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Life Cycle Cost Analysis of a Standalone PV System

Abdul Qayoom Jakhrani
Faculty of Engineering, Universiti Malaysia Sarawak,
Kota Samarahan, Sarawak, Malaysia
e-mail: aqunimas@hotmail.com

Al-Khalid Othman
Faculty of Engineering, Universiti Malaysia Sarawak,
Kota Samarahan, Sarawak, Malaysia
e-mail: okhalid@feng.unimas.my

Andrew Ragai Henry Rigit
Faculty of Engineering, Universiti Malaysia Sarawak,
Kota Samarahan, Sarawak, Malaysia
e-mail: arigit@feng.unimas.my

Saleem Raza Samo
Faculty of Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Sindh, Pakistan
e-mail: sfaizsamo@yahoo.com

Shakeel Ahmed Kamboh
Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak,
Kota Samarahan, Sarawak, Malaysia
e-mail: shakeel.maths@yahoo.com

***Abstract*—The purpose of this paper is to assess the viability of standalone photovoltaic (SAPV) systems for the supply of electricity in remote areas of Sarawak. In order to achieve the objectives, the life cycle cost (LCC) of a SAPV system was computed by means of net present value (NPV) technique. All anticipated costs were discounted to their present values by considering the time value of money. It was found that the capital cost makes up around 58% and future costs shares 42% of all expenses. PV modules contribute 9% and battery bank shares 52% with almost 8 days of autonomy at LLP of 0.01. Controller adds 5%, inverter 8%, civil work 17% and O&M 9% of total life time system cost. The estimated net energy cost from SAPV system was found to be US$2.5/kWh, which is 20 times higher than average electricity tariff in Malaysia. It is concluded that the SAPV systems could only be preferred where the extension of power transmission lines is expensive for the supply of electricity in isolated areas.**

Keywords- life cycle cost; discount rate; net present value; standalone photovoltaic system

I. INTRODUCTION

Economic analysis is an organized approach to find out the optimum solution of specific objective under the given assumptions and constraints [1]. In SAPV systems, the economic evaluations are being carried out to quantify the projected costs incurring from the system lifetime. Typically, two different types of costs are expected from solar PV systems, namely capital costs and future costs Capital costs are acquisition costs incur prior to the occupation of the facility including the installation cost and purchasing cost of system components [2]. Future costs are the forthcoming expenditures projected from the system operation [3]. Future costs are further classified into two parts, such as recurring and non-recurring costs. Recurring costs take place every year over the span of study period for example the operation, maintenance and repair costs. Operation and maintenance costs (M_c) are planned costs to keep the PV system in good condition by deliberate inspections. Repair costs are unforeseen, and very difficult to predict when they will happen. For simplicity, the maintenance and repair costs are treated as recurring cost. For mature conventional systems, the annual M_c is considered to be about 1% to 2% of the system's initial capital cost [4]. Non-recurring costs are known as onetime costs and they do not take place every year over the span of PV system life. These include replacement of major components. These costs are predictable expenditures that are required to maintain the smooth operation of facility.

A. Economic Factors

The major economic factors required for economic evaluations are life cycle length of system, inflation rate and discount rate. The length of the analysis period is chosen to be the best service life of the longest-living system component i.e. PV modules in case of SAPV systems. Inflation rate refers to a general rise in prices measured against a standard level of purchasing power. Typical annual inflation rates for remote power systems are 5 to10 % for fuel and 3 to 8 % for non-fuel expenses [4]. The mean inflation rate in Malaysia was 2.77% reaching an historical high of 8.50% in July of 2008 and a record low of -2.40% in July of 2009 from 2005 to 2010 [5]. Discount rate is defined as a rate of interest reflecting the investor's time value of money. The real discount rate in Malaysia from 1987-2010 was reported as 4.2% [5]. Discount rates have two types, real and nominal. Nominal discount rate includes the rate of inflation, whereas, the real discount rate excludes it. However, the use of either discount rate in its corresponding present value calculation derives same result [4]. The

