A Transportable Solar Power Generator

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***Abstract*—This paper presents the design of a 2kW portable photovoltaic (PV) stand-alone facility (PV generator) that converts directly solar irradiance into electricity for immediate use or storage. The project aims to build a stand-alone solar power source for use in rural villages, mountainous and remote areas that are distant from the national grid. It can also be very useful for powering camping tents, fishing boats, small farms, and greenhouses. Equally, it could be used for disaster stricken areas and during power outages. However, the proposed generator will be more suited for camping trips that Emiratis take almost in weekly basis. The paper will focus on presenting the main features of the designed prototype. It will also investigate the performance of the proposed stand-alone PV generator. Parameters investigated include geographic location, climate condition, solar irradiance, load consumption, ambient temperature, array voltage, battery voltage, and energy output from the array. The work presented is based entirely on the work carried out by final year electrical engineering students, during their capstone design project. The project work, presented, is a manifestation of the students learning during earlier semesters. It puts into practice the application of solar energy technology, that the student learned in his course on renewable energy systems.**

***Index Terms*—Solar energy, transportable solar system, stand-alone system, PV, photovoltaic system.**

I. INTRODUCTION

Renewable energy sources (solar, wind, tidal, and geothermal, etc.) are attracting more attention as alternative energy sources. Among the renewable energy sources solar photovoltaic energy has been widely utilized in a stand-alone and grid connected modes. It is also the most promising candidate for research and development for large scale applications as the cost of photovoltaic devices is decreasing. For stand-alone applications, increasing the energy output of the PV system can make a difference from the economic point of view. PV power generation, which directly converts solar radiation into electricity, contains significant advantages such as inexhaustible and pollution-free, silent and with no rotating parts, and size-independent electricity conversion efficiency.

Positive environmental effect of photovoltaics is replacing electricity generated in more polluting way or providing electricity where none was available before. In fact, an EPA study showed that 1 kW of PV could offset between 600 and 2300 kg of CO_2 per year as well as substantial amount of pollutants [1]. In addition, the United States and Europe are focusing more and more on using PV for electricity generation. Statistics show that worldwide photovoltaic production increased by 40 percent in 2006 [2].

With the improved manufacturing processes, the increase in solar modules efficiencies and better battery technology that we have been seeing recently, portable solar chargers and power packs are now widely affordable, effective and practical. However, the need for bigger reliable power banks that could power homes, boats, and small farms is increasing.

Despite the United Arab Emirates' vast electricity grid coverage, there will always be a need for alternative sources while camping at the outskirts of the city, living at locations where electricity sources are scarce, or, in the case of a worksite where power is not readily available. The present work offers a solution that is more efficient and more cost effective than the use of conventional diesel/gasoline portable generators that are widely used across the Middle East and other communities worldwide. Portable generators provide a viable option, to fully or partially satisfy electricity requirements where needed. The most popular generator types include gasoline and diesel powered for the home and business. A typical gasoline generator is shown in Fig. 1 [3].

Whether using a diesel generator or a gasoline generator, users have a good selection of generator types to choose from. The exact type needed depends in large part on the application to be used for. Different types of generators are available, including portable, camping, and standby generators.

Even portable generators are cheap to acquire, they are still expensive to run and maintain. Also, sometimes safety risk (explosion) is associated with them.

The work presented, here, is the outcome of a 4th year final year project inspired by the students' excursions and camping days. The students felt the need for a free-energy source to meet their outing trips requirements. Their project work proposes a "solar generator" as an alternative to the conventional portable engine generator.

The proposed fuel-free generator will be pollution-free, maintenance-free, noiseless, and above all free to run. All over the UAE, solar irradiation is widely available and easily accessible than gasoline or diesel fuels. Unlike petroleum-derived fuels, which are considerably expensive and changing in prices on daily basis, solar energy is totally free all year long. Therefore, compared to the conventional diesel/gasoline powered portable generators, the PV powered facility will be a better investment, more economical and completely safe to operate and maintain.

The stand-alone PV generator will be designed to provide the energy requirement for small DC and AC loads, such as light tubes and fans. This is a typical situation of camping sites and remotely isolated small farms.

The generated power will be utilized as per requirements of the user. Since the facility is not grid-tie, if the generated power is not completely used the excess power will be wasted when the battery bank is fully charged.

