A Techno-Economic Viability Analysis of the Two-Axis Tracking Grid-Connected Photovoltaic Power System for 25 Selected Coastal Mediterranean Cities

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Abstract—Generating energy from renewable sources, particularly solar energy, offers significant benefits and achieves a more clean and sustainable development. In the present paper, the potential of developing a 4.2kW grid-connected rooftop two-axis tracking PV system in 25 selected coastal Mediterranean cities located in different Arabic countries is evaluated using RETScreen software. The proposed system is serving the basic household energy needs according to the load profile from monthly electrical bills. It is found that the proposed system produces about 8824kW annually, which helps to reduce CO$_2$ emissions. Also, the average energy production cost is assumed to range from 0.0337 to 0.0475$/kWh. It is concluded that the proposed system can provide an effective solution for energy poverty in developing regions with a very positive socio-economic and environmental impact. The small-scale grid-connected PV system will provide the domestic energy needs at a lower energy production cost than the electricity price grid-connected consumers pay. This study demonstrated that generating electricity from solar energy will help reduce the electricity tariff rates and the dependence on fossil fuels.

Keywords—coastal Mediterranean cities; two-axis sun tracking system; solar energy potential; grid-connected; small scale PV system; RETScreen

I. INTRODUCTION

The energy sector is the most prominent of the economic crisis and the environmental disaster in Arabic countries such as Lebanon, Syria, Palestine, and Libya [1]. This sector is the biggest waste producer and the primary cause of budget deficits and debt ballooning, in addition to being the primary cause of air pollution and related deaths. Moreover, the electricity crisis has increased in many Arabic countries due to the population growth, the rising living standards, and the growing industry sectors, which have led to an increase of the energy demand, and the increased electricity cost associated with fossil fuel-based electrical energy production [2]. Generally, most Arabic countries do not suffer from poverty in electrical energy sources, such as oil, gas, sunlight, and wind. For instance, Libya is a rich country in natural resources, however, it has faced power outages for several years due to the poor maintenance and civil war. The electricity crisis is not new in most developing countries and the electricity sector has suffered from decades of mismanagement, weak policies, and the absence of proper planning. This problem has been increased due to the dilapidation of old power stations, accompanied by sabotage operations. As a result, the hours of power cuts increased, ranging from 8 to 20 hours per day. For this reason, citizens are dependent on domestic power generators or small home generators, both of them adding financial burdens to the residents.

Nowadays, all countries are looking to utilize renewable energy resources instead of fossil fuels to mitigate climate change [3]. Additionally, the utilization of renewable energies, such as solar, as power sources, can be an alternative solution for solving the electricity crisis in most countries and reducing the consumption of fossil fuels [4, 5]. Globally, solar energy is one of the most popular alternative energy resources for electricity production. Photovoltaic (PV) panels are used to convert sunlight into electricity. In the literature, utilizing the PV systems helps to meet the basic domestic needs globally, especially in the developing countries [6]. PV systems can be categorized as stand-alone systems or grid-tied systems for domestic and commercial settings. The grid-tied PV systems...
Mediterranean climate conditions is discussed based on a the NASA database. For example, authors in [16] assessed the solar potential of different regions is usually evaluated using the selected cities are listed in Table I. In the literature, the Libya, Lebanon, Syria, Palestine, Tunisia, and Algeria have and 34% more power than the fixed-tilt systems. vertical-axis and two-axis tracker system could produce 20% connected solar system under different tracking systems in Gulf demonstrated that the two-axis tracking solar system was an technologies in Nahr El-Bared, Lebanon. The results investigated by several scientific studies [13-15]. For instance, authors in [17] found that the NASA database. Authors in [17] found that the NASA database showed good agreement with the measurement data of global solar irradiation. Therefore, the solar potential of 25 coastal locations is assessed using the monthly NASA database.

