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Performance evaluation of stand alone, grid connected and hybrid renewable energy systems for rural application: A comparative review

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ABSTRACT

The energy demand across the globe has increased in many folds due to technological advancement, rapid growth in industries and increase in household energy demand. This led the engineers and planners to think and find the means to harvest the alternative energy sources other than the fossil fuel. Solar, wind, biomass, mini hydro are some of the resources used worldwide to generate energy as per the availability of resources. This paper presents a comparative performances of various stand alone solar photovoltaic(PV), grid connected PV and hybrid renewable energy system (HRES) studied across the globe. The standalone PV system is used to supply electricity to a small habitats/hamlets or to a single household. Hybrid energy system consists of two or more energy sources for generation of power for rural electrification in off grid locations and in grid connected PV systems, excess electricity produced is injected to the grid thereby generating additional income. The research works carried out by various researchers around the globe on renewable energy sources particularly for rural electrification is discussed in this paper. Besides this the utilisation of renewable electricity for Plug-in-Electric Vehicles (PEV) studied across the globe were also discussed.

1. Introduction

Fossil fuel is the major source of electricity and it discharges huge quantity of harmful gasses to our surroundings. It is a serious global concern now a days to reduce green house gases from our atmosphere and this can be achieved by producing cleaner energy by renewables. Renewable sources such as solar PV, wind, biomass, biogas, small hydro, concentrating solar power etc. are extensively used now a days to generate electricity all over the world to reduce the pressure on fossil fuel and to reduce environmental pollution. An initiative has been taken by UN to encourage the nations for generating clean and green energy [1]. As a result, different countries have initiated different strategic measures to reduce their green house gasses. Utilisation of non-conventional energy sources are steadily increasing all over the world to resolve the acute shortage of energy and reduce the effects of global warming. Renewables are the world's fastest-growing energy source now a days and its consumption is estimated to increase by about 2.6% per year from 2012 to 2040. Source wise world electricity generation in 2015 is shown in Fig. 1 which indicates 23.70% (1849 GW out of total generated energy 6399 GW) global electricity is generated by renewables [2]. The energy consumption by different energy sources is shown in Fig. 2 which indicates there would be sharp increase in renewable energy, coal and liquid fuel by 2040 [1].

The total renewable power generating capacity in the world excluding hydro power is 785 GW and 1849 GW with hydro power up to the end of 2015. The top seven renewable energy producing countries in the world are China, the United States, Germany, Japan, India, Italy and Spain. The capacities of these top seven countries including hydro power are shown in Fig. 3. Governments of different nations including India are now providing financial assistance for promoting the production and use of renewable energy for meeting the basic energy needs of rural communities [3–9].

Extensive research has been conducted worldwide in the area of renewable energy, including feasibility studies, computer modelling, control, and experimental work [10–24]. Research was done extensively on optimum sizing, modelling and feasibility study of stand alone solar PV system either ground mounted or rooftop system for energy generation [25–36]. Erdinc and Uzunoglu [37] studied different methods for optimization of hybrid energy system and concluded that each sizing approach has its own features and potential for sizing hybrid energy system and the choice may be made as per type of application and user's requirement. Hafez and Bhattacharya [38] designed and optimised the renewable energy based micro grid in Canada and revealed that increase in diesel price results significant reduction of CO_2. They also concluded that diesel-renewable mixed micro grid has lowest NPC with lower carbon footprint as compared to

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Nomenclature

SPV	Solar photovoltaic
UN	United Nation
HRES	Hybrid renewable energy system
Wh	Watt hour
GW	Giga watt
MWh	Mega watt hour
kWh	Kilo watt hour
kWp	Kilo watt peak
CPP	Clean power plan
CSP	Concentrating solar power
PR	Performance ratio
NPC	Net present cost
LCOE	Levelised cost of energy
COE	Cost of energy
CF	Capacity factor
SDP	Stochastic dynamic programming
DP	Dynamic programming
EMS	Energy management strategies
CSC	City suburban cycle
NPV	Net present value
L/h	Liters per hour
LCC	Life cycle cost
HOMER	Hybrid optimization model for electric renewable
INR	Indian rupees
USD	US dollar
h/d	hour/day
DG	Diesel generator
IRES	Integrated renewable energy system
MHP	Micro hydel power
SHP	Small hydro electric plant
PHEV	Plug in hybrid electric vehicle
PEV	Plug in electric vehicle
EV	Electric vehicle
CO_2	Carbon dioxide
UK	United Kingdom
SOC	State-of-charge
OBC	Orange country bus cycle
SOH	State-of-health

