Fully Renewable Energy Systems

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Abstract

Many organizations adopted have long-term goals of reducing or eliminating carbon emissions, such as the signatories of the Paris Climate Agreement, yet concrete plans to reach these goals are universally absent. This article takes the necessary first step of providing a cost estimate to meet typical residential loads entirely by renewable energy. The proposed system implements photovoltaic generation supported by a hybrid energy storage configuration, consisting of lithium-ion batteries and gas production.

I. Background

THE intermittency of renewable energy generation presents itself as a barrier in transitions to fully renewable energy systems. Renewable energy systems must be able to compensate for daily cycles (night time), adverse weather patterns, as well as seasonal variations in energy supply. Much work has been done on designing systems to meet electrical load, largely relying on curtailment. Perez et. al. proposed curtailment in models of cost effective renewable grids in [1] and studied it as a mean to address intermittency in [2]. The shortcoming of designing systems for electrical load is it only addresses a portion of fossil fuel usage. Heating needs in temperate climates can exceed energy usage for electricity. In non-electrified grids, which largely do not rely on electricity to meet heating needs, peak electrical load also often coincides with seasons of strong renewable generation. Thus limiting study to electrical loads favors the case for curtailment alone. Heating loads largely occur in the winter, amid times of reduced sunlight and weather phenomena that inhibits photovoltaic generation. While sizing renewable generation for curtailment is an important part of a fully renewable grid, the greatest barrier to renewable energy penetration is energy storage.

II. Approach

Battery storage (with electrified heating) is a potential solution to meet deficits such as nights and short-term weather intermittency but is cost prohibitive to meet the last kWhs of seasonal deficits arc. An alternative storage technology is required to handle the requirements of operating in temperate climates. The approach proposed is a hybrid system with LI batteries for short term storage and compressed methane storage to meet seasonal needs. Gas is produced in months of surplus renewable generation when energy usage and conversion efficiency are of little concern due to PV system oversizing. Converting to methane allows existing gas distribution networks to meet heating needs directly. Batteries are only sized to meet the load of most summer nights as well as to allow the power-to-gas (PtG) to run continuously overnight. The seasonally continuous PtG operation allows for chemical processes which otherwise may be infeasible to cycle on a sub-daily basis. For electrical loads, the system is intended to meet electricity demand in a similar manner to a hybrid car. By necessity, the battery storage is large enough to meet power and grid stabilization requirements, while the gas-to-power infrastructure (conventional gas turbines) only needs to meet electrical loads sustained in excess of the battery size. A dynamic range of PtG power is assumed for the methanation and judicious use of forecasting allows for controls to avoid depleting battery storage ahead of inclement weather. The system architecture is illustrated below in figure 1:

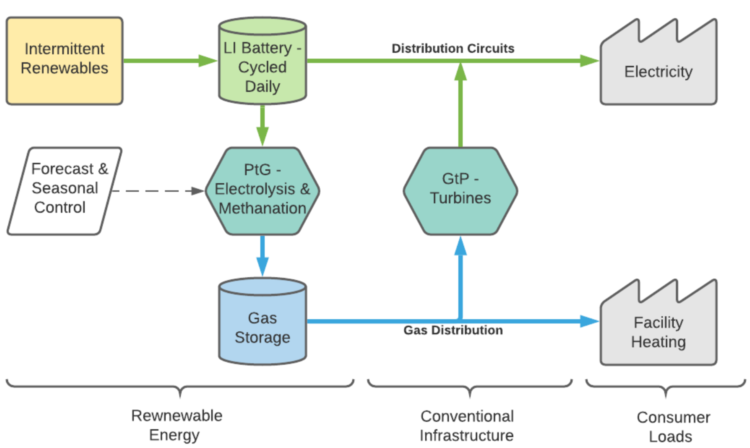

Fig. 1: Fully Renewable Energy System Structure

III. SIMULATION

While a minimum cost solution is subject to the climate and load profile of the application, a simulation is provided to demonstrate the concept. The hybrid system is evaluated on AY data of a residential unit representative of generation, load, and weather patterns in temperate climates. The purpose of using residential data over a utility scale set is twofold: 1) both load and renewable generation are tightly coupled to local weather phenomena, 2) an exhaustive record of heating loads is available. Equipment parameters and costs are assumed as detailed in table 1: Battery and PtG contribution to the LCOE is

Component	Cost	Units	Efficiency	Equipment Life
PV	\$0.06 [3]	kWh	-	LCOE cited
LI Battery	\$380 [4]	kWh	1.0	10 yrs
Power-to-gas	\$37,200 [5]	w/w$_e$	0.54 [6]	10 yrs
Gas-to-Heat	-	w/w	1.0	-
Gas-to-Electricity	-	w$_e/w$	0.48 [7]	-

TABLE I: Cost & Efficiency

calculated as capital cost divided by years of service. Photovoltaic (PV) system size in this study is expressed as a ratio of energy generated to the sum of annual load. This is calculated such that a PV/load ratio of 1.0 would be sized exactly for net metering. An average PV LCOE is cited for the cost per gross kWh available and, if desired, the necessary system size in kW could be found based on the insolation of the system's location. This example is designed to target a 10% annual surplus in energy storage. The resulting parameters are tabulated in table 2.

