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Research Paper

Polygeneration for an off-grid Indian village: Optimization by economic and reliability analysis

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HIGHLIGHTS

- Optimization for a polygeneration using LPP with economic modelling is done.
- Electricity, cooling and ethanol are output utilities of this polygeneration.
- Solar radiation and local biomass are inputs to the polygeneration.
- It is a sustainable solution for a remote village of India using local resources.

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ABSTRACT

Indian power supply is dominated by large coal based power plants connected to the national grid. Though it is economically viable for large consumption in industries but it may not be sustainable for many poor Indian villages, specifically for remote off-grid connection. Decentralized small scale power or even multi utility systems using local resources may be a sustainable option for these villages. Multi-utility energy system, i.e. polygeneration helps to cater to the secondary energy needs of a locality. But the secondary energy supply should be available at affordable cost. Minimization of the cost of secondary energy helps to increase the economic acceptability of a distributed energy system. In this paper, a polygeneration with solar PV, biomass power, ethanol production unit and cooling is proposed for an Indian off grid village. An economic model developed in MATLAB using linear programming approach to determine the optimal size of the system by maximization of the annualized profit has been reported. Results show that multiple energy utility supply is possible through distributed polygeneration. This renewable energy based polygeneration reduce CO_2 emission significantly as compared to diesel generator set. Reliability and sensitivity analysis as well as comparison of estimated performance for four different locations in India is reported.

1. Introduction

Grid based power supply from the large/very large power plants is the existing practice to meet the electricity demands in most parts of India. Moreover, coal based thermal power has the 60% share in the Indian grid power mix [1]. The announced policy of the Government of India (GoI) for a long term is to provide electricity to all the Indian villages as access to electricity plays a pivotal role in the social and economic development of the villagers. The Indian Parliament passed the Electricity Act in 2003 which mentioned for the first time the scope of rural electrification in a law [2]. That was the beginning that the GoI started thinking about the decentralized distributed generation (DDG) systems to supply electricity to the villages. Subsequently, the Rajiv Gandhi Grameen Viduytikaran Yojna (RGGVY) was formulated by the GoI in 2005 to reach power to the Indian villages [3]. In 2014, the GoI announced the Deendayal Upadhyay Gram Jyoti Yojna to carry forward the task of RGGVY in a faster manner [4]. In 2015 it has launched the Ujwal Bharat programme to reach 24×7 power for all people of India by 2019 [5]. The use of DDG systems for providing power in rural areas was advocated in the Electricity Act, 2003. It has found utmost importance in all the subsequent policies framed by the Indian Government. Under Village Electrification programme, Ministry of New and Renewable Energy (MNRE) has identified 12,771 villages across the country where the grid connectivity is either not possible or economically not viable due to the terrain conditions [6].

Providing electricity from coal based thermal power plants may not be sustainable in the long run. Electricity generated from

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Nomenclature

Abbreviations

AC	annualized cost, INR/year
AE	annualized expenditure, INR/year
AI	annualized income, INR/year
AP	annualized profit, INR/year
AS	annualized savings, (INR/year)
BG	biomass gasifier
GoI	Government of India
OP	optimized profit, INR/year
RGGVY	Rajiv Gandhi Grameen Viduytikaran Yojna

