A techno-economic assessment of grid connected photovoltaic system for hospital building in Malaysia

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Abstract. Conventionally, electricity in hospital building are supplied by the utility grid which uses mix fuel including coal and gas. Due to enhancement in renewable technology, many building shall moving forward to install their own PV panel along with the grid to employ the advantages of the renewable energy. This paper present an analysis of grid connected photovoltaic (GCPV) system for hospital building in Malaysia. A discussion is emphasized on the economic analysis based on Levelized Cost of Energy (LCOE) and total Net Present Post (TNPC) in regards with the annual interest rate. The analysis is performed using Hybrid Optimization Model for Electric Renewables (HOMER) software which give optimization and sensitivity analysis result. An optimization result followed by the sensitivity analysis also being discuss in this article thus the impact of the grid connected PV system has be evaluated. In addition, the benefit from Net Metering (NeM) mechanism also discussed.

Keywords: optimization, grid connected, photovoltaic, levelized cost of energy, net present cost, net metering

1 Introduction

Recently, the tremendous increase in fossil fuel prices and emission problems that caused by traditional power generation has contributed to a transformation of latest technology in generating electricity by using clean renewable energy source such as solar and wind. A report by U.S Environmental Protection Agency (USEP) [1] shows that 32% of the total greenhouse gas emission(GHG) was comes from the electric power industry and another report of “Trends in global CO2 emission,2015” [2] indicate that almost 61% of total global CO2 emissions country or region are China (30%), the United States (15%), the European Union (EU-28) (10%) and India (6.5%). The statistic has present the serious challenges to the stake holder, engineers and researchers to find the solutions to reduce the pollution and at the same time full fill the energy requirement. Thus, a distributed generation(DG) especially photovoltaic(PV) technology systems are being utilized means of mitigating this challenges by generating electricity directly from sunlight[3].

Grid connected photovoltaic (GCPV) system is one of the PV technology where an electricity generating by solar panel is connected to the utility grid. A GCPV system consist of a numbers of solar panels, one or several unit of inverters, a power conditioning unit (PCU) and a grid connection equipment. The system size can range from a small residential and commercial rooftop (2 – 10kW) to a large utility scale solar farm stations (1-10MW). In comparison to stand alone photovoltaic (SAPV)
system, GCPV system is more reliable power source and considered low cost since they do not need a storage system[4]. Also, GCPV allow the power trading since it will supply power back to the grid if there are excess electricity generated by PV as well as GCPV system will help in reducing greenhouse gas emission. This is done with the displacing power needed to the connected or local load and providing additional electricity to grid. In addition, during the maximum solar irradiance hours, only fewer generations’ plants are required. Thus, it will reduce a transmission and distribution (T&D) losses. Installing the GCPV also will help to reduce the stress on the utility grid. This is because when demand goes up in urban areas, the utility has to upgrade its distribution network capacity.

Due to numerous benefits provided by GCPV system, many articles in literature have been discuss about this system that cover the area like modelling [5]–[8], sizing [9], [10] and control of GCPV [9], [11]–[13]. A review of trends and challenges of grid-connected photovoltaic systems including the standards framework for the system is discussed in article [14]. The technique for sizing grid-connected photovoltaic system using evolutionary program is presented in reference [9]. Aris in [15] presents the application of Particle Swarm Algorithm (PSO) method to optimize the photovoltaic grid-connected systems. In other work, Masoud [16] focuses on optimization of a grid-connected PV-based power plant. In this article, the portion of the purchased power from the utility grid and the area of the installed PV system are optimized in order to have a cost-effective and reliable energy system. A design of a grid-connected solar PV system for Uganda using HOMER energy software tool is presented in [17].