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discount rates can also be converted from real to nominal or vice versa by incorporating the inflation or deflation rates as:

$$d_r = \frac{1+d_n}{(1+e)} - 1 \tag{1}$$

B. Economic Measures for Cost Estimation

Various economic measures could be found in literature. The cost-effective alternatives are those with the lowest life cycle cost (LCC), revenue requirements (RR), levelized cost of energy (LCOE), simple payback (SPB) and depreciated payback (DPB), and the highest net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR), benefit to cost ratio (B/C) and savings to investment ratio (SIR) [6-8]. Different measures may not always provide the same answer when comparing alternatives [9]. For example, SPB approach rejects an alternative that have a longer payback period, though it shows high long-term returns.

C. Life-Cycle Cost (LCC)

Life cycle cost is the sum of all the costs associated with an energy delivery system over its lifetime or over a selected period of analysis in today's dollars [10-11]. It discounts the all expected costs to their present value and takes into account the time value of money. It is also an important tool for ranking the cost of ownership between mutually exclusive alternatives [12]. However, LLC is not recommended for the economic evaluation of approval or refusal of any investment. In LCC analysis, the future costs are adjusted to present value by applying the discount rate over the period between the present and the time when the cost will be incurred. If the real discount rate is used in present value calculations then the cost should be expressed in constant dollars [13]. Larson and Society [14] model is selected for economic analysis with some modifications. It is expressed as [10]:

$$LCC = \frac{(I_{pc} + I_c + M_c + R_c + P_c) - R_v}{E} \tag{2}$$

where I_{pc} is initial purchasing cost of equipments, I_c is installation cost, M_c is operation and maintenance cost, R_c is replacement of system components cost, P_c is environmental pollution mitigation and disposal cost of residues, R_v is salvage value of remaining materials and E is the energy produced by the system. The cost of civil work and installation will be around 40% and M_c 1% of initial purchasing cost of components [14].

However, the batteries, controller and the inverter need to be replaced periodically during the system lifetime. The other components are assumed to have the system life. Both environmental protection cost (P_c) and salvage value (R_v) are future cost and often difficult to estimate because these are varied from case to case. Environmental protection cost (P_c) may be taken from 3% to 20% of initial purchasing cost. R_v is the only costs of LCC analysis, which is acceptable because it minimize the system cost [15]. All types of projected costs such as maintenance, repair, operation, replacements and residual value are discounted to their present value for LCC of the project.

D. Calculation of Net Present Value of LCC

For a fixed amount of money to be paid in n years, the present value (P_v) of non-recurring costs (replacement costs) is determined by:

$$P_v = \frac{F_n}{(1+d)^n} \tag{3}$$

where F_n is constant dollar cash flows in year n. All the costs are converted into constant dollars in base year, where $n=0$, and d is real discount rate. For annual recurrent expenditures, the present value (P_v) for every future year's cash flows are calculated separately when the each future year's cash flow is uneven or differs in amount. The P_v for of all individual years' cash flows can be determined by:

$$P_v = \sum_1^n \frac{F_n}{(1+d)^n} = \frac{F_1}{(1+d)^1} + \frac{F_2}{(1+d)^2} + \frac{F_3}{(1+d)^3} + \ldots\ldots + \frac{F_n}{(1+d)^n} \tag{4}$$

If the annual recurrent expenditure or future expenditures (cash flows) are fixed in size and regularly occur over a specific number of periods, the situation is known as an annuity. Then, the P_v is calculated as:

$$P_v = F_n \frac{(1+d)^n - 1}{d(1+d)^n} \tag{5}$$

II. METHODOLOGY

The load demand for a residential home in Malaysia is typically between 4 kWh/day to 10 kWh/day [16]. Therefore, a load demand of a typical house in Kuching $(\phi = 1.48^o)$, Sarawak was considered as 6.3 kWh/day for this study. After the incorporation of system and component losses, the load demand for the SAPV design was found to be 10.0 kWh/day. The net cost per kWh of energy is calculated by using the actual solar irradiation and ambient temperature data acquired from Malaysian Meteorological Department Regional Office Kuching [17-18]. The cost analysis is carried out by using LCC method with NPV technique [10].