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Fig. 1: A Typical Gasoline Powered Portable Generator

The PV generator can supply both AC, with an onboard inverter, and DC loads. It can provide several different output outlets (USB, 12V DC, standard mains sockets rated at 220V).

II. SOLAR ENERGY PROSPECTS IN THE UNITED ARAB EMIRATES

The United Arab Emirates (UAE) has a dry tropical climatic zone characterized by extreme heat in the summer around June and coolness in the winter around January. UAE enjoys a high degree of solar radiation throughout the year and high sunshine hours. This is mainly due to a high ratio of "sky clearness" and extensive daily solar radiation ranging from 5.5 to 6.0kWh/m^2/day in July to 2.5 to 3.0kWh/m^2/day in January, giving it one of the highest solar energy densities in the world.

The UAE could economically deploy solar power generation capacity of more than 20GW by 2030 if avoided and opportunity costs of new fossil power generation are fully considered and transparent, stable, predictable and enforceable regulatory and policy frameworks are implemented [4].

From an operational point of view, a photovoltaic array may experience large variations of its output power under intermittent weather conditions. However, these phenomena are less significant in sunny countries such as the UAE. In addition, the mismatch between the load demand and the PV system can be an important issue as well. To overcome this problem, backup systems such as diesel generators, wind energy systems and fuel cells are often used in stand-alone applications. Storage batteries are another option and are proven effective.

In addition to its richness with solar energy, the UAE also possesses a variety of camping sites that include stunning mountainous landscapes, beautiful sand dunes, and pristine wadis. Fig. 2 shows a popular camping site regularly frequented by camping lovers. Most campers to these beautiful sites rely on battery-powered torches and wood or gas stoves to cater for their daily energy needs. A few of them will usually consider taking a diesel-powered generator, for longer stays. In a country, such as the UAE, one can easily realize that most of the campers' energy needs can be easily fully met using the abundance of solar energy across all regions of the country. The UAE has already implemented large scale solar energy projects and proved itself as a potential world solar energy producer. But, still there are great opportunities for further enhancement and improvement to increase the use of solar energy in our daily activities. In the following section, a small-sized portable solar (PV) power generator will be designed to cater for the need of campers, small businesses, remote construction sites, and small farms. The work done here represents a very small step towards the exploitation of this free source of energy.



Fig. 2: A Popular Camping Site in the UAE [5].

III. DESIGN OF A PV GENERATOR

The geographical site considered for the design of this project, and taken as a reference, is the Lahbab Sands, which is a very popular night-time camping site. It is located in the about 50 km south of Du bai. The selected reference region (temperature range 7°- 43°) is indicated in the satellite image, shown in Fig. 3, and lies within the coordinates [6]:

Latitude: 25.04214°

Longitude: 55.59127°

The horizontal radiation throughout the year is plotted in the bar chart shown in Fig. 4. The solar radiation, shown, is optimized at tilt angle equal 23° and at azimuth 0°. The yearly sunshine radiation is estimates as equal to 2245.96 kWh/m²/year.



Fig. 3: Lahbab Sands satellite image.

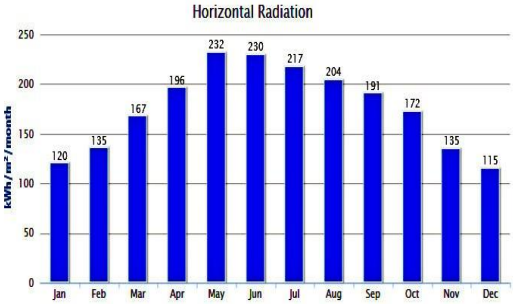


Fig. 4: Monthly Horizontal Radiation at Lahbab Region.

The proposed PV-powered generator facility is a self-contained 1.3 kW system. It is configured as shown in block diagram depicted in Fig. 5.

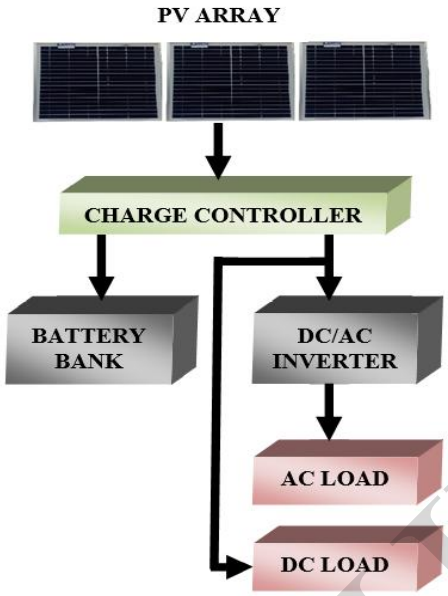


Fig. 5: PV Generator Block Diagram.

