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# Optimal Sizing and Cost Minimization of Solar Photovoltaic Power System Considering Economical Perspectives and Net Metering Schemes

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**Abstract:** In this paper, economic feasibility of installing small-scale solar photovoltaic (PV) system is studied at the residential and commercial buildings from an end-user perspective. Based on given scenarios, the best sizing methodology of solar PV system installation has been proposed focusing primarily on the minimum payback period under given (rooftop) area for solar PV installation by the customer. The strategy is demonstrated with the help of a case study using real-time monthly load profile data of residential as well as commercial load/customers and current market price for solar PVs and inverters. In addition, sensitivity analysis has also been carried out to examine the effectiveness of net metering scheme for fairly high participation from end users. Since Saudi Arabia's Electricity and Co-generation Regulatory Authority (ECRA) has recently approved and published the net metering scheme for small-scale solar PV systems allowing end users to generate and export energy surplus to the utility grid, the proposed scheme has become vital and its practical significance is justified with figures and graphs obtained through computer simulations.

**Keywords:** capacity optimization; cost minimization; net metering schemes; renewable energy; solar PV

## 1. Introduction

Renewable energy sources (RES) are the key to sustainable energy development as these are inexhaustible and non-polluting [1]. The technologies used in RES have also been improved day by day, and upgraded RES generation units are now commercially available in markets [2]. Most distinguished resources include solar photovoltaic (PV), wind power, solar thermal systems, and biomass. Many studies have been performed in order to optimize the size and operation of such plants [3–5]. Solar PV is one of the longest lasting, easy to handle, and environmentally friendly energy supplies developed by recent research. The use of solar PV avoids depletion of fossil fuel resources and environment pollution through carbon emissions, oil spills, and toxic by-products. A 1 kW PV system producing 150 kWh each month prevents 75 kg of fossil fuel from being mined. It prevents 150 kg of $CO_2$ from entering the atmosphere and keeps 473 L of water from being consumed [6]. This research investigation aims at sizing the solar PV in local load demands at the consumer's level for cost minimization. A case study with real data will be considered in order to obtain the best size of solar PV under the given scenarios for residential and commercial loads while considering the power from the national grid. The combination of conventional and renewable energy sources is being implemented in many micro-grids in order to serve the load, especially with the assistance of the national grid. Net metering at the customer end will be used to minimize the cost of energy [7,8].

Energy security is now the subject of intense debate in policy circles around the world. Due to the availability of oil in the Kingdom and its status as the world's leading producer and exporter of oil, Saudi Arabia has not been widely investigated for energy security. The Kingdom is not only the world's leading producer but also among the top oil-consuming countries per capita in the world. Due to the growth of domestic energy consumption and limited oil resources due to peak oil producer of the world, Saudi Arabia has to face energy crisis issues which comes under the energy security of the Kingdom. Renewable energy sources play a major role for the issues related to energy security in Saudi Arabia [9]. Fossil fuel based power generation systems have created serious environmental problems, i.e., air pollution, acid rain, climate change, and global warming, which are harmful to human life. Solar PV energy is clean, silent, abundant, sustainable, and renewable as well as inherently safer than any other traditional electricity generation systems. Renewable energy systems can solve many environmental problems that were created by traditional fossil fuels [10,11].

The residential and commercial solar PV systems will share the burden to generate power by using conventional means and provide ease to distribution companies. At this stage, the purpose of a net metering scheme/gross metering scheme is to overcome future energy needs and provide a public awareness message for saving energy for the future. The future energy demands in the region require bigger DGs, which will increase environmental problems as discussed above. As per the directives of net metering scheme/gross metering scheme provided by many countries, the user will receive incentives by installing a solar PV system. Some of the countries are listed in Table 1.

In Figure 1, all the red areas have high ambient temperature than compared to the light orange areas. Although the red areas have higher solar irradiance than compared to the light orange areas, due to the higher ambient temperature, power loss may vary from 10 to 30%, but the solar PV degradation rate is considered flat for all the cities in Saudi Arabia.

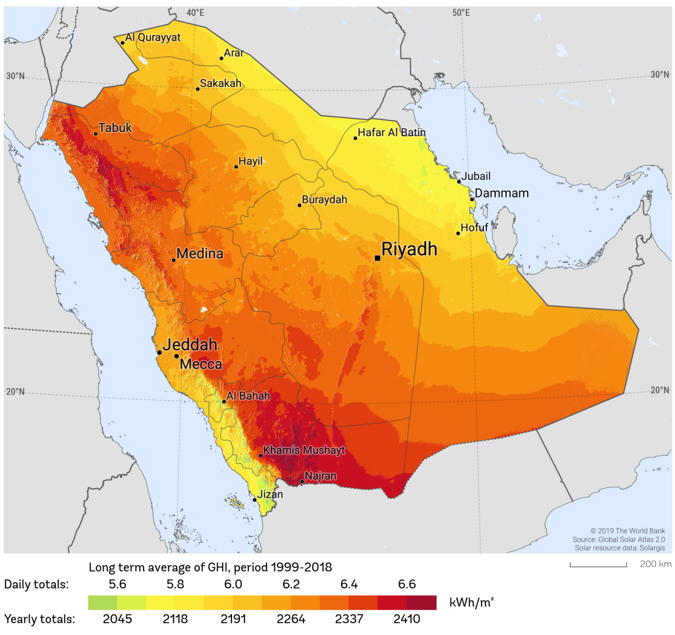


**Figure 1.** Horizontal irradiation showing candidate areas for installing solar PV in Saudi Arabia [12].

A net metering scheme relies on a bidirectional meter to measure the power import (or export) from (to) the grid and to calculate the net to charge (compensate) at the user end, as shown in Figure 2. It is used extensively in the United States and some countries in Europe. In net metering, the investor generates revenue from solar systems by electricity bill savings only when an energy surplus exists [13–16]. RESs have become an emerging topic for the current energy generation industry since the technology has been significantly improved. Moreover, upgraded renewable generation units are commercially available in markets, i.e., solar PV, wind turbine, solar thermal generators, and biomass. However, the most suitable power generation in the remote areas would mainly be solar PV in terms of the ease of installation [17,18].

