# MODELLING OF DECENTRALIZED ENERGY SYSTEMS FOR DIFFERENT APPLICATIONS IN NORTH-EAST INDIA


## ABSTRACT

This work investigated the feasibility of decentralized energy systems (DESs) for resource-rich but grid-outage ridden North-Eastern region of India with an emphasis on the Rangpo area of Pakyong district, Sikkim. The demand of the region is already met by the grid whose major contributing source comprise of the renewable mega hydro power of the Teesta River. However, the unreliable energy supply scenario due to frequent grid outages caused by the complex topography and frequent natural calamities and the long history of damages to life and property caused by the mega-hydropower projects in the region has driven this investigation.

The investigation consisted of five case-studies mainly governed by the location, the type of load demand, the resource availability and the end-use. HOMER Pro Microgrid Tool, developed by the National Renewable Energy Laboratory, United States of America was used as the primary modelling software for the investigation in each of the case-studies. Additionally, innovative techniques, software tools and methods, specific to the needs of each case-study, were also implemented to comprehensively investigate the viability of DESs for each case-study. Further, each case-study also comprised of issues limited to the application or end-use which were investigated and resolved independently. The input parameters were further sensitized for every case-study to realize the viability of DESs over a broader region especially India as a whole.

Case-Study 1 investigated the techno-economic-spatial-environmental feasibility analysis of an off-grid/autonomous hybrid renewable energy system (HRES) for providing electricity to an academic township in the Pakyong District of Sikkim, India. The resources considered for the system were solar energy, wind energy, biogas, syngas and hydrokinetic energy with batteries as back-up. Load demand in the form of real-time hourly data was available for the township. Various constraints were implemented to limit the maximum installation capacities of the components considered. All the technical and financial specifications of the components were availed from the local Indian markets. A total of 31 possible combinations of the different resources were analyzed for net present cost, Levelized cost of energy, battery storage, emissions, area requirements and employment potential. The best combination was identified by applying a very prominent multi-criteria decision-making (MCDM) technique named Analytical Hierarchy Process. The Photovoltaic-Wind-Biogas-Syngas-Hydrokinetic-Battery based Hybrid Renewable Energy System was found to be the best combination with a Levelized Cost of Energy (LCOE) of 0.095 $/kWh. Finally, sensitivity analysis was carried out for various parameters to comprehend the behavior of the system for a broader application in the region.

Case-Study 2 investigated the techno-economic viability of an off-grid hybrid renewable energy system (HRES) comprising of solar photovoltaic panels (solar energy) and wind turbines (wind energy) as main supply with Lead Acid Batteries (LABs) as back-up for electrification of a grocery shop located at Majhitar area of Sikkim, India. Remote-Areas Multi-energy-systems-load Profiles (RAMP) software was used to promptly generate the stochastic demand data for the shop located in an unreliable electricity area which was imported to HOMER PRO software for simulation on a minute-by-minute basis for determination of LCOE. It was observed that the PV-Battery based system came out to be the best system with an LCOE of 0.311 US $/kWh while the Wind-Battery based system came out to be the worst system. Sensitivity analysis with respect to climatic conditions across entire India was conducted for the cheapest configuration to comprehend the LCOE for such a load profile across the country. None of the systems were found to be competitive to existing grid prices. However, it has been proposed that with subsidies or with further reduction in PV panel prices the cost of PV-Battery systems may become competitive with grid prices in future.

Case-Study 3 investigated the techno-economic-spatial feasibility of an off-grid rooftop photovoltaic nanogrid (solar energy) for residential sector in the cosmopolitan urban locality of Rangpo, Sikkim, India with unreliable electricity. RAMP was used for load modelling and an innovative technique for spatial feasibility analysis was implemented. 269 houses were surveyed and innovatively classified, based on number of dwelling rooms and demand profile similarity. Correlation and sensitivity analysis were conducted to understand the impact of individual and grouped load profiles, plinth area per household, number of dwelling rooms, climatic conditions, building types and component specification availability in market on the overall cost, configuration and feasibility of the system. Sharing of photovoltaic nanogrids and higher durations of daily occupancy in houses reduce the Levelized Cost of Energy (LCOE) from the system due to reduction in percentage variations of load. The LCOE of shared nanogrids ranged between 0.151 $/kWh to 0.195 $/kWh in India. The study recommended 50 % subsidy on system capital cost against grid prices. Batteries operated at higher Depth of Discharge (DOD) and having longer life at higher DOD reduced the system LCOE. Apartments in locations with high annual solar radiation, low annual temperatures, large plinth area, low monthly demand and unobstructed rooftops were found to be good candidates for PV nanogrids. The study also realized that in India, high-rise buildings with monthly loads up to 30 kWh/household, mid-rise buildings with loads up to 50 kWh/household, low-rise buildings with loads up to 100 kWh/household and double-storey buildings with loads up to 200 kWh/household can successfully adopt autonomous rooftop PV nanogrids.

