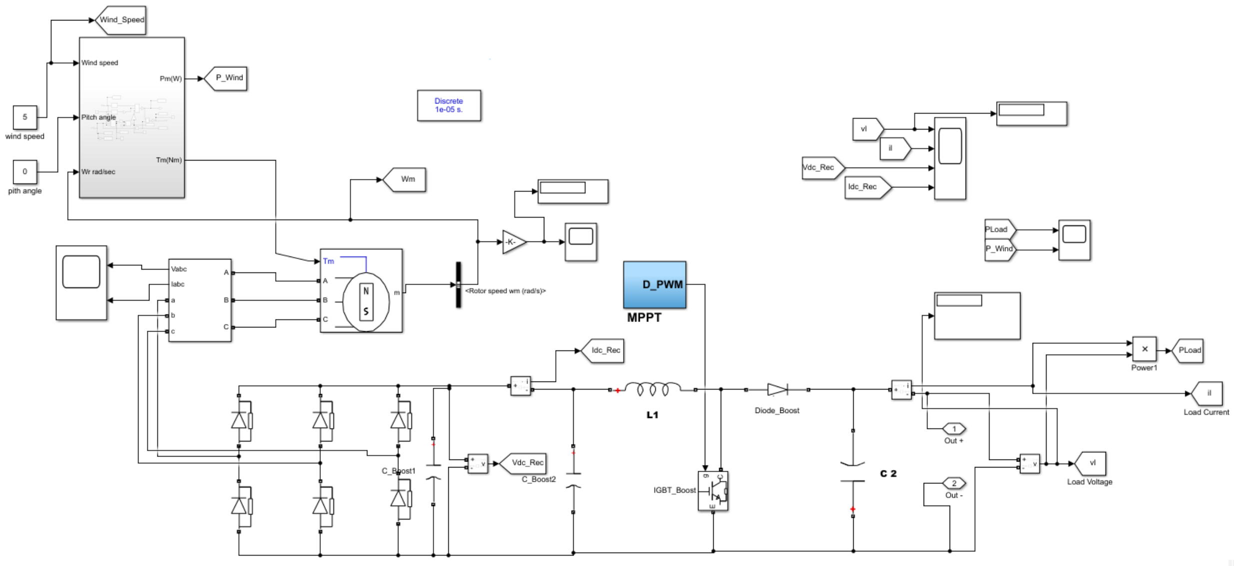


Figure 5. Wind Energy Conversion System based on PMSG
(Şekil 5. PMSG tabanlı Rüzgar Enerjisi Dönüşüm Sistemi)

3.4. Battery (Pil)

The battery is one of the sources that feed the multilevel inverter circuit with a voltage of ±20 V. This means it supports the multilevel inverter in two levels, and Fig. 6 shows the battery circuit.