| Country | City       | Latitude [°] | Longitude [°] |
|---------|------------|--------------|---------------|
| Libya   | Az Zawiyah | 32.76        | 12.74         |
|         | Tripoli    | 32.89        | 13.19         |
|         | Al Khums   | 32.65        | 14.21         |
|         | Misratah   | 32.33        | 15.10         |
|         | Sarti      | 31.19        | 16.57         |
|         | Benghazii  | 32.12        | 20.09         |
|         | Turboq     | 32.07        | 23.94         |
| Lebanon | Tripoli    | 34.43        | 35.84         |
|         | Beirut     | 33.89        | 35.50         |
| Syria   | Tartus     | 34.90        | 35.89         |
|         | Al Ladihiyyah | 35.61      | 36.09         |
| Palestine | Gaza Strip | 31.35        | 34.31         |
| Egypt   | Port Said  | 31.27        | 32.30         |
|         | Alexandria | 31.20        | 29.92         |
|         | Marsa Matrh| 31.36        | 27.22         |
|         | Djerba Medoun | 33.81      | 10.85         |
| Tunisia | Gabes      | 33.89        | 10.10         |
|         | Sfax       | 34.74        | 10.76         |
|         | Sousse     | 35.82        | 10.63         |
|         | Tunis      | 36.81        | 10.18         |
| Algeria | Annaba     | 36.91        | 7.74          |
|         | Skikda     | 36.87        | 6.91          |
|         | Bejaia     | 36.75        | 5.06          |
|         | Algiers    | 36.70        | 3.06          |
|         | Oran       | 35.70        | -0.63         |

B. Two-Axis Tracking PV Arrays

In general, solar tracking systems are utilized to maximize energy production by the PV system due to the maximization of the incident beam radiation [18]. The rotation of these systems can be about a single axis or about two axes. Maximum energy can be achieved using a two-axis solar system due to its total freedom of movement. In two-axis PV systems, the solar panels are mounted on the structure, which can move the modules in two axes [19] as shown in Figure 1. For a two-axis PV system, two motors are required for the rotation of the axes [19]. Thus, the panel’s orientation with the two-axis tracker system is dependent on the solar position. Generally, this system is required a control module to direct it. The solar tracker PV systems utilize a SR sensor to control the system orientation [20]. Moreover, the performance of the PV system depends on the parameters of the system components and weather. Additionally, existing power producers are trying to increase the output power of the PV system by improving Operation and Maintenance (O&M) activities [20]. The O&M is considered one of the important aspects of a PV solar system. Improving the O&M can help reduce the energy production cost and improve the impact returns on investment. Furthermore, there are several issues that the PV system faces during its lifecycle, such as natural degradation, component failures, weather conditions, etc. [21]. Therefore, a holistic approach can address these issues under the O&M aspect, which is divided into three categories (preventative maintenance, corrective maintenance, and condition-based...
The PV module was selected. It is made of mono-crystalline-silicon cells with a maximum power of 300Wp. A total number of 14 modules are required with an area of about 28m². The specifications of the selected PV panel and inverter are available at [22, 23].

C. Design of the PV Power System

To build the 4.2kW PV system, a mono-Si-CS6X-300M PV module was selected. It is made of mono-crystalline-silicon cells with a maximum power of 300Wp. A total number of 14 modules are required with an area of about 28m². A FRONIUS SYMO 4.5-3-M LIGHT 4.5 KW SOLAR INVERTER with a capacity of 4.5kW and 98.6% efficiency was chosen in this study. The specifications of the selected PV panel and inverter are available at [22, 23].

D. Simulation Tool

There are many simulation tools such as HOMER energy, RETScreen, etc. that may be utilized to evaluate the energy production and Levelized Cost Of Energy (LCOE). The comparison between these simulation tools is available at [24]. In this study, HOMER is utilized to evaluate the economical feasibility of the proposed systems. RETScreen is developed by Natural Resources Canada (NRC). It utilizes the long-term monthly average meteorological data from the NASA database as a source of meteorological information for a specific location [3, 16]. In the present study, the most important economic indicators of financial analysis including Net Present Cost (NPC), Cost Of Energy (COE), Simple Payback (SP), and Equity Payback (EP) are estimated with the RETScreen software. Also, the Greenhouse Gas (GHG) emission reduction, energy production, and Capacity Factor (CF) for the proposed system are determined.

