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Comparison of LCOE of Battery Storage and P V System

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Abstract: Sustainable energy is a key topic of research globally for more than two decades. The research for alternate sources has found sufficient inputs from various dimensions. Distributed energy resources(DERs) available for utilization ranges from biomass to solar power. Selection of the resources to meet the load is always dependent on the economic values involved. The levelized cost of electricity (LCOE) is one such metric that helps in this process by evaluating the life time energy generation cost. This paper is an attempt to compare the LCOE of two different DERs with the utility energy price.

Keywords: LCOE, LCC, PV, Lithium ion, Battery, DERs

I. INTRODUCTION

Energy being a crucial commodity plays a vital role in economic and technical development of a country. The electricity usage of a country determines the degree of development of the country. Ever increasing demand of energy has posed tremendous pressure on its limited resources and has necessitated optimum use of its resources [14].The proper choice of the available energy resources thus becomes essential. The energy source with least cost always appeals to the consumers. The solar power generation is gaining much importance with the advent of distributed generation. It created a new pattern of power generation and distribution leading to the development of micro grids and nano grids. The output power obtained from the photovoltaic (PV) system is not constant throughout the day. Weather patterns also affect the power output. In order to obtain uniform power from the PV system MPPT technique is used. Different algorithms are used for designing the MPPT technique. The performance of a photovoltaic system can further be improved by making the MPPT algorithm more efficient. The renewable/ sustainable energy resources are now being popularly used for distributed generation rather than diesel generators and other unconventional energy resources. Researches for harnessing solar and wind energy most effectively are progressing nonstop. Now it's possible to charge the electric vehicles using solar and wind energy reducing the burden of existing transmission line. Vehicle to Home (V2H) capability describes a scenario in which a plug-in electric vehicle (PEV) not only receives charge from the grid to power the vehicle, but also provides backup power to an islanded load such as a home during an outage, similar to a stand-alone emergency generator [4]. Combining a plug-in electric vehicle (PEV) with a PV system provides the opportunity to create a single home microgrid with considerable capabilities to provide backup power. Particularly with curtailed or shifted load during a grid emergency situation, an electric vehicle based V2H-PV microgrid system could provide considerable backup duration capability supporting the conventional home load [5]. For the proper determination of the cost of a given energy generation technology, a bench mark needs to be developed for comparing variety of technologies. The levelized cost of electricity (LCOE) serves as such a metric. All relevant parameters are considered and the end result is expressed in price per kilowatt-hour. LCOE can be considered as the price at which energy must be sold enough to break even over the lifetime of the technology. It is the net present value expressed in terms of unit price of electricity (rupees per kilowatt hour).It is an economic assessment of energy cost of a technology over its life time and energy production during the time. LCOE can also be regarded as the average minimum cost at which electricity must be sold in order to break-even over the lifetime of the project [19]. LCOE analysis help determine the benefits and drawbacks of various energy systems. When comparing conventional generating sources with renewable systems such as solar, wind or nuclear a LCOE analysis can tell the most suitable system that can be implemented.

The general equation for calculating LCOE is given in Equation (1) [19]

$$LCOE = \frac{Life\ Cycle\ Cost\ (Rs)}{Life\ time\ energy\ production\ \ (kWh)} \qquad (1)$$

The different costs to be determined for every energy system: a. capital costs b. annual energy cost c. Operation and maintenance costs d. Renewal costs and e. other cost [16]. The importance of the factors varies among the technologies. The energy generation from renewable have no fuel costs and they have negligible variable O&M costs. For such DERs the LCOE varies in rough proportion to the estimated capital cost [3].

II. LCOE OF BATTERY STORAGE AND PV SYSTEM

A. *Battery Storage in Electric Vehicles*

Large-scale deployment of intermittent renewable energy may pose new challenges in power industry and power prices change rapidly and unpredictably in liberalized electricity markets. Energy storage can diminish this imbalance, relieving the grid congestion, and promoting distributed generation [14].