It consists of the following components: Photovoltaic array, battery bank, charge controller, and DC/AC inverter. It is equipped with wheels for easy transportation and ease of portabiliy. It can easily moved indoors and outdoors, as needed. Or, it can be shared between users for specific days and applications.

A design procedure was followed, using high power density solar panels designed by LG Electronics. The solar module chosen is the monocrystalline LG300N1C-B3. The proposed panel has the following parameters:

Table I: PV Module Parameters

Parameter	Value
Peak Power	300 W
MPP Voltage	32 V
MPP Current	9.4 A
Allowed Voltage	1000 V
Efficiency	18.3%
Open Circuit Voltage	36.9 V
Short Circuit Current	8.05 A
Module Area	1.64 m^2
Temp Coefficient Uoc	- 0.29 %/°C
Temp Coefficient Isc	0.04 %/°C

For the calculation of the battery, the energy, the system voltage, the depth of discharge, and autonomy of the system in days are considered.

- Battery nominal voltage: 24 V
- Depth of discharge of batteries: 60 %
- Autonomy System: 3day
- Actual capacity batteries calculated: 498 Ah

The number of battery elements required, as determined by the calculation procedure, was 8 ECOSAFE TVS-6 TUBULAR-PLATE.

An inverter is used to convert the DC output, from the charge controller, to AC output for powering AC loads. The inverter parameters are summarized in Table II.

Table II: Inverter Parameters

Inverter Parameters	
DC Input Data	
Max DC Power	1500 W
Max DC Voltage	400 V
Max DC Current	10 A
AC Output Data	
Rated AC Power	1250 W
Max Allowed AC Power	1250 W
Max AC Current	6.25 A
Max Efficiency	95.5%

The design results, of the 1.3 kW PV generator, are summarized in Table III. As indicated, in the table, three PV modules will be required for such a design. Three 300-W modules will ensure a yearly energy output of 1546 kWh and contribute to the reduction of 1 tonne of CO2 per year. The total area of all 3 modules does not exceed 5 m^2.

Table III: Design Summary

Design Summary	
Maximum Allowed PV Power	1300 W
Maximum Allowed AC Power	1100 W
Total PV Power	900 W
Modules	3
Total Module Area	5 m^2
Inverter	1250 W
Annual Energy	1546kWh/Year
Yearly CO2 Reduction	1T/Year

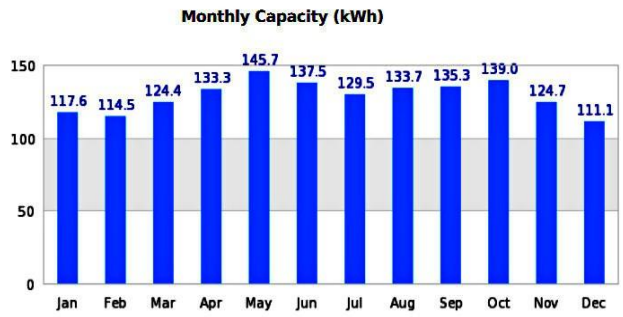


Fig. 6: The Proposed PV Generator Monthly Capacity.

The spread of the proposed system monthly capacity is clearly shown in Fig. 6. It has to be noted that for ease of portability and reduction of weight, it was decided at the onset of the project to use no more than 3 PV panels. However, the proposed system can easily be modified to provide higher powers using higher number of PV modules. But, as it has already been mentioned, the system will become heavier and more cumbersome to handle.

Prior to above detailed design of the PV generator, an economic analysis was carried out to establish the financial benefits of proposed system. Therefore, to determine if the proposed system will be cost effective, an analysis of the life-cycle cost was conducted. It has been estimated that the cost the proposed PV generator will be approximately 45% of the cost of an equivalent diesel generator. Details of this analysis will be included in future publications.

