A CAPACITY PLANNING MODEL FOR MICROGRIDS IN RURAL INDIA

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Overview

Motivated by the global inequality in modern energy access, this study develops a cost minimization model to optimize microgrid design and operation, and applies it to rural electrification in India. Our study demonstrates how load profiles can be constructed from the bottom-up by considering the various end-uses and appliances that a local community might choose to electrify.

Electricity is unavailable for 1.1 billion people globally, or 14% of the world's population (IEA, 2017). An additional billion can only access intermittent or unreliable electricity. For this third of the world, the lack of electricity negatively impacts quality of life and fundamentally limits the modernization of healthcare, education, and governance (Mawhood and Gross, 2017). As the global population increases and countries like India and China develop economically and show an increase in the standard of living, worldwide energy demand is expected to rise. Since India and other developing countries use a vast amount of coal as their primary fuel source, development of these regions is expected to contribute significantly to greenhouse gas emissions and climate change (Khanna and Rao, 2009). Many have proposed microgrids as the most cost-effective solution to rural electrification challenges that can simultaneously incorporate more sustainable, cleaner resources into the global energy profile (Groh, 2015). Microgrids are electricity systems that operate autonomously from centralized grids by aggregating (or bundling) distributed energy resources such as diesel generators, solar panels, and wind turbines (Murenzi and Ustun, 2015). Despite recent cost reductions, underinvestment remains a significant limitation for small-scale electrification. Many expect privatization to counteract underinvestment but cite the need for regulatory incentives. Considering this emerging trend in small-to-intermediate-scale electrification, it is important to perform cost analyses on various electrification strategies. This study provides a method-based approach for capacity planning and cost minimization with an example case study. The work serves as a tool for private and government investors in developing countries seeking to electrify rural areas with renewable energy. The goal is to provide equations, inputs and constraints that together form a transparent set of tools that are not software specific or overtly complex to apply. Due to institutional barriers, demand data about newly electrified rural areas are not abundant or easily available. Several studies available about rural electrification in developing countries using decentralized systems assume an aggregate load profile (Lau et al, 2010; Hafez and Bhattacharya, 2012). This paper focuses on building a monthly load profile with a bottom-up approach which can easily be modified to include different devices with various power requirements. As rural Indians become more computer-literate, this tool serves to emphasize community involvement in the planning process so that demand is not over or underestimated. This tool is not only limited to determining the energy requirements of an Indian village but rather can be applied to any developing country.

Methods

A linear program model was developed using Matlab and CPLEX Solver to find an optimal capacity planning strategy for distributed energy systems. Inputs include region-specific fixed and variable costs and hourly capacity factors that were gathered for four small-scale energy resources - solar, wind, mini-hydro, and diesel. Electricity demand profiles were developed from the bottom-up by determining a representative village size and modeling five different levels of electrification: residential, agriculture, health and safety, education, and social and commercial. The profile for this case study is meant to serve as a tool for villagers to interact with (by adding or removing number, type, and wattage of devices and hours of usage) and predict their energy usage. Sensitivity analysis was done to determine the impact of different levels of CO_2 taxes on the composition and total amount of capacity installed. The cost of electricity generation per kWh, percentage of renewable capacity installed and composition of capacity installations was also analyzed separately for each sector. The period of economic analysis was limited to one year. A portion of the agricultural load (irrigation) was made flexible so that the model could find economically optimal time to irrigate.

Results

A hybrid system comprising wind, mini-hydro and diesel coupled with battery storage is determined to be the most cost effective system for the load profile developed when a carbon dioxide tax of $50/ton is applied. The monthly dispatch strategy is shown below in Figure 1. The annual cost of electrification is about $50,000, the cost per kWh is

\$0.05 and 74% of renewable capacity is installed. As the CO_2 tax is increased, the amount of diesel installed decreases, as expected, while the total annual capacity installed increases since the capacity factors for the renewable sources are lower.