In Malaysia, a government is committed to decrease the GHG emission by 40% in year of 2035 , compared to 2005 level [18]. Hence, various programmes throughout several policies [19] is introduced to promote renewable energy particularly solar energy [20]. Also, the launch of feed-in-tariff (FiT) scheme for renewable energy electricity has started and supervised by Sustainable Energy Development Authority (SEDA)[21]. The updated status of grid-connected PV installed in Malaysia are presented in references [22] and [23]. There are 125 sites with total PV capacity power is approximately 1137.21 kWh of Grid Connected Building Integrated Photovoltaic (GCBIPV) systems until the end of June, 2011. In article [24], an economic evaluation of GCPV system for residential houses in Malaysia is conducted. Ali in [25] discussed the Malaysian Energy Centre (PTM)’s Suria1000 project which have several problems associated with rooftop PV systems. Due to support from the government in PV technology, many research papers have been published discuss a current research and prospectus scenarios for the solar energy development in Malaysia, including the solar potential [26], incentives for solar energy [27],[28] and solar installation either in off grid or grid connected system. The potential of PV system in low voltage (LV) distribution network is reviewed in [29] while an economic analysis for grid connected hybrid PV-wind is conducted in article [30]. The articles in literature reviews presented mostly highlight the research work and implementation of GCPV system through the development of BIPV in Malaysia. Yet, a development of GCPV system in a ground area for commercial building application like school, hotel and hospital are still limited. Therefore, this paper present an analysis of GCPV system to be installed in a commercial building. The selected area is a ground area of public hospital building in Malaysia. The evaluation is based on techno-economic point of view which employing the HOMER simulation software to carry out the technical and economic analysis. Net metering (NeM) mechanism also discussed to show the profits that hospital owner can obtained from the GCPV installation. There are six sections outlined in this paper. After this “Introduction” part, section 2 explain a system description and followed by section 3 which describe the inputs parameters required for the simulation. The operation strategy is explained in section 4 while results and analysis is elaborated in section 5. Finally, the conclusion is described in section 6.

2 System description

A grid connected PV system under this study that compose of PV panel and inverter is shown in Figure 1. In this design system, the battery system is excluded therefore the cost of the whole system is decreases by around 40-50%, depending on the type of the batteries used and the capacity required. Besides, since the designed system is supported by the grid, it is not only improve the reliability
condition, but also it has the economic benefits by reducing a system cost. The following subsection will describe the techno-economic parameter setup for each element used in the system including PV panel, inverter and utility grid.

![Diagram of grid connected PV system](image)

**Figure 1: Grid connected PV system**

### 2.1 Solar PV

In order to utilize the PV panel, the component size consideration is important whereby the size of PV arrays is dependent to solar radiation availability, load profile and the renewable fraction required. Renewable fraction is defined as the energy derived from renewable resources and used as part of supply to the load. Here, the renewable fraction is related to the PV production. Size of PV array can either be increased or decreased which depends to the amount of unmet electric load and renewable energy fraction set in the design. The cost data for PV panel is provided in Table 1. PV lifetime is set to be 20 years as long as PV panels typically have their best performance within 20 years and their output will continuously degrades after 20 years. A derating factor is assumed to be 90%. The initial capital, replacement and operational & maintenance (O&M) cost of PV considered in this study are RM2500 per kW, RM2500 per kW and 10 RM/kW/year respectively for 500 kW panel. The O&M cost includes the cost to remove dirt and dust on the PV panel and the PV panel direction adjustment.

### 2.2 Inverter

The PV arrays that produce direct current (DC) at a voltage which depends on the specific design and solar irradiation have to be converted to alternate current (AC) before it can be fed to the grid. Inverters commonly used to do a conversion process. The inverter size depends on maximum DC input power (i.e. size of the PV array in peak watt) as well as the maximum specified output power (i.e. the AC power provided to the grid). The appropriate inverter size is able to maximize the quantity of energy harvested from the PV arrays in addition to minimizing inverter cost. However, the overall system performance will not be affected or reduced. In this project, the average price of PV inverter is set at RM400 per kW and the O&M cost is estimated to be 5% of the total investment per year. The replacement cost for inverter is RM375 per kW. The efficiency of the inverter is 90% for 10 years lifetime. The inverter cost data is presented in Table 1.

### 2.3 Grid

When the PV system is connected to the grid and inter-connected with other power generating devices, the grid capital cost is equal to the interconnection charge. Otherwise, the grid capital cost is maintained at zero. In HOMER, the replacement cost of the grid is always zero. The grid O&M cost is equal to the annual cost of buying electricity from the grid (i.e. cost of energy plus demand cost)
minus any income from the electricity sold to the grid. The grid O&M cost for the grid-connected PV systems also includes the standby charge.