VI. DESCRIPTION OF THE DESIGNED PROTOTYPE

A scaled down prototype (150 W) has been designed and manufactured to demonstrate the feasibility of the proposed system. The design prototype is shown in Fig 7. The system is designed as a modular unit that can easily be disassembled for maintenance, if needed, or modification. It consists of a metallic enclosure that contains 3 detatchable compartments. The top compartment has two horizontal openings cut on both sides to allow 2 PV panels to slide in or pull out of the compartment. The middle compartment accomodates the charge controller and the inverter and all the protection devices. It also holds the output panel components. The lower compartment is dedicated to hold the battery bank (the heviest component of the system). This compartment is mounted on 4 wheels, which makes moving the batteries around an easy task.

Wires from the different compartments are connected through connectors, in order to facilitate connecting and disconnecting the compartments. The lower compartment is also well insulated, against the heat transfer from the surrounding environment, and well ventilated with fans that circulate cool air around and expell the internally generated hot air outside. The system's wheels and sliding/folding panels allows easy tracking of the sun at different array tilt and azimuth angles to maximize the unit 's power output throughout the day.

The overall system layout of the prototype is shown in Fig. 8. It shows the panels pulled out of the top compartment and tilted at the desired angle. All the system major components are connected as indicated.



Fig. 7: A prototype of The proposed PV Generator

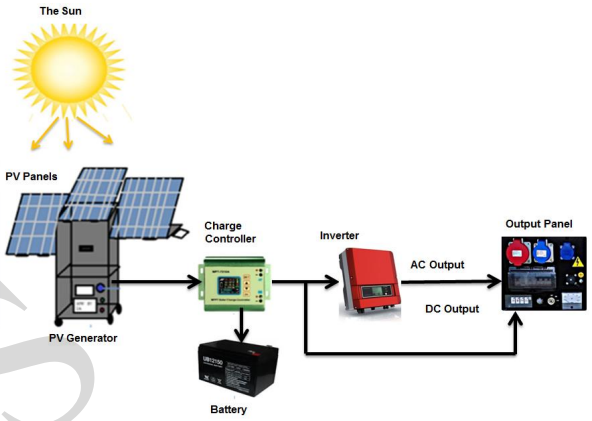


Fig. 8: The PV generator prototype components

The system major components specifications and properties are detailed below:

PV Array: The PV array (panel) is a collection of electrically connected photovoltaic modules. The designed PV generator prototype includes 3 panels of the same dimensions (685 x 510 x 25) and power output. Each panel is rated as P_{max}= 50W, V_{oc} =21.2 V, I_{Sc} = 3.3A, maximum power current 2.9A, maximum power voltage 17.2V. The panels are arranged to be an integral part of the unit. They slide in, when the system is not used or when being transported, and out, when the system is functional.

Battery: The solar batteries, selected, are rechargeable deep-cycle gel batteries which have been developed specifically for use in stand-alone photovoltaic systems. Four batteries have been fitted within the lower compartment of the generator. Each battery is rated as 12V, 100Ah/10HR.

Inverter: The inverter selected for this application is a 600 W stand-alone inverter, which is directly connected to the battery bank as the DC power source and operates independently from the PV modules. The PV panels charge the batteries, but do not interfere with the operation of the inverter. Its AC output is fully protected and directly connected to the output panel of the system (AC sockets).

Charge controller: The charge controller regulates the battery bank charge by controlling the charging voltage and current from the PV panels. It maintains the battery at its highest possible state-of-charge (SOC) while preventing overcharging from the PV panels or overdischarging by system connected loads. The charge controller of the proposed system, shown in Fig. 9 features the latest technology and has a colorful LCD display that indicates the system status and faciliatates its management, as shown in Fig. 10.



Fig. 9: Charge Controller

It has the following specifications:

Input Voltage: DC 12-60V
Output Voltage: DC 15-90V, Adjustable to accommodate 24V/36V/48V/60V/72V Battery
Output Current: 0-10A Adjustable
Output Power: 20-600W
Working Modes: MPPT and DC-DC

Its DC output is connected to the inverter and to the DC outlets on the output panel of the system.



Fig. 10: Charge Controller Color Display

Display Digital Meter: The output panel contains a bi-color DC voltage meter to measure DC voltage, current, power, charge and discharge capacity, watt, time, and other physical quantities, parameters can be set overcurrent protection, overvoltage protection, under voltage protection, and limit protection. A similar AC voltage meter that measures voltage, current, and energy is also provided.

Sockets: Two AC and one DC power single-phase sockets are fitted on the output panel of the PV generator middle compartment, to allow electrically operated appliances to be connected directly to AC power supply furnished by the inverter or to the DC power supply from the battery. The AC sockets are earthed UK-type sockets. In addition to the main power sockets, the panel offers 3 USB outputs for charging mobile phones and tablets.

