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On-grid Photovoltaic Power System for Governmental Office Electrification

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Abstract

Solar energy is one of the most promising renewable energy sources. The potential solar energy has a capacity to meet all energy requirements for human survival on planet earth. Some applications such as a thermoelectric generator, electric power generation with the assistance of solar panels and water applications are required to reduce the demand for electricity generated by conventional power plants. The current work evaluates the effectiveness of solar energy for supplying the police building located in Diyala, Iraq. The installed renewable power system consists of photovoltaic/ battery system set with grid connection installed on the roof of the building with a capacity of 5.52 kWp and battery unit (200 A, 48 Volt). Based on the daily average load kWh and daily average solar irradiance for the selected site (4.3 kWh/m2), the results of the energy generated by the system for two selected days showed that for a sunny day is about (11.63 kWh) and for party cloudy day is about (8.02 kWh). The average of energy fed to the grid for a sunny day was recorded more by more than 3.0 kWh and for party cloudy day by more than 4.0 kWh. The system installed at the first day of February of the year 2021. The obtained results encourage to install of photovoltaic systems in the selected site which can feed such facilities with renewable energy and deliver energy to the grid.

Keywords: On-Grid; Off-Grid; Solar system; renewable energy; PV

1. Introduction

The electrical system in Iraq suffered from unstable energy supply in the last four decades. The fluctuating of supplied electricity raised during the past ten years due to an increase in the energy demand add to that the lack of construction of new power plants and inadequate maintenance processes of the current power plants and transmission grid systems. The supply interruption of the electrical energy in whole Diyala governorate reached to sixteen hours/day, where the unsupplied hours increase during summer months and decrease during winter months [1, 2]. The use of solar technology provides several number of ways to meet human needs including, electricity generation, water heating, cooking, agriculture irrigation, water desalination etc. Despite of several advantages, the systems based on solar energy technology have not become popular due to the large initial investment cost and the lack of technicians that work in this field at the local level. There are several models types of solar energy have been designed and investigated the effectiveness for electrical energy supplying.

Sichilalu et al. [3], suggested the optimized Hybrid Renewable Energy System (HRES) with the photovoltaic (PV) component to feed the residential building in Pretoria, South Africa. The system consisted of 4.0 kWp PV, 7.0 kW Wind Turbine (WT), and the authors used MATLAB software for hourly simulation process. The results demonstrated that the suggested system capacity can meet 96% of the desired load and the remaining 4% fed by grid. Arcos-Aviles et al. [4], they used MATLAB Simulink for optimizing and sizing Renewable Energy Systems (RES) consisted of PV/WT/ BA (Battery) with grid connection to feed fifteen households in Pamplona, Spain at higher self-consumption and lowest energy form grid.

Nomenclature	
PV Photovoltaic	$P_{P,t}$ Power generated by RES (kW)
HRES Hybrid Renewable Energy System	$P_{Grid,t}$ Power taken from grid (kW)
WT Wind turbine	$P_{b,t}$ Power taken form the storage system (kW)
RES Renewable Energy Systems	$P_{PV,t}$ Power generated by PV system (kW)
BA Battery	C_{PV} Rated capacity of the PV system (kW)
FC Fuel Cell	η_{PV} Derating factor (%)
DG Diesel generator	$G_{T,t}$ Solar irradiance (kWh/m2)
BS Bio mass	α_P PV module temperature coefficient of power (%/oC)
HT Hydrogen tank	$T_{C,t}$ Temperature of the PV module (°C)
AC Alternative current	P_b Battery power (kW)
DC Direct current	$P_l(t)$ Electrical load demand (kW)
Abbreviations	s_g Self-discharge factor (-)
η_b Battery efficiency (%)	η_N Inverter efficiency (%)