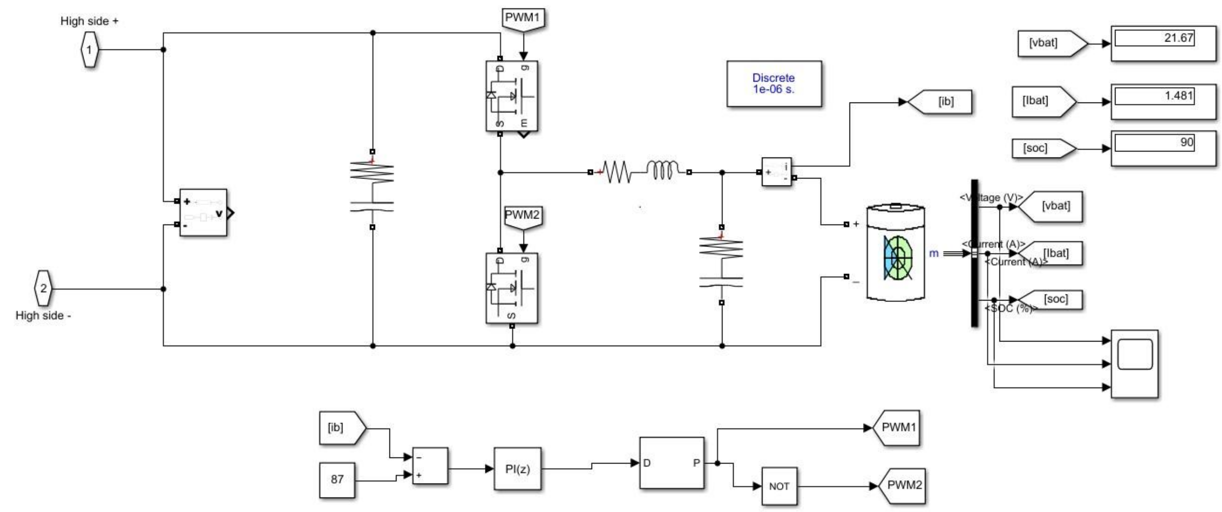


Figure 6. Battery circuit
(Şekil 6. Pil devresi)

3.5. Multilevel Inverter (Çok Seviyeli Evirici)

Inverters are power electronic systems used to convert DC power to AC power. Multiple-switch MLIs are increasingly used in high-power switching applications, such as those found in industrial sectors, electric cars, and train traction motors [19]. MLIs have multiple benefits over conventional types, including reduced THD, EMI, and dV/dt switch stress. In this study, the MLI is created based on four RESs with unequal DC voltage values. The control circuit is made using the multicarrier sinusoidal PWM method. This study adopts the topology of a 37-level inverter by cascading six cells, as depicted in Fig. 1. The respective feed DC voltages from the six H-bridge parts (H1, H2, H3, H4, H5, and H6) are (8:4:2:2:1:1)E. The output voltage is equal to the algebraic sum of each cell's output voltage, which is equal to ±18E. The switching pattern of the recommended MLI is depicted in Table (1).

Table 1. Inverter output voltages and switching status

(Tablo 1. İnvertör çıkış voltajları ve anahtarlama durumu)

Voltage Level	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
18E	1	1	1	1	1	1	1	1	0	0
17E	1	1	1	1	1	0	1	1	0	0
16E	1	1	1	1	0	0	1	1	0	0
15E	1	1	1	0	0	1	1	1	0	0
14E	1	1	1	0	0	0	1	1	0	0
13E	1	1	0	0	0	1	1	1	0	0
12E	1	1	0	0	0	0	1	1	0	0
11E	1	0	1	0	0	1	1	1	0	0
10E	1	0	0	1	0	0	1	1	0	0
9E	1	0	0	0	0	1	1	1	0	0
8E	0	1	1	1	0	0	1	1	0	0
7E	0	1	1	0	1	0	1	1	0	0
6E	0	1	1	0	0	0	1	1	0	0
5E	0	0	1	1	1	0	1	1	0	0
4E	0	0	1	1	0	0	1	1	0	0

3E	0	0	0	1	1	0	1	1	0	0
2E	0	0	0	1	0	0	1	1	0	0
1E	0	0	0	0	0	1	1	1	0	0
0E	0	0	0	0	0	0	0	0	0	0
-1E	0	0	0	0	0	1	0	0	1	1
-2E	0	0	0	1	0	0	0	0	1	1
-3E	0	0	0	1	1	0	0	0	1	1
-4E	0	0	1	1	0	0	0	0	1	1
-5E	0	0	1	1	1	0	0	0	1	1
-6E	0	1	1	0	0	0	0	0	1	1
-7E	0	1	1	0	1	0	0	0	1	1
-8E	0	1	1	1	0	0	0	0	1	1
-9E	1	0	0	0	0	1	0	0	1	1
-10E	1	0	0	1	0	0	0	0	1	1
-11E	1	0	1	0	0	1	0	0	1	1
-12E	1	1	0	0	0	0	0	0	1	1
-13E	1	1	0	0	0	1	0	0	1	1
-14E	1	1	1	0	0	0	0	0	1	1
-15E	1	1	1	0	0	1	0	0	1	1
-16E	1	1	1	1	0	0	0	0	1	1
-17E	1	1	1	1	1	0	0	0	1	1
-18E	1	1	1	1	1	1	0	0	1	1