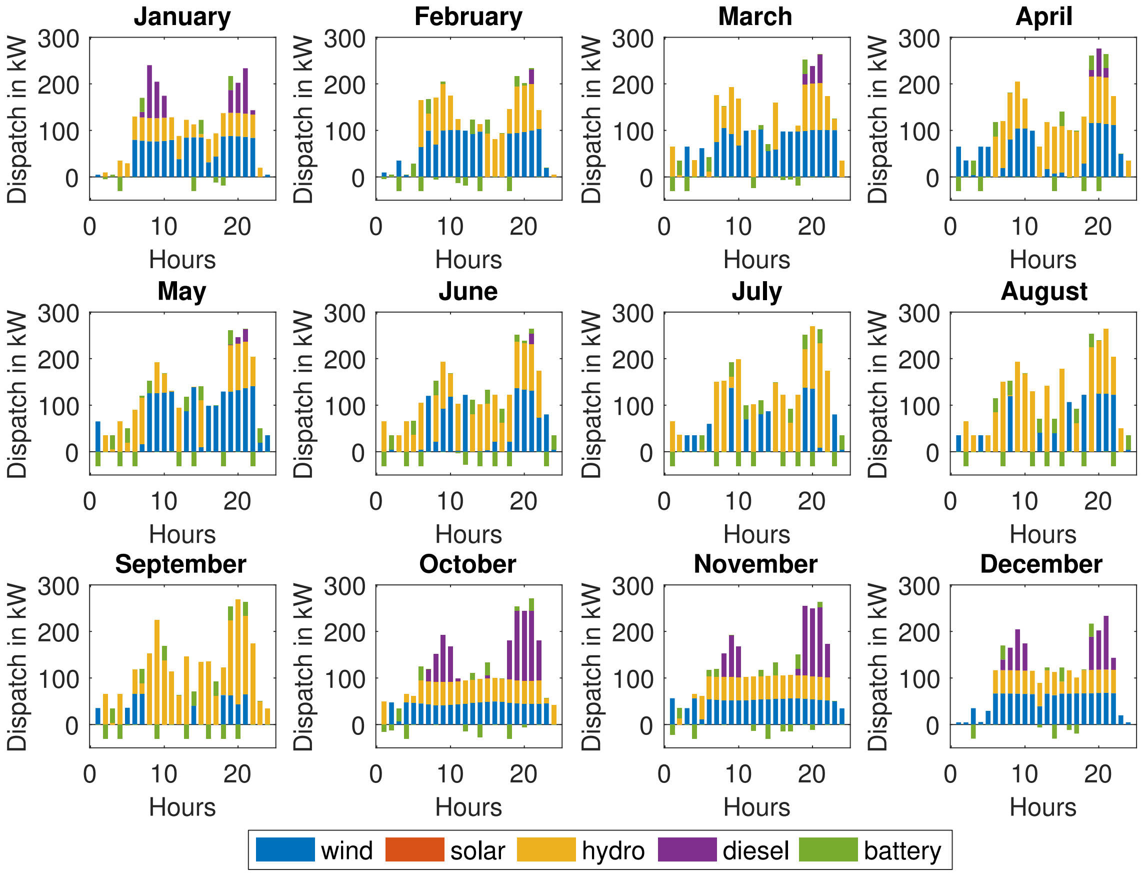

Figure 1: Monthly dispatch strategy of different fuels and battery for the base case

Conclusions

Rural electrification has recently benefited from cutting-edge technologies but remains a daunting challenge in many developing countries. Microgrid systems offer flexibility in scale, location, and electricity generation sources. The objective of our project was to investigate and model relevant energy sources for microgrids and develop an optimization tool for dispatch and capacity planning. Future work will include performing cost analyses of extending the grid to the village which would need to incorporate the complexities associated (for example, remoteness of the area) and modelling how socioeconomic growth as a result of electrification changes the demand.

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