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# A Study for the Design of a Hybrid Solar Energy System Connected to the Grid (On-Grid): The Deanship of the Technical Institute of Mosul as a Case Study

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# دراسة لتصميم نظام طاقة شمسية مدمج هجين (Hybrid) ومتصل بالشبكة (On-Grid): عمادة المعهد التقني الموصل نموذجاً

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**Abstract:**
This paper presents the design of On-Grid hybrid solar PV system to supply electrical power for Deanship building of the Technical Institute of Mosul at Northern Technical University. The system was developed to reduce the consumption of electric energy from the public grid and to provide 24 hours sustainable energy. The renewable energy system supplies electrical energy for the meeting room, lighting systems, the fire-detection system and the security cameras. In terms of the applied active and continuous load calculations, and sizing of the inverter, PV and battery for the Mosul city conditions (e.g., with available roof area = 1380 m2, seasonal solar declination angle, and shade distance between the PVs), a 20 kVA hybrid system could be installed, either consisting of four 5 kVA inverters or two 10 kVA inverters, to feed the continuous loads. Alternatively, a parallel 150 kW On-Grid system could be installed in the existing roof space using more than 220 high efficiency n-type HJT half-cut 550 W panels and would export approximately 52 kW of energy over the entire 8-hour day under sunny conditions per sub-array (i.e. per inverter). These results indicate that the proposed hybrid is technically feasible and can considerably reduce electricity costs and promote energy sustainability in educational institutions.
**Keywords**: Hybrid Solar System, On-Grid Photovoltaic, Renewable Energy, Inverter Sizing, Battery Storage, Technical Institute of Mosul.

**الملخص**
تقدّم هذه الدراسة تصميماً لمنظومة طاقة شمسية كهروضوئية هجينة متصلة بالشبكة الوطنية (On-Grid) لبناية عمادة المعهد التقني الموصل التابع للجامعة التقنية الشمالية، بهدف تقليل الاستهلاك من الطاقة الكهربائية المجهزة من المصدر الرئيسي وتوفير مصدر طاقة مستدام ومستمر للأحمال الحيوية كغرفة الاجتماعات والإنارة ومنظومة إنذار الحرائق وكاميرات المراقبة على مدار 24 ساعة. واعتمدت المنهجية على إجراء حسابات دقيقة للأحمال الدائمة والمستمرة، وتحديد قدرة العاكسات والألواح الشمسية والبطاريات اللازمة، مع الأخذ بنظر الاعتبار الظروف الجغرافية والمناخية لمدينة الموصل، والمساحة المتوفرة من السطح والبالغة نحو 1380 متراً مربعاً، وزاوية الميل الشمسي الفصلية، ومسافة الظل بين صفوف الألواح. وقد بيّنت النتائج إمكانية تنفيذ منظومة هجينة بقدرة 20 كيلو فولت أمبير لتغذية الأحمال المستمرة باستخدام أربعة عاكسات سعة 5 كيلو فولت أمبير لكل منها أو عاكسين بسعة 10 كيلو فولت أمبير، إلى

جانب منظومة On-Grid موازية بقدرة 150 كيلو واط تستخدم أكثر من 220 لوحاً شمسياً من نوع n-type HJT half-cut بقدرة 550 واط للوح الواحد، يمكنها توليد ما يقارب 52 كيلو واط لكل مصفوفة فرعية في يوم مشمس وعلى مدار 8 ساعات. وتؤكد الدراسة الجدوى التقنية للحل المقترح ودوره الفعّال في خفض الفاتورة الكهربائية ودعم استدامة الطاقة في المؤسسات الأكاديمية..

**الكلمات المفتاحية:** الطاقة الشمسية الهجينة، المنظومة الكهروضوئية، الطاقة المتجددة، تخزين البطاريات، المعهد التقني الموصل

## Introduction

Dynamic growth in worldwide demand for electrical energy and exhaustion of fossil fuel resources, combined with periodic failure or unreliability of the electrical grid supply in many countries, have spurred huge R&D efforts. Integrating renewable energy into the conventional electrical grid has become a very hot topic, especially PV energy because of its abundance, modularity, and the continuing decline in cost of PV modules and power-electronic converters. According to the International Renewable Energy Agency, the global installed capacity for renewables grew by 585 GW in 2024 alone. Of this total, 452 GW (77%) came from new solar PV systems, making it the world's leading technology for generation capacity growth [6]. Hybrid PV systems (grid-tied systems with battery storage) are of great interest where grid voltage stability is low to provide always on power to critical loads and to reduce the load on the public grid. [1] Distributed PV systems are also rapidly growing in countries with poorly developed power supply networks, where they and storage units are used to improve access to electricity and to shift demand to peak periods [7].