4. SIMULATION RESULTS (SİMÜLASYON SONUÇLARI)

The system consists of a wind turbine with an output DC voltage of 40V (wind turbine boost output), two battery systems each one 20V DC, and three PV systems with DC voltages output of 160V, 80V, and 40V, respectively, as given in Fig. 1b. The output power of the first PV system before the boost converter, which is the input of the boost circuit, connecting (4*2) panels in series and parallel is 2 kW (16.3A*122.8V). The output power of the second PV system, (2*2) panels in series and parallel, is 0.8 kW (10.74A*74.52V). In addition, the output power of the third PV system, (1*1) panels in series and parallel, is 0.2 kW (5.37A*37.26V). Figure 7 shows the voltage values for the three PV systems and the boost inverter output voltage values

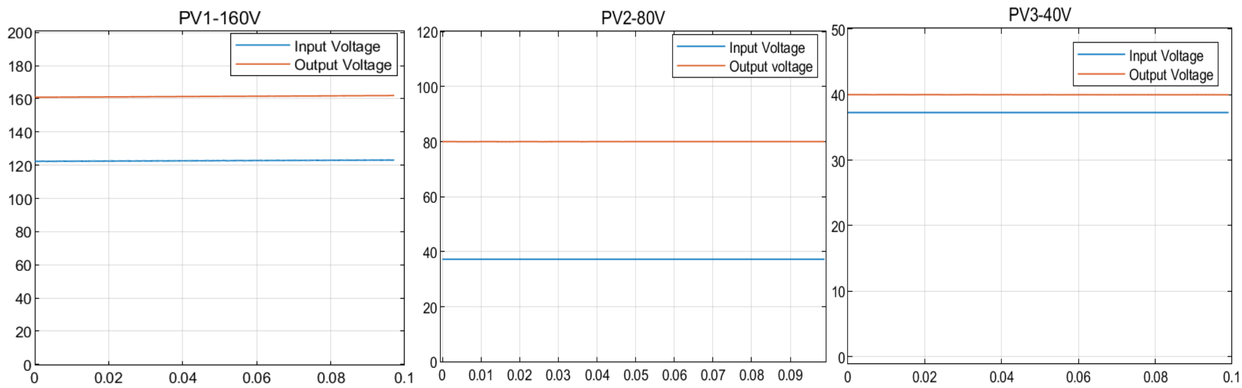


Figure 7. The input and output voltage of PV converter (a) PV system1 (b) PV system2, and (c) PV system3
(Şekil 7. PV dönüştürücüsünün giriş ve çıkış voltajı (a) PV sistemi1 (b) PV sistemi2 ve (c) PV sistemi3)

The PV boost converters circuit with 1% ripple output voltage uses Eqs. (2) and (3) to calculate the input inductors and output capacitors. The DC-DC boost converter circuit of the wind turbine illustrated in Fig. 5 is intended to convert 20 Volts DC to 40 Volts DC (2E). Figure 8 depicts the output and input voltage of the converter of wind turbine system.

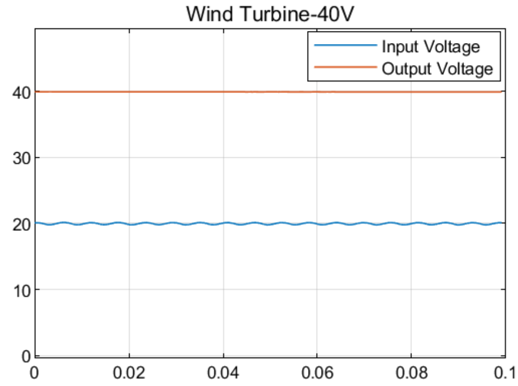


Figure 8. The output and input voltage of the converter of wind turbine system

(Şekil 8. Rüzgar türbini sisteminin dönüştürücüsünün çıkış ve giriş voltajı)

Each of the circuit including the three PV model, Wind turbine and two battery power sources where all tested individually to ensure that they meet the design requirements. Figure 9 shows the 37-level voltage with the FFT analyzer with existing all renewable sources. From the FFT analysis we can see the obtained THD to be 1.04% for both voltage and current, and RMS voltage and current of approximately 270V and 2.7A respectively. The THD is same for both current and voltage because of the type of load, if the load was change to an inductive load, the THD will be different. If the wind turbine stops working or there is no wind, the system driver is made to turn off the wind turbine system, so that the output voltage is 33-level, (8:4:2:1:1) E, as shown in Fig. 10. When the wind is disconnected, the RMS Voltage and currents are approximately 240V and 2.4A respectively with the THD been 1.19%.

