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Efficient utilization of solar PV for corporate building in Riyadh, Saudi Arabia

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Abstract.

This paper presents a case study for rooftop PV system mounted on corporate building of Saudi Electricity Company (SEC) HQ with a capacity of 277KWp. By collecting the generation data of the PV system along with the electrical loads of the building for the year 2021, the data showed that the amount of energy produced from the system, which was directly fed to the loads is about 404.8 MWh. Accordingly, the contribution rate of the PV system generation to energy consumption was calculated to be about 15.7% of the loads of the entire building, which totaled about 2547.8 MWh. The study showed that there is an excess of electrical energy produced from these solar panels. The system is programmed through the inverter to keep the production of solar panels equal or less than the electrical loads which is connected to due to the absence of the regulation for connecting PV systems with the electric grid at that time. The excess energy of PV generation was calculated as 478.5 MWh. Hence, the surplus energy is 69.1 MWh representing approximately 15% of the calculated PV generation. The study covered the economic perspective for the system by estimating the levelized cost of energy and payback period to be LCOE= 0.33 SR/kWh = 0.088 USD/kWh and Payback period= 23.9 years respectively.

Key words.

Photovoltaic, rooftop, solar, corporate

1. Introduction

Solar PV penetration in the Kingdom of Saudi Arabia has been increasing thanks to the ambitious goal of maximizing PV share in power by Saudi vision 2030 particularly the PV power plants that reached to low LCOE recently. With this orientation from the government in KSA, many entities started initiatives to install PV rooftop including corporates buildings. Saudi Electricity Company has its HQ at Riyadh located at 24º37'59''N, 46º43'0'E. In December 2018, a PV rooftop system was commissioned at one of its four headquarter buildings with capacity of 277kWp. The building area is 23808 m^2 and for the designated offices areas is 18276 m^2 with almost one thousand offices. A similar system with same capacity installed on the rest of the main buildings to be four systems with total capacity of 1.108MWp. In this research, only one of the systems has been studied, the system is feeding half of the building's loads and the other half is fed by grid directly. Some of the day's PV generation capacity remains higher than load demand because it has been limited to feed only one half of the building and the surplus energy is not allowed to be injected to distribution grid due to unavailability of regulations for grid interconnection of Solar PV Rooftop system from Water and Electricity Regulatory Authority (WERA) at that time. This study focuses on collecting data of PV generation and loads through Solar PV System monitoring tool "Sunny Portal"[3] and calculating the whole PV generation in case of grid interconnection or using the surplus energy to feeds other loads fed by external grid supply. There are some case studies in KSA for PV systems, which are feeding schools, mosques, malls and factories. However, there is no study focusing on PV performance on corporate or government buildings and their loads nature. This research presents a study to assess the interconnection between PV system and SEC HQ loads and how this system contributes in reduction of electric power consumptions from grid and GHG emissions. The peak loads in corporate buildings usually matches with peak generation of PV. since the working hours are during the daylight. Given the large size of corporate buildings and the different loads inside, it is not possible to cover the whole demand by only utilizing PV. Therefore, this leads to utilizing each watt generated from the system and there is no need for energy storage once it is a day time operation

Fig. 1 View of installed rooftop PV

2. Objetive.

The main purpose of this study is to assess the performance of PV rooftop mounted on a corporate building (i.e SEC HQ) that has its own load profile different from residential or commercial buildings. The study will be conducted by collecting generation and loads data during one year (2021). The objective of this study is to provide a comprehensive image of the loads profile of corporate buildings and how PV rooftop systems can contribute to cover some loads of corporate building by utilizing their roof area. The consumption of these buildings are mostly in daytime which matching the solar radiation intensity. In addition, the PV rooftop project reflects the efforts of S E C to contribute to carbon emissions reduction by exploiting the rooftop areas and this may lead to encouraging private and governmental entities for setting up similar systems for reduction of both electricity bill and carbon emissions.

3. Research Methodology

This section explains the design of PV system and architecture followed by data collection methodology through the System database via “Sunny Portal” [3]. The portal provides data for the PV generation as seen from the inverters output, so it is the AC generated energy that is being captured. Therefore, there is a shortage of data regarding the surplus energy in the system database because the inverters have been programmed to meet the load demand only and cannot export the surplus energy to the grid. Therefore, the energy yield from the PV system is estimated by simulation to determine the surplus energy from whole system and its’ capacity as mentioned in system design hereunder:

a. System Design

Before installing the system, the area of building’s roof was calculated to determine the number of PV modules that can be installed to get the maximum benefits of PV system. In addition, the measurements of solar irradiation (GHI) availability was taken from the NASA surface meteorology and solar energy data. The following diagram shows the average daily solar irradiation in Riyadh.