Many publications have appeared which detail the designs of stand-alone and grid connected PV systems to provide electrical energy to homes, businesses and schools. The design and sizing of stand-alone solar power systems for homes is documented in Al-Shamani [2]. Load demand, solar panel rating, and battery sizing are important to any system. Al-Najideen and Alrwashdeh [3] implemented a PV system to meet the power requirements of Mu'tah University's Faculty of Engineering in Jordan. The authors found that university buildings with daytime activity are promising candidates for BIPV systems. Khan et al. [8] performed a techno-economic optimization of a grid connected hybrid PV-battery system operating in a commercial building and showed that with correct sizing and rule-based energy management, savings of over 12% in electricity bill are possible with the constraints of limited rooftop area and feed-in tariff rates considered. Mariam et al. [9] proposed a grid-connected PV-battery technology to feed HVAC loads for their residential demonstrator unit at Universidad Politecnica de Madrid, and validated two BESS control strategies using real monitoring data. Similar techno-economic feasibility studies using HOMER software have also shown that the NPV and LCOE of grid-connected solar PV systems is much lower than that of grid feeding only systems for the administrative building of a technical institute [10].

The extent of solar energy on a PV system site highly depends on solar radiation at the site and the orientation of the installed PV modules. Hassan et al. [11] estimated the proper tilt angles for maximising solar radiation on PV systems in geographical regions throughout Iraq based on hourly meteorological data. Al-Damook et al. [12] estimated the efficiency of PV modules in the Iraqi climate and the impact of ambient temperature and dust deposition on energy generation. In these studies Mosul has high potential with an annual optimum tilt of ~31° South. This makes it a suitable location for PV installations as rooftop units. The choice of MPPT algorithm has an important role in the PV converter, as the PV array operating point changes continuously and dynamic patterns, like irradiance or cell temperature changes, are continuously occurring. Two thorough reviews by Bollipo et al. [13] and Motahhir et al. [14] classify MPPT techniques into customary techniques (Perturb-and-Observe and Incremental Conductance methods), clever techniques (fuzzy logic and artificial neural networks), and hybrid optimization techniques. They also evaluate techniques based on tracking speed, efficiency, and complexity.

On the operational side, Adhikari and Li [1] investigated coordination of V-f and P-Q controls of microgrid PV generators with MPPT and BESS, while Chakraborty et al. [4] investigated the effect of STATCOM and BESS on power system transient stability. In addition, hierarchical and master slave inverter strategies have also been proposed when integrating the grid-connected and islanded modes, with techno-economic analysis using HOMER to improve the economic viability of the campus level microgrids, and to improve the power system stability under grid perturbations [15]. Overviews of the energy/renewable energy status for the MENA region have been undertaken, including Abed et al. [5] showing the importance of increasing the use of solar energy within the region.

Accordingly, the present study is concerned with the design of a hybrid solar PV system composed of an On-Grid and battery supported off-grid configuration for the Deanship building of the Technical Institute of Mosul, the Northern Technical University, Iraq, which is an ordinary university building and it is operational from 8:00 a.m. to 4:00 or 5:00 p.m. which is the period within which the solar irradiance is maximum in the city of Mosul during the day. This means the building is a good candidate for a solar PV array to reduce the entire building's energy bill and to provide independent power for the building's features such as lighting, the meeting room, fire alarms and surveillance cameras.

The objectives of this paper include the modelling and estimation of a hybrid system that can deliver 24 h of critical load of approximately 20 kVA with battery backup, in case of blackout of national grid and solar irradiation, and design of a 150 kW On-Grid PV (without battery) system spread on available rooftop, such that the energy drawn from the grid is considerably reduced during daytime. In the following sections, Section 2 presents the materials and the mathematical models adopted to size the system, Section 3 reports the calculations, the layout and the proposed design with the figures of the rooftop plan and the obtained PV generation, and Section 4 draws the conclusion.

