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Grid Connected PV System for an Academic Building of KFUPM Campus in Saudi Arabia

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Abstract. Rising living standards through smart and sustainable development is crucial to advancing human life and protecting the natural environment. The smart grid is an ideal opportunity to create efficient and sustainable solutions for closed communities. This is to provide them with a robust and resilient infrastructure. Because the smart grid is a large system that can be developed in many forms, such as smart metering, sustainable power generation, demand response automation, and data management, each application can be developed independently and contribute to increasing the value of efficient and sustainable factors. This paper studies alternative power supplies for supplying an academic building in the King Fahd University of Petroleum & Minerals (KFUPM) Campus of Saudi Arabia. The extra power was sold to the electricity company and shared with the grid to reduce consumer bills. A small-scale PV system is modeled and analyzed using HOMER software for community purposes. A simulation-based model has been developed to optimize local power supply and demand for residential communities. Using HOMER, an economic analysis has been conducted and possible alternatives suggested based on the electricity consumption. According to the simulation results, the buildings' electricity supply could be generated most effectively by installing a PV power system on the roof. Though the total net present cost (NPC) and cost of energy (COE) of the system with PV is slightly larger than grid only system, it can be recommended by considering the ongoing increasing energy prices and nonrenewable energy sources.

Keywords. Grid-connected; Photovoltaic System; Energy Sustainability; HOMER.

1. Introduction

In recent decades, sustainability has become a major issue. The United Nations has set 17 goals for sustainable development (SDGs) [1]. In addition to affordable and clean energy, these goals emphasize the sustainability of cities and communities. These directions have been emphasized by recent national and international policies focusing on RES investment and smart cities. The development of RES-based microgrids on university campuses has also been considered by various studies, paving the way for sustainable electricity. There are many universities already converting their campuses into efficient microgrids (or planning to do so). In order to facilitate the green transition of educational and research activities, universities and research campuses can utilize novel technologies. This increases the investment value [2]. Towards the end of the article, a brief overview of existing solutions will be offered regarding smart campus microgrids.

Saudi Arabia, which makes up the bulk of the Arabian Peninsula, borders the Red Sea and Arabian Gulf along a 2,640 km coastline. The Saudi Arabian peninsula covers approximately 2,150,000 square kilometers, making it Asia's fifth largest state. In this region, there are at least a third of deserts composed of sandy terrain [2]. The largest desert region in the country is Rub' al-Khali in the south, which varies in elevation from 800 meters near the sea level in the southwest to near the sea level in the northeast. Rub' al-Khali's northern counterpart, An-Nafd, covers 57,000 km2. Located between Rub' al-Khali and An-Naf'd deserts, the Ad Dahna' Desert is called "the river of sand." The Mazhur Desert connects to the An-Naf'd Desert.

According to [3]–[9], in January, the western coast is much hotter than the eastern coastline. This is due to Direct Solar Radiation at a normal incidence ranging from Tabuk 6.5-7.0 kWh/m^2/day, Khamis Moshait 6.5-7.0 kWh/m^2/day on the west coast, and Dammam 3.5 – 4.0 kWh/m^2/day on the east coast. As of March, Tabuk and Khamis Moshait still exhibit the highest DNI of 6.5-7.0 kWh/m^2 daily. The southern belt shows DNI in the range of 6.0-6.5 kWh/m^2/day. Regardless of the various energy sources and massive income, oil is hardly the only hard-done source of energy and income in the Kingdom [10]-[13]. To meet excessive power demand in a kingdom, it has become necessary to utilize renewable energy resources. Photovoltaic and solar energy models can provide helpful information if designed correctly. The Kingdom must take responsibility for developing infrastructure in accordance with sustainable development and renewable energy with all its sections [14]-[16].

The KFUPM is one of the leading Saudi universities located in Dhahran, Saudi Arabia. Saudi Arabian universities' science, engineering, business, and management programs are highly regarded in the country and the whole region. The University's 3.6422 Km^2 is divided into three sectors: North, Central, and South. The North Sector comprises the Preparatory Year Campus, the North Faculty/Staff housing compound, and student dormitories. All academic facilities are located in the Central Sector: classrooms, laboratories, faculty offices, administration, the Research Institute, the Library, the Information Technology Center, and support facilities. Faculty and senior staff are housed in the South Sector. The typical academic building under this study is a simple rectangular building with a rooftop area of 6239.62 m^2. It has three floors and parking areas with 86,545.88 kW of expected total load lighting. The top two floors comprise classrooms and offices, while the bottom floor features a cafeteria, research labs, and lecture halls [17].

