Pamukkale Univ Muh Bilim Derg, 29(5), 458-467, 2023

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Analysis of transportable off-grid solar power generation for rural electricity supply: an application study of Sanliurfa, Turkey

Kırsal alanlarda elektrik temini için şebekeden bağımsız mobilite güneş enerjisi üretimi analizi: Şanlıurfa Türkiye'de bir uygulama çalışması

Batur Alp AKGÜL[1*], *Fatih ALİSİNANOĞLU*[1], *Sadettin ÖZYAZICI*[1], *Muhammed Fatih HASOĞLU*[2], *Bülent HAZNEDAR*[3]

[1]Department of Electrical & Electronics Engineering, Institute of Graduate Studies, Hasan Kalyoncu University, Gaziantep, Turkey.
baturalpakgul@gmail.com, fatih.alisinanoglu@hku.edu.tr, msadettin.ozyazici@hku.edu.tr

[2]Department of Computer Engineering, Engineering Faculty, Hasan Kalyoncu University, Gaziantep, Turkey.
mfatih.hasoglu@hku.edu.tr

[3]Department of Computer Engineering, Engineering Faculty, Gaziantep University, Gaziantep, Turkey.
haznedar@gaziantep.edu.tr

Received/Geliş Tarihi: 01.06.2022
Revision/Düzeltme Tarihi: 23.08.2022
doi: 10.5505/pajes.2022.87894
Accepted/Kabul Tarihi: 01.11.2022
Research Article/Araştırma Makalesi

Abstract

Despite the advances in technology, electrical energy needs in rural and less developed regions are not yet fully met in terms of cost and sustainability. Nowadays, small-scale Photovoltaic (PV) systems can be transported to other regions and easily reinstalled so that these systems can be used in areas where needed for home usage and humanitarian purposes. There is no doubt that a PV-based microgrid is needed in rural and remote areas where energy is often important, and grid energy is not available or unstable. Mobility microgrid design studies can reduce time, effort, and costs significantly in such cases. Therefore, the design, modeling, and technical simulation of an isolated system based on solar energy are investigated and analyzed in this paper. This study also highlights the future trends of transportable-based isolated (off-grid) microgrid design which provides a sustainable solution for small-scale PV power generation. Additionally, an optimal solution approach for power management with Energy Storage (ES) and PV energy technologies is presented in the developed of an off-grid PV system. Aside from the designed system's cost-benefit analysis, important criteria such as lifespan, battery performance, and energy production have been evaluated. The Distributed Energy Resources (DER) with the load flow in 24-hour scenario is modeled, and simulated, also the findings are presented. Specifically, an application study for a 60.75 kWp isolated (off-grid) PV system with the 105.98 kWh ES, and 16 kVA diesel generator is discussed in terms of financial, regional, and technical parameters as well as numerical modeling, and MATLAB simulation for the province of Sanliurfa in Turkey.

Keywords: Energy, Microgrid, Off-Grid, Solar, PV.

Öz

Teknolojideki gelişmelere rağmen, kırsal ve az gelişmiş bölgelerde elektrik enerjisi ihtiyacı maliyet ve sürdürülebilirlik açısından henüz tam olarak karşılanamamaktadır. Günümüzde küçük ölçekli Fotovoltaik (PV) sistemler başka bölgelere taşınabilmekte ve kolaylıkla yeniden kurulabilmektedir. Bu sayede ev kullanımı ve insani amaçlar için ihtiyaç duyulan alanlarda bu sistemler kullanılabilir. Enerjinin genellikle önemli olduğu ve şebeke enerjisinin mevcut olmadığı veya istikrarsız olduğu kırsal ve uzak bölgelerde PV tabanlı bir mikro şebekeye ihtiyaç duyulduğuna şüphe yoktur. Mobilite mikroşebeke tasarım çalışmaları, bu gibi durumlarda zaman, çaba ve maliyetleri önemli ölçüde azaltabilir. Bu nedenle, güneş enerjisine dayalı izole edilmiş bir (şebeke dışı) mikroşebekenin tasarımı, modellemesi ve teknik simülasyonu bu yazıda incelenmekte ve analiz edilmektedir. Bu çalışma aynı zamanda küçük ölçekli FV güç üretimi için sürdürülebilir bir çözüm sağlayan mobilite mikroşebeke tasarımının gelecekteki eğilimlerini de vurgulamaktadır. Ek olarak, geliştirilen mikroşebekede Enerji Depolama (ES) ve PV enerji teknolojileri ile güç yönetimi için en uygun çözüm yaklaşımı sunulmaktadır. Tasarlanan sistemin fayda-maliyet analizinin yanı sıra kullanım ömrü, pil performansı, enerji üretimi gibi önemli kriterler değerlendirilmiştir. 24 saatlik senaryoda yük akışı ile Dağıtılmış Enerji Kaynakları (DER) modellenerek, simüle edilmiş ve bulgular da sunulmuştur. Spesifik olarak, Türkiye'nin Şanlıurfa şehrinde, 105.98kWh ES ve 16 kVA dizel jeneratör ile 60.75 kWp izole edilmiş (şebeke dışı) PV sistemi için bir uygulama çalışması, finansal, bölgesel ve teknik parametrelerin yanı sıra sayısal modelleme ve MATLAB simülasyonu ile birlikte ele alınmaktadır.

Anahtar Kelimeler: Enerji, Mikroşebeke, Şebeke dışı, Güneş, PV.

1 Introduction

PV energy systems have started to become the main source of renewable electric power generation systems in the last decade as Photovoltaic (PV) and Energy Storage (ES) technologies have offered more efficient, movable, flexible, easy to install, and more accessible products. Microgrid offers a variety of technological options to integrate distributed energy sources with ES within a system, and feed into the loads in more systematic and functional ways [1]. The increasing demand in energy has led engineers and scientists to seek new technologies to provide energy being generated at near places of consumption. Off-grid PV systems can be used as a primary electricity supply without grid extension in a sustainable way [2]. It provides the necessary functionality to ensure power generation, transmission, distribution, and continuity when supported on a platform [3]. Therefore, the field of energy storage, PV energy, and off-grid PV systems have been studied deeply in the last decade [4]. Especially in recent years due to the reduction in PV panel prices and the increment in the

*Corresponding author/Yazışılan Yazar

production capacity, the microgrid systems have become possible to work as off-grid [5]. In some cases, the off-grid (isolated) microgrids are strongly depended on regional and meteorological circumstances to provide stable electrical power [6]. Correct design and development are essential factors for all microgrids with PV energy sources to operate satisfactorily and ensure the sustainability. The most important criteria in the design of an isolated microgrid are that the developed microgrid should be optimal in size, in affordable cost, and sufficient in terms of power. It is also essential the design of the PV system is carried out after gathering data such as daily energy use, autonomy time, and operating voltage, daily load profile, dept of discharge of the battery, closed days, efficiencies of PV panel and inverter. So, in this study, an off-grid isolated microgrid has been developed by covering all these criteria.