## Material and methods

The hybrid solar PV system will serve two types of loads in the Deanship building of the Technical Institute of Mosul: (i) critical constant loads with a total capacity of around 20 kVA, made up of lighting, the meeting room, the fire-alarm system and surveillance cameras. These loads must be supplied continuously, even if the public grid is switched-off; and (ii) normal day time loads with a total power of roughly 150 kW, supplied by the On-Grid configuration of the PV system, which will be exploited in order to reduce the consumption of the national grid electricity: this system sizing has the following steps [2]:

(1) fixing the magnitude of the loads to be supplied (in kW or A);

(2) Determining the supply to be either single-phase or three-phase.

(3) Specifying the number of hours that the installation must be able to operate without grid supply;

(4) How much roof space, not covered by shade, is available, which determines how many panels and thus the potential energy that can be generated.

(5) determining accurately the solar incidence angle (depending on the solar irradiance profile in the region and on the time of year) .

The inverter is sized according to the apparent power of the loads by means of (1):

$$S = IL \times V \qquad (1)$$

where ($S$) is the apparent power that defines the inverter rating, ($IL$) is the load current, and ($V$) is the supply voltage.

For the considered case, the calculation gives S = 22 × 4 × 220 = 20 kVA, which can be implemented either by four 5 kVA hybrid inverters or by two 10 kVA hybrid inverters.

The number of PV panels ($No.pv$ ) is then obtained from equation (2):

$$No.pv = S \,/\, (P.panel \times AF\_PV) \qquad (2)$$

where ($P.panel$ ) is the rated power of a single panel and (AF_PV) is the active factor of the PV energy, taken as 0.9. Using n-type HJT half-cut modules of 550 W and the available rooftop area of approximately 1380 m², the design results in a generation capacity of about 190 kW. Finally,

the battery capacity is determined from equation (3):

$$Wh = I\_load \times h\_offPV \times V\_AC \qquad (3)$$

where ($I\_load$ ) is the load current, ($h\_offPV$ ) is the number of hours during which the system must operate without solar generation and $V\_AC$ is the AC system voltage [3, 4].

## Results and discussion

According to the same procedure, the Deanship building of the Technical Institute of Mosul (TIM) has its roof surface divided into several areas of about 20 m × 20 m (400 m²) each, where after subtracting the area required for the inter-row distance in order to avoid the shading of the row next to it, the panels were distributed throughout the roof upper surface, as shown in figures 1 and 2. The panels' tilt varies from 22.5° to 28° at the winter solstice and from 28° to 32° at the summer solstice. These angles are in accordance with the proposed values for northern Iraq climate by Abed et al. [5]. The solar declination angle and its corresponding path over the year, needed to determine the appropriate fixed angles for the panels, can be produced using SketchUp software, as shown in Figure 3. The main design quantities (rooftop sub-area, number of rows of modules, modules per row and installed capacity) are summarised in Table 1.

**Table 1** Distribution of the proposed PV array on the available rooftop sub-areas of the Deanship building.

| SN. | Sub-area | Layout (rows × panels) | No. of Panels |
|---|---|---|---|
| 1 | Roof A (left, large) | 4 × 19 | 76 |
| 2 | Roof B (front, large) | 3 × 33 | 99 |
| 3 | Roof C (right, side) | 8 × 8 | 64 |
| 4 | Roof D (front-right) | 5 × 12 | 60 |
| 5 | Roof E (top, small) | 3 × 6 | 18 |
| 6 | Inter-row spacing | Considered | — |
| 7 | Tilt angle (winter) | 22.5°–28° | — |
| 8 | Tilt angle (summer) | 28°–32° | — |
| 9 | Total installed | — | ≈ 220 panels |

These layout values are estimates; the actual number of panels in a given sub-area is determined via shading analysis.

From the above results the proposed system is found to be able to supply the continuous critical loads of about 20 kVA through the hybrid inverters and battery bank during the unavailability of the national grid. The parallel On-Grid configuration of about 150 kW can reduce the amount of consumed energy from the national grid in the day-time period, Proportional to the amount of solar irradiance incident on the surfaces. Economically and technologically, the high overlap of the working hours of the teaching staff and the students (from about 08:00 to 16-17:00 hrs) with peak solar irradiance hours makes solar PV systems a very effective option for universities and institutes such as the Technical Institute of Mosul. The roof areas of the building are shown in (**figure 1**) from the top view of the Deanship of the Technical Institute of Mosul.

