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Life Cycle Costing of PV Generation System

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ABSTRACT

Life cycle costing (LCC) is a methodology used first time by the Department of Defense of United State, it's an economic calculation of all costs propagated during the life span of any technical system. For Renewable Energy (RE) systems, LCC is a good methodology, which shows the cost-effectiveness of using RE as an alternative source compared to conventional power generations. A LCC model was introduced for PV generation system. Data collection was done through four different cost data sources. The results shows that the average module price is $0.56/Wp and the capital investment cost is $1.184/Wp. For a 20 years PV project life-time, the operation and maintenance cost forms 27% of the total LCC of the system.

1. Introduction

Alongside with the growth of renewable energy (RE) market, the need for an accurate and precise evaluation for an economic feasibility of these technologies is a pressing issue. Accordingly, all costs regarding the project should be taken into consideration from the conceptual to disposal phases, or what it was called life cycle costing (LCC). The concept of LCC was firstly introduced in 1970s by the U.S. Department of Defense (DoD). Since the LCC concept was widely adopted in a wide range of industrial sectors including energy, construction, manufacturing, transportation and healthcare [2]. As it's known that the solar energy is directly converted to electricity through photovoltaic (PV) generation system. PV is a semi-conductor materials (i.e. silicon) that shows the PV effect [3].

1.1 Global Renewable Energy Status

Renewable energies (RE) jumped a high pass in the last few years as a result of the declared polices that bolstered energy security and manageability. By the end of 2015, the global harnessed renewable power is 1,985GW extended at its quickest rate to date. However, 8.3% is the total RE augmented in 2015 translated to 152GW installed capacity at that year [4]. Experts expected that REs would represent very nearly to 66% of the generated power energies extensions by 2020 [5]. Solar PV energy in the last decade has risen as the most developed RE in spite of decreased oil prices at 2015. Hence, $256GW_p$ globally cumulatively installed capacity at the end of 2015 and expected to reach $321GW_p$ by the end of 2016 with 34% increase from the last year [6-8], thanks to the drastically fallen prices of PV module

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in the last decade as it shown in Fig 3 [9-10]. Additionally, the automated innovations in manufacturing processes and metallization solutions also contributes to the current prices [11-13]. PV cells manufacturing costs has sharply declined from more than $\$100/W_p$ at the seventieth of the past century to approximately less than $\$0.5/W_p$ nowadays and expected to reach $\$0.36/W_p$ in 2017 [8, 14].

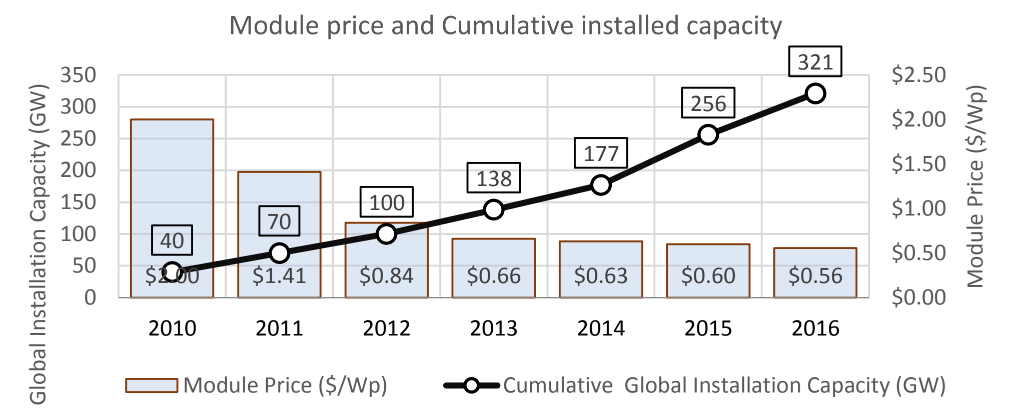

Fig 3. Cumulative global installation PV capacity and module price trends.

Accordingly, there are already 30 countries has been reached grid-parity (PV system generation costs less than domestic retail electricity prices) [15, 16].

1.2. Definition of Levelised Cost of Energy (LCOE)

The cost of solar PV system initially measured by $/Watt which lacks many aspects (e.g. financial policies, system life-time and solar equipment performance) [3]. LCOE, also called Levelised Cost of Electricity is a more accurate energy cost calculation; well-known, accepted and widely used technique and it has been adapted by many researchers and agencies [11, 17-27]. LCOE is defined as the ratio between the life-cycle cost (LCC) of the PV system to the whole life produced energy [28] as shown in Eq. (1).

$$LCOE = \frac{Life\ Cycle\ Cost\ (LCC)}{Life\ Cycle\ Energy\ produced\ (LCE)} \tag{1}$$

The LCE produced can then be calculated on an annual bases discounted with *r* discount rate as shown in Eq. (2).

$$LCE = \sum_{i=0}^{n} \frac{AEP\ x\ (1-\mathrm{df})i}{(1-r)i}. \tag{2}$$

Where *AEP* is the expected annual energy produced, which is the estimated life of the project, *r* represents the interest rate. With system life progress its output power yield will be degraded with a factor *df* in order to get a better energy harvest forecasting [29].

