SIP: Progress Report 2
Solar Project for Pine Ridge Reservation, SD, USA

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1 Scenario Analysis

Here we test the power system in a variety of scenarios designed to illustrate its behaviour and verify its sufficiency. Over the course of this analysis, the system was resized from the previous design in order to minimise the extent to which power would be dumped to or drawn from the grid during normal operating conditions. The solar and hydro nameplate capacities were modified by a factor of 0.5 and 1.5, respectively. The battery size was left unchanged.

1.1 Scenario 1: Winter

Scenario 1 focuses on the performance of the system during a representative week during Winter (the meteorological data is from January, specifically). Winter is characterised by low solar energy availability, and a relatively constant load-curve (i.e. a high base-load)

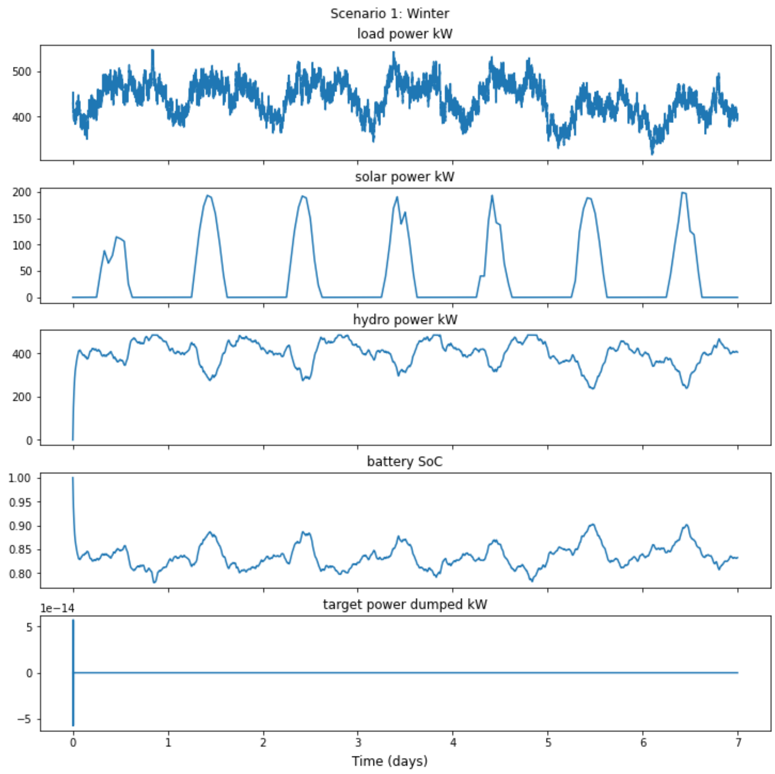

Figure 1: Illustration of the state of the system for a representative week during the Winter. Winter is characterised by a relatively even load-curve, and minimal solar energy.

In this case, the system provides much of its energy from the hydro-power installation. The solar energy contributes less than half of what it does in the Summer scenario (a 200 kW vs 400 kW peak, combined with shorter days). The battery state-of-charge is very consistently around 80%. This indicates the battery is more than large enough for this scenario (and were this the only case to consider, could be safely reduced in size by perhaps a factor of 4). The goal of complete autonomy from the grid is upheld in this scenario, as no power is dumped to or drawn from the grid.

1.2 Scenario 2: Summer

Scenario 2 focuses on the performance of the system during a representative week during Summer (the meteorological data is from July, specifically). Winter is characterised by high solar energy availability, and a load-curve which oscillates more widely than its Winter counterpart.