The NREL has developed the HOMER software to evaluate equipment options for optimizing small power systems over various constraints. Such analysis could help plan on/off-grid electrification projects [18], [19]. By running simulations, HOMER can help to identify cost-effective solutions that meet the energy demand of a project without compromising quality or reliability. The HOMER model simulates various energy sources and system configurations and sorts them by net present cost (NPC). In the first step, HOMER assesses whether the energy sources and system are technically feasible (i.e., whether they can satisfy the electrical and thermal loads imposed by the user). Second, it calculates the NPC of the system, which is its total lifetime cost of installation and operation [20]. For a year, HOMER simulates the operation of every system configuration hourly. Energy source systems are assessed as satisfying demand when the available renewable power is calculated and compared to the required electrical load [21], [24]. Whenever there is excess electricity, it is distributed to other secondary demands. To fill the deficit, alternative supplies are sought, either diesel or grid generation. With this in-depth analysis, HOMER can accurately determine the most efficient and cost-effective system configuration for any situation. In HOMER, the 1-hour time step captures most of the load's statistical variability and fluctuating renewable resources but does not overwhelm the calculations. To ensure reliability and sustainability, HOMER's 1-hour time step strikes the perfect balance between accurately analyzing load and renewable resources and avoiding overwhelming calculations [25]-[29].

The results could then serve as a starting point for the design of overall buildings on the KFUPM campus. HOMER simulated thousands of different system designs, with and without backup generators. It can then identify the most economical system regarding load size and other variables. This paper aims to resupply academic buildings with power to reduce grid consumption and increase reliability. As well as testing and experimenting with renewable energy in the local environment. This study has been applied to typical academic buildings in KFUPM, which have a total area of 6239.62 m^2. Electricity consumption has been defined and calculated, and the HOMER program has been applied to process the economic analysis and suggests possible alternatives.

2. Methodology

The stage of developing electricity networks and their components is a challenge facing universities that wish to develop their energy system. This is due to the multiplicity of internal and external links between these networks. However, this modernization remains achievable, especially if all the project elements are available, and foremost among them is the accuracy of information and diagrams of electrical networks. The KFUPM is not isolated from this challenge, and to achieve this, it is necessary to study the campus's internal grid and know the extent of its ability to absorb this type of transformation and what opportunities we can create by converting the campus’s grid into a smart grid and what challenges must be dealt with.

Since the university consists of buildings with a unified design, it was considered that a sample of each model be studied. This was to evaluate the quality and efficiency of implementing the smart grid system. It also formed a roadmap for other models to follow when assessing others. The sites studied in this project are one academic building KFUPM. To do that, we planned to use different software like Homer to calculate the PV design system. This will enable me to obtain the required PV panel, inverter, and battery. I'll also determine which methodology (on-grid or off-grid) suits each building. And to do that, we will calculate the loads for each case study and use these calculations as input data.

3. Assumptions and Model Inputs

Starting with google-map to get the actual dimensions of the rooftop, we progressed into exactly plotting and then calculating the panel shedding and solar array spacing using a line program to be able to know exactly how many solar panels can be used over the available rooftop surface area. Next, we entered all details into the HOMER program with the actual/historical power load for this specific store in Dhahran.

A. Solar energy resource potential in the KFUPM

The NASA Surface Meteorology and Solar Energy website was used to automatically calculate the solar resource for the site. A latitude of 26.3071°N and an easterly longitude of 50.1459°E was recorded. This area receives an average solar radiation of 5.6kWh/m2/day. Fig. 1 and Fig. 2 show the solar and temperature resource profile over one year, respectively.

B. Area and the Isometric view of the proposed buildings

As part of this work, we applied our analysis to a typical academic building in KFUPM. This building has a total area of 6239.62 m^2. As shown in Fig. 3, the building was taken using Google Maps. The building consists of six floors, with three floors used for parking. In contrast, the other three are used for teaching and work, which include a big main mosque, 13 washing areas, one cafeteria, nine stores, three workshops, six conferences, 12 service rooms, 12 electrical rooms, 141 office rooms, 30 labs, five PC labs, 27 classrooms, and tow tea rooms.