In general, an EES technology consists of two main sections: power conversion system (PCS) and energy storage section. PCS is used to control the voltage, current, and other power characteristics of the storage based on the load requirements. PCS may include two separated units for charging and discharging with different characteristics. Energy storage section is the other part of EES that is designated to contain the storage medium. Since PCS and energy storage units have inherent inefficiencies and losses, overall efficiency (AC-to-AC) of EES technologies is defined by Equation (2), in which E_{out} and E_{in} are output and input electric energy, respectively.[7]

$$\eta_{sys} = \frac{E_{out}}{E_{in}} \qquad (2)$$

1) *Capital Costs*

The capital cost (CC) of EES systems are usually expressed in per unit of power rating and storage capacity. CC can be calculated either from the costs of PCS, BOP, and storage part by using Equation (3) [7, 8] or be directly obtained from the manufacturer/literature.

$$C_{cap} = C_{PCS} + C_{BOP} + C_{stor} \times h \qquad (3)$$

Where $C_{PCS}, C_{BOP}, C_{stor}$ represent unitary costs of PCS, BOP, and storage compartment respectively, h is the charging/discharging time.

2) *Levelized Cost of Energy (LCOE)*

Life Cycle Cost (LCC) includes all the expenses related to operation and maintenance (O&M), replacement, disposal and recycling, in addition to initial capital costs. It can be presented in levelized annual costs (Rs/kW-yr), which is amount to be paid yearly.

LCC calculations can be performed, first, by annualizing CC, presented by ($C_{cap,a}$) in Equation (3). Based on the present value of money the capital recovery factor (CRF) is calculated by applying Equation (4), subject to the interest rate (i) during the lifetime (T) [9].

$$C_{cap,a} = \text{CC} \times \text{CRF (Rs/kW-yr)} \qquad (4)$$

$$\text{CRF}=\frac{i(1+i)^T}{(1+i)^T-1} \qquad (5)$$

Total annual O&M costs ($C_{O\&M,a}$) can be expressed by adding annualized costs of fixed O&M ($C_{FOM,a}$), and variable O&M ($C_{VOM,a}$) multiplied by yearly operating hours, as presented

$$C_{O\&M,a} = C_{FOM,a} + C_{VOM,a} \times n \times h \;\; \text{(Rs/kW-yr)} \qquad (6)$$

where n is the number of discharge cycles per year

Annualized replacement costs ($C_{R,a}$) can be calculated, given the number of replacements (r) during the application lifetime [10].

$$C_{R,a} = CRF \times \sum_{k=1}^{r}(1+i)^{-kt} \times \left(\frac{C_R \times h}{\eta_{sys}}\right) \text{ Rs/kW-yr} \quad (7)$$

Discharge time (h) and overall efficiency (η_{sys}) are given for one full cycle at the rated depth of discharge (DoD) of the batteries. Disposal and recycling costs are other cost items are usually neglected in the LCC analysis.

The annualized LCC costs (ALCC) is determined by

$$C_{LCC,a} = C_{cap,a} + C_{O\&M,a} + C_{R,a} \text{ Rs/kW-yr} \quad (8)$$

The levelized cost of electricity (LCOE) delivered can be then calculated, knowing the annual operating hours of the system [1]

.

$$LCOE = \frac{ALCC}{yearly\ \ operating\ \ hours} = \frac{C_{LCC,a}}{n \times h} \text{ Rs/kWh} \quad (9)$$

B. *PV System*

Photovoltaic (PV) installations have shown high growth rates around the world [11]. This growth results in a continuous decrease in PV electricity generation cost [13]. Global horizontal irradiation is normally used for determining the input energy to a PV system. The factors affecting the energy generation from a solar panel includes the technology used, azimuth angle, solar declination, zenith angle, temperature, dust, humidity etc. [17].

The best location for installing a PV system is usually rooftop of houses and buildings. Ground-mounted PV systems are comparatively less expensive than roof-mounted PV systems and hence they are usually used for large scale power generation projects incorporating PV systems. But a roof is a more suitable location from the view point of abundance of sunlight and is out of the way [17].

The National Renewable Energy Laboratory, Sandia National Laboratory and the U.S. Department of Energy together have developed a system performance model incorporating financing options ranging from residential to utility scale named the Solar Advisor Model (SAM). It represents the best tool publically available today for the industry to examine the financial feasibility of a solar project by performing a reliable LCOE calculation [18].

