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Design and Economic Analysis of a Solar Photovoltaic System for a Campus Sports Complex

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Abstract- This paper presents the design and economic analysis of a photovoltaic (PV) system for a campus sports complex located at the Sultan Qaboos University (SQU) in Oman. The designed PV system shows the ability to serve the total energy required by the various playgrounds in the sports complex and to sell excess power to the grid. Oman is one of the gulf countries that has the highest average solar irradiation. Besides, the temperature in Oman varies in a broad spectrum daily and seasonally. This variation in temperature, especially in a hot climate like in Oman, has a significant impact on the PV output. This paper addresses such a change of temperature in designing the PV system for the sports complex. This paper also presents the mathematical model utilized in designing the PV system and its design process in detail. The outcome of the design shows that the PV based renewable system can meet the energy requirement (78.568 MWh/year) by the load in a year. Moreover, the design system can sell energy (56.065 MWh/year) back to the grid that produces extra revenue for the system owner. The economic performance parameters of the design such as payback period (10 Years), net present value (USD 120755), internal rate of return (10%), and profitability index (3.09) without considering discount rate, further proves the financial viability of the solar PV system for the SQU sports complex.

Keywords Photovoltaic system, Sports complex in campus, Temperature effect, System design, Economic analysis.

1. Introduction

Energy is one of the essential factors for the socio-economic development of a country. Energy demand in the world is increasing at a high rate, and fossil fuel reserves are declining at a constant rate. The Sultanate's energy demand is growing and expected to rise in the coming years [1]. The Sultanate has aimed to extract at least 10% of its energy requirement using renewable sources by 2025 to compensate for the Sultanate's future energy demand [2]. Besides, the integration of renewable sources will reduce CO_2 emission significantly locally and globally.

Several researchers have evaluated the availability of renewable energy resources in the Sultanate of Oman. Past researches show that the Sultanate of Oman has an excellent potential for producing clean energy using solar and wind resources [3, 4]. The wind resource has significant potential in the coastal areas while the solar resource potential exists throughout the country. The Sultanate of Oman is currently meeting its electricity demand mostly (97.5%) from natural gas, and the rest comes from diesel, especially for the islands and rural areas. Therefore, to meet the increasing electricity demand in Oman, keeping in mind the target of reducing fossil fuel consumption, it is crucial to research applications of renewable generations in various scale and domains. To support such applications, the Authority for Electricity Regulation (AER), Oman, has introduced two programs called Sahim1 and Sahim 2.

Research on developing, designing, and integrating the Photovoltaic (PV) system for various applications have been carried out around the world over the last few decades [5-6]. The study in [7-8] presents the performance analysis and design of a rooftop PV system for home applications. Some researchers conduct a technical and economic evaluation of grid-interactive solar PV systems for home applications [9-11]. The feasibility study of a solar home system is carried out and presented in [12]. Setiawan et al. present the utilization of a solar PV system for industrial load application in [13]. The study in [14] has presented the design and analysis of the PV system for application to a boat system. Such an application helps to reduce fossil fuel-based power generation in the boat power system. The design of the building power generation system using solar PV has been presented and discussed in [15]. PV based electric vehicle charging system using available space in the car parking roof has been analyzed in [16, 17]. Chard et al. present the electrification of the Canadian sports stadium using a solar PV system in [18]. Canada has significant potential for using renewable power for sports stadium applications; however, four stadiums out of fifteen have considered the integration of renewable energy sources. A feasibility study of using renewable power generation for five European stadiums has been discussed in [19]. The study has revealed that the utilization of renewable power generation to these stadiums could produce 1500- 5000 MWh/year surplus energy after meeting their energy demands. Feasibility analysis for the effective installation of solar PV plants for Cricket stadiums in India has been featured in [20]. One of the largest stadiums, Kaohsiung stadium, in Taiwan, is currently powered by solar PV systems with a capacity of producing 2.6 GW energy. This amount of energy is produced from 8844 modules installed on the rooftop in an area of 14155 m^2. This enormous amount of energy, which comes from the PV system, reduces approximately 660 tons of CO_2 emissions annually [21]. From 2008 to 2017, the growth of the solar PV system for sports stadium application can be seen in Figure 1[22]. In Table 1, the growth has been further illustrated based on the total number of panels and sizes throughout the years.

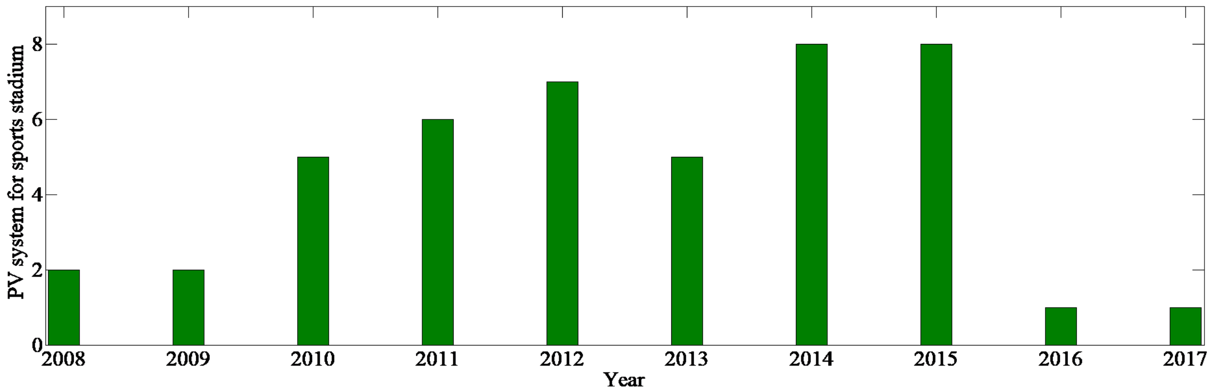

Figure 1. Installed number of solar PV systems for sports stadium per year in the world.