III. RESULTS AND DISCUSSION

A. Characteristics of Solar Energy in the Selected Locations

Generally, regarding PV panels and inverters, the characteristics of the installation, and the meteorological conditions (relative humidity, air temperature, solar radiation, etc.) are the major factors that influence the performance of the PV system. The meteorological conditions affecting the generating power by the PV system are mainly solar irradiance [25-27]. Therefore, global SR data were analyzed to estimate the potential of solar energy in the selected cities. Table II summarizes the average horizontal monthly daily SR for the selected locations. It is found that the average horizontal monthly daily SR varied from 2.01kWh/m²/day to 8.50kWh/m²/day. The maximum and minimum values of SR are recorded in Port Said (in June) and Skikda (in December) respectively. The highest and lowest annual SR are 5.87kWh/m²/day and 4.51kWh/m²/day for Alexandria and Skikda, respectively as shown in Figure 2. The highest value of Average Temperature (AT) was recorded in Port Said (21.23°C) and the next highest in Alexandria (20.79°C). Based on the value of SR at the selected locations, it is found that the solar resource of the selected locations is categorized as excellent (class 5) according to [16]. Therefore, these locations are suitable for installing a PV system in the future due to their high value of SR.
The environmental impact and economic performance of the proposed system were evaluated. In this study, the financial parameters (Table IV) are assumed based on other previous studies. The system cost is around $5000, with the estimation being based on recent market data. The estimation is consistent with cost prices available in the literature.
The results demonstrated that the proposed system can help in solving the electricity crisis while simultaneously reducing GHG emissions. Consequently, it can be concluded that the developed system provides a very good insight into the economic viability of the project for all regions. Additionally, the obtained results demonstrated that the development of the proposed 4.2kW PV power system is economically acceptable due to the obtained favorable economic results.

IV. LIMITATIONS AND CONCLUSIONS

Installing PV systems has become increasingly attractive for residential consumers due to increasing electricity tariff rates while it reduces a country's dependence on fossil fuels. The objective of the current study was to investigate the feasibility of a two-axis tracking PV system in coastal Mediterranean cities located in different countries using the RETScreen software. Before starting the main conclusions in the present study, it is essential to acknowledge the limitations of this work. First, the assumed financial parameters were...
based on historical values in the literature. Second, the influence of various parameters such as dust, irradiation intensity, air temperature, and relative humidity was neglected due to the limitations of the software. Third, the cost of the proposed projects was estimated based on the existing cost in the literature.

The findings from the present study showed the annual value of SR for the selected regions is within the range of 1645.85 to 2141.33 kWh/m². Based on these data, the analysis indicates that the selected regions selected cities have the potential for the distribution of PV power systems in household/residential applications. Moreover, the average annual energy output showed that the 4.2kW grid-connected PV system could produce 8824kWh, indicating that it can cover the required electricity needs for one house located in each selected city. These results are supported by the findings in [13].

Based on the financial assumptions used in this study, the average energy production cost ranges from 0.0334 to 0.0475$/KWh for the developed system. Thus, the energy production cost of the proposed system is competitive with the electricity company tariff in the selected countries, except for Libya. The results of this paper demonstrate that a small-scale grid-connected rooftop PV system has the potential to solve the electricity crisis, reduce the consumption of fossil fuel, and reduce the environmental pollution by minimizing the emissions of CO₂. The conducted analysis showed that the small-scale grid-connected rooftop PV systems are found to be technically, economically, and environmentally feasible solutions for generating electricity and reducing the dependency on fossil fuels.

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