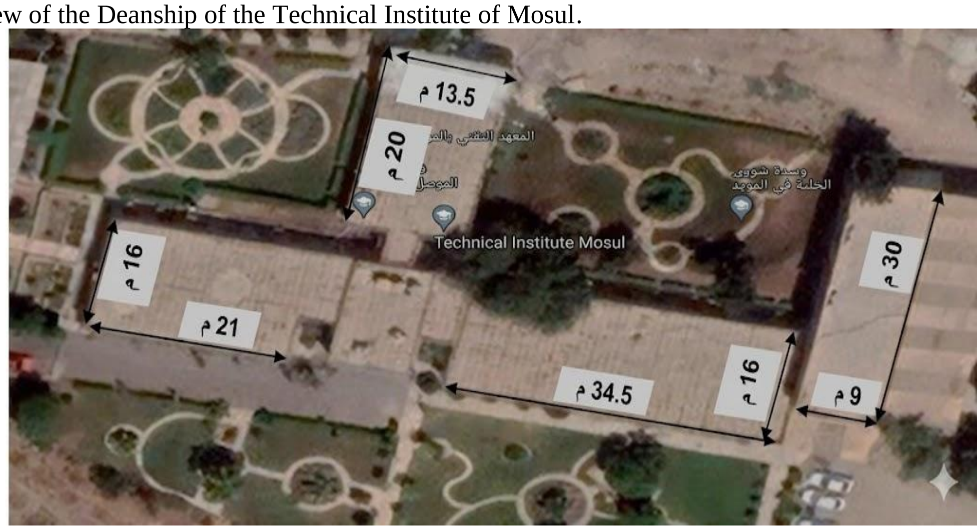


**Figure 1:** Top view showing the dimensions of the rooftops of the Deanship of the Technical Institute of Mosul.

**Figure (2)** shows the proposed PV modules distribution on these roof areas, and the number of rows and PV panels in each sub-area. The proposed installation's estimated fixed tilt angles, the annual azimuth and elevations for the sun, are shown in Figure 3 for winter and summer solstices.


**Figure 2:** Proposed distribution of the PV modules on the rooftops of the Deanship building (rows and panels per row indicated for each sub-area).

In the **figure (3)** below, the deviation from the winter solstice and summer solstice angles of solar radiation when solar panels are placed on the roof of the building throughout the year is displayed. The figure was prepared using the SketchUp program.

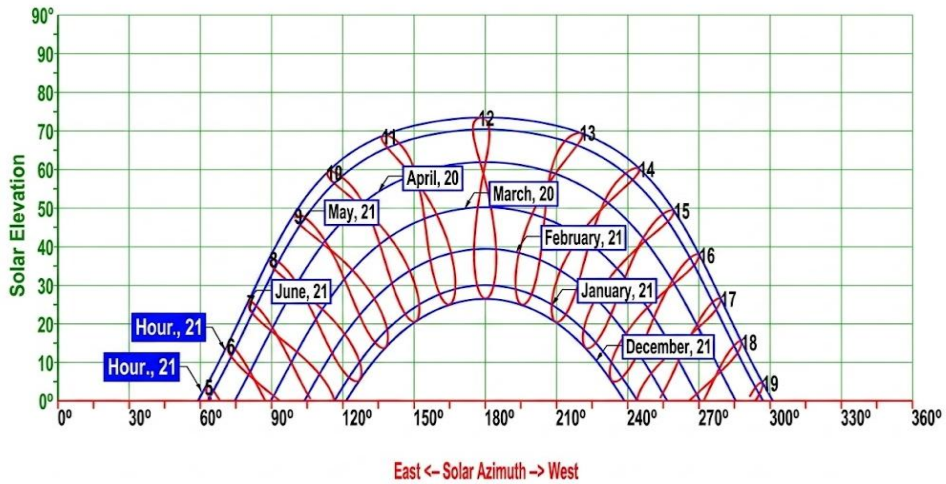


**Figure 3:** Annual variation of the solar elevation and azimuth angles, used to define the fixed tilt of the panels at winter and summer solstices.

**Figures (4 & 5)** show the distribution of the solar panels on the roof of Deanship of Technical Institute of Mosul. More than 220 solar panels are distributed, of which are taken into consideration the shadowing effect caused by the other rows of panels on the highest part of the left roof. The system produces 52 kW. The calculations are based on 8 hours of sun, and were done using SketchUp.