Table 1. Installed Number of solar panels with their total size.

Year	Size (kWp)	Number of Panels
2008	250	1690
2009	2000	22144
2010	6464	52997
2011	4441	23422
2012	964	4452
2013	5075	20435
2014	14321	59880
2015	4766	17593
2016	7067	26460
2017	817	3400

Besides, stadium solarization is becoming one of the requirements for successful bidding to host international games such as the Olympic games. Several researchers [23] undertook the initiatives of generating renewable power using solar PV for various applications in Oman. Such applications are solar PV system for eco-house and domestic water heaters applications, electric vehicle charging stations using a PV system, large-scale grid-connected solar power plants, and rooftop PV system for the home. Some of these systems are currently under operation in Oman. However, one of the potential applications, such as sports complexes that can be energized by solar PV systems across the country, has not been addressed yet. Table 2 shows the list of significant sports complexes and their capacity in the Sultanate of Oman [24].

Table 2. Major sports complex and stadium in the Sultanate of Oman

Stadium	Capacity (kWh)	Location
Al-Seeb stadium	14000	Al Mussanah
Al-Buraimi Sports Complex	10000	Al-Buraimi
Al-Saadda Stadium	12000	Salalah
Nizwa Sports Complex	10000	Al-Khaborah
Royal Oman Police Stadium	18000	Bowsher
Sultan Qaboos Sports Complex	39000	Bowsher
Sultan Qaboos Sports Complex	14000	Fanja
Sohar Regional Sports Complex	19000	Sohar
Sur Sports Complex	8000	Sur
Salalah Sports Stadium	8000	Salalah
Sultan Qaboos University Sports Complex	5000	Al-Khoud
Ibra Sports Complex (under construction)	15000	Al Sharqiyah

The activities in these sports complexes take place starting from late afternoon until late evening time. Thus, the electricity required by the load in these sports complexes is supplied from the grid. The electricity supplied from the grid ultimately comes from fossil fuel, which produces harmful gas emissions and depletes the reserve [25]. Solarization of these sports complexes can reduce harmful gas emissions and reduce the dependency on fossil fuel. These complexes mostly require electricity during the evening period. The PV system produces electricity during the day, which results in a mismatch between the time of PV generation and the time of power consumption by the load. This study provides a cost-effective and sustainable solution to power these sports complexes using locally available renewable sources. The Sultan Qaboos University (SQU) sports complex, which is located inside the campus and consumes local electrical energy from the grid, has been taken as a case study site in this research. The contribution of this paper has been summarized as follows.

- PV based renewable energy system design for a sports complex is a new study for a region (MENA) that has a hot and wide temperature variability climatic condition.
- PV system design framework for the sports stadium is developed, which includes the model to account for the broader spectrum of temperature variation. The effect of temperature variation is assimilated for each month instead of using an average temperature value for a year or more. Each month temperature variation provides better accuracy in the sizing of PV modules to avoid a significant reduction in the PV output during the temperature variation in the real application.
- Towards sustainable development, it is an example study for the investors to expand their green energy business, and to the sports complex owners' to reduce their dependency from the utility grid and an opportunity to earn additional revenues.

The rest of this paper is arranged as follows: Section 2 demonstrates the entire research method along with the proposed design model and economic model. The results of the model are presented in Section 3, with a detailed analysis. Finally, the paper concludes in Section 4 with a conclusion.

2. Research Method

Site characteristics are essential to consider in designing a renewable energy system [26]. Such characteristics are site location, space availability, grid connectivity, energy demand, and available renewable energy sources. The grid presence in the selected site provides an opportunity to design a grid-connected system that opposes the idea of designing the system using energy storage such as battery units for an off-grid system. The PV-battery system may not be cost-effective due to the high cost and frequent maintenance required for the battery units. Moreover, the Authority of Electricity Regulation (AER) in Oman has recently developed the technical guidelines for installing and operating the grid-connected rooftop PV system, including the energy tariffs [27]. The fulfilment of the AER guidelines and regulations, the cost-effectiveness of the system, and the potential of utilizing locally available renewable sources are the major driving forces to design a grid-interactive solar PV system in this study.

2.1. Site Selection and Load Estimation

In this study, the SQU sports complex has selected as a site, which has an outstanding potential of solar resources and space for installing the PV system. Moreover, the solarization of the SQU sports complex can enhance future research and development activities in the university. Figure 2 shows the SQU sports complex that is composed of a large soccer field, a small soccer field, a basketball court, a volleyball court, a tennis court, a handball court, a building for indoor games, and a swimming pool.

Figure 2. Sultan Qaboos University (SQU) sports complex.

The large soccer field contains four light poles, and each pole contains 30 lamps with a rated power of 60 kW. The total power requirement of the large soccer field is 240 kW. The electrical load demand for the large soccer field has been considered to be an irregular load because it depends on the activities that take place in the field. A series of activities take place in the large soccer field over the year. Apart from the scheduled activities, some other special activities also take place in a distributed manner throughout the year. Such activities are college days (9 days for nine colleges), a family day (1 day) for the hospital employees, foreign workers day (1 day), and a family day (1 day) for all employees in the university. The total number of days for individual activities is 12; these are distributed over 7 months since the stadium runs only for these months. The activities in the large soccer field take place approximately from 6 pm up to 9:30 pm, which is about three and half an hour each day. The daily energy requirement of the large soccer field was computed based on the total power required by the load of the field and the operating hours of the load. It has found that daily energy consumption is about 840 kWh/day. Furthermore, the monthly energy has computed by multiplying the daily energy demand by the number of working days of each month, as shown in Table 3.