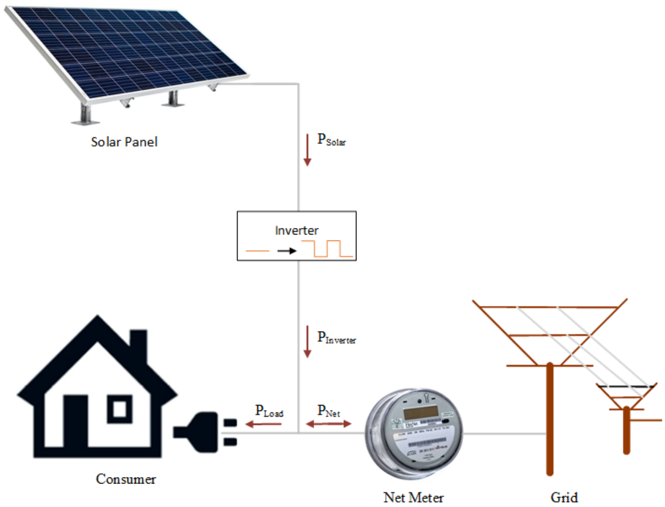


**Figure 2.** Signal flow diagram for net metering scheme.

Residential electrical power generation using customer-owned grid-connected solar PV systems has turned into an appealing suggestion for many households. The behavior towards the solar PV is due to the technological developments that have reduced the cost of solar PV power generation [19–21]. There are various programs initiated by countries listed in Table 1 that encourage households to install residential solar power generation systems. Under some of these programs, the electricity produced by residential systems (via PV-generated electricity) can be sold at a price favorable to power-generating households or set by conventional grids by net metering [22,23].

**Table 1.** International regulations and incentives survey.

| Country | Solar Rooftop PV Model | Type | Incentives |
|---|---|---|---|
| Germany [24] | Gross metering | Self owned and third party owned | ∘ Feed-in-Tariff |
| Japan [24] | Net metering and Gross metering | Self owned and third party owned | ∘ Capital Subsidy |
| Colorado, USA [25] | Net metering | Self owned or third party owned | ∘ Capital Subsidy (Rebates)<br>∘ Sales-Tax exemption available to owners<br>∘ Income Tax Credits<br>∘ Production Tax Credits |
| California, USA [25] | Net metering | Self owned or third party owned | ∘ Property Tax exemption<br>∘ California Solar Initiative-fully/partially subsidized PV system for low income households<br>∘ Performance based incentives to builders |
| New Jersey, USA [25] | Net metering | Self owned or third party owned | ∘ Sales Tax exemption-Purchaser fills out a form instead to paying the tax<br>∘ Property Tax incentives |
| India [26] | Net metering | Self owned and third party owned | ∘ Feed-in-Tariff |
| China [27] | Net metering | Self owned and third party owned | ∘ Feed-in-Tariff |
| Pakistan [28] | Net metering | Self owned and third party owned | ∘ Feed-in-Tariff |

For example, the Egyptian Electric Utility & Consumer Protection Regulatory Agency (EgyptERA) had published a net metering scheme for residential buildings in November 2013 and revised it in May 2020 with the contribution of the North Cairo Electricity Distribution Company. In this scheme, the service provider will install a net meter, and the concerned consumer will pay the fees and the net load remaining. Every surplus unit (if any) is purchased by the service provider at the highest tariff segment reached during the month and shifted as credit to the next bill. At year-end, the service provider pays for all surplus, if any [29]. A detailed and illustrative info-graphic summarizing the administrative and practical steps to implement the Egyptian net metering mechanism for small and medium solar PV projects up to an installed capacity of 20 MW has been published with the collaboration of the Regional Center for Renewable Energy and Energy Efficiency (RCREEE) and the Ministry of Electricity and Renewable Energy, Egypt [30,31].

In the US, net metering schemes have been widely implemented as a customer-sited distributed generation (DG) compensation mechanism at the state level in the United States since 1983. According to a recent study, there are 41 states in the USA including Washington, D.C., American Samoa, U.S. Virgin Islands, California, and Puerto Rico that are using net metering schemes [22]. Some utilities have voluntarily offered net metering arrangements to customers as well. For example, the states of Idaho and Texas do not have mandatory net metering policies, but some utilities in these states offer net metering. Net metering schemes are also developed in Brazil and their analysis, regulations, opportunities, and challenges are also discussed in [32,33]. The Kingdom of Saudi Arabia (KSA) is rich with higher levels of solar radiation, which makes it a strong candidate for the deployment of solar PV systems. The literature indicates that commercial/residential buildings in the KSA consume about 10–45% of the total electric energy generated. The average global solar radiation for a day ranges from 3.61 to 7.96 kWh/m$^2$ [34,35].

Contrary to net metering schemes, gross metering schemes are also in practice in some countries in Europe and Asia, i.e., Germany and Japan, as discussed in Table 1. The purpose of implementing gross metering by these countries is to encourage its end users to install RES not only to overcome the energy needs but also to make the environment clean. Gross metering can be easily understood by Figure 3 where the end user provides all the energy generated by RES, i.e., solar PV or wind, to the grid at a fixed Feed-in-Tariff (FiT) [36,37]. The gross meter is a unidirectional meter, and it counts the units exported to the grid. The amount for selling energy units to the grid is based on the tariff, which is fixed by the agreement of both parties distributed generation company and the end user. This amount will be given to end users by the end of each year but the end user is constantly charged for the energy units consumed separately depending on the country's policy. One of the drawbacks of using gross metering compared to net metering includes the following: in some countries, units are sold at a flat rate, and there is no concept for units sold at peak time with a slightly higher price [38,39].

Smart metering infrastructures (SMI) and net metering schemes in Europe are also widely used, and their policies are also considered while tacking the under-mind weather of the most European countries [40,41]. The economic evaluation of a series of net metering policies from a consumer bill, from the perspective of Greece, is also performed to evaluate policies provided by the government [42,43]. A linear program (LP) based algorithm is proposed to schedule battery storage for limiting reverse power flow with the customer objective of increasing operational savings in the context of net metering [44]. Similarly, net metering schemes are also developed in China to facilitate power production units, which results in small scale distributed generation through solar PV [45].

Net metering has been consistently recognized as a foundational policy to support the growth of a distributed solar marketplace. The advantages of net metering includes straightforward billing concept, no changes to existing retail rates if decided earlier, no need to build new infrastructure for net metering, and customers receive compensation for excess electricity that improves the financial return on investment of their on-site DG systems. The net metering model proposed by [46] having a typical customer with simple solar PV output calculations using solar irradiance, area, and efficiency of the solar PV is tested. The payback period is not reported but Net Present Value (NPV) and Internal Rate of Return (IRR) are mentioned. Solar PV degradation is also a major factor for calculating NPV as well as payback period. In [16], payback period and solar degradation are not discussed in detail, which results in a research gap that needs to be filled.