Fig. 2 Average daily solar irradiation

The location offers an average 6.67 kWh/m^2d and a yearly irradiation of approximate $2200kWh/m^2a$ – $2400kWh/m^2a$.

The angle of inclination and type of PV module were simulated to determine the optimal number of PV modules and to get the maximum benefit of energy yield.

The comparison of inclination angle was between (15^o – 20^o – 25^o). The system with the angle 20^o was recommended for better usage of the available space as well as better energy yield and best economic solution. Even though in 15^o angle case the total PV modules will increase by 55 modules but this will lead to reducing the space between PV modules, which will have an effect on the maintenance and the PV cleaning. Shading was taken into consideration based on the angle of sun relatively to horizontal surface. In case of 20° angle installation the required distance between the module to the one’s behind is

0.77 m and the total space per module is 2.64 m.

Monocrystalline PV modules rated at 320 W (1993 x 1001 x 33 mm). The module is manufactured by Solar World with model ID SW320 XL MONO. After simulation and calculations, the total number of PV modules was determined to be 855 modules.

b. Power Control System

There are 12 inverters connected with PV system with output control which has been programmed to be zero export of surplus energy to the electric distribution grid. These type of inverters is an ideal inverter for large –scale commercial and industrial plants with an efficiency reach around 98.4%. Each inverter can be monitored and controlled through SMA platform.

Fig. 3 inverters room

4. Results & Discussion.

The building loads are varied from time period to another due to the climate conditions and day works as it is a workplace. For the period of the year 2021 the total loads consumptions were 2547.82 MWh. Table 1 shows the loads consumption per month in 2021.

Table 1 Building's consumption

Time period	Total consumption [MWh]
Jan-21	238.76
Feb-21	202.08
Mar-21	206.5
Apr-21	197.84
May-21	200.16
Jun-21	190.66
Jul-21	205.2
Aug-21	212.64
Sep-21	209.16
Oct-21	208.14
Nov-21	220.32
Dec-21	256.36
the whole year	2547.82

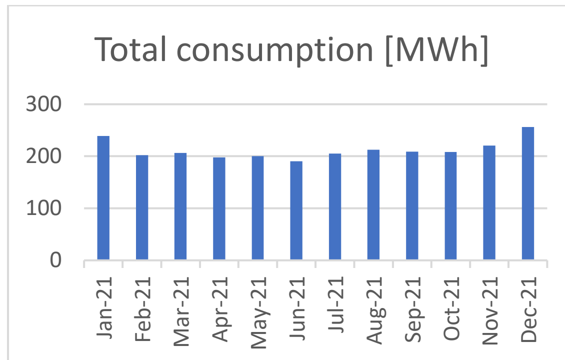

Fig. 4 Building's total consumption

The loads have been feeding from three main distribution panels, one of MDP feeding half of the building through distribution grid, the second one feeding the building by PV system and distribution grid and for the third one is being used for emergency purpose. The extracted data from the sunny portal showed that direct consumption from the PV system to feed the loads was 404.2 MWh represent almost 15.8% of the whole building load. While PV system covers some loads the rest was fed directly by the grid with 871.74 MWh representing 84.2% of the total load consumption.

Table 2 Loads consumption sharing

Time period	PV consumption [MWh]	Total consumption [MWh]
Jan	28.9	238.76
Feb	28.1	202.08
Mar	36.2	206.5
Apr	35.3	197.84
May	37.5	200.16
Jun	37.7	190.66
Jul	38.5	205.2
Aug	40.2	212.64
Sep	38.2	209.16
Oct	33.5	208.14
Nov	28.1	220.32
Dec	22.7	256.36
Total	404.8	2547.82