C. Load profile of the building

The load profile of the assumed study building is explained in this section. Table I and Table II represent the corresponding load demand for the academic building. The academic building has 1,249 lights divided into three types, as shown in Tables. Assumed is the maximum load expected throughout the day and depends on the electricity source all day, and the daily load profile is displayed in Fig. 4. Fig. 5 represents a block diagram of a basic structure of a grid-connected PV system control overview. The block diagram outlines the control architecture for a grid-connected PV system, showcasing its essential components and signaling pathways. A Maximum Power Point Tracking (MPPT) algorithm determines the maximum power point for the PV system operation, which is achieved using the Perturbation and Observation method.

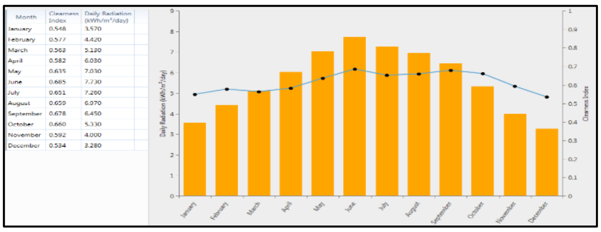

Fig. 1. Solar radiation profile for Al-Dhahran city.

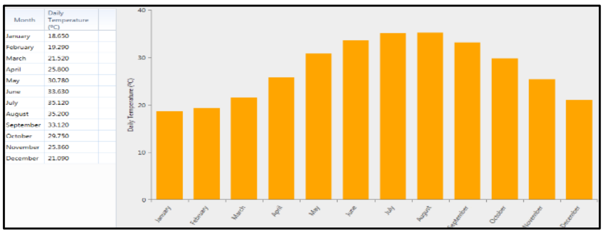

Fig. 2. Temperature profile for Al-Dhahran city.

Fig. 3. Area and overview of the selected Academic building.

Table I: Electrical Load for Academic Building.

Floor	Number of lights	Total Load (W)
2nd floor	Led spotlight = 54, 15 watts for each	810
	Regular tube light = 367, 36 watts for each light; each box consist of 2	26,424
1st floor	Led spotlight = 54, 15 watts for each	810
	Regular tube light = 367, 36 watts for each light; each box consist of 2	26,424
Ground Floor	Led spotlight = 73 & 15 watts for each	1,095
	Regular tube light = 392 & 36 watts for each light; each box consists of two	28,224
Parking	Regular tube light = 162 & 36 watts for each light; each box consists of two	11,664
External Lights	Regular tube light = 42 & 36 watts for each light; each box consists of two	3,024
Total		98475

Table II: Overall Interior and External Lighting Load.

Category	Duration (H)	Lighting Load (W)
Interior Lighting	24	95,451
External Lighting	12	3,024
Total		2,327,112Wh/d 849,545.88kWh/y

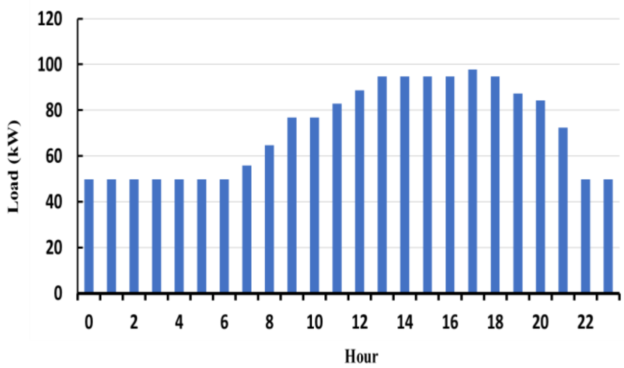

Fig. 4. Daily average load demand for Academic building.

As well as providing AC voltage that complies with grid requirements for connection and synchronization, a DC-AC inverter and a control unit also make up a DC-AC generation system. The implementation of control units will be part of our future research. Fig. 5 illustrates a basic grid-connected PV system. Furthermore, integrating the DC-AC inverter and the control unit is essential for providing a stable AC voltage that meets grid requirements for connection and synchronization. This emphasizes the importance of further research into the control unit implementation. This is necessary to complete the mathematical modeling of the system shown in Figure.