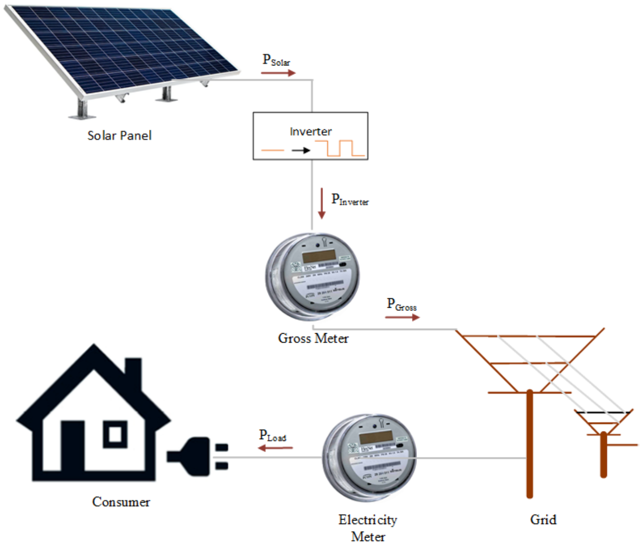


**Figure 3.** Signal flow diagram for gross metering scheme.

This paper presents the economic perspective of using net metering scheme applied for solar PV in Saudi Arabia as a recently approved and published scheme for net metering for small-scale solar PV systems by Saudi Arabia's Electricity and Co-generation Regulatory Authority (ECRA) that allows end users to generate and export energy surplus to the utility grid. The novelty and the contribution of this paper are as follows:

1. Proposed a new expression ($\chi$) for discounted payback period with solar PV degradation under on-grid net metering. The $\chi$ includes time value of money in terms of compound interest of the initial investment.
2. Developed an amortization expression for solar PV degradation factor as salvage value after the committed number of years and integrating this method with the main objective.

The study will provide a clear vision to the size of the solar PV system to be installed with the minimum payback period. A case study is conducted while considering monthly load profile data. Moreover, we will consider sensitivity analysis to examine how attractive net metering scheme is for high participation from end users. The outcome of the study also defines the size of the solar PV system based on the average load profile of residential as well as commercial load/customers.

The remainder of the paper is organized as follows: Section 2 describes the proposed methodology where modeling of SEC, solar PV price, area occupied by the customer, and mathematical model for discounted payback period are discussed in Sections 2.1–2.4, respectively. In Section 3, a case study with 60 customer's real load data is conducted, and the results are discussed in detail followed by conclusion, future work, and acknowledgment in Section 4.

## 2. Proposed Methodology

According to ECRA, the installed small-scale solar PV system capacity shall not exceed 15% of the rated capacity of the transformer from which the load of the eligible consumer is fed [47]. Considering the worst case (spring season) in which consumers have maximum solar PV output and peak load, the size of the solar PV should meet either that load or 15%

of the rated capacity of the transformer, but keep in mind that the consumer has minimum cost per kWh in the entire 20 to 25 years period while using the national grid as well as solar PV [48].

### 2.1. Saudi Electric Company Price Model

Saudi electricity tariff for residential and commercial loads is shown in Table 2; there is also a fixed fee, as shown in Table 3, depending on type of breaker capacity installed for the consumer. From this tariff scheme provided by the SEC, cost per unit of energy supplied by SEC can be found.

**Table 2.** Saudi residential and commercial electricity tariff schemes [49].

| Consumption Categories (kWh) | Tariff-Saudi Arabian Riyal (SAR) | Consumer Type |
|---|---|---|
| 0–6000 | 0.18 | Residential |
| More than 6000 | 0.30 | Residential |
| 0–6000 | 0.2 | Commercial |
| More than 6000 | 0.30 | Commercial |

**Table 3.** SEC meter reading, maintenance and line rent per month [49].

| Capacity of Breaker ($\mu$) (Ampere) | O&M Cost (SAR) |
|---|---|
| $20 \leq \mu \leq 100$ | 10 |
| $100 \leq \mu \leq 200$ | 15 |
| $200 \leq \mu \leq 300$ | 21 |
| $300 \leq \mu \leq 400$ | 22 |
| $\mu = 400$ | 25 |
| $\mu \geq 400$ | 30 |

### 2.2. Solar PV Price Model

Now considering the life time of the solar PV, which is either 20 or 25 years based on the PV material (a function of price), the capital cost of the solar PV generation includes the cost of solar PVs, inverters, and operational and maintenance costs. Total investment cost for solar PV generation can be calculated by using the following. Equations (1)–(4).

$$\Sigma_T^{pv} = Q^{pvy}\Gamma^{pv} \tag{1}$$

$$\Sigma_T^{inv} = Q^{inv}\Gamma^{inv} \tag{2}$$

In order to obtain the total investment cost of the solar PV system, it is important to include the operation and maintenance cost relative to the total cost of the system:

$$\Sigma_T^{o\&m} = 0.15(\Sigma_T^{pv} + \Sigma_T^{inv}) \tag{3}$$

$$\Sigma_T^{I} = \Sigma_T^{pv} + \Sigma_T^{inv} + \Sigma_T^{o\&m} \tag{4}$$

where $Q^{pv}$ is the total number of solar PV panels, $\Gamma^{pv}$ is the cost for single solar PV, $Q^{inv}$ is the total number of inverters, and $\Gamma^{inv}$ is the cost for single inverter. $\Sigma_T^{o\&m}$ is 15% of the total investment for solar PV and inverter for the case study included in this paper. The solar system output is calculated by using Equation (5), which considers environmental effects and solar irradiation in the concerned area:

$$E_t = A_t\eta_t G_t(1 - 0.005(T_o - 25)) \tag{5}$$

where $A_t$ is the solar PV panels occupied area, $\eta_t$ is the PV panels efficiency, $G_t$ is the irradiance in the concerned area W/m$^2$, and $T_o$ is the outside air temperature (°C) [50,51]. Moreover, according to [50], DC cables losses shall be less than or equal to 3%.

### 2.3. Area Modeling

The area occupied by the customer to install solar PV is the data provided by the customer, but one method of finding this area can be accomplished by using Equation (6):

$$A_j = \frac{DL_j}{CLF_j.DF} \tag{6}$$

$$DL_i = \frac{\text{Average load per month in kVAh}}{\text{Total no. of hours in a month}} \tag{7}$$

where $DL_j$ is the demanded load in $kVA$ for the $j$th customer; the demand factor ($DF$) for residential loads is 60%, and it is 70% for commercial loads. The connected load factor $CLF_j$ for the $j$th customer taken from the ECRA database is 0.145 kVA/m$^2$ for residential and 0.214 kVA/m$^2$ for commercial loads [47]. In this model, any residential or commercial building is to be considered as a single-story building in order to simplify the analysis.