The small soccer field, the basketball court, the volleyball court, the tennis court, and the handball court are the other loads of the SQU sports complex. The time of operation of the small soccer field is from 6:00 pm to 8:00 pm on Monday and Wednesday every week. In addition, the activities in the other courts run from 6:00 pm to 8:00 pm every day.

Table 3. Monthly energy consumption by the large soccer field in the SQU sports complex

Month	Number of Activity days	Energy consumption per day (kWh)	Energy consumption per month (kWh)
January	12	840	10080
February	11	840	9240
March	9	840	7560
April	2	840	1680
May	0	0	0
June	0	0	0
July	0	0	0
August	0	0	0
September	0	0	0
October	13	840	10920
November	10	840	8400
December	16	840	13440

Table 4. Load demand and monthly energy demand by the courts and the small soccer field

Name	Load demand (kW)	Monthly energy demand (kWh/month)
The small soccer field	14	224
Basketball court	8	320
Volleyball court	4	160
Handball court	28	1120
Tennis court	16	640

Table 4 shows the amount of the load demand and the energy consumption per month by these courts and the small soccer field. Figure 3 shows the monthly energy consumption by loads of the SQU sports complex. It has been found that the highest amount of energy consumption by the load of the sports complex is in December, while the lowest amount of energy consumption is in April. The energy consumption in December and April are 15.904 MWh and 4.144 MWh, respectively. The annual energy consumption has been calculated by summing the energy requirements for seven months, which is 78.568 MWh/year.

Figure 3 also reveals that the energy consumption by the load of the sports complex for May to September is zero since there are no activities that take place in the sports complex during these months.

2.2. Solar Resource and Temperature

Solar irradiation and temperature are considered the factors that directly affect the output of the PV system [28]. The data have been collected for the year 2018 from the Eco-house project in the SQU campus, and the Eco-house locates 1.5 km away from the SQU sports complex [29]. The measured data of solar intensity and temperature have been recorded every 20 seconds, which provides approximately 4320 readings daily. The monthly average solar intensity has been calculated by taking the average of all the solar intensity data measured for each month, which has been enlisted in Table 5. The annual average solar intensity is 482 W/m^2/day, which indicates an excellent solar resource availability in the selected site. The monthly average solar irradiation, as shown in Figure 4 and the peak sun hour, has been calculated from the measured average solar intensity and the total sun hour.

Table 5. Solar resources with temperature variation

Month	Temperature Variation ($°C$) Range (Minimum-Maximum)	Solar Irradiation ($kWh/m^2/day$)
January	15-32	4.4
February	16-35	5
March	20-41	5.8
April	25-45	5.9
May	28-46	6.4
June	27-45	6.3
July	27-48	6.1
August	26-47	6.2
September	27-47	6.2
October	24-42	5.8
November	18-37	4.3
December	15-30	3.5

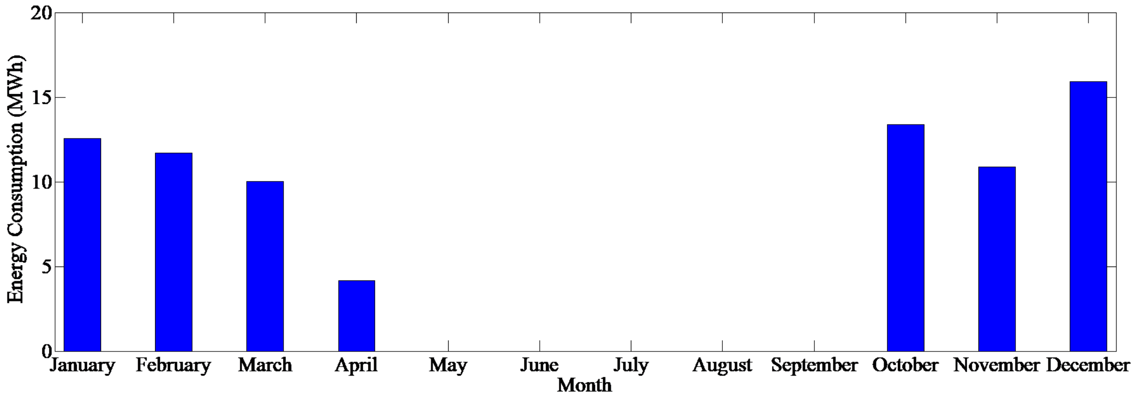

Figure 3. Monthly total energy consumption by the SQU sports complex: there is no activity in the complex from May to September, for which the energy consumption is zero.