Table 1: Economical data of PV and inverter

| 1. PV Panel [31] | Value   |
|------------------|---------|
| Rated power (W)  | 315     |
| Lifetime (years) | 20      |
| Derating factor  | 90%     |
| Capital cost per kw (RM) | 2500 |
| Replacement cost per kw (RM) | 2500 |
| O&M cost (RM/kW/yr) | 10     |

2. Inverter[32]

| Rated power (kW) | 60     |
| Lifetime (year)  | 10     |
| Efficiency       | 90%    |
| Capital cost per kw (RM) | 400 |
| Replacement cost per kw(RM) | 375 |
| O&M cost per kW per year(RM) | 20   |

3 Input parameters for simulation

The hospital situated in East Peninsular Malaysia with coordinate of 3.4500°N and 102.4167°E is selected as a case study. The area of the hospital is 178,061.68 m² with 10 blocks of clinic and 24 wards. The area allocate 5975.90 m² for wards where the hospital have 650 beds and 13 units of operating theatre. The area of kitchen and canteen and public area are 2001.42m² and 16206.79m², respectively. However, in the analysis only use Block 1 and 2 load profiles for the simulation purpose.

3.1 Load profile

The load profile for the building is generated in HOMER software using monthly data and also the daily load data from the same source. The daily load profile for Block 1 and 2, HOSHAS is shown in Figure 2, and the variation of the monthly load profile is illustrated in Figure 3. The highest load consumption in this hospital is 922 kW daily in peak time for almost 24 hours. This is due to the activity of the hospital routine in the clinical and ward block. The average load consumption is 850 kWh/day distributed as peak load of 22.5 kW, with load factor of 0.464.

Figure 2: Hourly load profile of HOSHAS
3.2 Solar radiation

In HOMER, the solar resource input can be represented by either the solar radiation data or the clearness index. The solar radiation data was obtained from National Aeronautics and Space Administrative, NASA [33]. The data is 22-year average monthly solar radiation data of the location. The latitude and longitude, 3.4500°N and 102.4167°E were considered in the HOMER software, from which it received the radiation data. Figure 4 shows the solar radiation data for the studied location. The irradiance ranges from 5.056 kWh/m²/day to 6.036 kWh/m²/day and the annual average of solar irradiance is estimated to be 5.05 kWh/m²/day. It is noticed that solar irradiance is high in February, March, April, September and October, and is low in May and November. The reason of low solar irradiation is because of the South-West Monsoon season during this period.

3.3 Energy price

Main utility in Malaysia, Tenaga Nasional Berhad (TNB) charged the consumers not based on peak time usage but based on kWh of usage. TNB charged consumer based on kWh usage per month in step of 100kWh. As an example, for the first 100kWh, TNB charges 21.8 sen/kWh and it followed by 33.4 sen/kWh for another 100kWh. As this is the analysis on the hospital as a commercial building, a commercial tariff from TNB is take into consideration. Table 2 listed the electricity tariff in Malaysia for commercial customer like hospital[34]. In HOMER software, the term grid power price is refer to the electricity charged for energy purchased from the grid while a demand rate is referred to the price charges for the peak grid demand. Sellback rate is refer to the price that utility pays for power sold to the grid. The rate charges can be modelled in HOMER which is varies according to the time of the electricity used. However, based on Malaysia situation, HOMER cannot analysis the energy trading based on tariff data. Therefore, by using average method, it was assumed that tariff charged by the TNB is flat rated at 36.5 sen/kWh.
4 Operating strategy

The designed system operates based on grid connected system and Net metering (NeM) mechanism. Net metering is a billing mechanism that will give credits solar energy system owners for the electricity they add into the grid. NeM allow the residential and commercial customer who generate their own electricity from solar power to feed electricity they do not use back into the grid[35]. As an example, if the residential customer has a PV system’s on their rooftop, they may generate more electricity than the home demands during daylight hours. If the home is net-metered, the electricity meter will run backwards to provide a credit against what electricity has been consumed at night or at other periods where the home’s electricity use has exceeds the system’s output. In NeM, customers are only billed for their ‘net’ energy use. In this study, the generated power from PV will be used to supply the load demand in the building. Here, electricity generated by such system will reduce the power bill and the producer may be able to sell surplus electricity produced to the local electricity supplier. When renewable resources and storage system are insufficient to satisfy the load demand, the electricity of the grid would supply the deficit power [36]. In a grid- connected PV-based power plant, the use of a storage device can truly enable the power system to fully meet the power demand and increase the reliability of the power system. The grid itself acts as a virtual store of electricity, when electricity produced by PV is sell back to the grid. In Malaysia, Sustainable Energy Development Authority (SEDA) will manage the registration and installation of any renewable energy sources. The meter arrangement in NeM mechanism is illustrated in Figure 5.