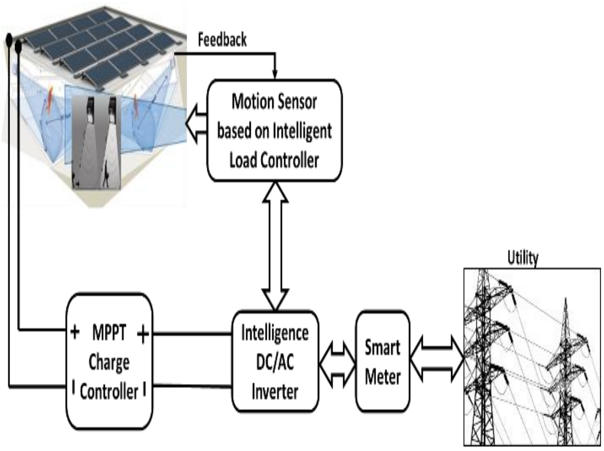

Fig. 5. Grid-connected PV system control overview.

D. Optimum array orientation and Placement

In order to install PV modules with the right compass orientation and tilt towards the sun, both simple and complicated steps must be taken. A blockage of sunlight to the module glass stops electricity from flowing. An array's outer edges may occasionally experience shades, but this is not a big deal. Nonetheless, if a tree shade completely engulfs an entire module at noon and it is connected to other modules in series, the whole kilowatt generation system may be destroyed instantly. The location of our array is therefore very important. Solar altitude angle refers to the sun's position. For shading scenarios to be identified, this trajectory must be plotted year-round with its daily movement from east to west. In order to get the whole picture, sun path charts and measurement devices are needed because what we see the day we check for shade is not necessarily indicative of what we see six months later.Note that fixed-mount solar panels will be at their least efficient during the summer, spring, and fall when the sun moves across a large area of the sky. Panel systems that "track" the sun's position are more efficient and expensive. As a result, the tilted angles of the fixed solar arrays for the proposed study building are calculated and presented in Table III for the four different seasons for the proposed study building. Therefore, it is crucial to consider the angles at which the panels are tilted when designing a fixed-mount solar array, as these angles will significantly impact the system's efficiency. There is no shade from surrounding buildings or trees, but the solar panel creates shading. Therefore, solar arrays need to keep some space between them. So, the post-to-post, back-to-front, and front-to-rear spacing of panels according to panel dimensions is calculated. Considering the suggested panel dimensions (1.558 m *1.046 m), per the preliminary design, the quantity of panels on the roof is estimated to be 6947 units.

Table III: Solar Tilt Panel Angle Calculation

Season	Tilted angle (Latitude =26.3 degree)
Winter	52.67 degree
Summer	47.17 degree
Spring and Fall	23.8 degree

4. HOMER Simulation Results and Discussion

A new project is created using HOMER software with the following criteria:

- A grid-connected module with a PV system and load.
- The cost of energy from the grid is 0.053$/kW [30].
- PV, Sun power X21-335-BLK Flat plate, price from internet (Most Efficient PV panel with 21% module efficiency guaranteed for 25 years)
- A generic system converter has a lifetime of 15 years and an efficiency of 95%.

HOMER software defines the levelized cost of energy (COE) as the average cost per kWh of usable electrical energy produced by the system.

$$\mathrm{COE} = \frac{C_{\mathrm{Tot.Ann}} - c_{\mathrm{boiler}} H_{\mathrm{Served}}}{E_{\mathrm{Served}}} \qquad (1)$$

Where, $C_{\mathrm{Tot.Ann}}$ is the total annualized cost of the system [$/yr], c_{boiler}, is marginal boiler cost [$/kWh], H_{Served} is total thermal load served [kWh/yr], and E_{Served} is total electrical load served [kWh/yr]. The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. This term is zero in systems like wind or PV that do not serve a thermal load (Hthermal=0). Other economic metrics such as Payback, Internal Rate of Return (IRR), present worth, and return on investment are calculated using HOMER. The grid power price of 0.053 $/kWh is assumed [31]. However, due to the absence of data for the Grid Sellback price, we assumed a government incentive of ~13% of the above price. This encouraged commercial business people to invest capital in Capex for Solar Panel system installation. Thus, we used 0.06$/kWh. A one-year temperature data profile and the monthly average radiation with clearness index are entered into the program software (see Fig. 1 and Fig. 2). Our simulation was built by using actual data collected from the building's load profiles throughout the day and the maximum loading capacity, with checking the working time for four seasons and the variations per month, Fig. 4. A PV Sun Power X21-335-BLK model is selected with a life of 25 years, and a DC/AC converter with a life of 15 years is also chosen. A brief schematic is the last