The equation for calculating the LCOE for a PV system is given in Equation (10) below [12]:

$$\text{LCOE} = \frac{\sum_{t=0}^{n} (I_t + O_t + M_t + F_t) / (1+r)^t}{\sum_{t=0}^{n} E_t / (1+r)^t} \quad (10)$$

$$= \frac{\sum_{t=0}^{n} (I_t + O_t + M_t + F_t) / (1+r)^t}{\sum_{t=0}^{n} S_t (1-d)^t / (1+r)^t} \quad (11)$$

I_t is the initial investment . It should not be discounted and should be taken out of the summation. The degradation factor of PV modules is also taken into account. The energy generated in a given year E_t is the rated energy output per year S_t multiplied by the degradation factor $(1 - d)$ which decreases the energy with time. The maintenance costs, operation costs and financial expenditures for time year t are denoted as M_t , O_t and F_t respectively [12] **.**

III. COMPARISON OF RESULTS

Lithium ion (Li-ion) batteries are now considered to be the standard for modern battery electric vehicles. Many types of Li-ion batteries are available in market, each having their own independent characteristics. But vehicle manufactures focused variants that have excellent longevity. Li-ion batteries possess excellent specific energy and energy density, making it perfect for battery electric vehicles [6]. However, Li-ion batteries have been comparatively a very expensive battery technology.

Initial cost has been taken from battery manufacturers/literatures. The cost parameters and other specifications taken are given in Table I [14] and Table II [14]. The salvage value has been neglected. The calculations shows that LCOE value for battery to be around 7.7 Rs /kWh.
The cost of electric vehicle is not used in calculating LCOE.

TABLE I COST SPECIFICATIONS FOR LITHIUM-ION BATTERY

Cost item	Average
Fixed O&M (Rs/kW-yr)	546
Variable O&M(Rs/MWh)	166
Replacement cost(Rs/kW)	129158

TABLE II LITHIUM –ION BATTERY PARAMETERS

Parameter	Value
Discount rate	8%
Interest rate	8.5%
System efficiency	85%
Life time	10

In the case of PV system, a 5 kW panel is considered with fixed roof top installation. The specifications and other parameters taken are shown in Table III [15].
The maintenance cost is taken as 1.5 %of PV capital cost. The energy output is calculated with respect to Indian weather pattern. An average of 300 days of sunshine and a degradation factor of 0.8 % is assumed. The average sunshine hours is taken as 5 hours per day. The calculations shows that LCOE value for PV system to be around 3.3 Rs /kWh.
The unit price of electricity from the utility is also taken for the comparison.

TABLE III P V SPECIFICATIONS

Component	Specification
Total PV Module	5 kW
PV module capacity	250 kwp
No. of Panels	20 nos.
Solar PCU (Inverter)	5 KW
Batteries (150 Ah X 12V)	8 Nos.

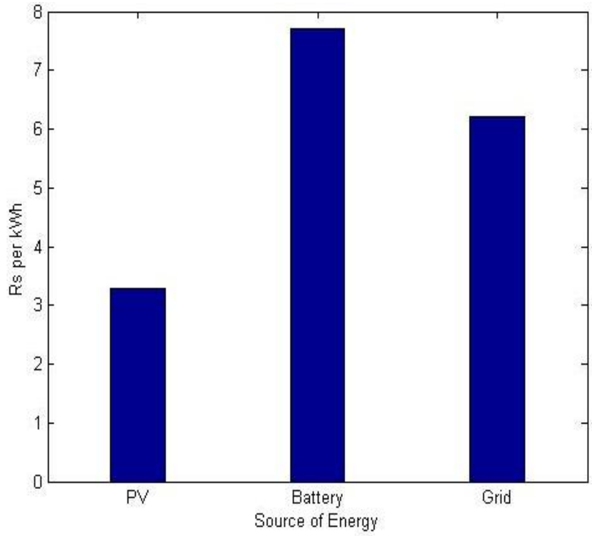

Fig. 1. Bar plot showing the LCOE for PV, Battery, and Grid

IV. CONCLUSION

The results show that LCOE analysis gives a clear comparison of energy generation using different methods. It helps us to choose the source that provides energy at the least cost.

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BIOGRAPHY

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