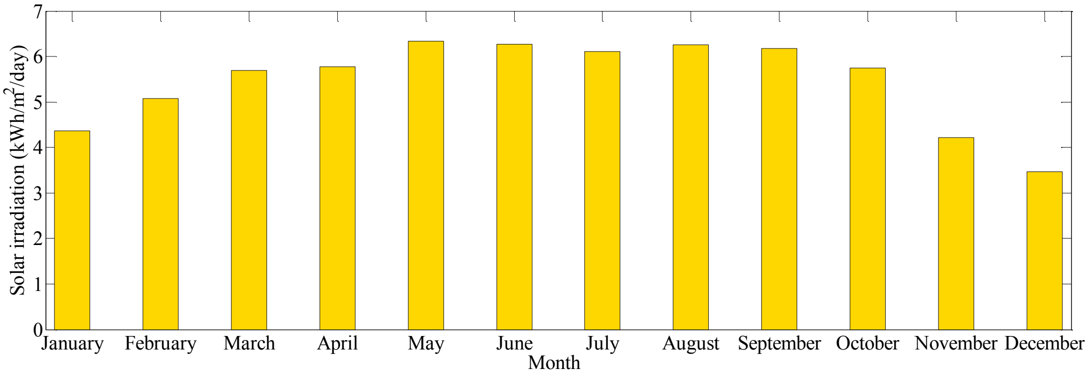

Figure 4. Monthly average solar irradiation available in the SQU campus

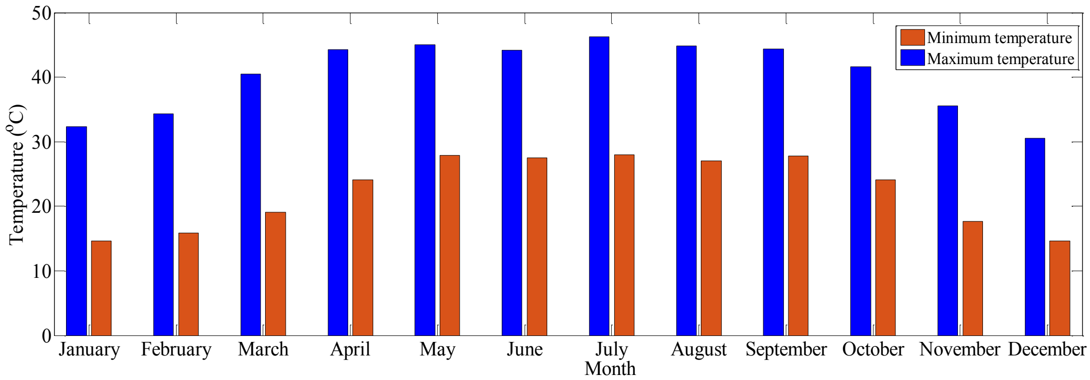

Figure 5. Variation in temperature profile for each month in SQU campus.

The annual average solar irradiation has been found to be 5.45 kWh/ m^2/day, and the average Peak Sun hour (P_{sh}) has been found to be 5.45 hours.

Figure 5 illustrates the range of temperature variation for each month at the selected site. The highest temperature was found to be 46.300C in July, and the lowest temperature was found to be 140C in January. The highest average temperature was found to be 37.1350C in July; however, the lowest average temperature was found to be 22.550C in January. It is important to note that there is a wide range of changes in temperature every month, which is the reflection of the temperature variation of each day. The temperature variation in the coldest month, December is 56.7%, while it is 40% in the hottest month, July. Such a variation between the minimum and the maximum temperature in a day or month is critical in designing the PV system for any application as the PV system's efficiency reduces with an increase in its ambient temperature.

2.3. System Sizing and Design Model

The output DC power of the PV panel is calculated as [30]

$$P_{DC} = \frac{E_{load}}{D_f P_{Sh} N_{day}} \tag{1}$$

where P_{DC} is the dc power generated by the solar PV panel in kW, E_{load} is the energy demand by the load in a year in kWh/year, D_f is the derating factor due to the temperature and the other components in the system, P_{sh} is the peak sun hour, N_{day} is the number of days in a year.

The derating factor, D_f is employed in calculating DC output power of the PV panel to account for the effect on power losses due to the temperature variation, different from the standard testing condition (STC), at the PV operating site. The cell temperature is calculated as [31],

$$T_{cell} = T_A + \left(\frac{T_{NOCT} - 20^0 C}{S_{NOCT}} \right) \times S_{site} \tag{2}$$

where T_A is the ambient temperature in ^{0}C, S_{site} is the average solar intensity in kW/m^2, S_{NOCT} is the solar intensity at STC in kW/m^2, T_{NOCT} is the normal operating cell temperature of the module in ^{0}C, which is considered as per the module data sheet at STC.

The percentage reduction in maximum power output of a module due to the temperature variation is determined as

$$P_{\text{module}} = \beta \times \left(T_{cell} - 25^0 C \right) \tag{3}$$

where β is the reduction in maximum power for per ^{0}C temperature variation of the module in %/^{0}C. Thus, the derating factor, $D_{f,Temp}$ due to the temperature variation is expressed

$$D_{f,Temp} = 1 - P_{\text{module}} \tag{4}$$

The derating factor due to the other system components, $D_{f,comp}$ was considered based on the available literature [30]. Such derating factors include DC rating on the nameplate of the PV module, inverters, module discrepancy, DC and AC wiring, and shading. The total derating factor, D_f is determined as

$$D_f = D_{f,Temp} \times D_{f,comp} \tag{5}$$

The area required for the PV panel installation is determined as

$$A_{PV} = \frac{P_{DC}}{\alpha S_{STC}} \tag{6}$$

where A_{PV} is the area required for PV panel installation in m^2, α is the module efficiency obtained from the data sheet and S_{STC} is the solar intensity in kW/m^2 at STC.

The number of modules required in the PV panel is determined as

$$n_{\text{module}} = \frac{A_{PV}}{A_{\text{module}}} \tag{7}$$

To design the number of strings required and the number of modules to be connected in a string, the effect of the temperature has been considered in order to compute the module output voltage at the maximum power point. The new module output voltage has been computed as [31]

$$V_{mo} = V_{mo,\text{STC}} \times \left(1 - \kappa\left(T_{cell} - 25^0 C\right)\right) \tag{8}$$

where $V_{mo,STC}$ is the module output voltage at STC, κ is the reduction in module output voltage for per ^{0}C temperature variation in %/^{0}C.