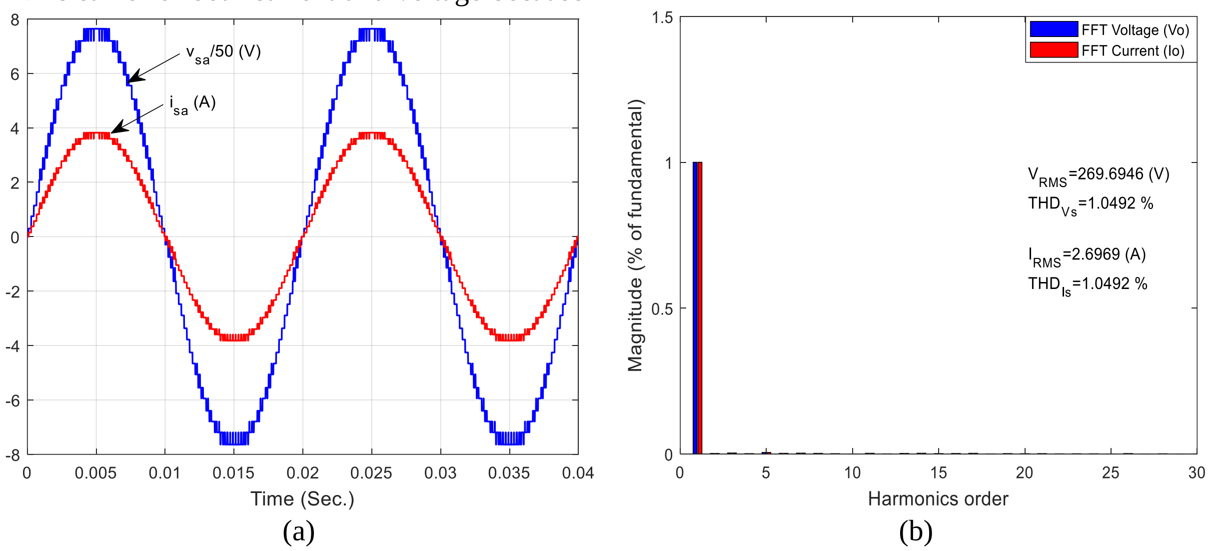
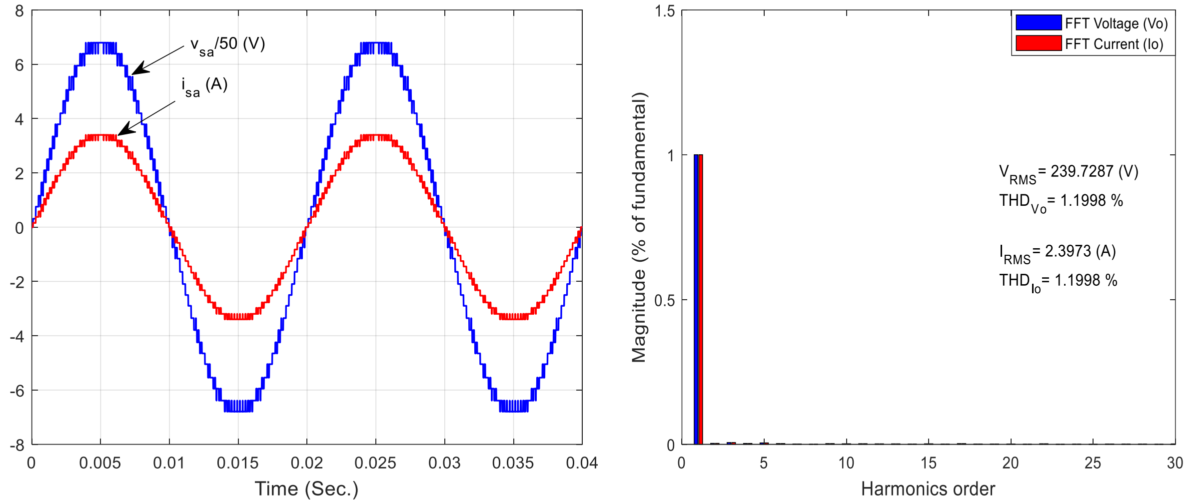