### 2.4. Investment Payback Period

The payback period ($PBP$) given in Equation (8) is a simple payback period that provides an indication of the period, and the invested money will be recovered. The total cost of investment will cover all components costs, fees, and operation and maintenance costs where the annual revenue comprises the resultant energy bill savings in addition to surplus sold if any.

$$PBP = \frac{TCI}{AES} \tag{8}$$

However, this payback period does not consider the time value of money; thus, this model needs improvements. The time value of money can be incorporated with the amortization formula with $PW$ denoting present worth, $i$ denoting interest rate, $n$ denoting number of years, and $A$ denoting annual installment given in Equation (9). The present worth in Equation (10) is the same as in Equation (9) but with variable name changes, i.e., $PW$ with $\Sigma_T^I$, $n$ with $Payback$, and $A$ with $M$:

$$PW = \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] A \tag{9}$$

$$\Sigma_T^I = \left[\frac{(1+i)^{Payback} - 1}{i(1+i)^{Payback}}\right] M \tag{10}$$

where $M$ is savings per year (in SAR) due to solar PV. The annual energy produced by solar PV is the total PV energy produced by the entire life span divided by the total life span (in years). To find annual savings, multiply this annual PV energy with the unit price provided by the distributed generation company. The final form of the equation can be observed in Equation (11).

$$M = \frac{TotalPVenergy}{Totalno.ofyears} \cdot \frac{price}{\text{kWh}} \tag{11}$$

By rearranging Equation (10), payback is separated and denoted by $\Delta$ and reported in Equation (12) for better understanding and in order to simplify the problem, assuming same irradiance, temperature, and all other losses in each year for the life span of solar PV system, which means that the solar PV system produces the same amount of energy each year if the degradation factor is not considered as according to Equation (4).

$$\Delta = \frac{ln\left(\frac{M}{M-i(\Sigma_T^I)}\right)}{ln(1+i)} \quad (12)$$

Similarly, degradation can be considered as simple degradation or, to be more accurate, compound degradation, which will be modeled on the same principles of Equation (9), i.e., present worth is replaced with present degradation ($PD$), annual installment is replaced with annual degradation ($A_D$), and interest factor is replaced with degradation factor ($D$), respectively. Equation (9) is reconstructed with a constraint, as in Equation (13).

$$PD = \left[\frac{(1+D)^n - 1}{i(1+D)^n}\right] A_D \qquad 0 \leq PD \leq 1 \quad (13)$$

Degradation of the solar PV plays the same role as interest rate for investments, and the problem becomes more simplified by assuming the same degradation factor each year for the entire lifespan of the solar PV system. Thus, degradation can be treated as interest rate and added to the interest rate for more accurate payback period results. The ($\chi$) in (14) provides the discounted payback period with present degradation.

$$\chi = \frac{ln\left(\frac{M}{M-(i+D)\Sigma_T^I}\right)}{ln(1+i+D)} \quad (14)$$

The model derived in Equation (14) incorporates the degradation factor.

## 3. Case Study

In order to test the discounted payback period model as discussed in Section 2.4, a case study is conducted with 60 customers' real data taken from Al Hassa, a city in Saudi Arabia. Solar PV and inverter data are taken from the local market, as listed in Table 4. According to different solar PV manufacturers, the average degradation of solar PV per year is from 0.5% to 1% excluding year one, and in year one, degradation of solar PV is around 3%. Thus, with the worst-case, flat degradation 1.5% is used [52]. The customers with minimum payback period for considering residential/commercial loads are listed in Table 5. The exchange rate from SAR to USD at the time of this study is USD 1 = 3.75 SAR. Minimum and maximum solar PV sizes of each type of load are also listed based on the data, i.e., units consumed by a customer per month. Due to discrete size of the inverter (1 kW in this case study), the minimum solar PV size is 1 kW. The upper limit for solar PV size is based on the area acquired by a customer to install the solar PV, which in this case is calculated through their consumption of electricity.

The total losses of the system are 25.94%, which includes losses due to temperature, power output tolerance, dirt effect of solar PVs , and transmission cable. Residential and commercial customers possessing monthly consumption of less than 6000 kWh in a given year cannot install solar PV systems below 1000 W. If a solar PV system is installed below the specified range, then invested money cannot be returned (dead loss) because the total discounted investment cost for solar PV system becomes more than the cost of the energy supplied by the system to the load for an entire lifespan. Table 5 shows the maximum size of solar PV each customer can install.

**Table 4.** Specifications for solar system components.

| | |
|---|---|
| **Solar Inverter** | |
| Max. input PV Power | 1200 W |
| Max. output PV Power | 1000 W |
| Max. Efficiency | 98.2% |
| Weight [kg] | 4 |
| Solar Inverter price for 1 kW | 800 SAR |
| **Solar PV Panel** | |
| PV panel output | 250 W |
| PV panel size | 1.6 $m^2$ |
| PV Panel Efficiency | 16.94% |
| PV Panel Price | 300 SAR |
| **System Losses** | |
| Temperature Coefficient | 0.41% |
| Reference Standard Temperature | 25°C |
| Power output tolerance | 1.54% |
| Dirt affect | 5% |
| Cable loss | 3% |
| **Economic Statistics** | |
| Degradation factor ($D$) | 1.5% |
| Bank interest rate ($i$) | 3.675% |