The first objective of this study is to develop an isolated microgrid in which electricity is produced from PV cells and stored in the ES. The produced electricity is used to support microgrid loads. The second objective is to optimize ES and PV capacity of the developed microgrid to maintain energy flow regularly, keep energy production at sufficient level, make a stable energy balance, and ensure a stable energy supply of generation-distribution systems. The third purpose is to keep operating costs at low and affordable levels for the developed microgrid. The operation cost depends on the optimal capacity of the ES and PV. Last but not the least important purpose is to analyze the cost and benefit of the designed PV system for the non-commercial investors and donors.

In this study, the priority is given to the production of the necessary energy for grid loads and to reduce dependence on external energy sources (fuel generator, on-grid electricity). It is very important that the microgrid is easily installed in place where needed. So, the physical dimensions of the microgrid also should be considered to be transportable. For off-grid systems with transportable solutions, it is needed to calculate the amount of energy production, consumption precisely, and microgrid's load design accordingly. In this study, the emphasis is placed on application and design engineering. In this aspect, this study offers a different approach and solution to these areas. In the region where microgrid is planned to build (Sanliurfa, Turkey), the problems persist in rural areas regarding access to electricity. Besides, humanitarian migration to the region due to the Syrian war further increased the need for electricity. As to our knowledge, there is almost no existing study available in literature for the off-grid systems in this region. So, a detailed cost-benefit analysis of the microgrid setup for this region has also been made. For all these reasons addressed above, it is planned to establish a transportable isolated microgrid in the region as depicted in Figure 1 that provides electricity to refugee camps or rural living areas.

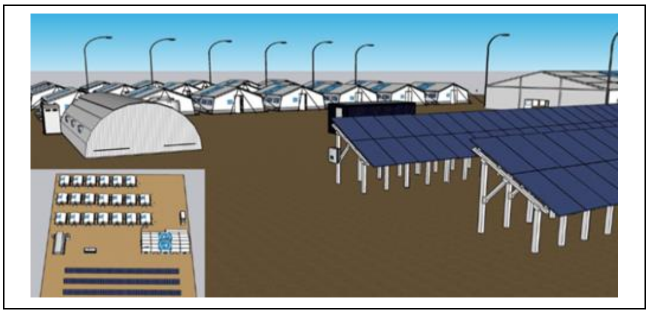

Figure 1. 3D drawing of habitat and PV plant.

So far, we have defined the goals, scope, and basic knowledge about the developed microgrid as shown in Figure 2. The remainder of the paper is structured as follows: Literature review and related works of this field is presented in Section 2. Section 3 presents numerical modeling of the microgrid, and calculations related to this study. In section 4, system design methodologies of the microgrid such as load capacity, PV, and ES technologies are presented. Section 5 presents the solar climatic parameters and simulation of the region to be installed PV system as well as the MATLAB/Simulink model of the microgrid. Section 6 presents a cost-benefit analysis of the microgrid. In section 7, results are evaluated, relevant discussions and comments are made. The last section includes concluding remarks for this study.

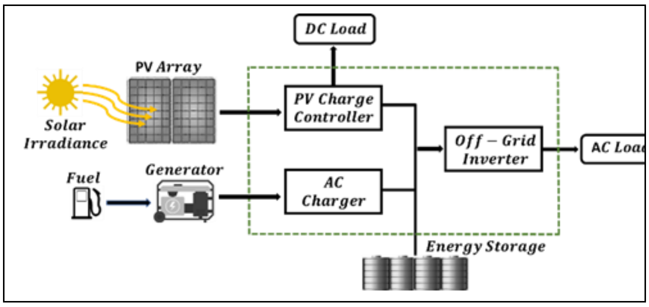

Figure 2. A simple diagram of the PV energy model.

As detailed in the following sections, a 60.75 kWp PV system supported with a 16 kVA fuel generator and 105.98 kWh capacity energy storage to meet a 115 kWh load for 20 families is designed considering climate and regional conditions. It has been seen that designing the system by utilizing the findings in the light of technical simulations and setting the PV system at an optimal fixed angle provides an annual energy production of 39.83 MWh. It is calculated that the surfaces inclined at a constant angle throughout the year contribute 10.18% more to the annual production, and the payback period of the system becomes 10.67 years. It is foreseen that this study can be used in the areas where refugees and migrants live in camps or in rural areas for meeting the needs of electricity.

2 Literature review and related works

Many studies focusing on the modeling of insulated PV systems are available in the literature. The development of PV plants has progressed rapidly throughout time with new research studies concentrating on optimal performance of PV applications, case study, cost analysis, design, and numerical modeling. In literature, there exist several studies related to our research interest are presented below. Power management, performance analysis and optimization for PV energy system studies were conducted [7]-[13]. Techno-economic and cost analysis studies were performed [14],[15]. The feasibility of setting up a PV facility in a rural clinic was performed, the optimum system cost and electricity cost were calculated [16]. Solar system was established with the solar tower model, technical and cost analyzes were made [17]. Small (54.15 kW) off-grid PV power generation was proposed for communities. The environmental and energy analyzes of the system with the life cycle emissions were the focus of the research [18]. The technical and financial viability of 50 kWp PV systems with 50kW of ES capacity was investigated with some indicators [19]. In another study, a one-year performance analysis was conducted on the PV plant. It was observed that the results obtained from the field measurements verify the theoretical models [20]. To address the electrical energy demands of a residence, an isolated PV system was created, the microgrid was modeled and simulated using MATLAB/Simulink [21]. Besides, off-grid PV-powered small microgrids for humanitarian action in refugee camps were designed [22]. Apart from these, other related works are also referred in the relevant parts of this study. It can be seen that previous studies are not focusing on transportable design, and the objectives and criteria defined in this study have not been addressed completely in other types of research topics previously. In addition, the previous studies have not sufficient focus on a system design with the simulation environment presented in this study.

3 Numerical modeling of the microgrid

One of the main issues of the present study is to minimize and balance the storage size by decreasing energy consumption. So, in this section, PV, ES and generator sizing, and energy flow and breakdown calculations are carried out to take into account the load capacity planned to use in the microgrid is explained. The flowchart of the off-grid model with fuel generator designed in this study is shown in Figure 3.

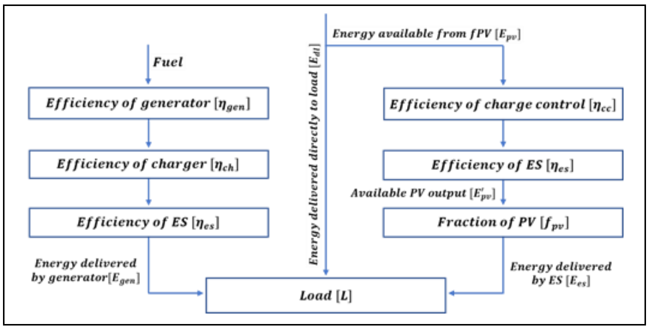

Figure 3. Flowchart for off-grid microgrid with fuel generator.

3.1 Average efficiency of PV array

The PV model is based on simplified method for predicting PV output [23]. Average efficiency of PV is a function of average PV temperature as expressed in Eq. 1 and the average PV temperature is expressed by Eq. 2.

$$\eta_{pv-avg} = \eta_{pv}[1 - \beta_p(T_{pv-avg} - T_{ref})] \tag{1}$$

$$T_{pv-avg} - T_{amb} = (219 + 832K_{mt})\frac{NOCT - 20}{800} \tag{2}$$

Where η_{pv-avg} is the average PV efficiency, η_{pv} is the PV efficiency, T_{pv-avg} is the average PV temperature, T_{ref} is the reference temperature (25°C), T_{amb} is the monthly ambient temperature, β_p is the temperature coefficient, K_{mt} is the monthly clearness index, and $NOCT$ is the nominal operating PV cell temperature ($Mono - Si = 45$°C).