2.4. Economic Model

To know about the financial viability of the investment in any renewable energy system development, the economic analysis of such a system is essential [32]. The model of simple payback period, net present value, internal rate of return, profitability index has been used to obtain the economic parameters that are used to assess the economic performance of the PV system for the SQU sports complex. The payback period defines the number of periods that takes to recover one's investment in the project before starting to accumulate profit. The payback period (PP) method does not account for the time value of money and has calculated as [33].

$$\text{Payback period (PP)} = \frac{\text{Initial capital cost}}{\text{Annual cash inflow}} \tag{9}$$

The net present value (NPV) is the sum of all present values of cash outflows and cash inflows related to the investment over a period. The calculation of NPV accounts for the time value of money that eliminates the limitation of the PP period method. The NPV is calculated using equation (10).

$$\text{Net present value (NPV)} = \sum_{n=1}^{N} \frac{C_n}{(1+d)^n} - C_0 \tag{10}$$

where C_o is the total initial investment, C_n is the net cash flow at the period n, d is the discount rate, and n is the number of periods. Since the NPV calculation primarily depends on the discount rate that uses some assumptions, there is a potential of deviating the calculated value of NPV. Therefore, the NPV, in conjunction with the internal rate of return, is the most compelling measure in this study.

The internal rate of return (IRR) determines the rate at which the cash outflows become equal to the cash inflows in a project. The IRR has calculated by setting the NPV zero in equation 10, which is as follows.

$$0 = \sum_{n=1}^{N} \frac{C_n}{(1+IRR)^n} - C_0 \tag{11}$$

The profitability index (PI) refers to the ratio between the net present value (NPV) and the initial investment cost.

$$\text{Profitability index (PI)} = \frac{\text{Net present value}}{\text{Initial investment cost}} \tag{12}$$

The methodology described in this section is implemented according to the flowchart as shown in Figure 6.

3. RESULTS AND ANALYSIS

The methodology of designing and economic performance evaluation of the SQU sports complex has been implemented using the Matlab tool, and the outcomes are analyzed and presented in this section. The space limitation and grid connectivity have been taken as the design constraints in this research. The suitable PV module (ASM-7-PERC-AAA) and the inverter (PVS800-57-0100kW-A) are selected, and their detail specifications are available in the manufacturer datasheet.

3.1. Design of PV System for Sports Complex

The solar PV system for the SQU sports complex is designed to meet the energy demand of the loads in the complex. The energy demand by the load has been found to be 78.568 MWh that is effectively required for seven months while the activities run in the complex, and the monthly energy requirement of the sports complex has been found to be 11.224 MWh. Figure 3 reveals that there are five months in a year during which the sports complex has no activities, and consequently, the energy demand is zero; however, the design system has the potential to generate and export power to the utility grid during these months. Therefore, the total energy that the PV system has been designed for is 134.688 MWh/year.

The effect of temperature on the PV system output is employed using the derating factor that is computed for every month using equations 2-5. Figure 7 shows the variation in the derating factors for each month in a year, which is an indicator of variation in PV system output due to the temperature variation. The lowest derating factor is 0.8462 in July, the hottest month of the year. This derating factor reveals that there is a 15.38% reduction in PV output

