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Resource assessment for hybrid solar-biomass power plant and its thermodynamic evaluation in India

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ABSTRACT

Hybrid solar-biomass thermal power generation systems are important for continuous power generation installations which supplement each other seasonally in India. In this paper, several aspects associated with hybrid biomass-solar power generation installations such as state wise availability of biomass resources, solar direct normal irradiance (DNI) has been discussed. Month wise daily average DNI is considered as 20%, 40%, 60%, and 80% and remaining heat is taken from biomass resource in the proposed hybrid plant. The thermodynamic evaluation (i.e. Energy and Exergy) of hybrid solar-biomass power plant have also been investigated. The total input energy of the proposed hybrid system is taken from the heat transfer fluid through parabolic trough collector (PTC) as per availability of solar resource and remaining from biomass to maintain the steam at superheated state of 500 °C and 60 bar and supplied to turbine at steam mass flow rate of 5 kg/s. The energy and exergy analyses of 5 MW hybrid system with series mode was carried out to identify the effects of various operating parameters like DNI, condenser pressure, turbine inlet temperatures, boiler pressure on net power output energy and exergy efficiencies.

1. Introduction

Biomass energy has provided sustenance to mankind through the ages and also attracting greater attention for power generation in India. Government of India recognized the potential role of biomass power in the Indian economy quite early and since then has been the vanguard of its promotion. If it is used as much as it is produced its benefits will include its renewable nature, wide availability, carbon neutrality and the potential to provide large productive employment in rural areas. As a further outcome of the carefully planned mix of policy and financial incentives introduced by the Government, capacity has been built up in the country for biomass power technologies, their operation and maintenance, management of biomass collection, manufacturing of equipment and resolving grid interfacing issues. The availability of crop residues like bagasse, rice husk, coconut shells and the wood processing wastes inherently limit the growth of the capacity of biomass power generation (Sahoo et al., 2015). One of the major barriers confronted by the biomass power plants is a secured supply of required quality and quantity at a competitive price for sustainable operation of the plant. Now the price of biomass resources has slowly increased due to non-availability of biomass at right price in recent years (Larson, 2001). On the other hand, solar thermal power plants (STPP) do not continuously generate power due to daily & seasonal variations and low level of direct normal irradiance (DNI; short transients) for at least 100–150 days in a year in most of places of this country. Although STPP with storage is one of the solution to maintain required amount of heat (Casati et al., 2015; Wittmann et al., 2011) due to DNI variations or short transients but difficult to store for the long duration of time for night cycle (Montes et al., 2009; Hoshi et al., 2005). Hybridization with STPP is most important for continuous generation of power for fulfilling the energy requirements. So, the choice of biomass resources is a judicious selection for hybridization with STPP for continuous power generation, which supplement with each other seasonally. Several authors investigated on hybrid solar biomass for power generation where water gets heated to saturated state through solar thermal technologies and superheated state through biomass boiler (Kaushika et al., 2005; Gordillo and Belghit, 2011; Ravaghi-Ardebili et al., 2015). Electricity production cost from hybrid solar thermal power plant is lower than that of stand-alone system (Spelling et al., 2013; Kotowicz et al., 2013) and reduction in the amount of CO_2 emitted to the atmosphere is also observed (Peterseim et al., 2013). The literature survey shows the limited focus in the area of resource assessments on solar and biomass for hybridization. The paper mainly focuses on the resource assess-

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Nomenclature

A_{ap}	aperture area of the parabolic trough collector field (m^2)
T	temperature (°C or K)
h	specific enthalpy (kJ/kg)
s	specific entropy (kJ/kg K)
η	efficiency of hybrid solar-biomass power plant (%)
W	rate of work transfer (kW)
Q	rate of heat transfer (kW)
E_x	exergy (kW)
E_{xD}	exergy destruction
Subscripts	
b	biomass residue
C	condenser
E	energy
Ex	exergy
FWH	feed water heater
HE	heat exchanger
HSB	hybrid solar-biomass
i, e	exergy flowing stream at inlet and outlet
j	heat source of each state points of the system
opt	optical
$P1$ & $P2$	pump 1 and 2
PTC	parabolic trough collector
T	turbine
w	water
o	surrounding (or reference environment) condition
1 to 9, c, a, x, y and o	state points of HSB system

ment for hybrid solar-biomass, optimum use of solar and biomass resource for power generation and its Modeling for energy & exergy analysis.

