



Standalone PV-diesel system vs. PV-H₂ system: An economic analysis

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ABSTRACT

Hydrogen as a long-term storage medium in photovoltaic systems has been a subject of interest in recent years. Such a system uses an electrolyser – H₂ storage – fuel cell combination along with battery as short-term storage to minimize the loss of load probability. Conventionally, the same goal is achieved including a diesel generator (DG) in the photovoltaic (PV) systems. In present work, an economic comparison is carried out between DG based system and various possible configurations of H₂ based systems suitable for standalone application in the range of 5 kW. Both the systems are compared with the help of boundary curve obtained from life cycle cost analysis and excess energy available in the PV-DG system. Boundary curve enables in determining cost-effective system for a site, specified by on-site fuel cost including transportation cost and seasonal solar energy difference. It is found, a system with unitized regenerative fuel cell (URFC) and metal hydride storage offers most cost-effective solution. Further, the scope of the PV-H₂ system is enhanced if the salvage value of the fuel cell is considered. With steeply rising fossil fuel prices and developments in H₂ technology, globally more regions will be cost-effective for PV-H₂ systems.

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1. Introduction

The increasing concern on national and international level about the climate change and energy security is the motivating factor towards a dramatic paradigm shift from fossil fuels to renewable energy sources. The intermittent natures of the renewable energy sources are the main hurdles towards the wide implementations. Lead-acid batteries show excellent behaviour to overcome the diurnal variation and they are widely used in photovoltaic (PV) system to achieve higher energy supply reliability. However, due to high self-discharge they fail to overcome the seasonal mismatch in the renewable energy systems.

To minimize the loss of load probability (LOLP) in standalone PV systems, conventionally diesel generator (DG) is used as a backup in combination with battery. In such a system peak loads can be met by the DG set together with the stored energy in the battery or the renewable energy converter. The system is sized to reduce the fuel consumption of the diesel generator by 70–90%, therefore, relying heavily on the renewable resource [1]. Nema et al. [2] has reported various cases which clearly indicate that the optimal sizing of the different components in a PV-DG hybrid system is must to minimize LOLP and costs. To achieve high power supply reliability

either the energy converter or the battery is usually oversized [3]. As a consequence, a large amount of energy is wasted in the system and the average state of charge (SOC) of the battery also remains high for prolonged period during good season.

The generator can be replaced by a long-term storage system which is complementary to the battery storage. Such a system consists of hydrogen storage in combination with an electrolyser for on-site hydrogen generation and fuel cells to overcome the disadvantages in a DG based hybrid system. In such a system, the surplus energy during the good season is utilised in the electrolyser to produce hydrogen for the long-term use. The deficit in the system during the bad season is overcome by using stored H₂ through the fuel cells. Since, such systems are capable of producing fuel (H₂) on-site; they are more attractive for remote applications where continuous fuel transportation is difficult and expensive. Various configurations of such systems for stationary applications have been studied [4,5].

Compressed air energy storage (CAES) is considered to be a cost-effective alternative for storing renewable energy [6,7] and using in diesel generator system with improved efficiency [8]. However, mostly it is used for energy storage in the power plants in the MW ranges for peak load saving and the effectiveness of such storage in small scales (few kW) is yet to be proven.

Ghosh et al. [9] has compared H₂ storage with diesel generator in a PV-Wind hybrid system and the least cost for H₂ storage is