Figure 9. (a) 37-level output voltage with its (b) spectrum analyzer

(Şekil 9. (a) 37 seviyeli çıkış voltajı ve (b) spektrum analizörü)

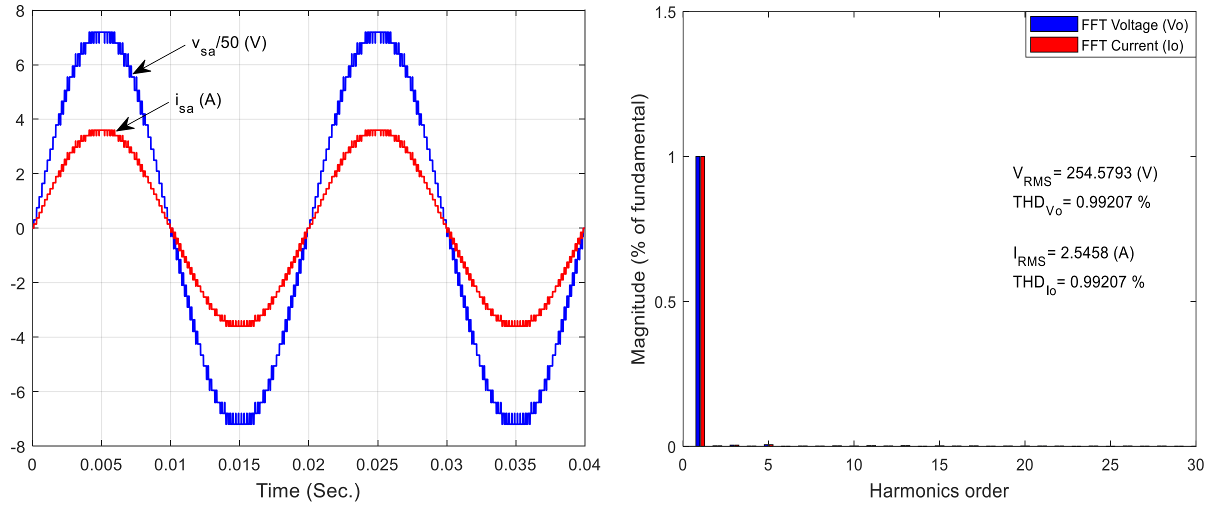
If one battery doesn't work, the system processor is set up to turn off that battery, so that the output voltage is 35-level, (8:4:2:2:1) E, as shown in Fig. 11. In the 35-level, the obtained THD is 0.99%, and the RMS voltage and current are approximately 255V and 2.55A respectively. While the wind turbine and one battery system are not working, the power system is projected to produce an output voltage of 31-level, (8:4:2:1) E, as shown in Fig. 12. The THD values of the output voltage at different voltage levels with different renewable energy sources is illustrated in Fig. 13. The THD result obtained from each level shows how the changing in Level affects the THD. The higher the voltage level, the lower the THD. The result obtained are similar to the result obtained in [15], which shows a reduction in THD values. These results prove the effectiveness of the suggested circuit with suggested controller by managing the renewable sources.



(a) (b)

Figure 10. (a) 33-level output voltage with its (b) spectrum analyzer

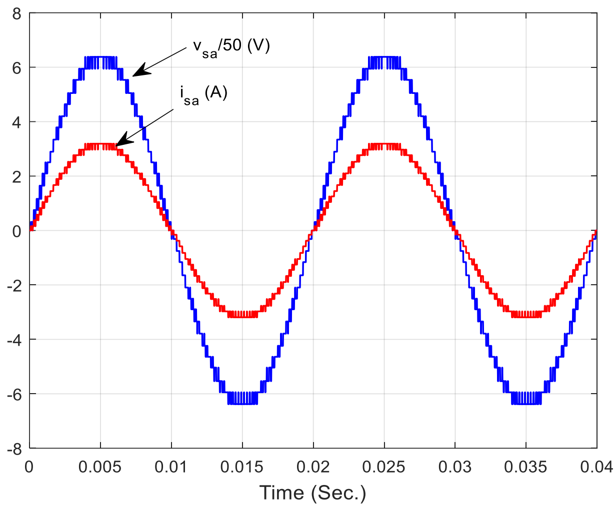
(Şekil 10. (a) 33 seviyeli çıkış voltajı ve (b) spektrum analizörü)