![Net metering mechanism topology](image)

Figure 5: Net metering mechanism topology

| Table 2: Electricity tariff in Malaysia for commercial customer |
|---------------------------------------------------------------|
| **Tariff category** | **Current rates(1 January 2014)** |
| **Tariff C1 - Medium Voltage General Commercial Tariff** | |
| For each kilowatt of maximum demand per month | 30.3 MYR/kW |
| For all kWh | 0.365 MYR/kWh |
| The minimum monthly charge is RM600.00 | |
| **Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff** | |
| For each kilowatt of maximum demand per month during the peak period | 45.1 MYR/kW |
| For all kWh during the peak period | 0.36 MYR/kWh |
| For all kWh during the off-peak period | 0.22 MYR/kWh |
| The minimum monthly charge is MYR600.00 | |
5 Result and analysis

Through HOMER software, the economic analysis will be performed base on net present cost (NPC), levelized cost of energy (LCOE) and annual interest rate. In case of this optimization results, total NPC will represent the life cycle cost of a system, while the revenue includes an income from selling power to the grid. The cost analysis is done by comparing the optimal configuration of load grid connected system and GCPV system. The annual interest rate is stated for sensitivity analysis and it is varies from 1% to 4% in duration of 20 years project lifetime.

5.1 Payback period

Payback period can be defined as the expected number of years required to recover the original investment. The economic analysis for the payback period for the PV module is called energy payback time (EPBT). Based on [37], the formula to calculate the EPBT is as in the (1):

\[
EPBT = \frac{kWh_e}{E}
\]  

(1)

Where \( kWh_e \) is embodied energy and \( E \) is energy generation rate of the PV array. In this study, embodied energy is equal to 5600, PV array rated power at 50 kW and \( E \) taken from HOMER simulation equals to 60000 kWh/year. Hence, the EPBT is

\[
EPBT = \frac{5600 \times 50}{60000}
\]  

(2)

\[
EPBT = 4.67 \approx 5 \text{ years.}
\]

So, the payback time for this system is 5 years.

5.2 Installation Area of PV panels

As this is the grounded grid connected PV system, a suitable and sufficient area to place the PV panels have to be satisfied. This is to ensure the PV panels can produce certain power needed by the load. Based on the [27], the formula to find the exact area is defined in (3):

\[
A = \frac{P_{PV}(t)}{R(t) \eta_{PV}}
\]  

(3)

Where \( R \) is solar insolation in kW/m\(^2\), \( \eta_{PV} \) is efficiency of solar panels and \( P_{PV}(t) \) is power generated by the PV plant. In this case, the sufficient area to installed the solar PV panel in the hospital area is 182m\(^2\).

5.3 Optimization result

The optimal size indicates for the GCPV designed consist of 1000kW grid, 60 000kW PV and 4000 kW inverter, to full fill the average load profile of 0.922MW. This optimal size made the PV panel produce 108,169,616 kWh/yr and only need to purchase 3,795,915 kWh/yr from the grid, which is help the building owner to decrease their energy bill. The electricity produced by solar PV is shown in Figure 6. The excess electricity is 98,866,640 kWh/yr which can be sell back to the grid. In this GCPV, the unmet load is 247,376 kWh and renewable fraction is 0.96. The emission caused of carbon dioxide, sulphur dioxide and nitrogen dioxide are 318,746 kg/yr, 1,382 kg/yr and 672 kg/yr , respectively. Compared to conventional power generation, the emission caused of this gasses reduced almost 50%. The optimal cost needed for this optimization design are $153,200 (RM 679,579.81) and $165,489 (RM 734,109.05) per year for initial capital cost and operating cost, respectively. The total net present cost (TNPC) and levelized cost of energy (LCOE) require $2,615,252 (RM11,601,257.11) and $0.022 (RM0.0975) per kWh , respectively. This system have the renewable fraction of 0.97 and the capacity shortage is only 0.022. Furthermore, the optimal result on economic expenditure for this GCPV is tabulated in Table 3.
A sensitivity analysis is executed on the uncertain parameters that should give a significant effect on the TNPC. In HOMER software, the variable can be determined within certain value. The variable will be measure on how it will change the input variable can be specified. In this simulation analysis towards the economic view, an annual interest rate is selected as a sensitivity variable. The reason is because the inflation rates that fluctuate in every year may give the impact on the annual interest rate. According to Bank Negara Malaysia (BNM) [38] [39], the annual interest rate varies from 1% to 3.25% (current). Nevertheless, in this sensitivity analysis, the annual interest rate is assumed from 1% to 4% for 20 years of lifetime. The sensitivity parameters are set in order to observe the effect to the total NPC and LCOE. The increment in the annual interest rate does not affect the PV array capacity but it will give a significant impact to the LCOE, as shown in Figure 7. The result shows that although the annual interest rate is increase up to 4% in coming 20 years, the TNPC for GCPV is decrease. Means, the life cycle cost for GCPV is still considered cheap compared to the conventional system. However, the LCOE has shown a significant increment when there are changes in annual interest rate from 1% to 4% for 20 years lifetime, as shown in Figure 8.
5.5 Benefits from NeM scheme