3.2 Calculation of load

The total DC energy demand, as well as the total AC energy demand of the microgrid load, are specified by the microgrid developer in kWh/d. AC energy demand is converted to a DC equivalent using the inverter efficiency, the total DC equivalent is expressed by Eq. 3. The DC equivalent has three components and is expressed by Eq. 4.

$$D_{DC,eqv} = D_{DC} + \frac{D_{AC}}{\eta_{inv}} \tag{3}$$

$$D_{DC,eqv} = D_m + D_c + D_{es} \tag{4}$$

Where $D_{DC,eqv}$ is the total DC equivalent of the total microgrid AC energy demand, D_{DC} is the total DC demand, D_{AC} is the total AC demand, and η_{inv} is the inverter efficiency. D_m is the demand directly met by the PV, D_c is the demand that remains constant throughout the day, and D_{es} is the demand primarily met by the ES.

The critical PV absorption level is the load corresponding to the constant energy demand and is expressed by Eq. 5.

$$P_{crt} = \frac{D_C}{24} \tag{5}$$

Where P_{crt} is the critical PV absorption level and is expressed in W. D_C is met either directly by the PV during the enough sunshine or through the ES during the not enough sunshine is expressed in kWh.

3.3 Energy breakdown

The total energy demand of the continuous load can be met directly by the PV without being stored in the ES firstly. The energy delivered directly to the continuous load is expressed in Eq. 6 by handling monthly average daily utilizability [24]. Also, the energy delivered to the matched load, the energy delivered directly to the load, and the energy delivered to the ES are expressed by Eqs. 7-8.

$$E_{cl} = (1 - \emptyset)E_{pv} \tag{6}$$

$$E_{ml} = \min(D_{m,}E_{pv-}E_{cl}) \tag{7}$$

$$E_{dl} = E_{cl} + E_{ml} \tag{8}$$

Where E_{cl} is the energy delivered directly to the continuous load, $\emptyset$ is the monthly average daily utilizability, E_{pv} is the energy available from the PV, E_{ml} is the energy delivered to the matched load, E_{dl} is the energy delivered directly to the load.

3.4 Load fraction, and energy flow

Fraction of the load for an off-grid PV system is determined by two factors: the PV size and the ES size. The loss of load probability (LOLP) is the probability that the system is failed to meet the load. In the literature, there are some ways for calculating LOLP [25]-[28]. The monthly fraction of the load met by the PV based on the ES/L and the PV/L ratios are expressed by Eqs. 9 and 10. Also, the part of the load is not met directly by the PV, as well as the available output of the PV decreased by the energy delivered directly to the load are expressed by Eqs. 11 and 12.

$$f_{pv} = PVLR = E'_{pv}/L' \tag{9}$$

$$f_{pv} = ESLR = ES_{uc}/L' \tag{10}$$

$$L' = L - E_{dl} \tag{11}$$

$$E'_{pv} = (E_{pv} - E_{dl})\eta_{cc}\eta_{es} \tag{12}$$

Where f_{pv} is the fraction of PV, $PVLR$ is the PV/L ratio, $ESLR$ is the ES/L ratio, E'_{pv} is the available output of the PV decreased by the energy delivered directly to the load, L' is the part of the load not met directly by the PV, ES_{uc} is the usable ES capacity, L is the load, η_{cc} is the charge control efficiency, and η_{es} is the ES efficiency.

The energy delivered by the generator is the differentiation between the load and what can be provided by the PV directly or through the ES and is expressed by Eq. 13. Also, the energy used by the generator is expressed by Eq. 14.

$$E_{gen} = L - E_{dl} - E_{es} \quad (13)$$

$$Q_{gen} = \frac{E_{gen}}{\eta_{ch}\eta_{gen}\eta_{es}} \quad (14)$$

where E_{gen} is the Energy delivered by the generator, E_{es} is the energy delivered by the ES, Q_{gen} is the energy used by the generator, η_{ch} is the efficiency of charger which is the energy to charge the ES in 8 hours, η_{gen} is the generator efficiency, and η_{es} is the ES efficiency.

3.5 PV, ES and generator sizing

The desired number of days is used to size the ES. The usable ES capacity is expressed by Eqs. 15 and 16. Then the nominal capacity that means the design ES capacity is expressed by Eq. 17. Lastly, the generator capacity is considered as the maximum of the AC demand, and it is expressed by Eq. 18.

$$ES_{uc} = ES_{nc} f_c \quad (15)$$

$$ES_{uc} = \frac{L_{DC} n}{d_{dod}\eta_{es}} \quad (16)$$

$$ES_{nc} = \frac{ES_{uc}}{f_B} \quad (17)$$

$$\frac{1}{8} = \frac{ES_{nc}}{\eta_{ch}} \quad (18)$$

where ES_{nc} is the nominal capacity, f_c is the fraction of capacity depends on ES temperature and on discharge rate, L_{DC} is the equivalent DC load, n is the number of days, d_{dod} is the maximum depth of discharge.

4 Methodology and PV system design

Choosing the correct location for a PV system is very important to provide a strong impact on energy generation. The choice of PV energy technology and storage depends on the balance of energy demand in the microgrid. It also depends on the environmental and meteorological conditions, microgrid structure, and usage purposes. In this section, microgrid design issues related power and energy are handled with the climatic and radiation parameters of the target region. Also, the load capacity for the microgrid has been discussed and calculated according to needs. The PV electricity generation model is shown in Figure 2.

4.1 Load capacity

The Sanliurfa province of Southeastern Anatolia region where the microgrid will be installed is partially rural area which has a dense immigrant and refugee population. Therefore, electricity production is required for humanitarian purposes to meet daily electricity needs as stable. Table 1 shows the weekly estimated electricity need of a family of 5 people, and considering the values taken from Table 1, the average daily electricity consumption is calculated as 5.75kWh. In this study, the average daily electricity consumption is considered to be 115kWh of 20 families, and the PV system capacity is determined accordingly.

4.2 PV Technology

PV modules work with chemical-electrical interaction between solar radiation and a semiconductor to collect DC electricity. The amount of electricity is produced directly depending on solar intensity, and PV module is produced electricity even in cloudy winter weather. The production rate varies according to the orientation and solar angle.

Table 1. Weekly electricity requirement of a family.

Appliance	(W)	(h)	Unit	(Wh)	Days	W. (Wh)
Refrigerator	44	24	1	1056	7	7392
49" LED TV	98	5	1	490	7	3430
Laptop PC	90	4	2	720	7	5040
Iron	2600	2	1	3200	1	3200
Oven	2500	1.5	1	3750	1	3750
Washer	303	3	1	909	3	2727
Dishwasher	510	2.5	1	1275	4	5100
Vac. Cln.	750	1	1	750	1	750
LEDs	12	5	6	360	7	2520
Toaster	2000	0.25	1	500	2	1000
Kettle	2200	0.2	1	440	7	3080
Microwave	800	0.1	1	80	4	320
Blow Dryer	2200	0.2	1	440	3	1320
FAN+Charger	320	1	1	320	2	640

Weekly estimated energy consumption: 40,269Wh.