Case-Study 4 is an extension of the work done in Case-study 3 and conducted a techno-economic investigation to identify the changes in configuration an off-grid renewable energy system comprising of Solar Photovoltaic Panels (solar energy) as main supply with battery as back-up for electrification of a house situated in a location with unreliable electric supply named Borjhar, Guwahati, Assam, India. RAMP software was used to generate the demand data for simulation using HOMER PRO software on a minute-by-minute basis for determination of net present cost and levelized cost of energy. It was observed that the load profile varied considerably with changes in the user behavior including the change in load factor and peak demand. For the system configuration, simulations for annual power demand with higher load factor, lower day-to-day percentage variations and higher daily load demand provided a lower levelized cost of energy compared to annual power demand with lower load factor, higher day-to-day percentage variations and lower daily load demand. This is the only Case-Study conducted outside of Sikkim in the North Eastern Region and spatial investigation has been not considered.

Case-Study 5 investigated the techno-economic-spatial-environmental feasibility of a Rooftop Photovoltaic System (RTPVS) for electrification of a grid outage-ridden, space-restricted public school in Chanatar, Pakyong, Sikkim and the techno-economic impact of electric cooking (e-cooking) against gas cooking to tackle rising Liquified Petroleum Gas (LPG) prices used in Pradhan Mantri Poshan Shakti Nirman (PM POSHAN) scheme, for enhancing student enrolment in public schools. RAMP was used for load modelling and PVsyst for estimating maximum Photovoltaic panel capacity and optimum Performance Ratio (PR) which were then imported to HOMER PRO for techno-economic investigation. 5 Dispatch Strategies (DSs) were implemented for three RTPVS configurations including two customized HOMER PRO-MATLAB DSs for the grid-connected configurations to understand the impact of employment of advanced and traditional grid-tied and hybrid converters during grid outages. Further, the impacts of transitioning to energy-efficient appliances, grid unreliability and various sensitivity parameters on the modelled system outcomes wee also investigated to generate broader comprehension of the system performance. For unreliable grid, PV-grid-battery configuration with grid sales yielded the best feasible result with a lower Global Warming Potential (GWP) and a reduced Levelized Cost of Energy (LCOE) at 0.0548 $/kWh than both the presently implemented grid-diesel generator (DG)-LPG configuration at 0.306 $/kWh and prevalent grid-battery configuration at $0.212 $/kWh, while the standalone PV-battery configuration is also economically competitive at 0.269 $/kWh with the least GWP. The PV-grid-battery configuration also showed economic viability across entire India for various component costs, grid tariffs and climatic conditions. The optimum converter capacity was conflictingly impacted by grid sales and converter costs. The advanced hybrid converter despite their high costs will be economically more viable over traditional hybrid converters in PV-grid-battery configuration for locations with high frequency and duration of grid outages. The charging of batteries

via grid was not recommended as it increased LCOE and system GWP. In locations with high grid tariffs and high percentage sellback rates, the PV-grid-battery configurations can be oversized to increase grid sales and system reliability without impacting the economic viability of the configuration. The degradation of Lead Acid Battery (LABs) increased LCOE and GWP. Policy implementation like carbon credits and subsidies on RTPVS and e-cooking appliances equivalent to LPG may further promote the RTPVS and e-cooking adoption in public schools.

Based on these 5 investigations, it can be comprehended that not all but specific configurations of DESs are technically-economically-spatially and environmentally viable for different applications in Sikkim and the North-east India. For standalone configurations, an HRES comprising of multiple renewable energy resources namely solar, wind, producer gas, biogas and especially hydrokinetic energy is the most viable option due to its low LCOE, low emission, low area requirements. For standalone systems involving mono energy resource, hydrokinetic and solar-based DESs are two of the most promising prospects in this region if energy autonomy is expected out of system in standalone configurations. Wind energy turns out to be very expensive in the region and economically infeasible while biomass and biogas-based systems fail to reach autonomy in the location. Further, hydrokinetic energy generated from a public asset like river for local use may face regulatory restrictions and limitations of site specificness despite being cheap and thus are not likely to be feasible in every location in region. Similar issues will also arise for biomass-based producer gas which is obtained from forest resources. Thus PV-based systems are likely to be the best alternatives in terms of mono energy resources in this region when regulatory restrictions are considered and hydrokinetic energy-based systems are the best when regulatory restrictions are not taken into account. For standalone PV-battery configuration, LCOE can be reduced by sharing the PV-battery configuration with multiple diversified users which is likely to smoothen the demand and also increase the load factor. For grid-connected DESs involving PV with battery-backups, the LCOE will reduce with grid sales. However, duration of grid outages and the type of converter system used plays a significant role in the overall viability of the system as longer outage duration can increase the LCOE and make the systems spatially infeasible.

Implementation of these DESs either in standalone mode or grid-connected mode on a larger scale for various applications like residential sector, market sector, official and school sector and townships across the country will significantly reduce the pressure of demand on the already unreliable and dominantly fossil-fuel based grid in India and reduce the fossil fuel-based imports and also reduce the global warming potential of the grid as a whole in the country. A combined demand of electrified conventional and cooking load can also be possibly met by these DESs if sufficient area is available for their installation of the DESs. The demand management will always remain a critical aspect in design of these systems for individual type of load or end-user, as it can significantly impact the LCOE.

Barua

.....

Signature of the Candidate

Date: 20.06.2025

Mousumi Basu 20.06.2025

Prof. (Dr.) Mousumi Basu
Thesis Advisor
Department of Power Engineering
JADAVPUR UNIVERSITY
Kolkata-700098

Professor
Dept. of Power Engineering
Jadavpur University
Salt Lake, 2nd Campus
Kolkata-700 098