1.3. Life Cycle Costing (LCC) Model for Solar PV

The developed LCC model of solar PV generation system distributed into five cost categories: development/planning ($\mathbf{C_{Dev}}$), PV panels ($\mathbf{C_{Panel}}$), electrical apparatus ($\mathbf{C_{Elec.}}$), mounting structure and civil work ($\mathbf{C_{Civil}}$), in addition to operation and maintenance ($\mathbf{C_{O\&M}}$) as shown in Eq. (3).

$$LCC = C_{Dev} + C_{Panel} + C_{Elec.} + C_{Civil} + C_{O\&M} \tag{3}$$

Each category of PV system's LCC has a sub-category for a deeper details as depicted in Fig 1.

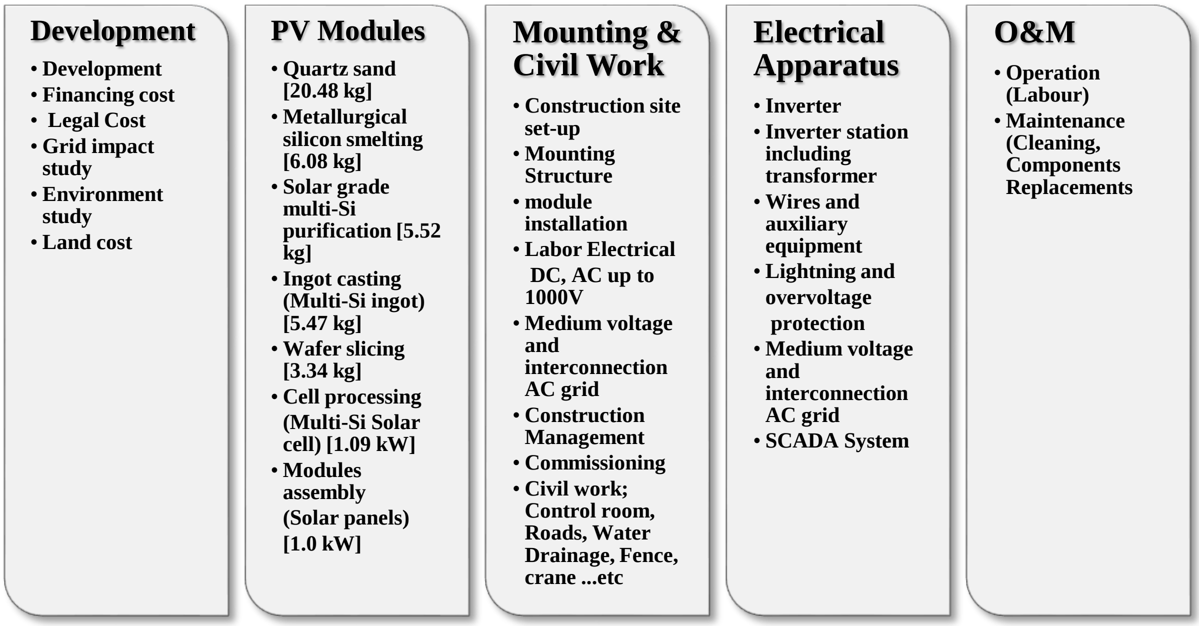

Fig 1. Life Cycle Costing (LCC) model for PV system.

2. Methodology

Based on our constructed LCC model of PV plant Eq. (3), the PV plant cost data was collected from four sources as in Fig 2.