**Table 5.** Payback period based PV sizing.

| **Customer Number** | **Min. Payback Period (Year)** | | **Max. Solar PV Size in (kW)** | | **Customer Number** | **Min. Payback Period (Year)** | | **Max. Solar PV Size in (kW)** | |
|---|---|---|---|---|---|---|---|---|---|
| | **Residential** | **Commercial** | **Residential** | **Commercial** | | **Residential** | **Commercial** | **Residential** | **Commercial** |
| 1 | 4.05 | 4.05 | 7 | 7 | 31 | 8.32 | 8.56 | 1 | 0.75 |
| 2 | 4.05 | 4.05 | 64 | 42 | 32 | 8.32 | 7.16 | 4 | 2 |
| 3 | 4.05 | 4.05 | 33 | 21 | 33 | 8.32 | 7.16 | 4 | 2 |
| 4 | 4.05 | 4.05 | 78 | 45 | 34 | 8.32 | 7.16 | 4 | 2 |
| 5 | 4.24 | 4.21 | 2 | 2 | 35 | 8.32 | 7.16 | 5 | 2 |
| 6 | 4.31 | 4.27 | 7 | 7 | 36 | 8.32 | 7.16 | 3 | 1 |
| 7 | 5.08 | 4.88 | 8 | 8 | 37 | 8.32 | 7.16 | 4 | 2 |
| 8 | 5.93 | 5.53 | 7 | 5 | 38 | 8.32 | 7.16 | 2 | 1 |
| 9 | 6.42 | 5.88 | 9 | 5 | 39 | 8.32 | 7.16 | 2 | 1 |
| 10 | 6.42 | 5.88 | 5 | 5 | 40 | 8.32 | 7.16 | 5 | 3 |
| 11 | 6.42 | 5.88 | 5 | 4 | 41 | 8.32 | 7.16 | 2 | 1 |
| 12 | 6.42 | 5.88 | 9 | 6 | 42 | 8.32 | 7.16 | 5 | 2 |
| 13 | 7.13 | 6.38 | 1 | 1 | 43 | 8.32 | 7.16 | 4 | 2 |
| 14 | 7.51 | 6.64 | 4 | 4 | 44 | 8.32 | 7.16 | 5 | 3 |
| 15 | 8.32 | 7.16 | 10.25 | 6 | 45 | 8.32 | 7.16 | 7 | 4 |
| 16 | 8.32 | 7.16 | 10.25 | 5 | 46 | 8.32 | 7.16 | 5 | 3 |
| 17 | 8.32 | 7.16 | 2 | 1 | 47 | 8.32 | 7.16 | 2 | 1 |
| 18 | 8.32 | 7.16 | 2 | 1 | 48 | 8.32 | 7.16 | 3 | 1 |
| 19 | 8.32 | 7.16 | 2 | 1 | 49 | 8.32 | 7.16 | 2 | 1 |
| 20 | 8.32 | 7.16 | 3 | 1 | 50 | 8.32 | 7.16 | 3 | 2 |
| 21 | 8.32 | 7.16 | 3 | 1 | 51 | 5.31 | 5.06 | 1 | 1 |
| 22 | 8.32 | 7.16 | 5 | 3 | 52 | 5.47 | 5.18 | 1 | 1 |
| 23 | 8.32 | 7.16 | 3 | 1 | 53 | 8.32 | 7.16 | 4 | 2 |
| 24 | 8.32 | 7.16 | 3 | 2 | 54 | 6.06 | 5.62 | 1 | 1 |
| 25 | 8.32 | 7.16 | 3 | 1 | 55 | 5.92 | 5.52 | 7 | 7 |
| 26 | 8.32 | 7.16 | 2 | 1 | 56 | 6.98 | 6.27 | 1 | 1 |
| 27 | 8.32 | 7.16 | 4 | 2 | 57 | 4.05 | 4.05 | 3 | 3 |
| 28 | 8.32 | 7.16 | 2 | 1 | 58 | 5.02 | 4.83 | 3 | 3 |
| 29 | 8.32 | 7.16 | 4 | 2 | 59 | 4.05 | 4.05 | 34 | 20.25 |
| 30 | 8.32 | 7.16 | 2 | 1 | 60 | 7.51 | 6.64 | 1 | 1 |

The payback curve for each customer is based on the average monthly load profile, which means every customer has its own payback cure. To observe the behaviour of the payback curve obtained by the proposed expression, three customers are selected randomly. Figure 4 shows the behavior of payback period, where payback period converges to a single value. The ripple in Figure 5 shows the load on inverters connected to the system. The lower edges of the ripple demonstrate a fully loaded inverter with the maximum capacity of solar PV it can handle while the upper edges of the ripple show that the inverter is not fully loaded or more solar PV can be connected to it.