Component	kW(h) / annual load	Contribution to LCOE
PV	2.5	\$0.15
LI Battery	0.0045	\$0.17
Power-to-gas	0.00017	\$0.63
Annual Load Met	1.0	\$0.95

TABLE II: Simulation Parameters

The parameters are designed such that, per residential unit with a 10,000 kWh annual load of combined heat and electrical energy, the system requires an annual production of 25 kWh of PV, 45 kWh of LI battery storage, and 1.7 kW_e of PtG power. The system is simulated in figure 2, subject to AY data of residential loads in a temperate climate [8], [9]. The vertical axes are scaled per unit of annual load.

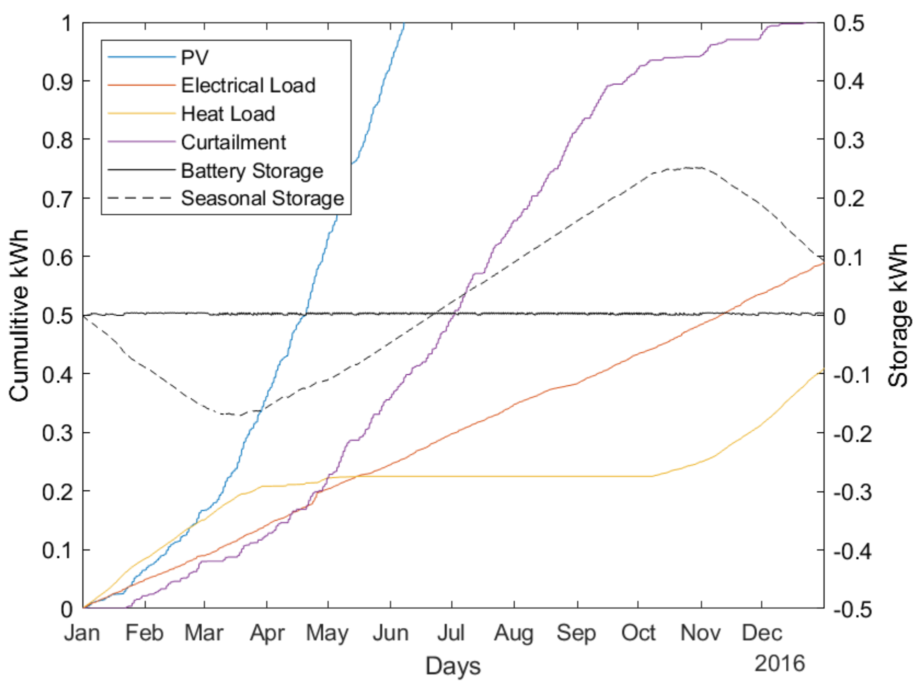

Fig. 2: Hybrid Storage Simulation

IV. Results

This generation and load profile exhibits an LCOE of approximately \$0.95 /kWh. The cost breakdown from table 2 is illustrated below in figure 3. Two thirds the cost is accounted for in the PtG equipment, not including the excess PV and LI required to support the PtG operation. While loads can be partially met at grid parity for most of the year by renewables [9], this system demonstrates that the largest challenge in transitioning to a fully renewable grid is long term storage. The requirement for short term storage capacity, such as LI batteries, is limited to 0.5% the of annual load. Despite oversizing the renewable generation by a factor of 2.5x the annual load, PV only constitutes a small fraction of the cost. The renewable energy system as proposed establishes an LCOE estimate based on today's technology and identifies seasonal storage as a priority for development. Further reductions in renewable energy technology cost are necessary to reach a feasible price point for the transition in regions with seasonal generation and load patterns as evaluated in the subject data. Fossil fuel usage with non-seasonal load patterns may see significantly lower cost to displace with renewables than reported in this study.

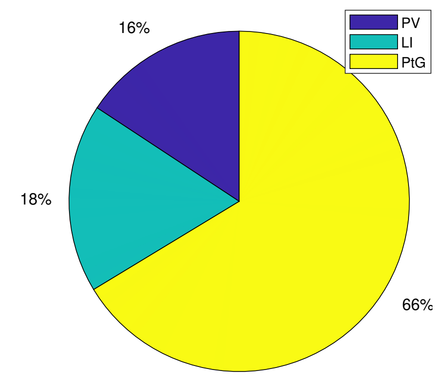

Fig. 3: Cost Breakdown by Component

The benefits of relying on methane for long term storage are the existing infrastructure, which allows a safe transition, minimal conversion costs, and leaves existing extraction available for emergency deficits. The primary limitation to methane as a storage medium is the PtG technology remains in a research stage. PtG costs are inferred from the cited pilot projects [5], [6]. An alternate PtG approach using ammonia as the seasonal storage medium may be feasible, however the necessary equipment for reformation to access the hydrogen requires full grid electrification to effectively distribute heating energy. Using either gas allows remote production and long distance transmission, such that gas may be produced economically in a favorable climate. Introducing wind generation to the system may reduce costs if the location of the system demonstrates a strong wind resource in the winter months.

References

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