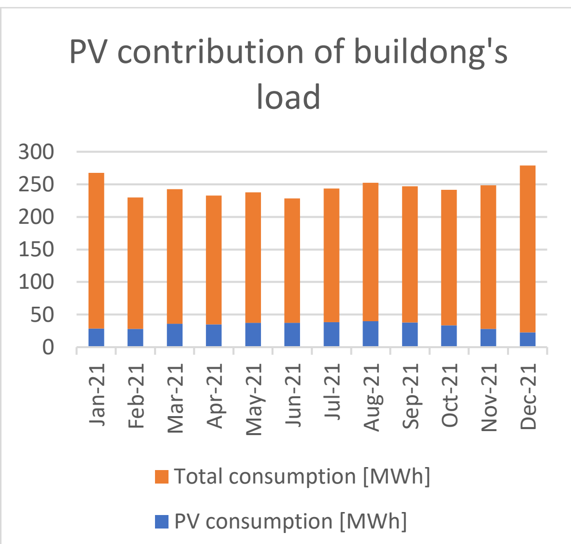

Fig.5 PV contribution of the building's load

From the data above and the chart we can see the PV production of months were approaching to each other except the winter season. The highest solar PV contribution was in summer season due to highest solar radiation and the lowest loads as a result of absence air conditioning units being connected to different circuit fed directly from the grid. In contrast, the lowest contribution of solar PV was in winter season especially, in December where the PV production was around 9% and that is as result of both minimum solar radiation compared to other months and highest monthly electricity demand due to more electric loads such as electric water heaters as well as electric air heaters for buildings warming purposes.

a. Surplus energy.

Due to the limitation of feeding only half of the building, the energy yield from the PV system was not fully utilized such that surplus energy is used to the other half of the building or any loads. The excess energy calculated is enough to provide proper solutions to exploit the full potential of the PV system, the total excess energy for the whole year was around 69.1 MWh. This amount comes according to the PV generated equation:

$$E= A * r * H * PR$$

Where:

E: PV electric energy output

A: Total area of PV modules

r: PV module efficiency

H: global solar irradiation

PR: Performance ratio

From the equation above, the factor that were given as: the total area is 1710 m^2. The PV module efficiency is 16%. Global solar irradiation was measured for each five minutes and taking in account for intraday. Performance ratio was assumed 0.65 in solar winter season from the beginning of November until the end of February (four months) and 0.75 for the rest of the year. The table and chart below show the comparison between the generated and calculated energy of the PV system for all months in 2021:

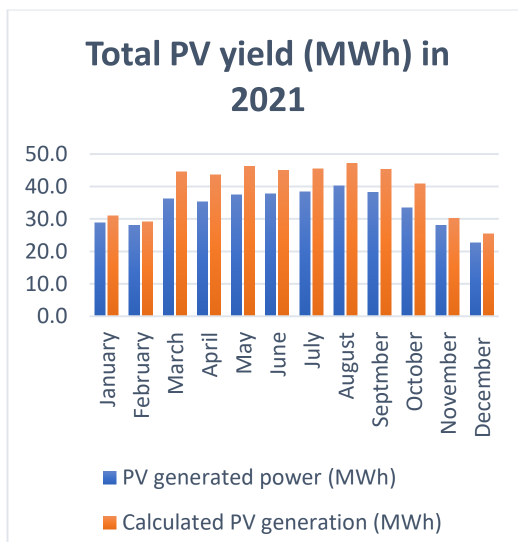

Fig. 6 Estimated and actual PV generation

Table 3 Estimated and actual PV generation data

Month	PV generated power (MWh)	Calculated PV generation (MWh)	Surplus energy (MWh)
January	28.9	31.0	2.1
February	28.1	29.2	1.1
March	36.2	44.6	8.4
April	35.3	43.6	8.3
May	37.5	46.2	8.7
June	37.8	44.9	7.2
July	38.4	45.4	7.0
August	40.2	47.1	7.0
September	38.2	45.3	7.2
October	33.5	40.9	7.4
November	28.1	30.2	2.2
December	22.7	25.5	2.7
Total	404.8	474.0	69.1

b. Capacity Factor.

The capacity factor is the ratio of the actual annual energy yield of PV array to the energy it would produce when operating at full capacity over one year. Capacity factor estimates the percentage of the PV array that is usable, and the most ideal CF is 50% because of the daily sun availability (almost 12 h at maximum) [6]. The monthly capacity factor ranges between 19% in June, July and August and 11% in December as shown in Figure.

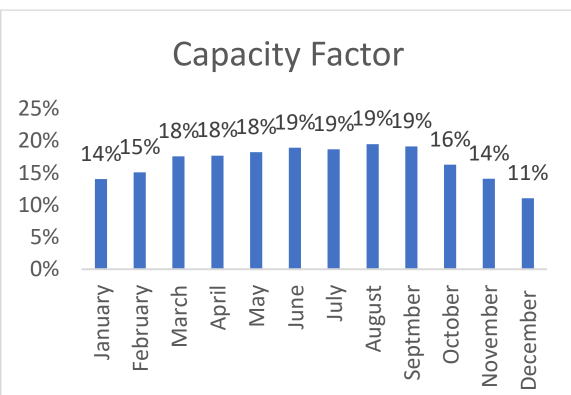

Fig. 7 actual monthly power factor

c. Environment impact.