Cooling Fans: Two medium DC fans are used to expel warm air from the inside of the lower compartment, where the batteries are located, of the unit to the surrounding environment. Cooling plays an important role for the proper functioning of the different electronic devices and the batteries.

The designed system is fully transportable and can fit within a 4x4 car, a camper trailer, or a pickup. It can easily be set up, connected, and switched-on to the load at the desired location. Overall, the designed system initial tests proved satisfactory.

As a students' final year project, it has been a successful proposal. The students have learned a great deal in designing stand-alone solar systems. They have also been greatly inspired and encouraged to look forward to designing other PV systems for their communities, to enhance energy usage and help reducing CO_2 emissions.

IV. SYSTEM TESTING

Testing the system over 12 hours' period has proved its feasibility and demonstrated its capability in delivering the required power when needed and wherever need. The power, voltage, and current that were recorded on a typical spring day (May 5th, 2017) are illustrated in Fig. 11. The system was tested supplying a small load. The battery voltage and solar panel voltage output were constant around an average value of 13.5V.

But, the power and current varied with the variation of the solar irradiance. The ambient temperature and the temperatures of the battery units and of the solar panels, in degrees Celsius, are shown in Fig. 12. The average ambient temperature was 40^{o}C. The highest solar panel temperature reached 53^{o}C measured at the center of each panel. The maximum temperature of the battery case reached 40^{o}C only, due to the forced cooling auxiliary DC fans.

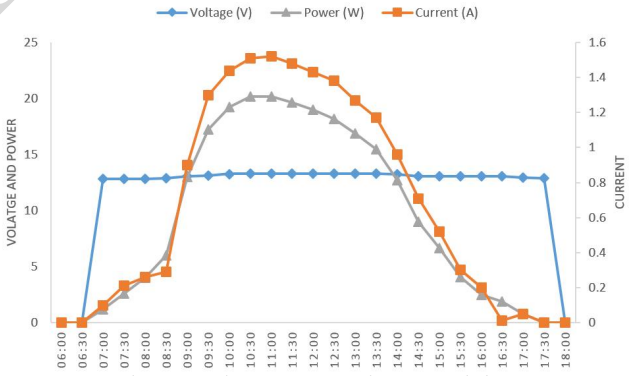


Fig. 11: Voltage, Current, and Power Variations

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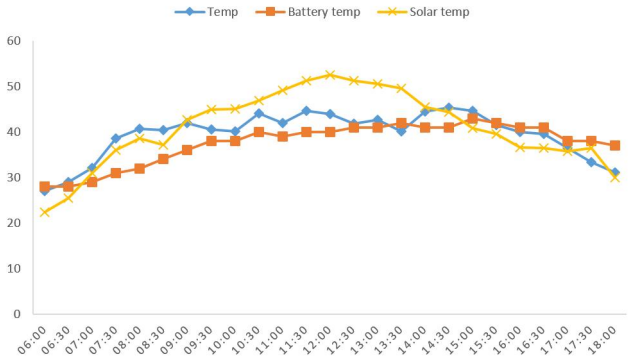


Fig. 12: Temperatures Variations

V. CONCLUSION

Portable engine generators allow business owners or individuals to power their homes or businesses during an outage or emergency, such as from the loss of power during inclement weather. They also give those who participate in outdoor activities, such as camping, picnicking, or recreational vehicle use, access to some of the comforts of home. The work presented in this paper proposes a PV-powered alternative to the diesel/gasoline powered generator.

The proposed portable PV generator can produce enough energy to satisfy the requirements of small loads, in some situations and at certain locations. This may include the use of some electric kitchen appliances, bathroom accessories like hair dryers, TVs, radios, laptops, and more during camping. The portable PV generator can also be the perfect solution for powering a small business or construction site that does not have access to electricity. In addition to its financial benefits the PV generator there will be no noise, no pollution, no storage of large quantities of toxic fluids, no regular deliveries of fuel, less maintenance, and very safe and easy to operate.

As a student's final year project, the proposed system is still undergoing further development and improvement. Further work that is still under consideration is the increase of the size of the prototype and the automation of its operation. However, the preliminary calculations and simulation results obtained are encouraging and give an early indication of the future success of such solar generator in the UAE market.

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