The results demonstrated the maximum capacity that obtained from renewable energy system are 4.0 kW for PV, 4.0 kW for WT and 36 kWh for BA unit as a storage system. Jaszczur and Hassan [5], investigated for using the ultra-super capacitor for supporting PV system connected with the grid. The study conducted using the experimental measurements for the (electrical load and weather data at 1-minute resolution for the household in Krakow, Poland. The results showed for 5.5 kWh the daily energy consumption used of super capacitor with capacity (2.7 Volt 100 Farad) 20 unit with 1.04 kW PV system can increase renewable energy fraction to 54.75 %. Hassan [6], presented the optimal solar-hydrogen energy system to supply the renewable energy in Diyala, Iraq. The simulation and optimization process conducted using MATLAB software for obtaining the optimum Fuel Cell (FC) capacity that used as a storage unit. 6.5 kW daily energy consumption, the results showed the optimal FC capacity about 2.3 kW, and at 1.9 kWp PV system can increased the percentage of renewable energy from 32% to 96%. A study carried out by Bonanno et al. [7], for size finding of a hybrid renewable energy system consist of PV/WT connected with the grid to supply the renewable energy to the university building in Catania, Spain. The study obtained the optimum system capacity is 24.4 kWp for PV and 15 kW for WT which provided 89% of the desired system energy. For 15 homes connected with the gird in Hanga Roa (Easter Island), Chile, Caballero et al. [8], investigated the techno-economic visibility for the PV system. The simulation process carried out using MATLAB Simulink at 1-hour resolution and the results of PV system with a capacity 70 kWp can generate daily energy between (39.48-61.2 kWh) which is very promising value on the basis of an average of the available solar irradiance 4.3 kWh/m2/day) in the selected site. Palej et al. [9], designed and optimized HRES with two optimization objectives (technical aspects and ecological aspects). The authors indexed that the optimum system capacity at ecological aspects is higher than capacity at economic aspects and the optimum system cost at ecological aspects is higher than economic aspects. Furthermore, the authors obtain the relation between tow optimization objectives is the polynomial equation of second order. Jaszczur et al. [10], suggested four HRES scenarios for a multi-objective criterion, and these selected scenarios are PV/BA, PV/BA/grid, PV/WT and PV/WT/grid. The target of research for obtaining the optimum system configuration to feed the household with renewable energy at the lowest cost and low environmental emissions. The research results demonstrated the scenarios without storage units are the lower cost than the scenarios with storage units even though the storage unit systems supplied higher renewable energy percentage. Ramli et al. in Malaysia [11], they used off-grid HRES consisted of PV/WT/BA to feed the electrical energy for a typical urban house. The study applied a parametric, economic and energy analysis using the HOMER software. The results showed the maximum of daily average energy can be generated by the system is 3.5 kWh from PV, 28.5 kWh from WT and 44.16 kWh from BA. Ma and Javed [12], proposed hybrid system HRES consisted of PV/WT/BA to supply the electricity to the remote island in China. The aim of study to feed the island by renewable energy at highest. The simulation results showed the WT unit is high energy supplier than PV system and storage BA. Furthermore, to the above literature review, table 1 shows the several renewable energy systems executed at different sites and purposes.

Table 1 A review for renewable energy sizing an optimization

Scenario	Grid mode	Country	Purpose	Study tool	Year	Ref.
PV/WT/BA/DG	Off-grid	South Korea	Different types of buildings	MATLAB	2019	[13]
PV/WT/BA/DG	Off-grid	Sweden	10 households	OPAL-RT	2017	[14]
PV/WT	Off-grid	India	Residential buildings	None	2019	[15]
PV/WT	On-grid	Greece	Manufacturer factory	MATLAB	2017	[16]
PV/WT	On-grid	China	_	MATLAB/Simulink	2019	[17]
PV/WT	On-grid	Yemen	50 households	HOMER	2017	[18]
PV/WT/BA	On-grid	Poland	Household	HOMER	2019	[19]
PV/WT/FC/DG	On-grid	Egypt	Small village	HOMER	2018	[20]
PV/WT	On-grid	Australia	City electrical supply	HOMER	2017	[21]
PV/WT	On-grid	Algeria	A village with hospitals and schools	HOMER	2016	[22]
PV/WT/BS	Off-grid	Philippines	Electrification of Carabao Island	GAMS	2019	[23]
PV/WT/FC/HT	Off-grid	Turkey	Household	MATLAB/Simulink	2018	[24]
PV/WT/FC/HT	Off-grid	Senegal	Telecommunication base station	MATLAB/Simulink	2019	[25]

Where DG is the diesel generator, BS is the biomass and HT is the hydrogen tank. The modelling of renewable energy systems and hybrid renewable energy systems is not innovative, but its highly required to investigated because the intensity of the renewable energy resources are different from site to another.