2. Biomass resource availability and status of biomass power in India

In India over 500 million tons (MT) of biomass is produced every year in different states like; Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Odisha, Punjab, Uttar Pradesh and West Bengal (Directorate of Economics and Statistics, 2012-13). Out of total resources, 350 MT of agricultural based major biomass resources are contributed by bagasse, rice husk, straw, cotton, coconut stalk, coconut shells and groundnut shells. Uttar Pradesh is one of the states, which produces the highest quantity of major biomass (56 MT) followed by Maharashtra (40 MT) and Punjab (37 MT) as shown in Fig. 1.

As per 12th five year plan, the proposed biomass power generation installation capacity of India is 1000 MW. The targeted power potential for 13th five year plan is estimated as 5730 MW (Road Map for Biomass Energy Report, 2011). Biomass based power generation capacity of 10,000 MW by the year of 2022 has been predicted for India (Renewable Energy Investment, 2015). A grid connected biomass gasifier based project of 1 MW capacity in Haryana has been installed for meeting the captive power needs of the industry. The installation of 50 biomass gasifier and combustion based system with cumulative installed capacity of 8.54 MW to meet the captive demand for electricity & thermal applications are under installation in different states (www.mnre.gov.in). World's largest coconut tree waste based power plant has been installed in Coimbatore district of Tamil Nadu with the generation capacity of the plant is 10 MW (Bio Power, India, 2014).

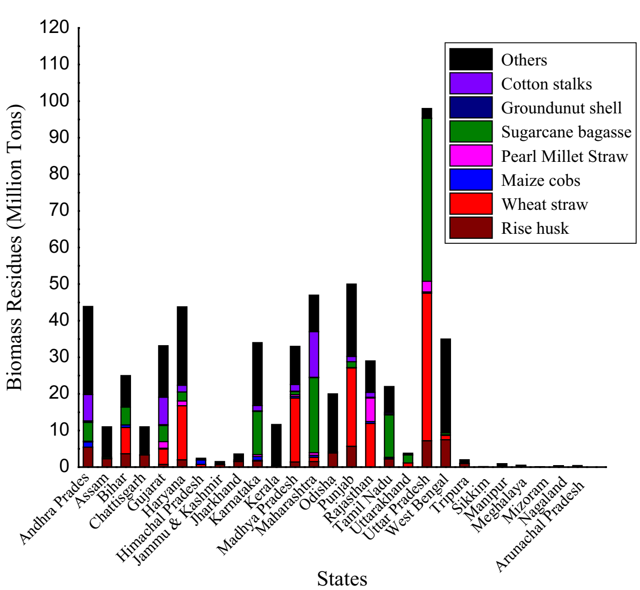

Fig. 1. State wise major agricultural based biomass residues.

3. Solar resource availability and status of solar thermal power in India

Most of the places in the country are having good sunshine, about 5000 trillion of kW h per year incident over India's land area with the most of the parts receiving Direct Normal Irradiance (DNI) of 4–5.5 kW h/m^2/day (Solar Radiation Energy over India, 2008). About 200–250 sunny days are available in a year in most parts of the country. Solar thermal for the generation of heat and electricity can be deployed during these sunny days. Fig. 2 shows the state wise annual average DNI available in India. This is based on daily average of DNI mapping resulted from the data available with National Renewable Energy Laboratory-National Institute of Solar Energy and Indian Meteorological Department (IMD) (Solar Resource Assessment based on satellite imagery, 2013; Solar Radiation Energy over India, 2008). State wise availability of DNI results indicated in Fig. 2 are reliable indication of the solar thermal potential.

The present installed capacity of total power generation in energy sector of India is 305×10^3 MW as on July 2016. This includes, 44.3×10^3 MW (14.52%) from renewable energy sources & 5.78×10^3 MW (1.89%) from nuclear. Out of 44.3×10^3 MW renewable energy, solar power is 7.8×10^3 MW (17.6%) (Ministry of Power, Govt. of India, 2016). To harness the solar energy potential for various applications including power generation, the Ministry of New and Renewable Energy (MNRE) launched Jawaharlal Nehru National Solar Mission (JNNSM) with a target of deploying 20,000 MW of grid connected solar power (i.e. both PV and Thermal) by 2022. The launching of the JNNSM symbolizes both and indeed encapsulates the vision and ambition for the future of solar energy. One of the aims of program is to reduce the cost of solar thermal technologies by deploying large solar thermal power generation capacity in various high potential areas of the country (IEA, 2014). The STPP grid connected power projects are being installed in India. In the country CSP based power plants of total 380 MW