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Nomenclature

Bat_{use}	battery use factor	n_{MH}	number of stable cycles for metal hydride storage
CV_{fuel}	heating value of fuel ($kWh\ l^{-1}$)	$N_{use/annum}$	tank use factor per annum
$E_{diff,s}$	seasonal solar energy difference ($kWh\ m^{-2}$)	P_a	life cycle maintenance factor with general inflation
$E_{s,solar}$	total solar energy during good season ($kWh\ m^{-2}$)	P_f	life cycle maintenances factor with fuel inflation
$E_{s,xs}$	surplus energy in good season (kWh)	P_{FC}	power rating of fuel cell (kW)
$E_{w,solar}$	total solar energy during weak season ($kWh\ m^{-2}$)	P_G	power of the generator (kW)
$f_{Pt,rec}$	platinum recovery factor	Pt_{load}	platinum loading in fuel cell ($g\ kW^{-1}$)
f_{salv}	salvage factor	r	discount rate
i_f	fuel inflation	RY_{DG}	rebuild year for diesel generator
i_g	general inflation	RY_{HG}	rebuild year for hydrogen generator
$K_{CFC/l}$	critical fuel cost per litre ($\$ l^{-1}$)	$T_{engine,D}$	lifetime of the diesel engine (h)
K_{DG}	investment cost of diesel generator ($\$$)	$T_{engine,H}$	life time of the hydrogen engine (h)
K_{DGM}	life cycle diesel generator maintenance cost ($\$$)	T_{life}	life time of the system (year)
$K_{DGM/kWh}$	diesel generator maintenance cost per kWh ($\$ kWh^{-1}$)	W_p	size of the photovoltaic array (kW_p)
K_{DGR}	life cycle diesel generator rebuilds cost ($\$$)	yr	future year at which platinum price is to be found
K_{DGS}	life cycle cost of diesel generator storage ($\$$)	η_{bat}	battery efficiency
K_{EL}	investment cost of electrolyser ($\$$)	η_{DG}	efficiency of diesel generator
K_{FC}	investment cost of fuel cell ($\$$)	η_{EL}	electrolyser efficiency
K_{fuel}	life cycle fuel cost ($\$$)	η_{LTS}	overall efficiency of long-term storage
$K_{fuel/l}$	cost of fuel ($\$ l^{-1}$)	$\eta_{LTS,HG}$	overall efficiency of long-term storage with hydrogen generator
K_{HG}	investment cost of hydrogen generator ($\$$)	CAES	Compressed Air Energy Storage
K_{HGM}	life cycle hydrogen generator maintenance cost ($\$$)	DG	Diesel Generator
$K_{HGM/kWh}$	hydrogen generator maintenance cost per kWh ($\$ kWh^{-1}$)	DOE	Department of Energy
K_{HGR}	life cycle hydrogen generator rebuilds cost ($\$$)	EL	Electrolyser
$K_{LTS,HG}$	life cycle cost of hydrogen storage, hydrogen generator ($\$$)	FC	Fuel Cell
K_{Others}	other life cycle costs ($\$$)	GEN	Generator
$K_{PR,DG}$	present cost per engine rebuild, diesel engine ($\$$)	HG	Hydrogen Generator
$K_{PR,HG}$	present cost per engine rebuild, hydrogen engine ($\$$)	HPE	High Pressure Electrolyser
$k_{pt,f}$	future price of platinum ($\$ g^{-1}$)	IC	Internal Combustion
K_{salv}	salvage value of tank ($\$$)	IEA	International Energy Agency
$K_{salv,FC,Pt}$	salvage value of platinum in fuel cell ($\$$)	LOLP	Loss of Load Probability
K_{Tank}	investment cost of tank ($\$$)	MEA	Membrane Electrode Assembly
$K_{Tank,initial}$	initial tank investment cost ($\$$)	MH	Metal Hydride
$K_{Tank,MH}$	lifetime investment cost for metal hydride storage	PE	Polymer Electrolyte
$K_{Tank,MH/kWh}$	investment cost of metal hydride storage tank ($\$ kWh^{-1}$)	PEM	Proton Exchange Membrane
$K_{Tank/kWh}$	investment cost of tank ($\$ kWh^{-1}$)	PGM	Platinum Group Metals
		PV	Photovoltaic
		SOC	State of Charge
		URFC	Unitized Regenerative Fuel Cell

obtained when used with only PV systems. Using a similar approach, an effort has been made in this present work to compare different PV-H₂ standalone systems, considering the life cycle costs.

In present study, various possible configurations for long-term storage loop is considered and compared with the conventional diesel generator system. The long-term storage configurations include hydrogen Internal Combustion (IC) engine systems, unitized regenerative fuel cell (URFC) based systems, High Pressure Electrolyser (HPE) based systems and metal hydride (MH) storage. Though Polymer Electrolyte Fuel Cells (PEFCs) offer many advantages over other types, the high cost resulted from the platinum catalyst poses main obstacles towards the commercialisation.

Commercialisation of PEFC systems will result in an increase in the demand of Platinum Group Metals (PGMs). Hence, platinum recycling is critical to the long-term sustainability of PEFCs in addition to the cost. A lion share of the platinum used in PEFCs can be recovered [10] at the end of their lifetime. Hence, there is a high salvage value at the end-of-life for PEFCs which is often neglected in the life cycle cost analysis. In present study the salvage value of the fuel cell is considered for the comparisons.

Different locations on the northern hemisphere are considered for analysing the economic feasibility of different configurations. In this purpose, different locations are being characterised based on the seasonal solar radiation variation and the accessibility of the location which is reflected on the fuel cost at the site of application.

2. System configurations

In present study, conventional PV-DG system is considered as a benchmark system and compared as a replacement with various H₂ based systems as discussed below.

2.1. PV-DG hybrid system

In a PV-DG hybrid system a PV array is configured in parallel with DG systems to meet the load. Energy flow in a PV-DG hybrid energy supply system is shown in Fig. 1.

Diesel generator based systems have low capital cost as the technology is fairly well established. However, such systems are typically oversized, and during the months with high solar

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