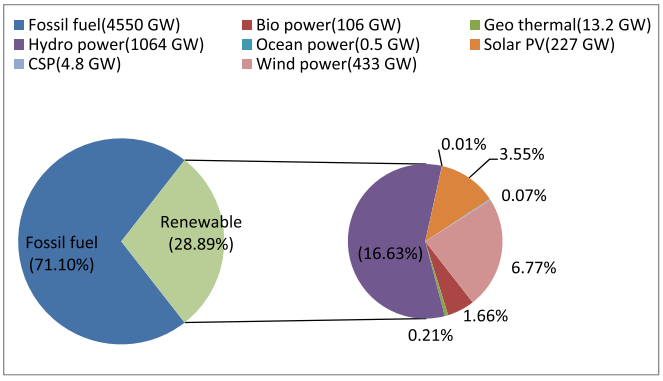

Fig. 1. World Electricity production by different sources in 2015. (Source: Renewables 2016: Global Status Report, REN 21)

stand alone diesel based micro grid and fully renewable based micro grid having zero carbon footprint is most preferred though it has higher NPC. Jahn et al. [39] analysed the performance data of 260 PV systems installed in different places across the globe and observed that annual performance ratio (PR) values depend on type of installed system. They calculated the PR of 170 grid connected PV system and found that PR significantly varies from plant to plant and ranges from 0.25 to 0.90 with an average of 0.66. The PR of off grid domestic system varies from 0.2 to 0.6 depending on availability of back-up system while PR of professional off grid system varies from 0.05 to 0.25. Khatib et al. [40] optimised the building integrated PV/diesel hybrid system in Malaysia and suggested that PV-diesel system is more feasible as compared to stand alone PV or diesel system as it reduces the system cost by 35%. Some studies conducted worldwide on standalone PV, grid connected PV and hybrid system for rural electrification are discussed below.

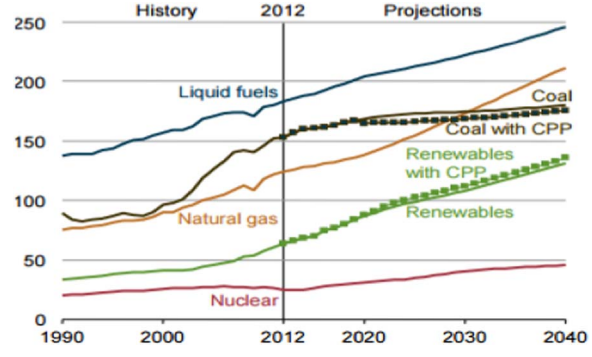

Fig. 2. Trends of energy consumption from 1990 to 2040 (quadrillion Btu). (Source: International Energy Outlook, 2016)

2. Stand alone PV system

Solar PV installations experienced a record growth during 2015 by adding 50 GW by year end resulting a total global capacity of 227 GW. Various solar projects were launched by different countries to electrify their remote and inaccessible areas and also provided incentives for installing many solar PV systems in roof top of public and private institutions and residential buildings. Many researchers studied the performance of these installations and suggested some valuable findings which would be of immense help for conducting further research.

Branker et al. [41] made a review on comparison of the levelised cost of energy (LCOE) of solar PV systems and opined that PV electricity achieved grid parity in some specific locations and it proved as an economically advantageous source of electricity. Barsoum et al. [42] made a study on standalone solar and biomass system separately. This study suggested a biomass energy system in rural areas due to its high efficiency and lower cost of energy (LCOE). Their cost optimization analysis by using HOMER shows that stand-alone biomass system

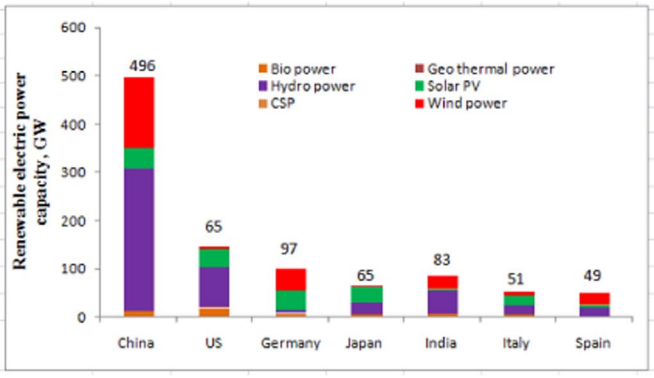

Fig. 3. Top seven renewable energy producing countries by the end of 2015. (Source: Renewables 2016: Global Status Report, REN 21)