The current study evaluates the supplying renewable energy to the governmental office located in Diyala, Iraq using an experimental set of PV system located on the roof of selected building. The study testes and the performance evaluation for two scenarios are Off-grid and On-grid with the variation influence of an irradiation and the ambient temperature, which such analysis highly required in Iraq.

2. Methodology and experimental set-up

The PV is system installed on the roof of the Diyala Police Directorate located in the city of Baqubah, capital of Diyala governorate with the latitude and longitude 33.7733° N, 45.1495° E. Figure 1 shows the installed PV system on the selected building which consisted of sixteen PV module connected in the parallel and the system connected with storage batteries for store energy that can feed the desired load when there is no grid electricity and no power produced by PV system. Table 2 shows the PV Batteries and modules specifications.

Fig. 1 The installed of PV system

Table 2 PV system components specifications

PV module [26]	
Type	LONGI (LR6-60OPG)
Max. power	345 W
Tolerance	±5
Voltage at $\mathbf{P_{Max}}$ $(\mathbf{V_{MP}})$	31.6 V
Current at $\mathbf{P_{Max}}$ $(\mathbf{I_{MP}})$	10.92A
Open circuit voltage $(\mathbf{V_{OC}})$	38.3V

Short circuit current (I_{SO})	11.72A
Operating temperature	-40 to +85 oC
Temperature coefficient of power	-0.48 % / °C
Module efficient	16.9 %
Solar Inverter [27]	
Type	REVO II 5.5 kW
Rate power	5500 W
DC input	48 VDC, 130A
AC output	54 VDC
Efficiency	97%
Battery [28]	
Type	AMARON
Current rate	200 A
Volt rate	48 V

The storage system capacity consisted of four batteries connected in series, which produce 38.4 kWh as shown in Figure 1.

2.1. Load Demand

The total load has taken into account is low power consumption including on-off load without air-conditioning and another high power devices because the needed load consider the essential devices which services the people's transactions. Table 3 is listed the total load that needed for this study.

Table 3 Total load demand

Device	No.	Power consumption (W) for single device	Power consumption (W) For all devices
Fan	21	55	1155
Lamp	40	25	1000
Lamp led	40	25	1000
Computer	7	65	455
Printer	6	65	390
Fridge	2	140	280
Total	-	-	4280

Figures 2 shows the experimental data of the electrical consumption for two selected days (17th February, 2021) and (22nd February, 2021). Which showed that the lowest energy consumption during the night hours (0:00-06:00 h), and the energy consumption increase with the beginning of a day when start the working after 07:00 h at the morning due to switching ON some of electrical devices.