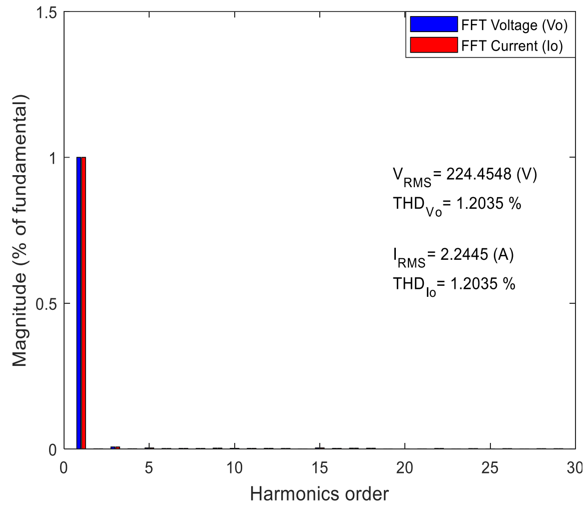


(a) (b)

Figure 11. (a) 35-level output voltage with its (b) spectrum analyzer

(Şekil 11. (a) 35 seviyeli çıkış voltajı ve (b) spektrum analizörü)





(a) (b)

Figure 12. (a) 31-level output voltage with its (b) spectrum analyzer

(Şekil 12. (a) 31 seviyeli çıkış voltajı ve (b) spektrum analizörü)

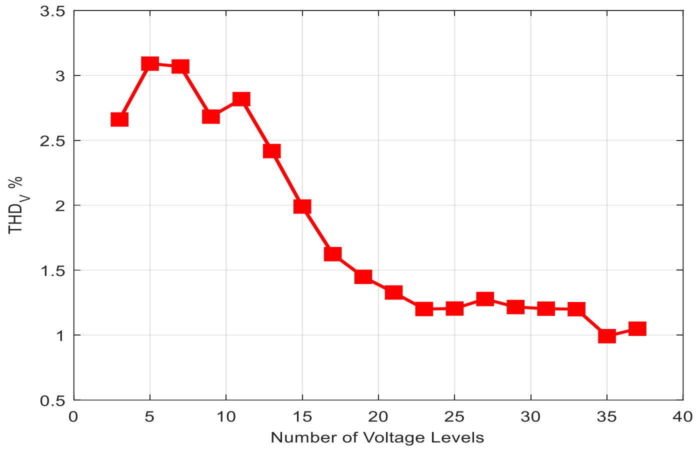


Figure 13. The THD values with different output levels for the suggested circuit

(Şekil 13. Önerilen devre için farklı çıkış seviyeleriyle THD değerleri)

5. CONCLUSIONS (SONUÇLAR)

In this study, a single-phase power system with 37-level output voltage is built and modeled from RESs of PVs, wind turbines, and two battery systems. The suggested circuit has three PV systems, one wind turbine system, and two battery backup systems. The structure of these sources is (8:4:2:2:1:1)E. The control circuit is made using the multicarrier sinusoidal PWM technique. The system is designed to produce 33-levels without wind turbine, 31-level without wind and battery systems, 35-level (without battery), 35-level (without one of battery systems), 11-level (without PV systems), 5-level without wind and PV systems, and 3-level just using one battery system. Therefore, the system is capable of generating different output levels based on the available renewable energy sources. The system is tested with a 37-level state in the output voltage waveform. The results are proved that the system has good THD responses according to IEEE 519-2022 standard [20]. The result obtained indicates a low THD value in the range of 3.2% to 1.04% as the voltage level increases. The system worked well, which shows how well the power and control circuits that were built and suggested worked. The model can be improved by connecting it to the grid in situations where more power is required. In this mode, an islanding control will be used to ensure that the system remains stable when there is a grid disconnection. One limitation of this research is that it does not consider the PV system during shedding when there is limited sunshine. This can greatly affect the obtained result.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Ahmed Yaseen Hamad, Ersagun Kürşat Yaylacı and Rakan Khalil Antar**:** they conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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