The loss of load probability (LLP) was fixed at 0.01 for maintaining the desired power reliability. LLP = 0.01 means that the power cannot be supplied to the residential house for 3.65 days (87.6 hours) per year. The tilt angle was taken as the 10^{o} due south. Monocrystalline PV modules with the rated power of 175 W and efficiency of 13.45% were considered for this analysis. However, the actual efficiency of PV array was calculated by means of selected empirical models [19]. The efficiency of other components such as charge controller, battery bank, inverter and the losses of distribution system (wires and cables) were assumed as 98%, 75%, 90% and 95% respectively as per literature review. The actual retail price of a unit PV module was US$ 899.00 with US$ 5.00/Wp capacity and the retail price of unit battery was US$ 485.00 with US$ 0.20/Wh capacity was considered. The unit cost of controller and inverter were US$ 1900.00 and US$ 3000.00 as per market values.

The depth of discharge of a battery bank was maintained at 50%. The temperature correction factor in the battery capacity was considered 0.006/°C and self discharge rate was taken 0.002/day [20-21]. The real discount rate was taken as 5% on the basis of 24 years average values of Malaysia [5]. The length of the analysis period was chosen to be the best service life of the longest-living component, i.e. the PV modules with a lifetime of 25 years. The life span of controller and inverter were assumed to be 9 years each and they will be replaced for 2 times in the life time of project. Battery life time was determined by using an empirical equation [22]. The cost of system installation, annual maintenance, pollution mitigation and recycle value of scrap material was assumed to be 40%, 1.5%, 3% and 5% of the purchasing cost of the system components respectively.

III. Results and Discussions

From the economic analysis of SAPV system, it is found that the capital cost makes up 58.5% and future cost shares 42.1% of all expenses, with an amount of US$ 46804.00 and US$ 33702.00 as shown in Figs. 1 - 3. The item-wise and category-wise cost of PV system components are given in Figs.1 and 2 respectively. The total electricity was produced by the plant was found 2294.00 kWh/year or 6.3 kWh/day. The total life time cost was estimated to be US$ 80014.00.

It is discovered that, PV modules contribute 9% battery bank 52% with almost 8 days of autonomy at the LLP of 0.01, controller 5%, inverter 8%, civil work 17%, O&M 9% of total life cycle cost. The share of pollution mitigation cost and salvage value is less than one percent each as shown in Fig. 3.

The net energy cost determined at Ipoh, Perak, Malaysia was US$ 1.75/kWh [23]. In Malta, the estimated energy cost was US$ 2.44/kWh [12]. The levelized energy cost for a SAPV system would be in ranges from US$ 1.039/kWh at lower Mediterranean countries to US$ 8.177/kWh in northern European countries [24]. In this analysis, the net energy cost was found to be US$ 2.48/kWh. The obtained cost per kWh was found within acceptable range as compared with other places of Malaysia and European countries.

At present, the average electricity tariff for industries and commercial purposes in Malaysia is US$ 0.125/kWh, which is 20 times lower than anticipated costs incurred from SAPV system. The prices of conventional power generation units are increasing due to inflation and cost of the PV system components are decreasing since last two decades. The PV systems are costly investment at present. However, these systems may be competitive in near future, because these are environmental friendly alternatives and did not produce any greenhouse gases. SAPV systems have no moving part. Therefore no maintenance is required for their operation. The users can adapt the system capacity up to the desired level due to their modularity and expandability [25].