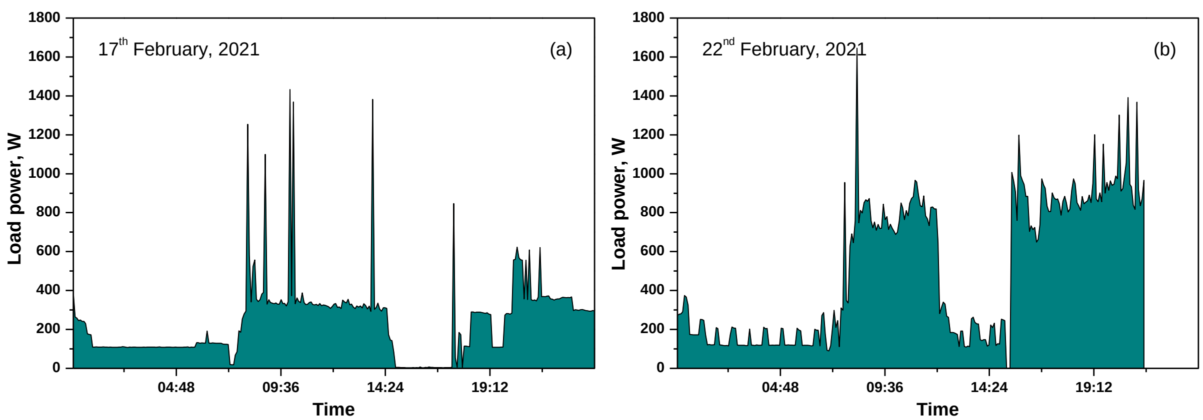

Fig. 2 Distribution of power consumption with time for the electrical load for two selected days partly cloudy (17th February, 2021) in (a) and sunny (22nd February, 2021) in (b)

2.2 Governing equations

The PV system consists of PV/BA set with the grid connection through the control unit. During the cloudy and partly cloudy days the rate of generated power that production by the PV panels less than the desired load. Therefore, the required shortage power is compensated from the storage system (Batteries in this case) and then from the national grid.

The instantaneous power can be generated by the suggested system (PV/BA) at any time can be described as:

$$P_{P,t} = P_{b,t} + P_{Grid,t}\, P_{PV,t} \tag{1}$$

where: PP,t is the instantaneous total power generated by the suggested system, PGrid,t is the instantaneous power taken from the grid.,Pb,t is the instantaneous power taken form the storage system, PPV,t is the instantaneous power generated by PV system.
The power generated by a PV system can be described by the following equation [29,30]:

$$P_{PV.t} = C_{PV}\, \eta_{PV} \cdot \left(\frac{G_{T,t}}{G_{T,STC}}\right) \cdot [1 + \alpha_P\, (T_{C,t} - T_{C.STC})] \tag{2}$$

where: CPV is rated capacity of the PV array, η_{PV} is the rate of derating factor [31], $G_{T,t}$ is the solar irradiance, α_P is the PV module temperature coefficient of power, and $T_{C,t}$ is the temperature of the PV module.
The battery power Pb,t depends on the battery state of charge and can be calculated from equations [32]:
charging,

$$P_{b.t} = P_b(t-1) \cdot (1 - S_g) + P_{PV,t} - P_l(t) \backslash (\eta_N) \cdot \eta_b \tag{3}$$

discharging,

$$P_{b.t} = P_b(t-1) \cdot (1 - S_g) + P_{PV,t} - (P_r(t) \backslash (\eta_b) \cdot (\eta_b) \cdot P_l\,(t)) \tag{4}$$

where Pb(t-1) is represented the end of battery power at time t, Pl(t) the electrical load demand at time t, sg is the self-discharge factor, and $\boldsymbol{\eta_N}$, $\boldsymbol{\eta_b}$, is the inverter efficiency and battery charger, respectively.

Figure 3 shows the power flow visualisation for the PV/BA/grid system which used in this analysis. The inverter used to convert the DC to AC to feed AC daily loads while the surplus power of PV panels is used to charge the batteries and feed the AC daily loads at night.

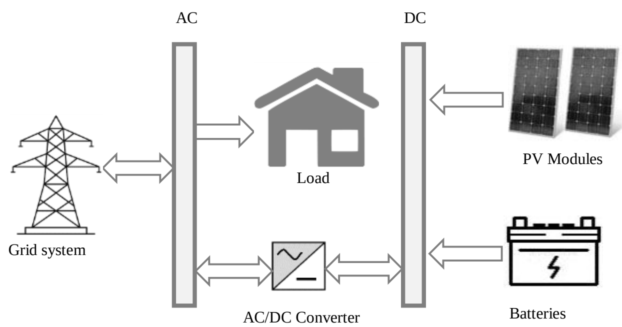

Fig. 3 Power flow visualization for the PV/BA/grid system

3. Results and Discussion

The The performed analysis is done using the experimental data of electrical load. The generation power from the PV system is distributed based on the power flow method using mathematical modelling of the system components that described in the equations (1-4). Figure 4 illustrate the PV power for two selected days are partly cloudy (17th February 2021) and sunny (22nd February 2021). From the results, it is very clear that the PV system generated power in sunny day higher than the partly cloudy day due to the higher solar irradiance.