Symbols

AL	agricultural load, kW
C_{straw}	annualized cost of straw, INR/year
C_{MoS2}	annualized cost of MoS_2 catalyst, INR/year
$C_{PV_{module}}$	annualized cost of solar module, INR/year
C_{BG}	annualized cost of gasifier, INR/year
C_{ethsyn}	annualized cost of ethanol synthesis, INR/year
C_{ethsep}	annualized cost of ethanol separation, INR/year
C_{vam}	annualized cost of vapor absorption cooling system, INR/year
C_{inv}	annualized cost of inverter, INR/year
C_{ge}	annualized cost of gas engine, INR/year
$CAGR$	cumulative annual growth rate, %
C_p	revenue from cooling, INR/year
COP	coefficient of performance
CV_{straw}	gross calorific value of straw, kJ/kg
CV_{wood}	gross calorific value of wood, kJ/kg
C_{GE}	annualized cost of gas engine, INR/year
C_y	yearly requirement of catalyst, kg
C_{inv}	cost of inverter, USD/watt-peak
CRF	capital recovery factor
C_r	revenue from cooling utility, INR/kW
C_{ckg}	cost of catalyst per kg, INR/kg
DG	diesel generator set
DDG	decentralized distributed generation
DL	domestic load, kW
E_R	revenue from ethanol, INR/year
E_{thy}	ethanol produced per year, litres
E_{thc}	ethanol produced per kg of catalyst
E_{ge}	electricity output of gas engine, kW h
E_{RR}	percentage of emission of CO_2 reduction per year
E_{solar}	CO_2 emission by solar module per kW h electricity produced, g
El_{solar}	total units of electricity generated by the PV module per year, g
E_{bio}	CO_2 emission of biomass gasifier per kW h electricity produced, g
El_{bio}	total units of electricity generated by the biomass gasifier per year, kW h
E_t	electricity generated per year, kW h
E_{year}	electricity generated per year, kW h
F_g	amount of flue gas generated per kW h of electricity, kg/kW h
GHG	green house gas
F_{sp}	Specific heat of flue gases, k Cal/°C
HDI	Human Development Index
INR	Indian Rupees
I_t	investment expenditure, INR/year
i	Bank discount rate, %
In_{cap}	capacity of the solar inverter, kW
In_{pp}	price per watt-peak of solar inverter, INR/watt-peak
$L(k)$	load at kth instant, kW
$LCOE$	levelised cost of electricity, INR/kW h
$LPSP$	loss of power supply probability
M_c	maintenance cost, INR/year
$MNRE$	Ministry of New and Renewable Energy
NPV	net present value
n	life of the plant, years
S	scale factor for biomass gasifier
S_{in}	straw input to gasifier, kg/h
S_e	scale factor for ethanol synthesis
S_s	scale factor for ethanol separation
SL	street light load, kW
T	unit cost of electricity, INR/kW h
TL	total load, kW
T	electricity tariff, INR/kW h
t_g	temperature at output of the turbo generator, °C
TC_{esyn}	total initial cost of the ethanol synthesis unit, INR
TC_{esep}	total initial cost of the ethanol separation unit, INR
TC_{WHRVAM}	Total cost of Waste Heat Recovery Vapour Absorption Cooling System, INR
$P_{biomass}$	electricity output of gasifier, kW
P_{solar}	electricity output of solar PV module, kW
P_{bioh}	least electricity output of the gas engine required to provide sufficient waste heat to WHRVAM, kW
PEC	per capita energy consumption
PV	photovoltaic
ppm	parts per million
P_r	reliability of power supply, %
$R(i)$	radiation at the ith instant, Watt/m^2
SD_{max}	maximum straw demand, kT/year
S_{cap}	capacity of solar module, kW
S_{pv}	cost of solar module per watt pear, INR/watt-peak
SC_{perkg}	cost of straw per kg, INR/kg
UL	unmet load
USD	United States Dollar
W_p	watt-peak
WH_{ge}	waste heat generated by the gas engine, k Cal/hr
$WHRVAM$	waste heat recovery vapor absorption machine

thermal power plants emits 1.03 tonnes of CO_2- equivalent/MW h [7]. Moreover the per capita energy consumption (PEC) in India had a cumulative annual growth rate (CAGR) of 4.53% from 2006 to 2014. On the contrary, the increase in the coal reserve of the country is only 0.7% in 2013–2014 [8] .Therefore fuel switching from coal to renewable may be a sustainable option for energy security within a definite time frame for this country. The industrial activities of the modern civilization including the use of fossil fuels have raised the carbon dioxide level from 280 ppm to 400 ppm over the last 250 years [9]. After the Paris agreement held in December 2015, India has a target of reducing the green house gas (GHG) emission by 30–35% from the amount that India emitted in 2005. India has also planned to increase by 40% transition of power from fossil fuel based power plants to renewable by 2030 [10].

Generating power from renewable resources of energy are generally environment-friendly. Nevertheless, it has to comply with the economic feasibility and social acceptability. Regarding this subject, the biomass resources are abundantly available in many Indian villages. The total national amount of surplus biomass amounts to 120–150 metric tons per annum having the potential to generate 18,000 MW of electric power [11]. In spite of huge potential, this resource is not efficiently harnessed due to non deployment of suitable technologies. The proper utilization of these resources with proper multi utility system may be the suitable option for social and economic development of the villages.