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Optimization of PV-biomass-diesel and grid base hybrid energy systems for rural electrification by using HOMER

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ABSTRACT

Decentralized renewable energy base hybrid system is an economic and convenient option for rural electrification where grid extension is not feasible. This study focuses on the design of a hybrid systems based on PV-biomass gasifier-diesel and grid and optimize the system configuration for different load profiles. The cost of energy is calculated for different peak load, energy demand profiles and grid availability. The cost of energy in case of off-grid hybrid system for peak load of 19 kW and energy demand of 178 kWh/day, is US$ 0.145/kWh. However, in case of a grid connected hybrid system, it is reduced to US$ 0.91/kWh for the same scenario. It is found that grid purchase of 9% and grid sales of 23% of the total energy demand or generation for the above load profile. The study concluded that the cost of energy for a grid-connected hybrid system is lower compared to an off-grid hybrid system for similar load profiles. Finally, the comparison of grid extension and the off-grid hybrid system has been performed, and economic distance limit is determined. The simulation result shows that the best option scenario for all the cases is biomass gasification system than photovoltaic system.

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1. Introduction

Energy is one of the major inputs for the socio-economic development of the rural areas of a developing country. It is also reported that rural electrification is a vital requirement for development of the remote rural areas so as to obtain economic growth, poverty elimination, employment generation and improvement of livelihood of the villages. According to Census 2011, more than 77 million households still use kerosene for lighting in India [1]. In rural India, more than 44% of the households do not have access to grid electricity [2]. Even in the electrified villages, quality and availability of power is low and irregular. There are at least 9000 villages in India where the grid may never reach due to their remoteness and geographical constraints. Government of India has initiated various programmes such as Remote Village Electrification Programme (RVEP), Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), etc. [2]. In addition to these, Jawaharlal Nehru National Solar Mission (JNNSM) is targeted to generate of 100 GW power from solar photovoltaic and solar thermal energy. The JNNSM aims to develop and deploy solar energy technologies in the country at both centralized and decentralized levels [3]. The RVEP aims to provide electricity to un-electrified villages through renewable energy sources whereas the RGGVY targets at providing electricity to the villages by using grid connection. The rural households which are yet to have electricity access usually in remote inaccessible village where extending the grid is technically not feasible or economically not viable or unconnected hamlets or un-electrified households in grid connected villages. Higher electricity line costs, T&D losses and the large infrastructure required for regular maintenance make the rural electrification through conventional grid extension an economically unattractive option for the remote villages. Thus, distributed generation is an economically viable option for electrification of the remote villages in a developing country [4].

Various authors has reported different options of distributed energy systems, cost of energy generation, comparison between gasification, photovoltaic system, diesel generator etc. and impact of energy generation from renewable energy systems on the livelihood of the remote villages [4–7]. Due to the intermittent nature of renewable energy, use of diesel generator as backup power generation along with renewable energy base systems improves the reliability of system [8]. Bhattacharyya reported that low electricity demand for the domestic use in the villages leads to

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partial capacity utilization of gasification plants and consequently energy generation cost becomes high [9]. Hence, integration of agro-processing loads like rice-mills improves the load factor and brings down the levelised cost of energy. Gokcol and Dursun investigated the effect of renewable energy penetration on net present cost (NPC) and cost of energy (COE) [10]. This study found that as the renewable energy fraction increases, NPC and COE decrease gradually. Silva et al. analyzed the performance of photovoltaic - fuel cell - battery system to supply electricity in Amazon region and found that the use of electrolyzer is not economical since the cost of energy from PV-battery-fuel cell is higher than PV-battery option [11]. It is also observed that with the reduction of interest rate and higher availability of solar radiation, the cost of energy will reduce. Fantidis et al. studied the potential of solar radiation and solar power plants at different location of Greece and found that PV system could reduce on an average 40.99 tons of greenhouse gases emission [12]. Giannoulis and Haralambopulos analyzed the economic effect of distributed generation in isolated grids and in particular to Lesvos Island in Greece [13]. The study concluded that distributed generation with a wind turbine is a promising technology for replacing the oil-fired plant in Greece and CO_2 emission can be reduce by increasing the renewable energy penetration. The optimum sizing of electric power to support the electricity demand of fish pond aeration system has designed using HOMER and it is observed that renewable energy based system incurs lower cost of energy production compared to grid electricity [14]. Ramli et al. analyzes the hybrid PV/diesel energy system performance with battery and flywheel energy storage using HOMER [15]. This study focused on economic and environmental benefits of the hybrid system. This study also analyzed on fuel consumption and carbon emission reduction by this system. Salehin et al. assessed solar-PV-diesel and wind-diesel energy systems for Kutubdia islands, Bangladesh using HOMER and RETScreen simulation tools [16]. HOMER is used to optimize the system configuration and RETScreen is used for cost analysis and emission analysis of the optimized system. Rahman et al. assess the implementation of hybrid energy systems for an off-grid community in Canada [17]. Various system configurations are proposed and the sensitivity analysis on various input parameters on the cost of energy generation is carried out. Economic assessment of the optimized hybrid PV-diesel-battery systems and wind-diesel-battery systems for residential load and off-grid loads for isolated settlements of Saudi Arabia has been carried out by using HOMER [18–20]. These studies conclude that increase in PV or wind system capacity reduces the dependency on diesel consumption.