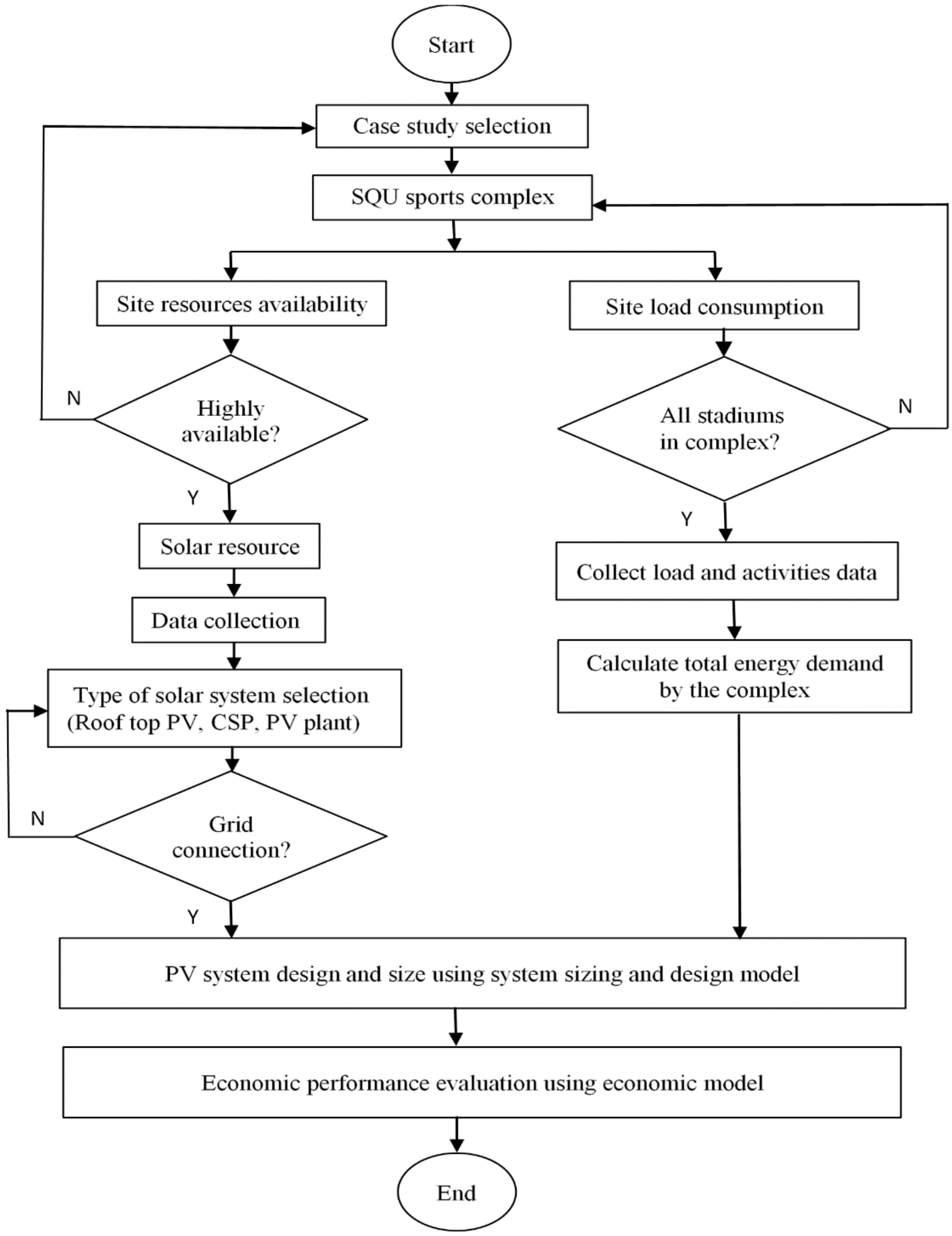

Figure 6. Flowchart of PV system design for SQU sports complex.

from its maximum value in July. On the contrary, the highest derating factor is found 0.9283 in December, the coldest month of the year. This derating factor shows that the PV output has reduced by 7.17% from its maximum value in December. The average derating factor, $D_{f,Temp}$, due to the temperature variation is calculated as 0.8749. The derating factor, $D_{f,comp}$ due to the other components in the system is found to be 0.7895 and is given in [34]. The total derating factor, D_f, is computed as 0.6907 using equation 5.

The DC power, PDC is calculated and found to be 98 kW using equation 1. The area required for this (98 kW) PV system has been found considering the efficiency of the module as 17.09%, as per the manufacturer datasheet, and the solar intensity at STC is 1 kW/m^2. Using equation 6, the area required by the PV system has been calculated as 574 m^2. According to the manufacturer datasheet, the area of each module is 1.96 m^2. Using equation 7, the number of modules required for the PV system has been determined to be 293. The range of the DC voltage at the inverter input has been taken as 450V to 750V according to the manufacturer datasheet to determine the module plan. Since the rated output voltage of a module is 37.96V at STC, the range of the number of module arrangements in each string has been found to be 12 to 20. This range has been computed without considering the effects of temperature on the output voltage of the module. Using equation 8, the range of the module in each string has been computed that accounts for the effect of temperature.

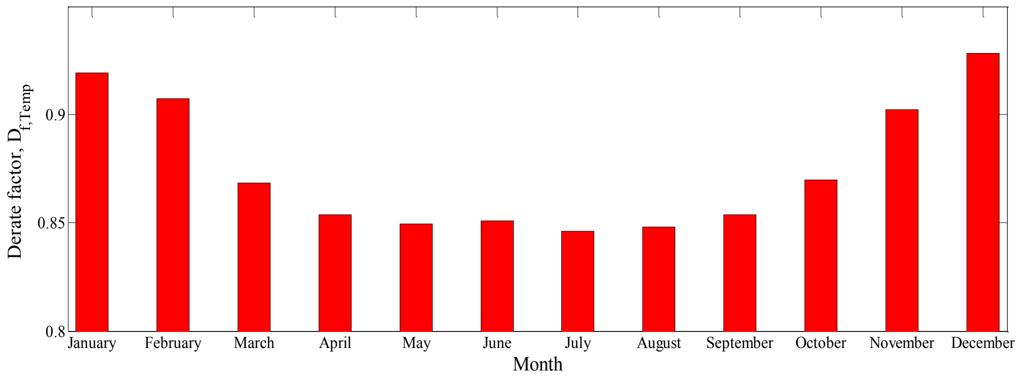

Figure 7. Variation in derating factor due to variation in the temperature.

Table 6. Module output voltage considering the temperature effect

Weather condition	Ambient temperature	Module output voltage without temperature effect	Module output voltage with temperature effect	Number of modules per string
Coldest	14.67^{0}C	37.96 V	37.51 V	12-20
Hottest	46.32^{0}C	37.96 V	33.75 V	14-23

Two extreme conditions are considered to determine the more appropriate number of the modules in each string. Such conditions are the hottest and the coldest day in a year.

Table 6 shows the effect of temperature on the module output voltage for two extreme conditions. There is a reduction in the output voltage of each module due to the increase in cell temperature and high ambient temperature. Table 4 demonstrates that the reduction in module output voltage is significant in the hottest conditions compared to the coldest condition at the site. The hottest condition refers to the worst-case scenario, which was considered to design the number of modules in each string. The module output voltage at the maximum power point has been computed as 33.75V, considering the worst-case scenario. The required number of modules per string is computed as 18 to maintain the inverter input voltage 600V at the maximum power point. Since the total number of modules required for the designed PV system is 293, the number of strings required has been found to be 17. The short circuit current level of each string is 9.39A, and thus the total amount of short circuit current that can be produced by the PV system is 160A, which would appear at the input to the inverter. However, the inverter short circuit capacity is 245 A, which is large enough to tackle the total short circuit current that may flow from the PV system.