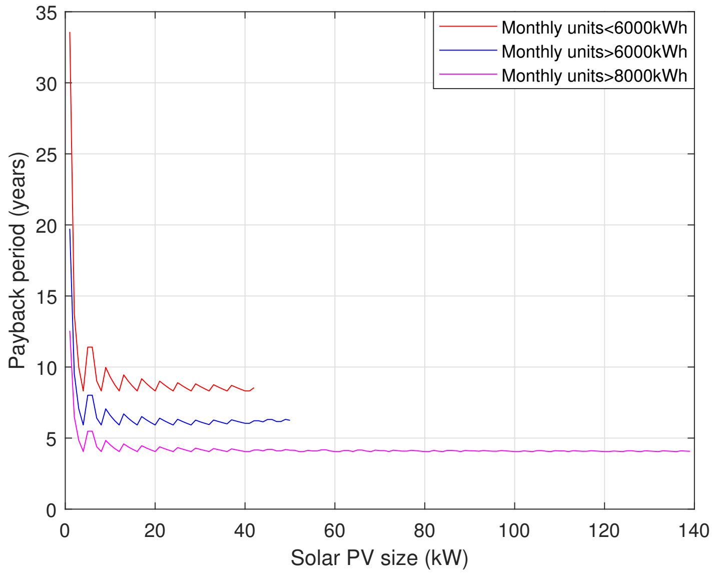


**Figure 4.** Payback period behaviour against solar PV size for three different residential loads with limited area.

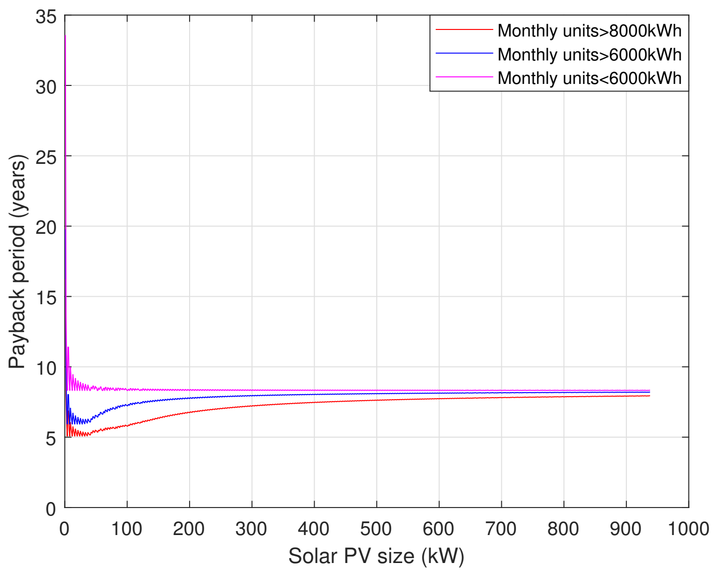


**Figure 5.** Payback period trends for three different residential loads with maximum area.

There are three cases with electricity energy units supplied by the SEC that are considered for residential load with solar PV under a limited area:(1) monthly energy units consumed less than 6000 kWh; (2) approximately equal to 6000 kWh; and (3) greater than two folds of 6000 kWh, as shown in Figure 6. Energy units consumed by a residential load greater than two folds of 6000 kWh have lower payback periods. The reason behind this lower payback period is the tariff breakdown applied by the distribution company, i.e., SEC. When energy units' consumption by a customer at a higher tariff rate is replaced by the flat and lowest tariff rate by using solar PV, that customer will receive more benefits, which results in achieving breaking even more quickly. Breaking even is directly related to the payback period. The payback period for energy units less than 7000 kWh but greater than or equal to 6000 kWh is the second lowest. The highest payback period is reported against the energy units utilizing less than 6000 kWh. In Figure 5, the residential load is not restricted to the limited area for solar PV, which results in the maximum solar PV size that the residential load can install with the minimum payback period. Similarly, commercial loads have same trends as the residential load but with different payback periods for maximum area with minimum payback period, as shown in Figure 7.

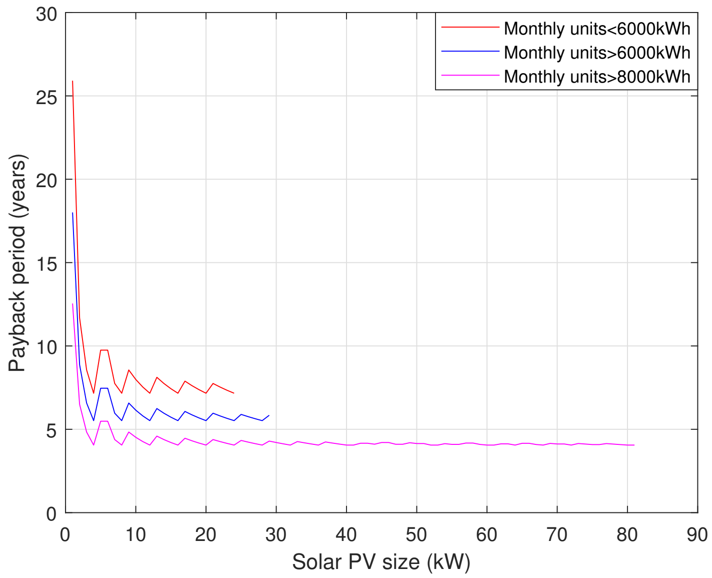


**Figure 6.** Payback period curves for three different commercial loads with limited area.

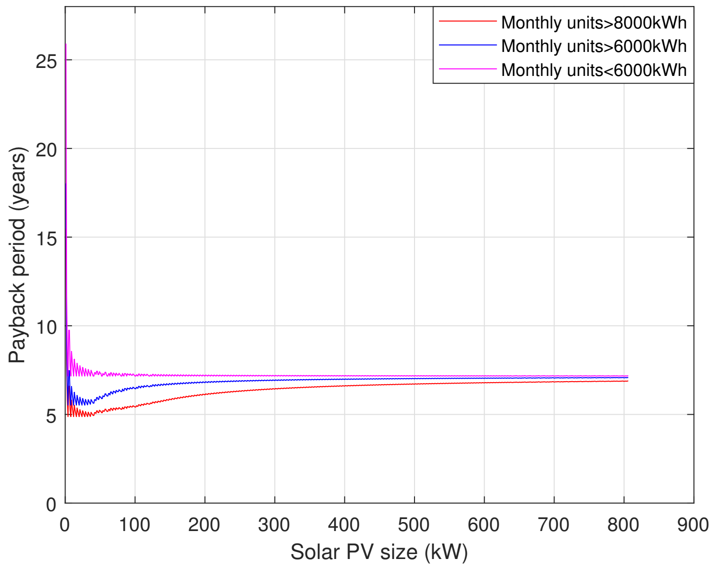


**Figure 7.** Payback period graph for three commercial loads with maximum area.

*Sensitivity Analysis for Residential Load*

Based on the above case study conducted for 12 months for each customer, after finding the desired payback period for each customer, 15 different payback periods were found for the given 60 customers. After analyzing the data, groups ($G_1$ to $G_{15}$) were created, comprising customers that share the same payback periods, and are reported in Table 6. The customers who have monthly units with consumption more than 6000 kWh for the entire year have the least payback period and on the top of the list in Table 6, which means that the capacity of the solar PV system for those customers will be at the maximum among all the customers. As the size of the solar PV decreases, payback periods increases with the given load profile of a regular customer under threshold limits. On the other hand, customers possessing less than 6000 kWh per month with different frequencies of occurrence are grouped and listed in Table 6.

**Table 6.** Payback period grouping based on load profile.

| Group Number | No. of Customers | Months with kWh = 0 | Months with kWh < 6000 | Months with kWh ≈ 6000 | Months with kWh > 8000 | Residential Payback (Years) | Commercial Payback (Years) |
|---|---|---|---|---|---|---|---|
| $G_1$ | 6 | 0 | 0 | 0 | 12 | 4.05 | 4.05 |
| $G_2$ | 1 | 0 | 0 | 0 | 11 | 4.24 | 4.21 |
| $G_3$ | 1 | 1 | 0 | 0 | 11 | 4.31 | 4.27 |
| $G_4$ | 1 | 0 | 5 | 0 | 7 | 5.02 | 4.83 |
| $G_5$ | 1 | 1 | 3 | 1 | 7 | 5.08 | 4.88 |
| $G_6$ | 1 | 0 | 5 | 1 | 6 | 5.31 | 5.06 |
| $G_7$ | 1 | 0 | 5 | 3 | 4 | 5.47 | 5.18 |
| $G_8$ | 1 | 0 | 8 | 0 | 4 | 5.92 | 5.52 |
| $G_9$ | 1 | 1 | 7 | 0 | 4 | 5.93 | 5.53 |
| $G_{10}$ | 1 | 0 | 8 | 2 | 2 | 6.06 | 5.62 |
| $G_{11}$ | 4 | 1 | 8 | 0 | 3 | 6.42 | 5.88 |
| $G_{12}$ | 1 | 0 | 9 | 1 | 2 | 6.98 | 6.27 |
| $G_{13}$ | 1 | 1 | 8 | 2 | 1 | 7.13 | 6.38 |
| $G_{14}$ | 1 | 0 | 11 | 0 | 1 | 7.51 | 6.64 |
| $G_{15}$ | 38 | 0 | 12 | 0 | 0 | 8.32 | 7.16 |

In Table 6, $G_1$ is the group that has six customers with monthly electricity units consuming more than two times of 6000 kWh for an entire year; no customers had monthly electricity units consumption equal to zero kWh, 6000 kWh, or less than 6000 kWh. The payback period of residential load for this group is 4.05 years, which is the smallest among all groups. $G_2$ is the group that comprises one customer having one month of electricity units with consumption less than 6000 kWh, zero months for monthly electricity units with consumption equal to zero or 6000 kWh, and 11 months with monthly electricity units' consumption greater than two times of 6000 kWh. Due to the one month, $G_2$ differentiates $G_1$ with a payback period of 4.24 years.