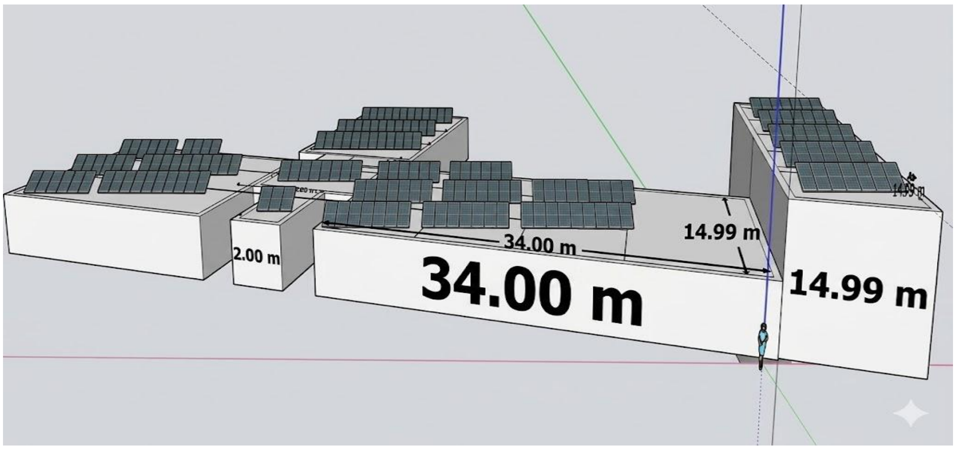


**Figure 4:** Side 3D view of the proposed PV installation on the Deanship building generated using SketchUp.

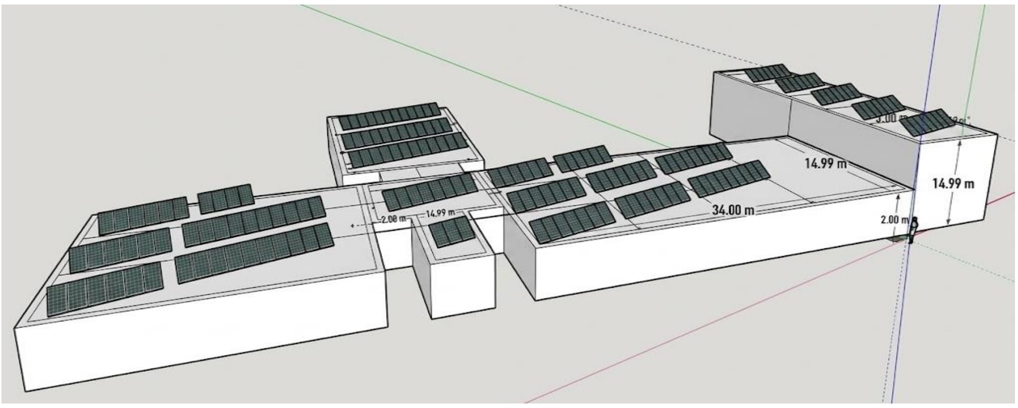


**Figure 5:** Front 3D view of the proposed PV installation on the Deanship building generated using SketchUp.

Thus, combining the above results, the system can supply the continuous critical loads of about 20 kVA through the hybrid inverters and battery bank during the national grid outages, while the On-Grid parallel configuration of about 150 kW can reduce the day-time energy consumption from the national grid in proportion to the available solar irradiance. From an economic and operational point of view, the strong overlap between the working hours of the academic staff and students (from about 8:00 a.m. to 4-5:00 p.m.) and the peak solar irradiance interval, makes solar PV systems a very effective option for universities and institutes such as the Technical Institute of Mosul.

## Conclusion

This project presented the design of a hybrid solar photovoltaic system, an On-Grid system and a battery hybrid system for the Deanship building of the Technical Institute of Mosul. The hybrid system (4*5 kVA inverters or 2*10 kVA inverters) with a capacity of 20 kVA is sufficient to feed the continuous critical loads (lighting, meeting room, fire-alarm and surveillance cameras) for 24 hours of autonomy. Similarly, a state-of-the-art On-Grid system of 150 kW (composed of more than 220 high-efficiency n-type HJT half-cut 550 W solar modules) distributed over the entire rooftop area theoretically available of about 1380 m2, would drastically reduce the purchase of energy from the national grid during daytime hours. The results confirm that the academic buildings with their daily usage profile and their flat roof are an ideal candidate for hybridization with PV technology and that a first step can be made towards energy sustainability and reducing the electrical costs for operation in other similar institutions in Iraq.

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