Previously, FiT mechanism is introduced and implemented in Malaysia where customers who generate electricity have to sell all their electricity as the FIT are RE payments of electricity in kilowatt-hour (kWh). Around the globe, Germany is a country that successfully implementing FiT in order to promote renewable energy resources. In 1990, Germany started to implement FiT to avoid cost. At that time, the tariff payment is linked to electricity price until in 1999, the capacity of electricity generated by wind energy had reached 4400MW, and they started to revise back the FiT scheme. The new tariff calculation is based on generation of the technology. In Malaysia, FiT scheme is launched to attract more independent power producers to generate electricity as well as it acts as a kick-start for the renewable energy generation. As for this analysis, if the FIT mechanism is considered, the hospital management will benefit from MYR1200 for each 40kW a month. However, the FIT mechanism has been stopped due to limited quota. Then, NeM is introduced in Malaysia with more benefits where customers can avoid the dependence to TNB. Also, the implantation of NeM is aimed to encourage job creation in the downstream solar PV market, provide further impetus to growth of clean technology in Malaysia and to reduce the level of carbon emissions. Throughout this GCPV installation, if the hospital is net-metered, the hospital owner will benefit from the reduction in energy bills as well as the billing structure for NeM consumer are as shown in Table 4. NeM customer will only receive one bill every month. If NeM Rebate (RM) is more than utility supply (RM) then customer is given the net amount to utility. If NeM Rebate (RM) is more than utility supply (RM) then customer is given
monetary credit in the next bill. Unused credit amount will carry up to end of calendar year. At the end of each calendar year, change in tariff category or upon the termination of NeM contract with utility, any remaining credit will be adjusted to zero. The credit rate for energy excess to utility classified into two categories based on utility displaced cost. For low voltage connection, credit rate is at RM0.31/kWh and medium voltage connection rate is RM0.238/kWh (with assumption RM1 = USD0.2257).

### Table 4: Billing structure in NeM mechanism for customer in Malaysia

| Item                                          | RM               | Total Payable                                      |
|-----------------------------------------------|------------------|---------------------------------------------------|
| kWh import from utility X tariff              | A                | TNB supply : (A+B+C+D+E)                          |
| Good & Services Tax (GST) 1 : (A +E) X 6%     |                  | B                                                 |
| RE fund: A X 1.6%                             |                  | C                                                 |
| Penalties                                     |                  | D                                                 |
| Imbalance Cost Pass Thru                      |                  | E                                                 |
| kWh export X solar rate                       | F                | NeM Rebate : (F+G)                                |
| GST 2: F X 6%                                 |                  | G                                                 |
| Total Payable                                 |                  | (A + B+C+D+E) - (F+G)                             |

### 6 Conclusion

An optimal design based on economic point of view and technical sizing for grid connected PV system is presented in this paper. The configuration of grid connected system is installed to hospital building which have average load of 0.922MW, located in Temerloh Pahang, Malaysia. In order to generate the sufficient PV energy, a size of PV panel and inverter should be optimized. Therefore in this simulation through HOMER software, a 60 000 kW PV panel and 4 000 kW inverter is required to be installed in the area of 182m2 of hospital area. The installation of GCPV system in the hospital area will give a reduction in energy cost whereas the amount for TNPC and LCOE in 20 years period are $2,615,253 (RM11,601,257.11) and $0.022 (RM0.0975) per kWh, respectively. The sensitivity analysis is performed to observe the impact to both TNPC and LCOE due to changes in annual interest rate. Since the hospital is health and hopefulness building, the installation of GCPV is expected to give cleaner environment for the community inside the hospital. The implementation of NeM in the hospital will give the profit to hospital owner where they can reduce their energy bill. As a conclusion, although the initial cost to develop the GCPV, it will give a worth profits to the policy makers, building owners and society in terms of decrement in pollutant to the environment.

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