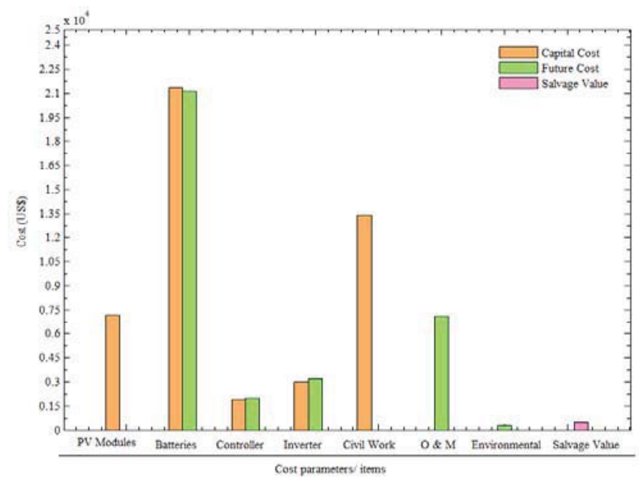

Figure1. Item-wise cost of a SAPV system components

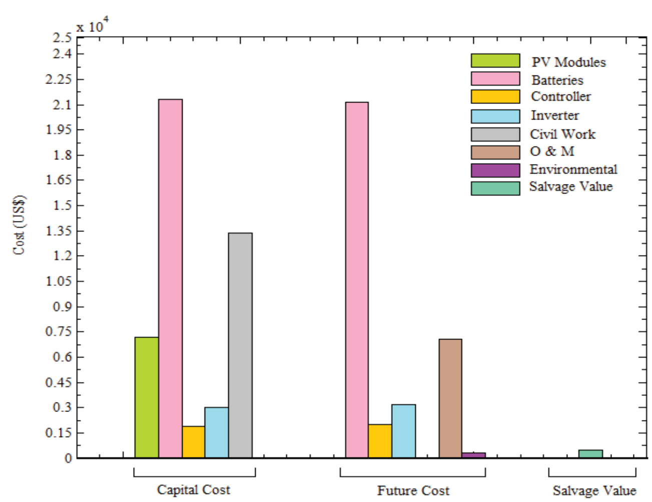

Figure 2. Category-wise cost of a SAPV system components

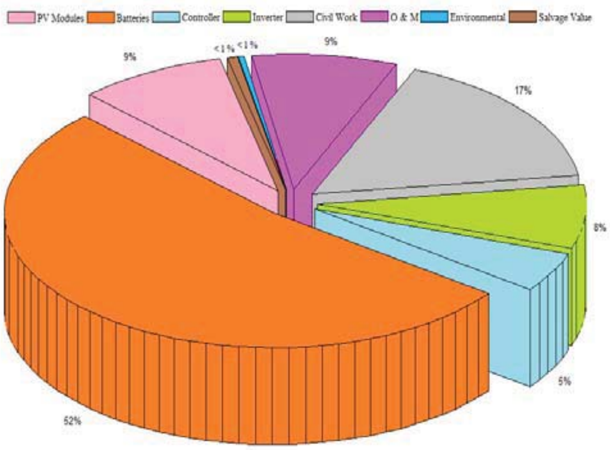

Figure 3. Percentage-wise cost of a SAPV system parameters

IV. CONCLUSIONS

It is found from the cost analysis of a SAPV system that the capital cost makes up about 58% and future costs shares 42% of total incurring expenses. The total electricity generated by SAPV system will be 2294.0 kWh/year or 6.3 kWh/day. PV modules contribute 9% and battery bank shares about 52% of cost with almost 8 days of autonomy at LLP of 0.01. Controller adds 5%, inverter 8%, civil work 17% and O&M 9% of total life time system cost. The pollution mitigation cost and salvage value contributes less than one percent each of the total anticipated system cost. Power generating by SAPV units facilitates to avoid 70 tones of CO_2 and 111 tones of CO_2 to the atmosphere emitted by a 2 kW and 5 kW rated power diesel generator with a load demand of 1.05 kW/hour (6.3 KW/day).

The estimated net energy cost from SAPV system was found to be US$ 2.5/kWh, which is 20 times higher than average electricity tariff in Malaysia. However, the diesel prices are rising and PV system prices are continuously declining since last two decades. Therefore, the SAPV systems could be preferred where the extension of power transmission lines is expensive for the supply of electricity in isolated areas.

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