For off-grid systems, it is necessary to make a design according to the worst-case scenario in which the average sunshine duration of the winter months in the region is taken into account for the continuity of the system. So, the climatic conditions must be carefully taken into consideration during the determining of the PV capacity and the PV power of the microgrid has been decided to be 60.75kWp. The 450W peak capacity ARCLK-144HC-450W PV panel [29] is preferred in the model design due to the domestic production, transportable planning, capacity, and dimensions of the microgrid. The PV specs to be used in this study are listed in Table 2. When calculations are made including with shading according to Table 2, it is quite possible to establish a 60.75kWp off-grid PV system on an area of 760 m^2. Due to its physical dimensions and weight, the developed PV system can be assembled, disassembled, and transferred to other locations. Array voltage sizing is configured by using a total of 135 PV panels in the form of 9 series and 15 strings.

Table 2. Specifications of the PV Module (ARCLK-144HC-450).

Electrical Data	
Nominal Power (Wp)	450 Wp
Power Tolerance (W)	+5 W
Open Circuit Voltage (Voc)	49.27 V
Short Circuit Current (Isc)	11.53 A
Module Efficiency (%)	20.7 %
Max Power Voltage (Vmax)	41.37 V
Max Current Voltage (Imax)	10.88 A
Max System Voltage (V)	1,500 V
Max Series Fuse (A)	20 A
Thermal and Mechanical Data	
Operating Temperature (°C)	(−40°C to +85°C)
Solar Cells	144, Monocrystalline
Junction Box	IP-68, MC4
Panel Dimension (H/W/D)	2,094x1,038x35 mm

4.3 ES, CCU, battery type, and off-grid inverter

The ES (battery) specifications and the experience of the system designs are typically quite important, although each ES technology has advantages for certain solar and UPS applications. If the ES is sized suitably to deliver the expected design life considering the operating temperature range, it can provide excellent performance. The battery should be the size of shallower average depth of discharge and a higher cycle life rating should be chosen to maximize the service life of the ES. Lithium Iron Phosphate (LiFePO4) battery for renewable energy technology is preferred owing to its high energy density, long cycle, standby life, low self-discharge, tolerance to heat during operation, and high efficiency [30]. ES capacity is configured by using 3.2V 230AH batteries in series. A total of 144 batteries are used and a capacity of 105.98kW is reached.

In the storage of surplus energy produced by the PV, the charge control unit (CCU) protects the battery efficiency and lifespan by preventing the batteries from overheating and overcharging. The technical specification of the all-in-one centralized Energy Management System (EMS) including the batteries, CCU, and off-grid solar inverter to be planned to use in the microgrid is introduced in Table 3 [31].

Table 3. Technical specifications of the ES and solar CCU.

Battery Parameters	
Cell type, rated capacity, cycles	LiFePO4, 105.98kWh, 5000
Battery configuration	3.2V, 230Ah, 144Pcs in series
Nominal capacity, nominal voltage	230Ah, 460V
Charge voltage, charge current	504Vdc, 115A
Discharge voltage, discharge current	389Vdc, 115A
Charge and ischarge temp range	1~45℃,-10~45℃
Solar Charge Controller Parameters	
Max input voltage and power of PV	<900Vdc, 60kW
Battery system voltage	460Vdc
Max charge current	80A
Charging and recovery voltage	511.2Vdc, 486.5Vdc
Over voltage disconnect and reconnect	569.4Vdc, 525.6Vdc
Undervoltage recovery and disconnect	432Vdc, 374Vdc
Working temperature	-10~45℃
Inverter Parameters	
Rated Power and isolation mode	50kW, LFT
DC input rated voltage and current	360Vdc, 139A
DC Input voltage range	324~480V
AC output rated voltage and current	380V±3%, 76A
AC output voltage range	220-480VAC (optional)
Output frequency	50Hz / 60Hz
Inverter efficiency	>93%
Power factor and phases	0.99, 3 phases
Overload ability and cooling	150%,10s, FAN-cooled
Method of working	Working continuously
Working temperature	-20~+50℃

A centralized EMS system has advantages in terms of control, maintenance, cost, and space-saving installation. From a technical point of view, EMS centrally manages charge and discharge, effectively controls the charge and discharge current within the cell usage conditions, protects the cell, and extends the service life.

The ES (battery) autonomy is the time during which the load can be met with the ES alone without any solar inputs [32]. It is a function of battery charge state, load size, and capacity. The ES should ensure the energy demand during the night, therefore, the ES autonomy has been calculated to average 10.5 hours. It is more cost-effective to combine an ES with a fuel generator. If the PV array cannot produce enough energy, ES and fuel generator are capable of meeting the load during cloudy, rainy, or night periods in an autonomous system [33]. Number of autonomy days depend on the system, location, and total load. The system autonomy has been taken into account as 3 days for microgrid load.

4.4 Fuel generator

In stand-alone systems, it is an inevitable necessity to have a fuel generator in order to prevent the energy continuity and fluctuations of the system. Therefore, a 16kVA diesel engine is integrated into designed microgrid to use a secondary power supply and provide fault tolerance. Diesel generator planned to be used in the developed microgrid is presented in Table 4 [34]. The generator's fuel tank capacity of 143 liters, and the fuel consumption is 4.2 liters per hour under 100% load.

Table 4. Technical specifications of the diesel generator.

Stand -by and prime power [kVA-kW]	16-13, 14-11
Power factor [Cos φ] and frequency [Hz]	0.8, 50
Fuel Consumption 100%, and %50 loaded [Lt/h]	4.2, 2.1
Fuel tank capacity [lt]	143
Alternator voltage [V]	231/400
Dimensions LxWxH [mm]	2000x900x1500

4.5 Energy losses of the PV energy system

Various methods have been developed in the literature to calculate energy losses. Total miscellaneous losses such as cable, angle of incidence, spectral effects are assumed for this analysis ~3% [35]. The total system losses are assumed ~14%, and the PV losses due to temperature and irradiance effects are assumed ~8% [36]. In off-grid PV systems, transmission, and distribution losses (T&D losses) are expected to be <1% due to the small installation area and limited load capacity. The energy loss parameters used in the study are stated in Table 5.

Table 5. Estimation of the energy losses.

System losses	~14%
Inverter losses	~2%
Miscellaneous losses	~3%
T&D losses	<1%

5 Regional analysis and simulation

PV energy generation is influenced by the environmental and regional conditions, aside from the technical structure of the microgrid. The data on solar radiation and PV system energy production used in this part of the study has been provided by the Photovoltaic Geographical Information System of the European Commission (EU JRC PVGIS).

5.1 Regional analysis

Solar climatic parameters greatly affect the radiation efficiency such as sunny days, cloudy days, sunshine, and irradiance values. PV energy production, capacity, and sustainability of the developed microgrid should be measured under climatic conditions of the region where the PV system will be installed for maximum efficiencies. Optimal tilt angels and monthly average daily radiation values are tabulated in Table 6. Table 7 summarizes the climatic values of the region.