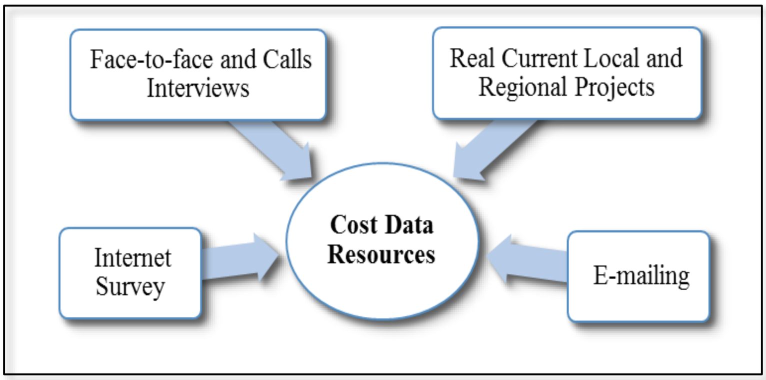

Fig 2. Cost data resources

2.1. Current Real Local and Reginal PV Projects

Depending on local and regional different PV plant sizes bidding contracts with up to date market prices. In our case, a 21MW and 5MW local projects, additionally, a 3.432MW PV project conducted with Almaiden Company in Jeddah, Saudi Arabia.

2.2. Face-to-face Interviews

Face-to-face interview was conducted with local and international PV providers, EPC contractors and expert engineers in the field. Specially, in JIMEX exhibition held in Amman May, 2016 where a various

PV companies participated from around the world. A one sample of these are YI.Solar Company where its system prices were taken as a reference.

2.3. Internet Survey

A thorough deep internet survey about the latest up to date prices regarding the main PV system components i.e. modules, mounting structure and inverter. Regarding the PV module prices, our survey covers the common used PV modules in the market and modules with high cost due to its high efficiency were excluded to make our prices more realistic. To get one representative price, we took the weighted average of the module prices based on their efficiencies.

2.4. E-mailing

E-mailing comprehends the international PV manufacturers and EPC contractors enquiring from them about the latest prices of PV system components.

Table 1. The survey resulted LCC's components of a PV plant normalized to ($/Wp).

Cost Item	21MW	5MW	3.432MW	YI.Solar	1MW JUST	1MW India	Survey	Average ($/Wp)
Development	0.054	0.072				0.060		0.062
PV Panels	0.634	0.628	0.594	0.44	0.531	0.617	0.4505	0.556
Inverter	0.107	0.124	0.126	0.15	0.100	0.160	0.1598	0.132
Electrical Parts	0.165	0.153	0.138	0.1	0.156	0.098		0.135
Rack steel	0.110	0.102		0.05	0.1		0.0710	0.087
Rack Installation	0.070	0.060			0.069			0.066
Civil & Installation	0.214	0.143			0.143	0.082		0.145
Total Investment	1.354	1.282						1.184
O&M	0.014	0.032				0.027		0.025

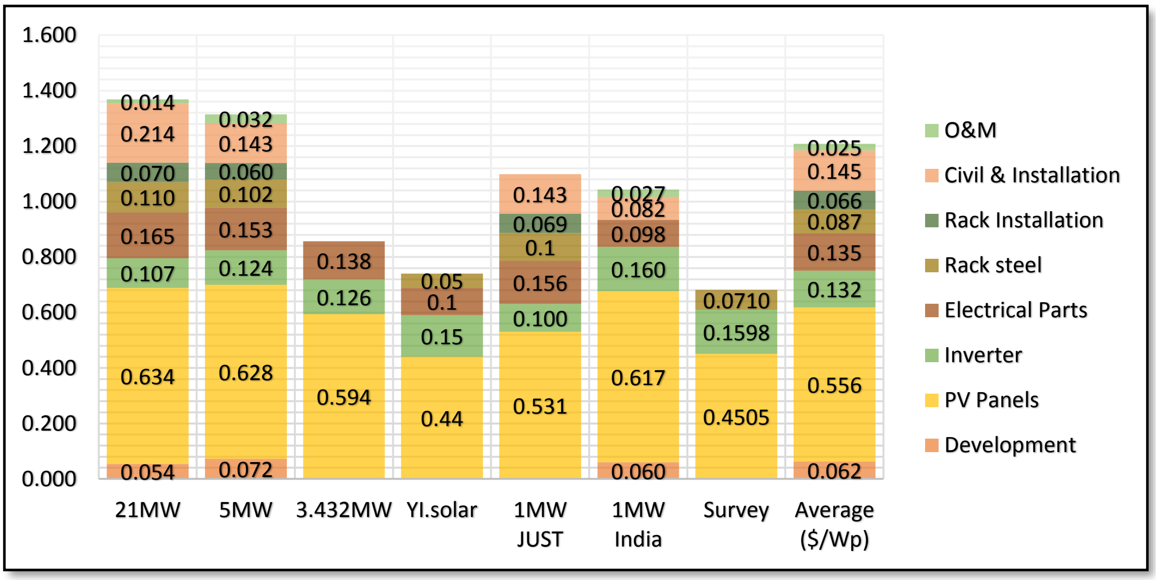

Fig 3. Summary of the normalized PV system component's costs in ($/Wp).