Producing power from renewable energy such as in this case where PV system is used instead of burning fossil fuel leads to limitation of GHG gases emissions and saving oil barrels to be used for other purposes. KSA has an ambitious target to achieve net zero carbon emissions by 2060, such projects led by governmental and private sectors would support achieving that goal. SEC has issued an annual Environmental, Social and Governance (ESG) report that aims to provide a balanced representation of its ESG performance from 1st of January to 31st of December. The report discloses SEC's sustainability commitments, policies, programs and activities, as well as the contributions that have been made towards important national and international sustainability-related ambitions [8].

GHG gases emissions reduction calculation obtained by considering CO2 production factor to be 0.53 ton/mWh based on ESG report. Therefore, the reduction of emissions for the energy production was 214 tons. Oil barrels saving has been calculated by assuming the equivalent barrel of oil produces 1.62-megawatt hour. Hence, the total saved oil barrels for producing were almost 655 barrels of equivalent oil.

6. Economic Analysis

Beside the technical analysis of the system, the economic analysis has been carried out to assess the system from all aspects. The system got purchased in 2016 when the prices were quite high compared to present prices, that increased the payback period and levelized cost of energy in study calculations.

a. Levelized cost of energy.

LCOE is used to compare the kWh cost of different power system technologies. LCOE is estimated by dividing the lifecycle cost of the project by the expected energy output [13].

LCOE = LCC/E grid

Where LCC is the lifecycle cost and E grid is the estimated produced energy for 25 years.

The lifecycle cost includes the initial capital cost, operation, and maintenance cost, as well as the replacement cost minus the salvage value, which is the project value at the system's end of life. It has been calculated to be 820,438 US$. In contrast, E grid is the sum of produced energy during 25 years taking into account the degradation of PV modules as shown in table below which will reach to 80.2% of effective output at the twenty fifth year which is calculated to be 9314.8 MWh.

LCOE = 820,438/9314800 = 0.088 USD/kW.

b. Payback Period

A simple payback period pertains to the period at which the revenue is equal to the investment cost, while a discounted payback period takes into consideration the time value of money. The simple payback period for residential PV systems is given by [14]:

Payback period = (PV price- Fedral ITC) / (Annual PV revenue-O&M)

Payback period = (690,000 - 0) / (34,278 - 5,429) = 23.9 years

7. Conclusion.

According to the data mentioned in earlier, the system can produce much more energy in each month. The incremental of energy is 69.1 MWh represents around 15% of total yield energy 474 MWh, which can increase solar contribution to loads feeding by 18.6 %. Such quantity of wasted energy could be utilized to feed the whole building and other surrounding facilities by reprogramming the inverter to export the whole generated energy especially with WERA announcing rooftop PV interconnection with the distribution grid regulations.

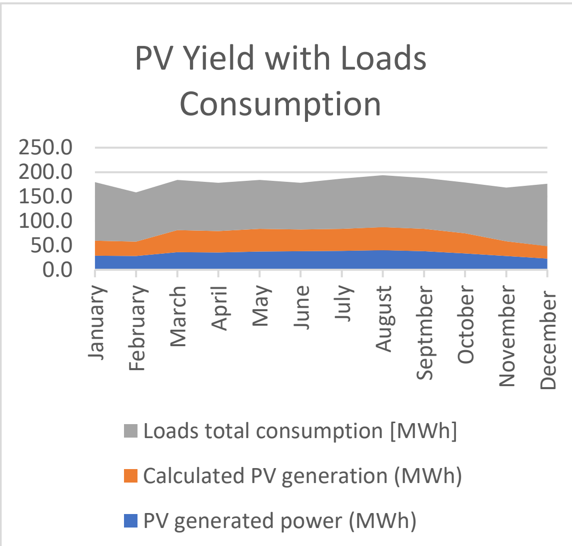

Fig. 8 Generated PV with loads consumption

By utilizing the surplus energy, the value of capacity factor will be increased to reach around 20% for the whole year. As well as GHG emissions reductions and the barrels of oil equivalent values will increase to reach 251 tons of CO^2 and 768 barrels of oil equivalent. Moreover, the LCOE will decreased to be reached 0.75 US$/kWh, payback period will decrease as well to be around 19.9 years.

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