Figure 8 illustrates the energy profile of the solar PV system for the SQU sports complex for one year. Energy production refers to the monthly energy produced by the solar PV system. The variation of monthly energy production has been observed due to the variation in solar irradiation and derating factors due to the temperature from one month to another. The energy consumption indicates the energy requirement by the load of the sports complex in a particular month. The energy balance indicates either the amount of energy to be received from the utility grid (negative balance) or the amount of energy to be sent back to the utility grid (positive balance).

In January, the energy demand by the load of the sports complex is 12.544 MWh, while the energy production by the PV system in this month is 9.624 MWh, as can be seen from Figure 8. Thus, the energy balance in this month is negative 2.92 MWh. This negative balance indicates that the load needs to receive this amount of energy from the utility grid. A similar scenario is also noticed for February, October, November, and December. In April, the energy requirement for the load of the sports complex is 4.144 MWh, whereas the energy generated by the PV system in this month is 11.287 MWh. Figure 8 reveals that the energy balance in April is positive and is 7.143 MWh. This positive balance indicates that there is excess energy production, which needs to be sent to the grid after meeting the load requirement. This scenario is also seen for March. In May, the energy requirement by the load of the sports complex is zero kWh, since no activities are running in the complex. However, the energy production by the PV system in this month is 12.912 MWh. Thus, there is a 10.912 MWh positive energy balance observed in this month. This positive balance indicates that the PV system can export the whole amount of energy to the utility grid in this month. This scenario is also noticed for June, July, August, and September. It has been found that the designed system can export 56.065 MWh energy after meeting the load demand of the SQU sports complex in a year.

Figure 8 also demonstrates the energy production variation from month to month due to the variation in solar irradiance and the derating factor due to the temperature. It is shown in Figure 4 that the average solar irradiance in June is 6.27 kWh/m^2/day, while it is 4.36 kWh/m^2/day in January. The solar irradiance in June is almost 43.80% higher

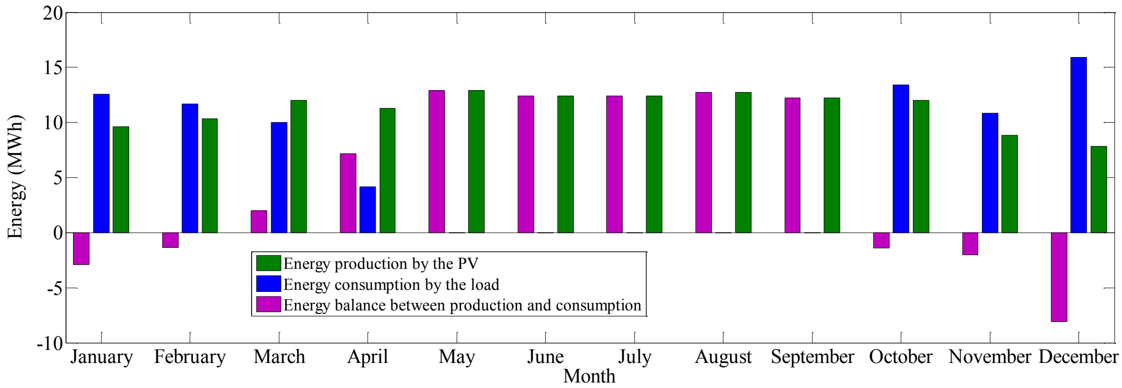

Figure 8. Energy performance of the designed PV system for the SQU sports complex.

compared to January. Therefore, it is expected to produce at 43.80% more energy during June. However, the actual energy production in June is 28.8% higher compared to January. Such a reduction occurs because of incorporating the effect of temperature in the design process as a derating factor, Df,Temp. It is also evident from Figure 5 that June is one of the hottest months in the year at the selected site.

3.2. Economic Analysis

The economic performance of the solar PV system for SQU sports stadium is analyzed using the economic parameters such as payback period (PP), net present value (NPV), and internal rate of return (IRR). The initial investment cost is determined based on the per kW cost of the PV system. According to the renewable energy market analysis: GCC 2019 by the International Renewable Energy Agency (IRENA), rooftop PV projects are implemented in 2018 at USD 700/kW in the UAE [35]. The initial cost of the PV system (98 kW rated) is calculated as USD 68600, considering the cost of USD 700/kW. The initial cost refers to the cost of the system components and implementation. The operation and maintenance costs are considered as 0.22% of the initial cost, as given in [36]. The initial investment and operating costs are considered as the cost outflows of the design system. The cost inflows of the system are computed based on the energy generated by the designed PV system. It is found that the design system generates 134.688 MWh/year. After meeting the load demand of 78.568 MWh/year, the rest of the energy, 56.065 MWh, can be exported to the utility grid. The cash inflows are calculated using the cost of energy that meets the load demand and the cost of energy that exports to the utility grid. The cost of per kWh energy is taken according to the energy export tariff chart obtained from the Muscat Electricity Distribution Company (MEDC) [37]. The project lifetime is considered to be 25 years that is the same as the replacement time of the PV panel.

Figure 9 shows the cash flow performance of the solar PV system that considers the discount rate, d as zero. The discount rate is assumed to be zero considering that this investment does not borrow any money from the bank. The positive annual cash flow is observed during the tenth year, and thus the simple payback period is found 10 years. Using equation 10, the net present value (NPV) is calculated as USD 120755, which provides the profitability index (PI) is 3.09 and calculated using equation 12. The profitability index compares the NPV with the initial investment cost. A profitability index of more than zero indicates that the project is profitable; however, the internal rate of return indicates how fast the invested money may recover [32]. Thus, the internal rate of return (IRR) has been calculated using equation 11 and found as 10%. The payback period, the net present value, the internal rate of return, and the profitability index reveal that the designed solar PV system is economically viable with an excellent return within a short period (10 years) if the money is not borrowed from the bank.