3. Results and Discussion

3.1. Collected Data

The collected data are summarized in Table 1 which shows the resulted LCC's components of a PV plant normalized to ($\$/W_p$). For better visualization of data, Fig 3 is a stacked Bar Chart shows clearer description of the tabulated data.

3.2. Investment Cost

Concerning total investment cost excluding $C_{O\&M}$, Fig 4 shows the Pie Chart of the main cost components. From Fig 4 we can see that how PV panels represents the major investment cost (~47%), followed by C_{Civil} (25% resulted from Rack steel 7%, Rack installation 6% and Civil & Installation 13%). C_{Elec} consists of Electrical parts 12% and Inverter 11%. C_{Elec} represents the third larger cost component with 23%. Eventually, the C_{Dev} represents the smallest portion of the investment cost with 5% share.

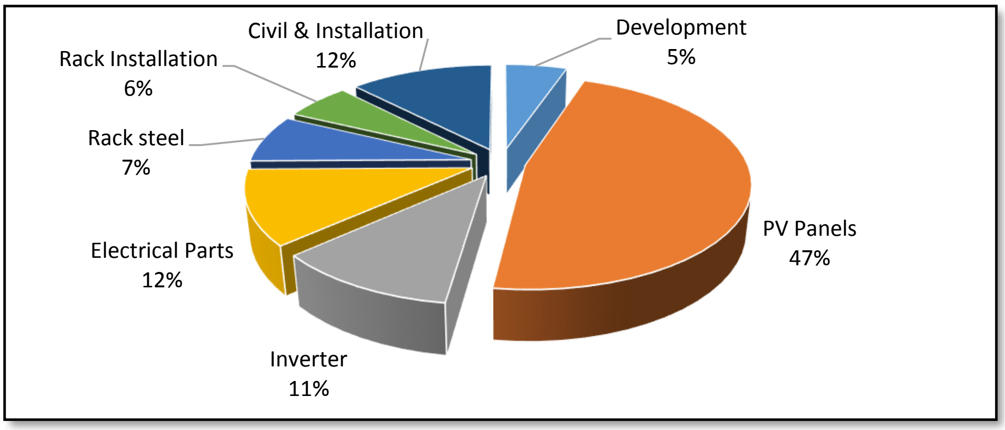

Fig 4. Average PV plant component investment costs (% of total investment cost).

3.3. LCC breakdown structure

By regrouping the cost structure harmonizing with our developed PV cost model as depicted in Eq. (3), the investment cost which include the Development, PV Panels, Electrical Apparatus, Civil Work and Installation in addition to 20 year discounted O&M cash flow (at 5% interest rate and 2% inflation rate) could be distributed according Fig 5. For a 20-year PV project life-time, the capital investment cost forms more than 70% of the LCC of the project, while the $C_{O\&M}$ complement the LCC which occupies 27%.

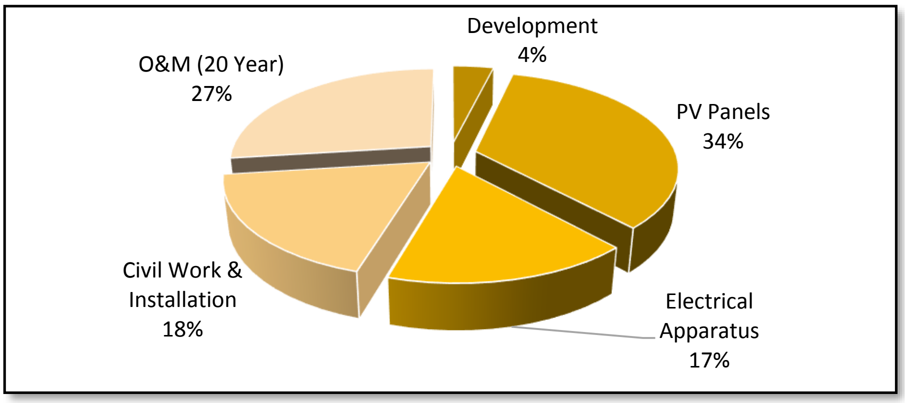

Fig 5. Average PV Plant LCC structure according to the developed model.

4. Conclusion

Life Cycle Costing (LCC) is a good methodology especially for a Renewable Energy (RE) systems which shows the benefits of using RE as an alternative source compared to fuel incurred costs. A model for LCC for PV generation system was introduced, and a methodology for cost data acquisition was followed depending on four different cost data sources. The results shows that the average module price is $0.56/Wp and the capital investment cost is $1.184/Wp. For a 20 years PV project life-time, the operation and maintenance cost forms 27% of the total LCC of the system.

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