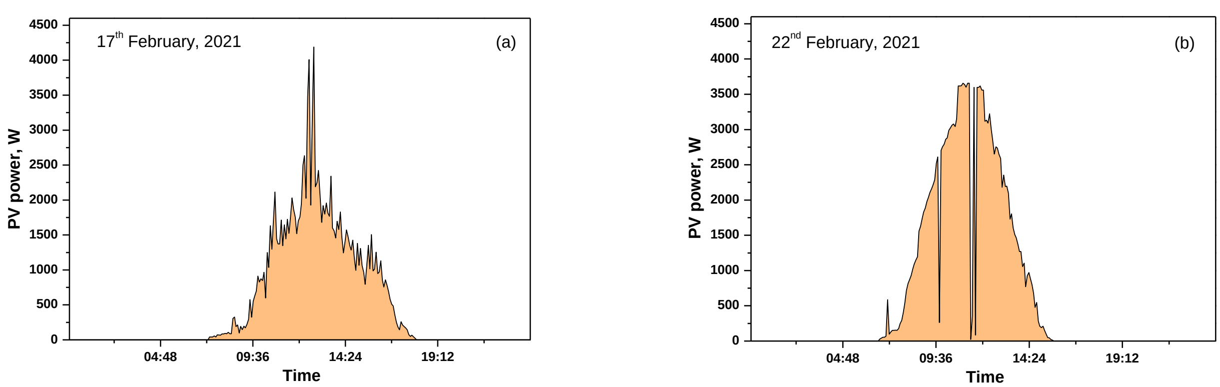

Fig. 4 The PV power generated for two selected days partly cloudy (17th February 2021) in (a) and sunny (22nd February, 2021) in (b)

Figure 5 shows the PV system output voltage in the partly cloudy day, the voltage is more stable than on a sunny day due to the low soar irradiance and the PV system did not generate high power which makes the system voltage more stable than a sunny day. While in the sunny day, the current of PV system is higher than the partly cloudy day.

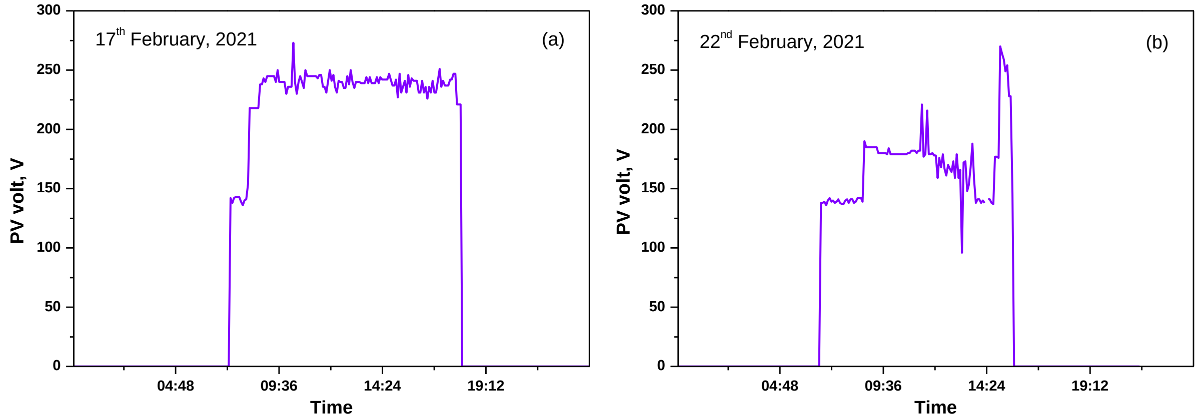

Fig. 5 The PV system voltage for two selected days partly cloudy (17th February 2021) in (a) and sunny (22nd February, 2021) in (b).