Studies have done by Munuswamy et al., Mahapatra & Dasappa, and Sen & Bhattacharya on off-grid options for electrification of remote villages, distant from central grid, and compared it with grid extension [21–23]. All these studies concluded that villages which are geographically remote and distant from central grid, off-grid options or decentralized electricity generation system is sustainable, techno-economically viable and environment friendly. Estimation of economic distance limit is necessary to choose the preferable option between renewable based hybrid system and grid extension for rural electrification. When the conventional grid is located beyond the breakeven distance/economic distance limit, then the local distributed generation is an economical and optimal option. There is an increase in net present cost with the increase in breakeven distance [22–24]. Fadaeenejad et al. have given an overview of a hybrid renewable system for worldwide with special attention on Malaysia [25]. This study concluded that renewable sources base hybrid system is a viable option for rural electrification and PV-wind-battery configuration is cost effective hybrid renewable energy system. This study also discussed on excess electricity generation that could be sold back to the grid if the system is connected to the local grid. Aagreh and Al-Ghzawi simulated the hybrid system considering grid and grid-renewable energy system [26]. Kumar and Manoharan analyzed the economic feasibility of hybrid system comprises of PV and diesel; which is installed in the areas where the grid is available only for 10 h per day [27].

Prodromidis and Coutelieris studied renewable energy base off-grid systems and grid connected hybrid systems for different Islands of Greek and observed that grid connected hybrid systems are economically more competative in compare to off-grid hybrid systems due to sale of excess electricity generated from renewable energy systems base hybrid systems [28]. Murphy et al. used HOMER simulation tool to address the unreliable electricity supply from the grid especially in rural areas, and integrate the unreliable grid with the distributed energy systems [29]. The study develops the methodology for the integration of unreliable grid with distributed energy systems in simulation tool for determining the optimal system configuration and cost of energy for reliable power generation. González et al. studied the optimal sizing of grid connected hybrid renewable energy systems (PV and wind) considering minimum life cycle cost of the optimized system by matching with the electricity demand [30]. The study has considered grid power price and price of electricity sold to the grid. The simulation results reveals that the grid connected system is most economical viable. Türkay and Telli also observed that grid connected hybrid systems produced electricity with a lower system cost in comparison with the standalone systems [31]. This study found that the renewable energy components are oversized to make the hybrid system reliable which resulted higher system cost. However, the integration of various of renewable energy systems along with storage in the hybrid systems reduced the system size and increase the overall energy output. It is also observed that grid-connected hybrid systems including grid, PV, and hydrogen systems is the most feasible solution and the cost of energy from the hybrid systems is found to be \$0.307/kWh [32]. Bhattacharjee and Dey investigated the viability of harnessing rice husk potential with a hybrid system of grid-connected PV-biomass gasifier system [33]. The grid-connected PV-biomass hybrid power system may conserve around 90% of grid electricity, which is utilized in rice mills.

An off-grid hybrid energy system consists of two or more renewable sources like solar or wind energy system which are intermittent in nature and cannot provide continuous supply of electricity to meet the load demand of the village. Hence, in the most of the studies, energy storage like battery or non-renewable energy systems like diesel generator is used as back up sources to meet the load demand. This type of systems is common in case of the villages, which does not have access to conventional grid electricity. Hence, it is important to design the hybrid energy systems based on the load and energy requirement of a village and able to provide quality and reliable electricity to a village. Hybrid energy systems can be of two types (i) off-grid system and (ii) grid connected system. In case of an off-grid system, different renewable energy systems along with conventional energy systems like diesel generator can be combined to supply the energy requirement of the village. In most of the electrified villages in remote areas, electricity available in the grid is only for few hours and that is also most of the time, when electricity requirement in the village is minimal. Hence, it is sensible to consider the grid-connected hybrid energy systems, which provides more reliable electricity supply to the villages, and electricity can be sold back to the grid, when excess electricity generated from the systems. This in turn improves the access, quality and reliability of electricity supply and in the same time cost of energy generation is also lower in compare with off-grid hybrid energy systems (standalone). The comparison of the off-grid hybrid system and conventional grid extension is

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