Table 6. Optimal tilt angels [°] and monthly average daily radiation gains [kWh/m2-day] of the region.

Month	Radiation	Monthly-Fixed		Annually-Fixed	
	Horizontal	Tilt	Rad. Gain	Tilt	Rad. Gain
Jan	2.37	59	3.94		3.63
Feb	3.36	50	4.75		4.57
Mar	4.52	37	5.33		5.32
April	5.49	21	5.77		5.68
May	6.60	7	6.64		6.21
Jun	7.73	1	7.73	33	6.94
Jul	7.75	4	7.76		7.09
Aug	6.66	17	6.85		6.64
Sep	5.35	32	6.04		6.04
Oct	3.69	46	4.86		4.76
Nov	2.70	58	4.39		4.05
Dec	2.10	62	3.71		3.33

Table 7. Climatic conditions of the region.

AVG Temp	18.1	AVG Radiation [kWh/m²/d]	17.9
MAX Temp. [°C]	46.5	AVG Soil Temp. [5CM, °C]	20.2
MIN Temp. [°C]	-12.4	AVG Relative Humidity [%]	49
AVG Open Days	176.2	AVG Sunny Days [h]	8.5

5.2 Simulation of the Region

Electricity generation fluctuates during the days of the year and production capacity depends on solar climatic data of the region. Provided inputs and simulation outputs of the location are presented in Table 8.

Table 8. Inputs and simulation outputs of the region.

Inputs & Outputs	Values
Location [Lat/Lon]	37.029, 37.973
Database used, Horizon	PVGIS-SARAH, Calculated
PV installed [Wp]	60,750
Battery capacity [Wh]	105,980
Discharge cutoff limit [%]	10
Consumption per day [Wh]	115,000
Slope and azimuth angles [°]	33 / 0
Percentage days with full battery [%]	86.47
Percentage days with empty battery [%]	15.95
Average energy not captured [Wh]	141,061.08
Average energy missing [Wh]	36,600.55

The developed microgrid is primarily intended to be used in the Sanliurfa province. For this reason, the microgrid has been simulated under the target location conditions using EU PVGIS application. The application also takes into account the impacts of ambient temperature, wind on the PV surface, and nominal operating cell temperature during the calculation of energy production. It is assumed that daily energy consumption is distributed over the hours of the day with most of the consumption during the daylight hours.

The estimated annual energy production capacity for an off-grid PV system is shown in Figure 4. The ES performance of an off-grid PV system is given in Figure 5 which tells the monthly statistics on how often the battery became full or empty during the day. Also, Figure 6 shows the probability of Battery Charge State (BCS) at the end of the day.

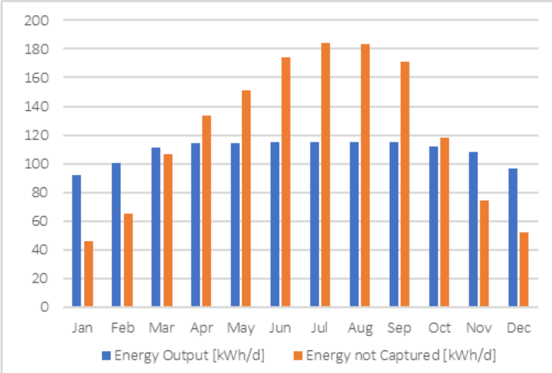

Figure 4. The power production estimated for the microgrid.

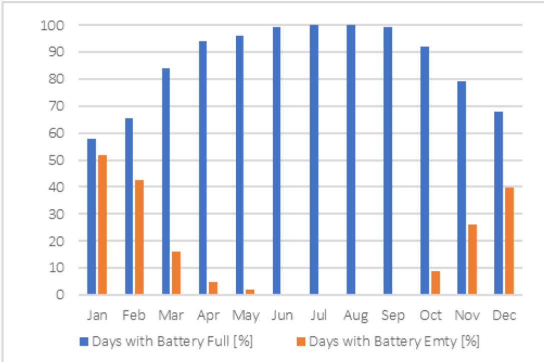

Figure 5. Estimated battery performance for the microgrid.

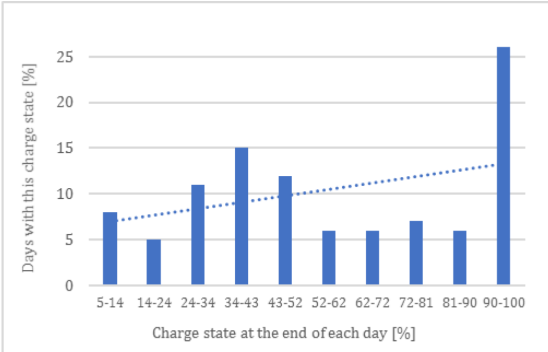

Figure 6. Probability of BCS at the end of the day.

Since the system is isolated (off-grid) microgrid, the energy production plan should be determined according to the worst-case scenario at the location to be installed. The worst-case scenario plan is achieved by identifying the month with the least sunshine duration and calculating the daily Peak-Sun Hour (PSH) values in that month.

5.3 MATLAB simulation of the designed microgrid

MATLAB Simulink is well simulation technique to control power electronics components under some scenarios and test system architectures prior to implementation. In stand-alone microgrids, EMS aids in the efficient use of Distributed Energy Resources (DER). In this section, DER that consist of energy storage, diesel engine and PV energy versus the load of the microgrid is simulated based on technical constraints and solar climatic data by using a heuristic state machine strategy [37], and the adaptive zero-crossing algorithm [38]. An overview of the designed microgrid model in the MATLAB/Simulink is shown in Figure 7, and general parameters and values used in the simulation are presented in Table 9.

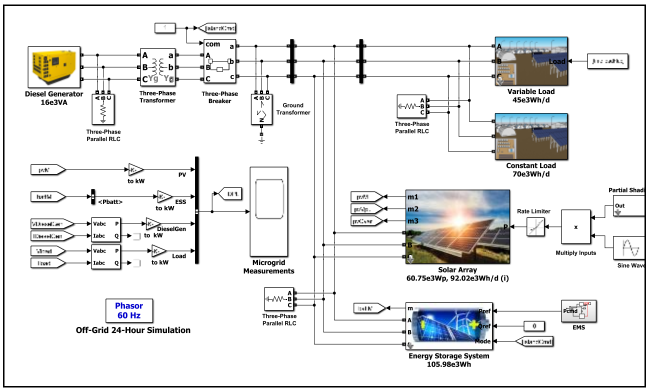

Figure 7. Overview of the simulation model in the MATLAB.

Table 9. General parameters and values used in the simulation.

Total AVG daily load	115kWh/d
Solar array capacity	59.9kWp
AVG daily PV energy generation in Jan.	92.06kWh/d
Generator rated power	10kVA
Microgrid frequency	50Hz
ESS rated capacity	105.98kWh
ESS SOC to recharge	10%
ESS recharge rate	50%
ESS initial state-of-charge	50%
ESS Upper/Lower Charge Limits	90-10%

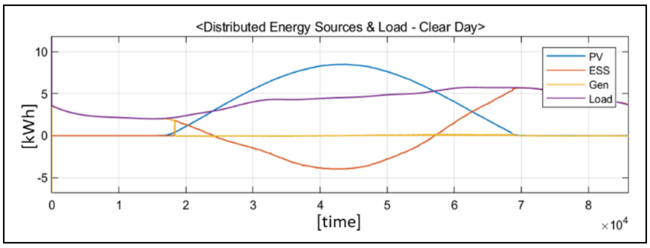

Figure 8. AVG load flow and DER for a clear day (24 hours).