Here, one observation is noted that $G_3$ is a special case of $G_1$ where customers having one month with zero kWh unit consumption changes the payback period. This behavior shows that if the customer is not a regular user of electricity, then one may receive bigger paybacks based on average load consumption. $G_4$ is the group that has one customer having 5 months with monthly electricity units consumption less than 6000 kWh, no month with monthly electricity unit's consumption equal to zero, and 6000 kWh or greater than two times 6000 kWh. $G_5$ is the group that has one customer having 3 months with monthly electricity unit's consumption less than 6000 kWh, one month with monthly electricity unit's consumption equal to zero, and no month with monthly electricity unit's consumption equal to 6000 kWh or greater than two times of 6000 kWh. The list in Table 6 is sorted with smaller to larger payback periods for both residential and commercial customers.

Sensitivity analysis was conducted based on three parameters that are uncertain in most situations, i.e., solar PV degradation, SEC tariff, and PV system cost. By varying the solar PV degradation, the effect of linearly varying degradation is not linear, as shown in Figure 8, but it is more than the varied input. The groups with higher payback periods are more affected by this linear increment, i.e., $G_{15}$ at 0.5 % degradation has a payback period of 7.9 years; after a 1% increment, the payback period (if directly linked then it) should be 7.98 years, but it has the payback period of 8.3 years, which is 5.06% of the original case. Similarly with 2% increments in degradation, it has a percentage increase of 9.39 from the original value. From the above discussion regarding solar PV degradation, the solar PV systems that are smaller in size have bigger payback periods, and these systems are more affected by solar degradation, which emphasizes the need to use solar PV systems for customers having bigger load profiles, i.e., $G_1$.

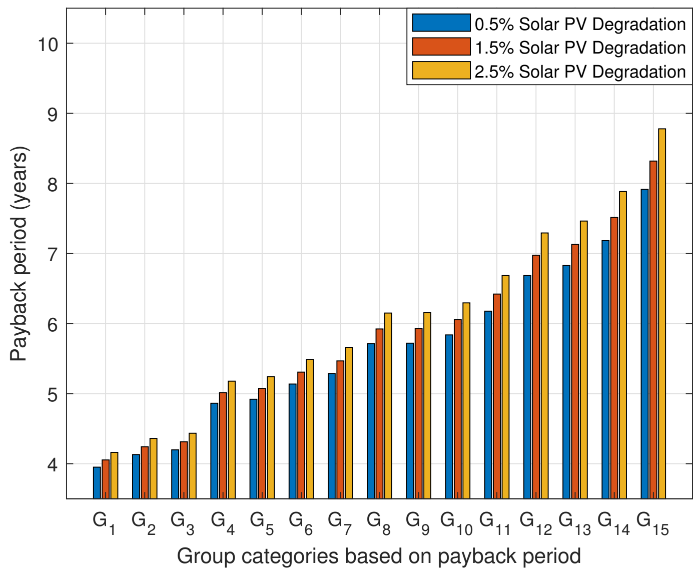


**Figure 8.** Solar PV degradation effect on different categories of payback periods.

Likewise, the case study with effect of SEC tariff increment on different group categories is also conducted and reported in Figure 9. With variations in the SEC tariff, the effect of linearly varying the SEC tariff is not linear, as shown in Figure 9, but it is more than the varied input. The groups with higher payback periods are more affected by this linear increment, i.e., $G_{15}$ at 0% SEC tariff increment has a payback period of 8.3 years; after a 10% increment, the payback period (if directly linked then it) should be 7.47 years, but it has the payback period of 7.3 years. Similarly with a 20% increment in SEC tariff, it has a percentage decrease of 22.89 from the original value (2.89% extra decrements). From the above discussion regarding SEC tariffs, solar PV systems that are smaller in size receive more benefits when SEC tariffs increase. Smaller systems are more affected by SEC tariff, which emphasizes the benefit they are taking from SEC tariff with only one tariff for all the units consumed by a load. This phenomenon of receiving benefits from SEC tariffs will be more effective when SEC tariffs have more than one range for the consumed units.

The linear variation in solar PV cost also have slightly nonlinear effects on the payback period, as shown in Figure 10. The payback period is more dissimilar than the varied input. By varying solar PV costs from 0% to 2.5%, the relative change in payback period is 3.61% (1.11% extra increment), and from 2.5% to 5%, the relative change in the payback period is 7.23% (2.23% extra increment).

The benefits of using the proposed methodology are directly related to end users as well as potential investors who are willing to produce green energy. The geographic location of Saudi Arabia on a world map is suitable for solar PV systems. Thus, the demand for the solar PV system introduces a new opportunity for investors. The proposed system not only helps in reducing carbon emissions but also saves water used in traditional methods of producing electricity and reduces the entropy of the earth by reflecting a part of the energy coming from the sun and heat produced by burning fossil fuels for steam turbines to produce electricity. Moreover, net metering scheme/infrastructure mitigates the potential voltage rise for reverse power flow by sharing generated energy with the distribution system [53].