Figure 10 demonstrates the cash flow performance, which considers the discount rate, d as 6.5% as given in [38]. This cashflow analysis provides economic performance for the investor if the investment money borrows from the bank. The discount rate refers here to the interest rate that uses for discounted cash flow calculation to find the present value of future cash flow. Figure 10 also shows that the annual cash flow becomes positive in the fifteenth year, and thus the payback period is found 15 years. Using equation 10, the net present value (NPV) is calculated as USD 23799 and using equation 12, the profitability index (PI) has determined as 0.59. Also, the internal rate of return (IRR) is calculated using equation 11 and has been found to be 3.315 percent. With the discounted cash flow analysis, it has seen that the payback period is high, the net present value is quite low, the internal rate of return is low, and the profitability index is less than one in comparison to the undiscounted cash flow performance shown in Figure 9. These reveal that the designed PV system is still economically viable, even if it implements through the bank loan. However, the return to the investor may not be faster, as indicated by the economic performance parameters.

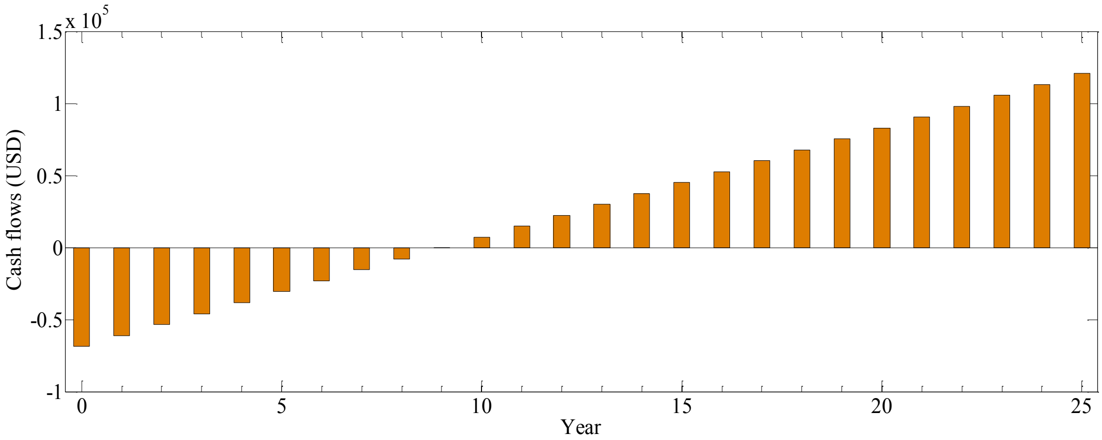

Figure 9. Cash flow performance considering the discount rate, $d = 0$ percent

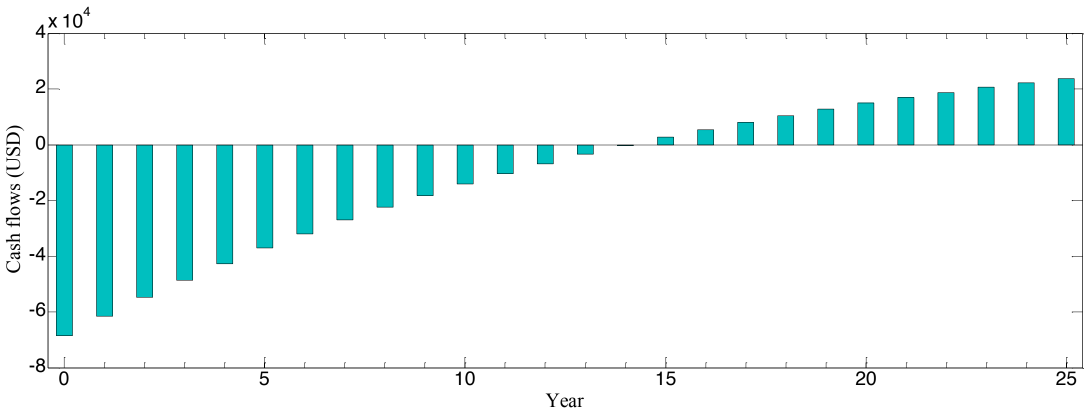

Figure 10. Cash flow performance considering the discount rate, $d = 6.5$

4. CONCLUSION

This study presents the design and economic performance analysis of a solar PV system for a campus sports complex located at the Sultan Qaboos University. The design process incorporates the effect of temperature variation on the PV generation. A framework of a systematic design process that includes temperature effect has been described in this paper. The design outcomes reveal that the PV generation degrades significantly due to the hot climate and a wide range of temperature variation at the selected site. The designed PV system can meet the sports complex energy demand (78.568 MWh/year) and able to export energy (56.065 MWh/year) to the utility grid. The size of the PV system has been found to be 98 kW that requires the rooftop area of 597 m^2, which is a little more than the available rooftop of the gymnasium in the sports complex. The total number of modules required for the PV system has been determined to be 293. Based on the inverter requirement and the PV module specification, this design has proposed 18 modules per string, which requires 17 strings. The economic performance of the designed solar PV system has been evaluated by utilizing different parameters such as the payback period, net present value, internal rate of return, and profitable index for justifying the viability of the system. The evaluation has been performed by considering two scenarios— with and without a discount rate. For both of these scenarios, the proposed design has been proved to be profitable, attractive, and sustainable. However, the impact of connecting such solar PV systems to the distribution network near to the sports complexes need further study in terms of power quality, voltage profile, flicker, and harmonics.

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