This simulation in which DER and load flow are modeled allows to observe the operations and behaviors of microgrid's DER of the under varying circumstances. The results show some essential parameters such as the performance, efficiency, and sustainability of the DER in a 24-hour scenario. The simulation is based on the worst-case scenario. So, data from January (see Figure 3), the month with the lowest PV energy production in winter are taken in the account. Average load flow and DER for a clear day and a cloud day in 24-hour period are shown in Figure 8 and Figure 9, respectively.

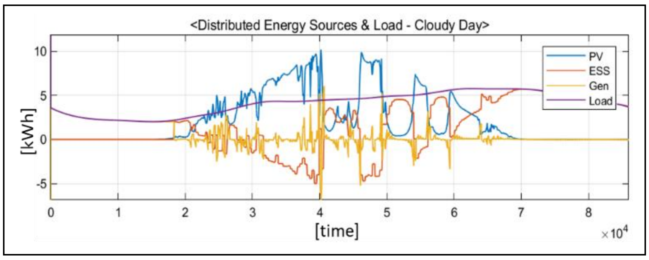

Figure 9. AVG load flow and DER for a cloudy day (24 hours).

6 Cost analysis of the microgrid

One of the aims of this study is to serve humanitarian purposes such as refugee camps by providing stable electricity to rural areas where access to electricity is very difficult, very expensive or not at all rather than economic benefit. The cost of a microgrid project is highly important. Although the off-grid PV system increases the cost, its humanitarian benefits are helped non-commercial donors to be positive about the cost of the system. Besides, climatic data availability in simulations is also helpful to predict system performance and microgrid lifespan.

Table 10. Cost of the PV power components of the microgrid.

Product	Quantity	Unit Cost ($)	Total Cost ($)
ARCLK-144HC-450W PV array	135	187	25,245
ESS (all in one) 100kW off-grid inverter, MPPT CCU, 105.6 kWh LiFePO4 lithium battery	1	17,500	17,500
6mm solar cable	400	1.5	600
Galvanized steel construction	135	22	2,970
MC+ solar PV connectors	set	288	288
Battery connection (jump) cables	set	128	128

The total cost of the power system components ($): 46,731

Table 11. The total cost of the isolated microgrid.

Initial Cost Items	Cost (USD)
Feasibility study	750
Development	1,250
Engineering	1,900
Transmission line	750
Power system components	46,731
Diesel Generator	5,750
Annual O&M cost	935

The total cost of the microgrid consists of power system components (PV, inverter, ES, CCU, etc.), diesel generator, feasibility studies, development, engineering, transmission, and periodic maintenance. Determination of a budget for operations and maintenance (O&M) is an essential for an off-grid PV system [39],[40]. O&M cost consists of preventive and corrective activities such as structure, cable connection, inspection, cleaning, repairing, replacing of solar panels, inverters, and batteries, etc. O&M cost of small PV plants is ~ 1-2% of the total initial cost [36]. The cost of the PV power system components, and the total cost of the isolated PV system are given in Table 10 and 11, respectively.

The total cost is high mainly due to battery cost in the microgrid. Batteries need to be replaced depending on the battery's technical specifications. Since a 5000-cycle life is equivalent to 12–13 years of operation, just one time battery replacement needs over the 25-years life of the microgrid [41].

7 Results and discussions

In this section, the findings for the developed microgrid regarding the essential parameters such as energy production, ES performance are presented and discussed as long with the Matlab/Simulink DER predictions specifically payback and lifespan of the microgrid under regional and solar climatic conditions. Furthermore, possible problems that may arise in terms of energy continuity and sustainability of the developed microgrid are evaluated, and possible solutions to take action are presented.

7.1 Power and energy production results

The simulation results for the location indicate that power production is extremely high during the summer months. In the simulation, the PV panel is considered as 60.75 kWp, and the ES is considered as 105.98 kWh ES. The estimated annual energy production capacity is shown in Figure 3. The monthly averages of daily energy production, as well as monthly average of energy not captured because the battery became full, are shown in Figure 4. These data show that annual energy production using annual fixed optimal angle is 39,828.80 kWh. Also, 44,394.95 kWh annual energy is not captured due to the ES limit. The annual electricity generation and the life span of the microgrid are given in Table 12.

It is observed that the certain times of the year including the winter months, the energy from PV panels is wasted regardless of the system load design (see Section 4.1) and day/night use. It is also seen that during some days in the winter months (Dec, Jan, and Feb), the ES and PV capacity can be increased in order to meet the determined daily electricity consumption, or the generator can be needed to run. However, making more use of daylight without increasing the microgrid power capacity is one of the important aims of this study. Therefore, especially during the winter months, the energy consumption should be planned based on the sunshine duration and hours, the high energy-consuming devices should be used during the sunshine period to ensure the continuous work of the system.

Table 12. Annual and life span electricity production.

Land requirement	760m^2
Considered lifespan	25 years
Fuel cost	1.39 $/Lt
Annual electricity production (AVG)	39.83 MWh
Life span electricity production	995.75 MWh

7.2 ES (Battery) performance results

It is understood that from Figure 4 and Figure 5, the battery remains full in the summer and the charge status of the battery remains enough until the end of the day in other months. However, it is also observed that the battery capacity falls below 10% on some days during the winter months. It would be appropriate to increase the battery capacity accordingly so that the energy flow continues without interruption. According to the calculations, in 29% of the year, the battery charge status remains over 90% while in 15% of the year battery charge rate fluctuates between 34% and 43%.

7.3 MATLAB microgrid simulation results

The clear day simulation model in Figure 7 demonstrates the energy consumption is provided directly from the diesel generator firstly, and then alternately PV and ES meet the energy consumption needs. If one needs to evaluate the DER components separately, it is seen that after the PV energy production starts during the sunshine period, the generator is cut off, the energy consumption is provided directly from the PV, and the ES is charged at the same time. It is also understood that in line with the decrease in the sunshine duration, the ES comes into play and meets the energy consumption, and microgrid performs well in terms of energy sustainability and continuity.

It is understood from Figure 8 that the generator plays a more active role on cloudy days than on clear days, and the generator usage will be higher on some days in the winter months. It is seen that the technical simulation performed in MATLAB/Simulink supports the results in section 7.1.

7.4 Effect of optimal tilt angles on energy efficiency

The differences in the amount of radiation gain as a result of the effect of the tilt angle of the PV surfaces for the Sanliurfa province are listed in Table 6. It is calculated that the optimal tilt angle values vary between 1° (June) and 62° (December) throughout the year. The average annual optimal tilt angle is determined to be 33° for the region. For the PV surfaces that do not have a solar tracking system, the tilt angles can be also set monthly to benefit from solar radiation more efficiently [42]. It is calculated that monthly tilted PV surfaces achieve 16.25% more solar radiation throughout the year compared to the PV surfaces that are not angled. When the tilt angles of the PV surfaces are not possible to set monthly as in this study, the tilt angles can be set annually. It is calculated that annually tilted PV surfaces achieve 10.28% more solar radiation yearly compared to PV surfaces that are not angled.