Figures 6 and 7 show the discharging and charging of batteries for two selected days respectively. The peak of maximum charge value reaches the 15 A (refer to Figure 6), while the discharge peaks reach more than 20 A in a party cloudy day (refer to Figure 7).

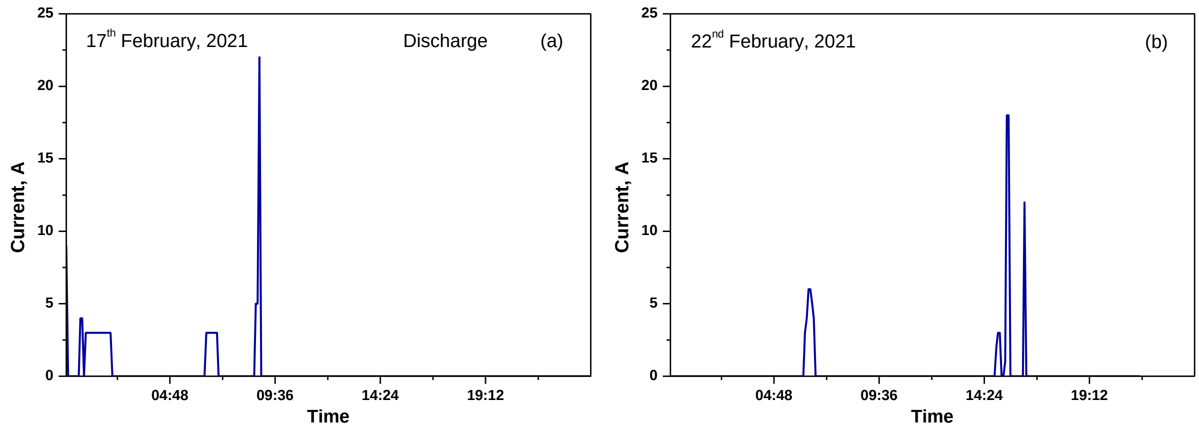

Fig. 6 Battery discharge current for two selected days partly cloudy (17th February, 2021) in (a) and sunny (22nd February, 2021) in (b)

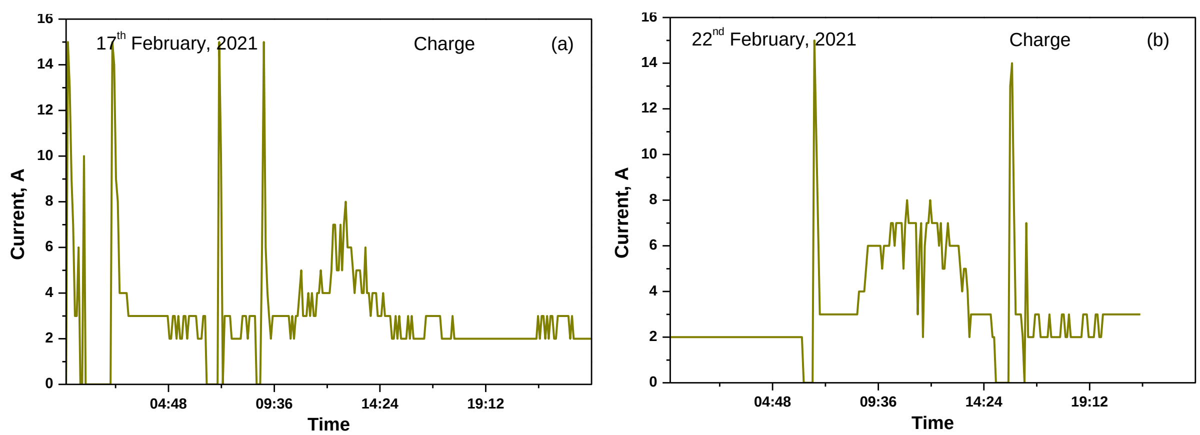

Fig. 7 Battery charge current for two selected days partly cloudy (17th February 2021) in (a) and sunny (22nd February, 2021) in (b)

The daily electrical load and PV power distribution for two selected days described in Figure 8. The variation of the desired load power has a high influence on the total power generated by the PV system based on the self-consumption power. When the daily power consumption is high, the power self-consumption is high and this reduces the power delivered to the grid.