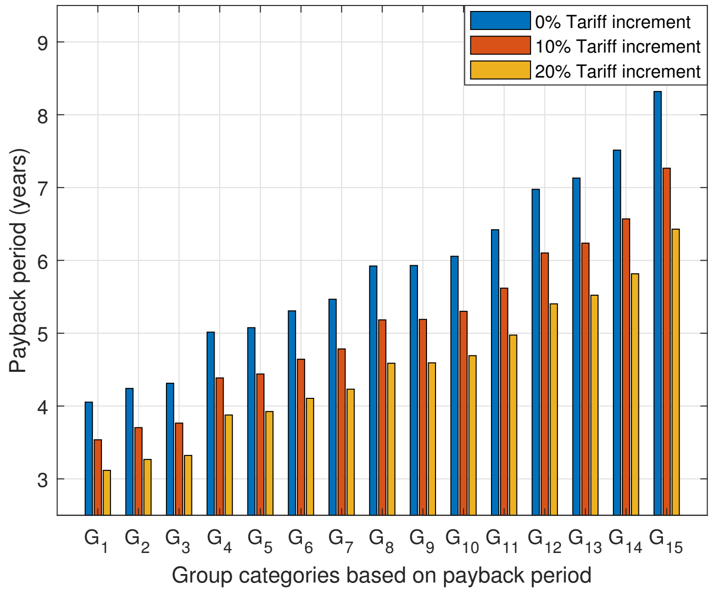


**Figure 9.** Effect of SEC tariff increment per kilowatt hour on different categories of payback periods.

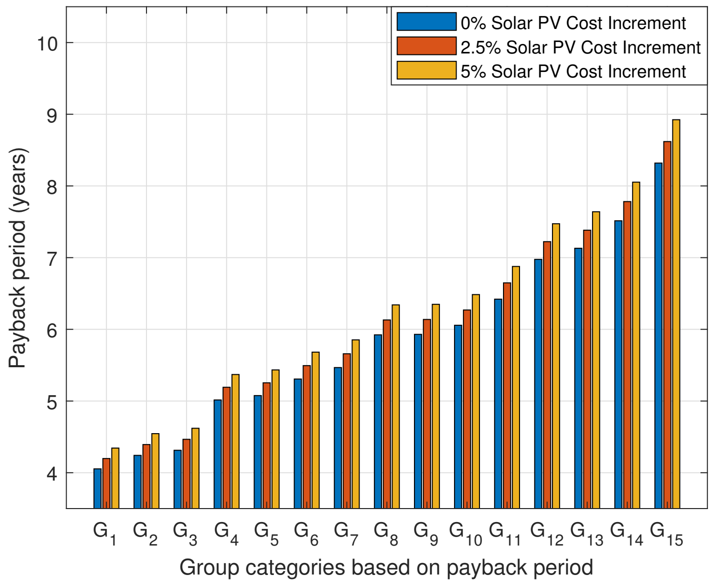


**Figure 10.** Effect of solar PV cost increment per kilowatt hour on different categories of payback periods.

## 4. Conclusions

The net metering scheme approved and published by Saudi Arabia's Electricity and Co-generation Regulatory Authority for small-scale solar PV systems allow end users to generate and export energy surplus to the utility grid. At this stage, the purpose of this scheme is to overcome future energy needs and to provide public awareness messages for saving energy for the future. In this context, this study is performed to provide residential and commercial load customers a clear expression as to the size of their solar PV system based on their yearly load profile in order to minimize payback period. The main findings by using the proposed expression include the categorization of customers based on their monthly unit consumption. It is vital to mention that the customers/loads with monthly unit consumption greater than 6000 kWh have lower payback period than compared to the customers/loads with monthly unit consumption less than 6000 kWh or 0 kWh. The reason behind this lower payback period is the tariff breakdown applied by the distribution company, i.e., SEC. When energy unit consumption by a customer at a higher tariff rate is replaced by a flat and lowest tariff rate by using a solar PV system, that customer will receive more benefits, which results in achieving breaking even more quickly. This break-even is directly related to the payback period. The proposed methodology is assessed with the help of a case study with real-time datasets from a city in Saudi Arabia. Furthermore, sensitivity analysis was also performed to observe the behavior of the payback period towards changing three parameters such as cost of solar PV system, SEC tariff, and solar degradation. Simulation results demonstrated the effectiveness of the proposed scheme. Sensitivity analysis for interest rate, solar efficiency, and inverter efficiency are key goals of our future research investigations. The proposed methodology is tested by using the already prepared scenarios to justify it. In the future, the model will be tested by using optimization techniques.

**Author Contributions:** Authors' contribution are as follows: Conceptualization, A.R. and M.K. (Mahmoud Kassas); data curation, A.T.A.-A., M.K. (Mahmoud Kassas) and M.K. (Muhammad Khalid); formal analysis, A.R., A.T.A.-A. and M.K. (Mahmoud Kassas); funding acquisition, A.T.A.-A. and M.K. (Muhammad Khalid); investigation, A.R., A.T.A.-A. and M.K. (Mahmoud Kassas); methodology, A.R., M.K. (Mahmoud Kassas) and M.K. (Muhammad Khalid); project administration, M.K. (Mahmoud Kassas) and M.K. (Muhammad Khalid); resources, A.T.A.-A. and M.K. (Muhammad Khalid); software, A.R., A.T.A.-A. and M.K. (Mahmoud Kassas); supervision, M.K. (Mahmoud Kassas) and M.K. (Muhammad Khalid); validation, A.R. and M.K. (Mahmoud Kassas); visualization, A.R. and A.T.A.-A.; writing—original draft, A.R., M.K. (Mahmoud Kassas) and M.K. (Muhammad Khalid); writing—review and editing, A.T.A.-A. and M.K. (Muhammad Khalid). All authors have read and agreed to the published version of the manuscript.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| $\chi$ | Discounted payback period with present degradation |
| $\eta_t$ | Solar PV panel's efficiency; |
| $\Gamma^{inv}$ | Single inverter's cost; |
| $\Gamma^{inv}$ | Single solar PV's cost; |
| $A_D$ | Annual degradation; |
| $A_j$ | Occupied area by a particular residential or commercial load; |
| $A_t$ | Solar PV panel occupied area; |
| $\Sigma_T^{inv}$ | Total cost of inverters; |
| $\Sigma_T^{I}$ | Total investment; |
| $\Sigma_T^{O\&M}$ | Total cost of operation and maintenance of solar PV; |
| $\Sigma_T^{pv}$ | Total cost of solar PVs; |
| $CLF_j$ | Connected load factor by *j*th customer; |
| $D$ | Degradation factor; |
| $DF$ | Demand factor; |
| $DL_j$ | Demand load by the *j*th customer in $kVA$; |
| $E_t$ | Solar PV output; |
| $G_t$ | Solar irradiance; |
| $i$ | Interest rate; |
| $j$ | Customer number; |
| $n$ | Number of years; |
| $Q^{inv}$ | Total number of inverters; |

| | |
|---|---|
| $Q^{pv}$ | Total number of solar PV panels; |
| $PD$ | Present degradation; |
| $LP$ | Linear programming; |
| $PBP$ | Payback period; |
| $PV$ | Photovoltaic; |
| $PW$ | Present worth; |
| $RCREEE$ | Regional center for renewable energy and energy efficiency; |
| $RES$ | Renewable energy sources; |
| $SAR$ | Saudi Arabian riyals; |
| $SEC$ | Saudi electricity company; |
| $SMI$ | Smart metering infrastructure; |
| $TMI$ | Total cost of investment. |

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