7.5 Other optimization discussions

It is understood from the location results that it would be more beneficial to optimize the microgrid for the installation location. Tilt, azimuth, and orientation angles of the PV arrays are essential to provide better power-production and they can vary from location to location. The optimal angle should be set based on the maximum energy production in the winter months for off-grid PV systems. Besides, if needed more precise estimations, it is possible to change angels when panels are mounted on adjustable structures. Monthly or seasonally changing angles 4 times in a year further increases ES and PV module efficiency. Therefore, sensitive optimal tilt angels can be more helpful to fill up ES at a good level. In this study, the economic benefit is considered by keeping the panel structure unadjusted and simple, annual optimal tilt angle is determined, and all panels are set at this angle. section 7.1.

7.6 Payback period and lifespan estimation

The average time to gain back total microgrid cost (payback period) is an indicator of how long is expected to return back initial investment of the microgrid. When evaluated in terms of cost-benefit analysis, the smaller payback period is the more desirable for investors or donors [43]. The payback period is expected to be longer due to the cost of ES for the off-grid PV systems. The cost of ES can be higher than the cost of the PV. In this study, the payback period (depreciation time) of the microgrid to be installed in the desired location for the fixed axis system is calculated as 10.67 years. The ability to reduce this period is necessary for terms of financial and continuity, studies in this direction should be increased.

It is seen that from the studies, the lifespan of PV modules is beyond 25 years and current ones can be likely improved lifespan further. It is expected that 30-years lifespan or more [44],[45]. It should not be ignored that PV systems continue to produce after 25 years. Also, it is possible to increase the lifespan of the PV energy systems with the O&M activities.

8 Conclusions

In this study, a transportable isolated (off-grid) microgrid is developed based on PV energy production to meet electricity to serve in various fields by providing technical, regional, climatic, and cost analysis as well as numerical modeling for specifically Sanliurfa region of Turkey. So, this work proposes practical, effective, and reliable solutions that can be used for various applications for rural areas and humanitarian services. It is anticipated that this microgrid can be installed in refugee camps and rural areas with no electricity in the region, and the microgrid can be transported between the locations in line if needed.

The study is completed with 60.75kWp PV capacity, and 105.98kWh ES energy capacity for the Sanliurfa province in Turkey. Energy production efficiency, capacity, and sustainability of the region have been evaluated under climatic and regional conditions. Sanliurfa has the highest solar potential in Southeastern Anatolia. It is confirmed that the energy production is extremely high during the summer months in the region. The daily energy not captured due to the ES limit is considerably high. So, the ES and the PV power capacity can be also increased in case of any need to resize the load capacity in the future.

A strong PV energy production system is developed with a minimal size of the battery to ensure generation, transmission, distribution, and continuity of power. In order to provide energy flow regularly, to keep energy enough level, and to make a stable energy balance, the ES is optimized to provide a strong solution. A diesel generator is integrated into microgrid to balance the power and provide the startup power.

A considerable effort is also put into the system performance and dynamic behavior investigation of the microgrid by modeling DER and load flow on MATLAB/Simulink in a 24-hours scenario. The findings taken from the simulations show that the designed microgrid is reliable and stable.

In compared to similar installations in industrialized countries, the payback period is found to be rather long which shows that the cost of power system equipment like ES and PV module in the Turkey is still at high levels. It is highly recommended that the next studies should investigate the possibility of establishing an isolated PV system with a lower cost and larger capacity to decrease the payback period. Existing PV technologies should be analyzed and compared to determine the most suitable technology with a lower cost.

System performance results show that the annual energy production using a yearly fixed optimal angle is 39.83MWh. Considering the average life span of the system as 25 years, the total amount of energy to be produced is 995.75MW. In 29% of the year, the battery charge status remains over 90% while in 15% of the year battery charge rate fluctuates between 34% and 43%. It is calculated that monthly optimal tilted PV surfaces achieve 16.20% more solar radiation and annually optimal tilted PV surfaces achieve 10.18% more solar radiation compared to PV surfaces that are not angled. The payback period of the microgrid is calculated as 10.67 years.

It is also expected that this kind of study can contribute to increase energy security and sustainability in the region and facilitate the transportation and installation of such systems to the required regions. This study's data and findings can be used in similar applications and can shed light to future studies. It can also be served as a foundation study for off-grid PV installations in the region. The findings of the study can be considered an asset to support further studies and investigations in this region.

9 Author contribution statements

Batur Alp AKGÜL has taken part in the idea phase of the study, fictionalizing, and designing the system, regional and technical simulations, as well as contributed to all topics in the study. Fatih ALİSİNANOĞLU has contributed to the literature review and creation of the mathematical model, Sadettin ÖZYAZICI has contributed to the cost analysis, evaluation of the results and writing the article. Muhammet Fatih HASOĞLU has contributed to the critical review, article control and writing sections, Bülent HAZNEDAR has contributed to the data collection and analysis sections.

10 Ethics committee approval and conflict of interest statement

Ethics committee approval is not required for the prepared article. There is no conflict of interest with any person/institution in the prepared article.

11 References

[1] Sufyan M, Rahim AR, Tan C, Azam M, Rohani S. "Optimal sizing and energy scheduling of isolated microgrids considering the battery lifetime". *Journal of Plos One,* 14(2), 2-3, 2019.

[2] Faccio M, Gamberi M, Bortolini M, Nedaei M, "State-of-Art review of the optimization methods to design the configuration of hybrid renewable energy systems". *Front Energy,* 12(4), 591-622, 2018.

[3] Dorf RC. *Systems, Controls, Embedded Systems, Energy, and Machines.* 1st Edition, Boca Raton, 2017.

[4] Parhizi S, Lotfi H, Khodaei A, Bahramirad S. "State -of-Art in research on microgrids: A review". *IEEE Xplore,* 3(1), 890-925, 2015.

[5] Caspary G. "Gauging the future competitiveness of renewable energy in colombia". *Energy Economics,* 31(3), 445-450, 2009.

[6] Afgan NH, Carvalho MG. "Sustainability assessment of a hybrid energy system". *International Journal of Hydrogen Energy,* 29(13), 1327-1342, 2004.

[7] Mengi OO, Altas IH. "A new energy management technique for PV/Wind/Grid renewable energy system". *International Journal of Photoenergy,* 2015, 1-19, 2015.

[8] Aghajani G, Ghadimi N. "Multi-objective energy management in a microgrid". *Energy Reports,* 4(1), 218-225, 2018.

[9] Suchitra D, Jegatheesan R, Subramaniyan V, Venkatesam RS. "Energy management of a microgrid using multi-objective genetic algorithm". *Middle-East Journal of Scientific Research,* 24(4), 1266-1274, 2016.

[10] Gabbar HA, El-Hendawi M, El-Saady G, El-Nobi AI. "Supervisory controller for power management of AC/DC microgrid". *IEEE Conference on Smart Energy Grid Engineering,* Oshawa, Canada, 21-24 August 2016.