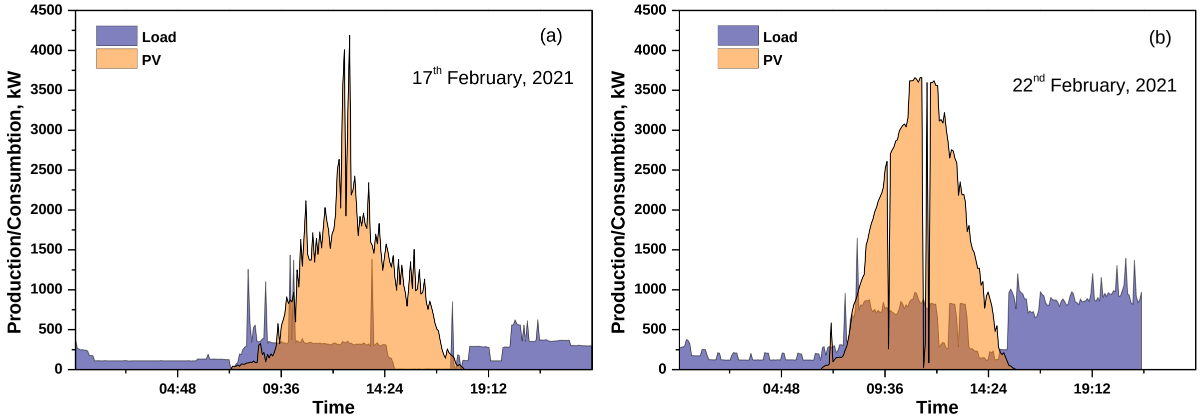

Fig. 8 The PV power generated and the desired load for two selected days partly cloudy (17th February, 2021) in (a) and sunny (22nd February, 2021) in (b)

Table 4 shows the energy distribution for the selected days, for the partly cloudy day of 17th February 2021 the energy consumption recorded 3.98 kWh and the produced power by PV systems recorded 8.02 kWh while for the sunny day of 22nd February 2021the daily energy consumption showed 8.46 kWh and the PV system generated 11.63 kWh which higher than a partly cloudy day for higher incident solar irradiance. The energy storage in the batteries did not use because the system connected with the grid that why showed the daily charge and discharge values are too low as demonstrated in table 4.

Table 4 Daily energy distribution

Day	Load (kWh)	Battery charge (A)	Battery discharge (A)	PV power (kWh)
17th February 2021	3.98	0.04	0.006	8.02
22nd February 2021	8.46	0.05	0.005	11.63

4. Conclusion

The study tested the effectiveness of using solar energy to feed the governmental office. Globally, the use of renewable energy sources is increasing especially with the developed technologies. Also, the increased population, industries and costs of fuel caused the people take interest in solar energy. In the presented work, an on-grid PV system is designed and implemented in Diyala Police Directorate. The presented design focuses on the economic analysis by providing the required power for local load and investing the surplus power to the national grid system with fewer losses and higher efficiency.

The experimental results show for the PV system with 5.0 kWp capacity set with the grid connection can generate energy that is higher in sunny days than partly cloudy ones due to the highest solar irradiance. The energy distribution for the selected days, for the partly cloudy day of 17th February 2021 were as follows: the energy consumption recorded at 3.98 kWh and the produced power by PV systems recorded at 8.02 kWh while for the sunny day of 22nd February 2021 the daily energy consumption showed 8.46 kWh and the PV system generated 11.63 kWh which was higher than that of the partly cloudy day for higher incident solar irradiance. The energy stored in the batteries were not used because the system was connected with the grid thus the daily charge and discharge values are too low (refer table 4). The results demonstrated for the energy system set with the grid connection shows that it is not recommended to use a storage system so as to reduce the cost of the system.

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