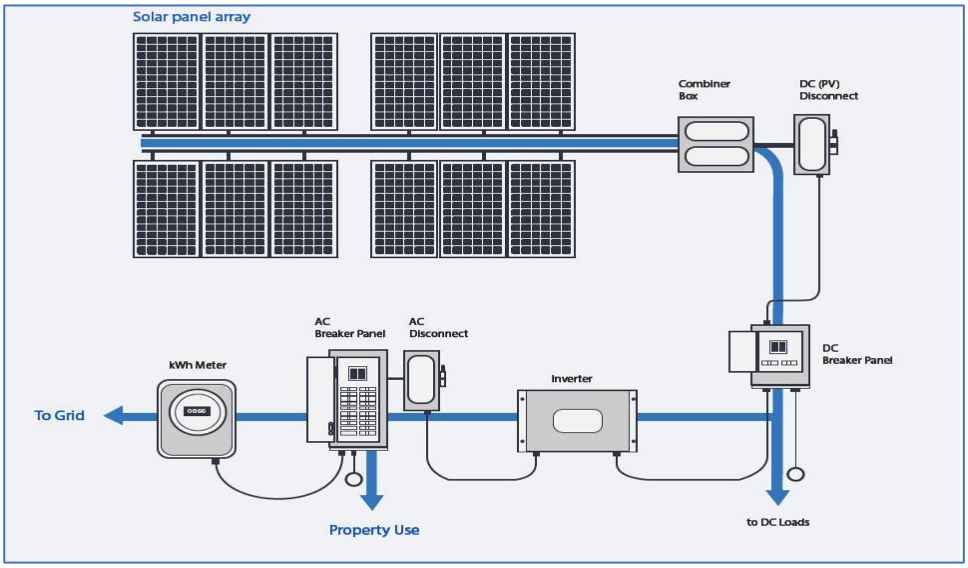

Fig. 6. Grid Schematic for the building

step before input is added and the simulation begins (Fig. 6).

The system is run after all PV arrays, Grid, Converter, and load values are set and an optimization result is obtained. This ensures that the system operates at its most efficient capacity. The energy production from the proposed system covers 73% of the overall load, with a product of around 965,351kWh/y. Table IV shows energy sharing between the PV and grid systems to meet the overall building load. A summary of monthly purchased and sold energy with the net purchased in kWh is presented in Table V. The optimized system allows the building to use all available resources more efficiently, yielding higher production values than other non-optimized systems. This optimization reduces the building's energy bills and allows for greater energy independence. According to the results, the proposed system's net present costs (NPCs) are $87,121 with capital expenditures of $117,660, as opposed to the grid's only NPCs of $581,971. Additionally, the Levelized Cost of Energy (COE) is 0.00532 ($/kWh), while the grid-only COE is 0.053 ($/kWh). This shows that the proposed system has significantly lower NPC and COE than the Grid only system, making it a more economically viable option.

Table IV: Overall Electrical Production for the System.

Production	kWh/yr	Percentage of total production
PV system	965,351	72.4
Grid	367,638	27.6
Total	**1,332,989**	**100**

Table V: Monthly Net Energy Purchased and Sold.

Month	Energy purchased (kWh)	Energy sold (kWh)	Net Energy purchased (kWh)
January	21,466	40,145	-18,679
February	16,124	40,940	-24,816
March	21,905	42,566	-20,661
April	21,510	37,322	-15,812
May	44,322	26,637	17,685
June	51,879	23,831	28,048
July	48506	26,432	22,074
August	43,081	29,053	14,028
September	37,370	30,281	7,089
October	25,076	38,701	-13,625
November	18,673	41,208	-22,535
December	17,726	40,175	-22,449
Annual	**367,638**	**417,291**	**-49,653**

5. Conclusions

In this work, an economic feasibility study of a PV system has been carried out using HOMER software. This is for a building located at KFUPM in Saudi Arabia. This study provides insight into the potential of PV systems in the region, which can be used to develop a more efficient and cost-effective energy solution for the building. The simulation results indicate that installing a PV power system on its rooftop could most effectively generate the building's electricity supply. Furthermore, the study shows that the PV system provides a reliable energy supply to the building with the added benefit of reducing its electricity bills and carbon footprint. Though the NPC and COE of the system with PV are more significant than the grid-only system, it can be recommended to consider ongoing increasing energy prices and nonrenewable energy sources. Moreover, the benefits of the PV system make it an attractive option, not only in terms of cost savings and reduced environmental impact but also in terms of energy security.

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