[11] Vera YEG, Dufo-López R, Bernal-Agustín JL. "Energy management in microgrids with renewable energy sources: A literature review". *Applied Sciences,* 9(18), 1-28, 2019.

[12] Shayeghi H, Shahryari E, Moradzadeh M, Siano P. "A survey on microgrid energy management considering flexible energy sources". *Energies,* 12(11), 1-26, 2019.

[13] Arıkan O, İşen E, Kekezoğlu B, "Performance analysis of stand-alone hybrid (wind-photovoltaic) energy system". *Pamukkale University Journal of Engineering Sciences,* 25(5), 571-576, 2019.

[14] Öztürk M, Bozkurt Çırak B, Özek N. "Life cycle cost analysis of domestic photovoltaic system". *Pamukkale University Journal of Engineering Sciences,* 18(1), 1-11, 2012.

[15] Sulukan E. "Techno-economic and environmental analysis of a photovoltaic system in Istanbul". *Pamukkale University Journal of Engineering Sciences,* 26(1), 127-132, 2020.

[16] Al-Karaghouli A, Kazmerski LL. "Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER". *Solar Energy,* 84(4), 710-714, 2010.
[17] Selbaş R, Yakut AK, Şencan A. "An application for electricity production with solar tower model". *Pamukkale University Journal of Engineering Sciences,* 9(2), 179-184, 2003.
[18] Akinyele DO. "Environmental performance evaluation of a grid-independent solar photovoltaic power generation (SPPG) plant". *Energy,* 130(1), 515-529, 2017.
[19] Patil VR, Biradar VI, Shreyas R, Garg P, Orosz MS. Thirumalai NC. "Techno-economic comparison of solar organic rankine cycle (ORC) and photovoltaic (PV) systems with energy storage". *Renewable Energy,* 113(1), 1250-1260, 2017.
[20] Yan R, Saha TK, Meredith P, Goodwin S. "Analysis of the year long performance of differently tilted photovoltaic systems in Brisbane, Australia". *Energy Conversion and Management,* 74(1), 102-108, 2013.
[21] Akgul BA, Cinkilic ME, Yegingil I. "Design and modeling an off-grid photovoltaic system to meet the electrical energy requirement of a house in Gaziantep region, performing technical analysis and basic simulation". *Euroasia Journal of Mathematics, Engineering, Natural & Medical Sciences,* 8(14), 145-159, 2021.
[22] Franceschi J, Rothkop J, Miller G. "Off-grid solar PV power for humanitarian action: from emergency communications to refugee camp microgrids". *Procedia Engineering,* 78(1), 229-235, 2014.
[23] Evans DL. "Simplified method for predicting photovoltaic array output". *Solar Energy,* 27(6), 555-560, 1981.
[24] Zlateva M. "Assessment of the annual performance of solar collectors by means of the utilizability method". *E3S Web of Conference PEPM.* 207(1), 1-10, 2020.
[25] Louis L, Bucciarelli JR. "The effect of day-to-day correlation in solar radiation on the probability of loss-of-power in a stand-alone photovoltaic energy system". *Solar Energy,* 36(1), 11-14, 1986.
[26] Klein SA, Beckman WA. "Loss-of-load probabilities for stand-alone photovoltaic systems". *Solar Energy,* 39(6), 499-512, 1987.
[27] Modiri-Delshad M, Kaboli SHA, Renani E, Rahim NA. "Backtracking search algorithm for solving economic dispatch problems with valve-point effects and multiple fuel options". *Energy,* 116(1), 637-649, 2016.
[28] Khorramdel H, Aghaei J, Khorramdel B, Siano P. "Optimal battery sizing in microgrids using probabilistic unit commitment". *IEEE Transactions on Industrial Informatics,* 12(2), 834-843, 2016.
[29] Arçelik AŞ. "Arçelik 144HC-450W Solar Panel". https://www.arcelikkurumsalcozumler.com/solar-panel/ (10.05.2022).
[30] Torreglosa JP, Garcia P, Fernandez LM, Jurado F. "Predictive control for the energy management of a fuel-cell–battery–supercapacitor tramway". *IEEE Transactions on Industrial Informatics,* 10(1), 276-285, 2014.
[31] Zhejiang Sandi Electric Co., Ltd. "100 kWh PV Energy Storage Lithium Battery with BMS System off-grid Inverter all in one". http://www.cnsandi.cn/sdp/911164/4/main-4781195/0/Home.html (10.05.2022).
[32] Romana A, Setiawan EA, Joyonegoro K. "Comparison of two calculation methods for designing the solar electric power system for small islands". *E3S Web of Conferences,* 67(1), 1-6, 2018.
[33] Samedi S, Singh C. "Reliability evaluation of generation systems with solar power". *International Conference on Probabilistic Methods Applied to Power Systems (PMAPS),* Durham, UK, 07-10 July 2014.
[34] KARJEN Karadeniz Generator Systems. "Diesel Generator Sets, KJPT/16 Diesel Type Generator". https://karjen.com/katalog/KJPT-16.pdf (05.04.2022).
[35] Kumar BS, Sudhakar K. "Performance evaluation of MW grid connected solar photovoltaic power plant in India". *Energy Reports,* 1(1), 184-192, 2015.
[36] European Commission, "Photovoltaic geographical information system for solar PV systems". https://ec.europa.eu/jrc/en/pvgis (10.05.2022).
[37] Alberto ADB, Simao A. "Iterative minimization of partial finite state machines". *Central European Journal of Computer Science,* 3(2), 91-103, 2013.
[38] Đurić MB, Đurišić ZR. "Combined fourier and zero crossing technique for frequency measurement in power networks in the presence of harmonics". *RE&PQJ,* 1(3), 463-469, 2005.
[39] Steffen B, Beuse M, Tautorat P, Schmidt TS. "Experience curves for operations and maintenance costs of renewable energy technologies". *Joule,* 4(2), 359-375, 2020.
[40] Canada S, Moore L, Post H, Strachan J. "Operation and maintenance field experience for off-grid residential photovoltaic systems". *Progress in Photovoltaics,* 13(1), 67-74, 2005.
[41] McKeon BB, Furukawa J, Fenstermacher S. "Advanced lead–acid batteries and the development of grid-scale energy storage systems". *Proceedings of the IEEE,* 102(6), 951-963, 2014.
[42] Akgul BA, Alisinanoglu F, Ozyazici MS. "Obtaining maximum radiation by determining optimum tilt angles in large-scale grid-connected PV plants, efficiency analysis of solar tracking systems: A case study for Sanliurfa, Turkey". *Int. Journal of Industrial Electronics and Electrical Engineering,* 10(7), 25-28, 2022.
[43] Sharma KR, Palit D, Krithika PR. "Economics and management of off-grid solar PV system". *Green Energy and Technology,* 1(1), 137-164, 2015.
[44] Skoczek A, Sample T, Dunlop ED. "The results of performance measurements of field-aged crystalline silicon photovoltaic modules". *Progress in Photovoltaics,* 227-240, 17(4), 227-240, 2009.
[45] Dunlop E, Halton D, Ossenbrink H. "20 years of life and more: where is the end of life of a PV module?". *IEEE Photovoltaic Specialists Conference,* Lake Buena Vista, USA, 03-07 January 2005.