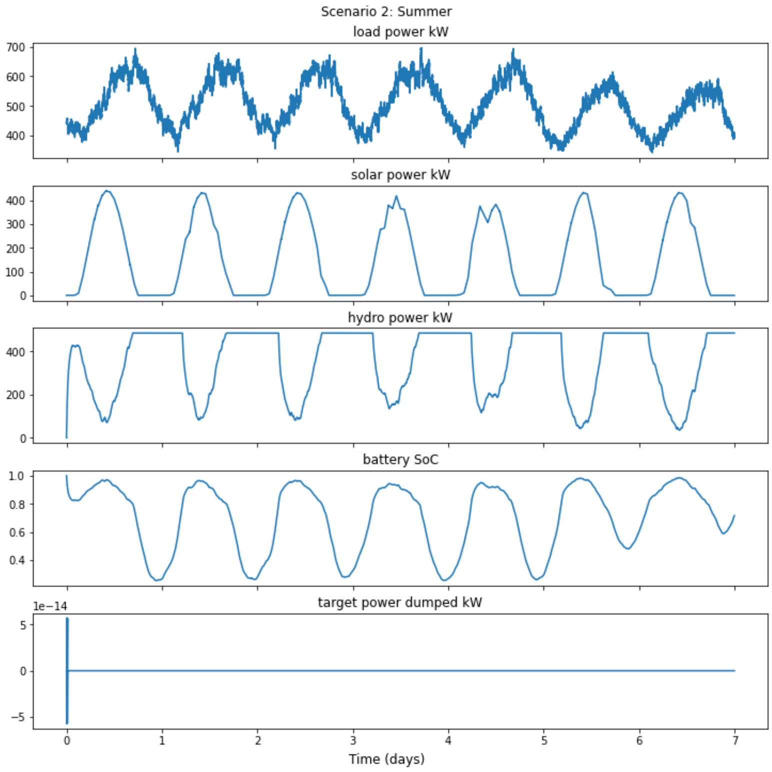

Figure 2: Illustration of the state of the system for a representative week during the Summer. Summer is characterised by a sine-like load-curve, higher overall consumption, and large amounts of solar energy.

In this case, the system strikes a roughly even balance between drawing hydro and solar power. The evening-overhang in power consumption compared to solar energy production was a driving design condition for the size of the hydro-power installation. The battery state-of-charge oscillates broadly between roughly 20% and 90%; this range is good, as it indicates that the battery has not been made too large, while still leaving comfortable margins; thus the Summer case also drives the design of the battery. The goal of complete autonomy from the grid is upheld in this scenario, as no power is dumped to or drawn from the grid.

1.3 Scenario 3: Solar-Failure (Summer)

Scenario 3 geminates the conditions of the above scenario, while adding a hypothetical long-term failure of the solar installation. This scenario was chosen in order to characterise the extent to which such a large failure would harm the system's grid-autonomy; Summer was chosen as it was observed above to be the design-driving condition for much of the system. In reality, smaller failures of individual solar modules or array-arms are perhaps more likely than a system-wide failure, so this case should be considered a worst-case analysis of this particular type of failure.

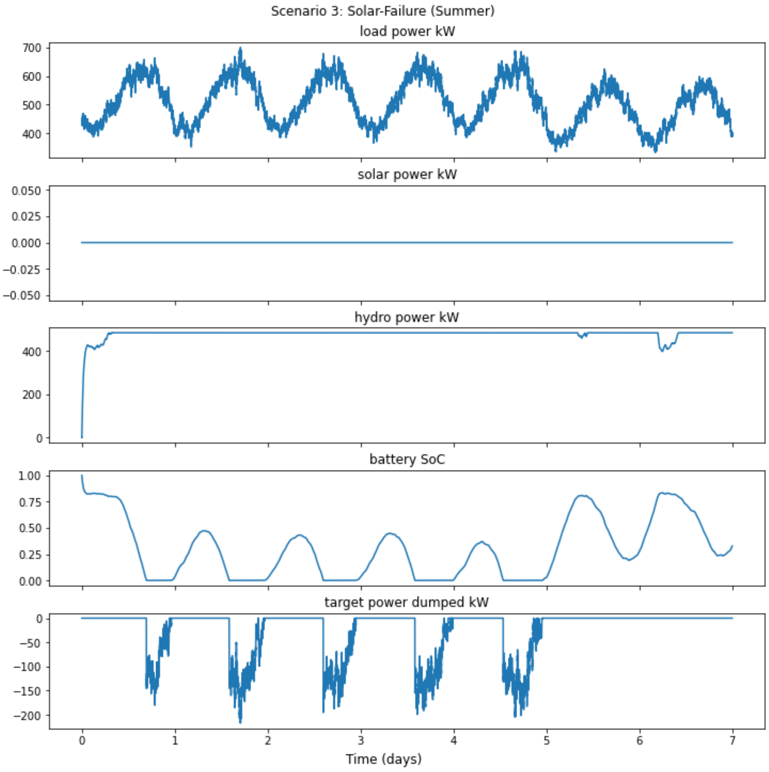

Figure 3: Illustration of the state of the system for a representative week during the Summer after a hypothetical week-long outage of the solar array. Compared to previous cases, the battery is highly depleted and the hydro nearly always at maximum; the remainder of power is drawn from the grid.

As is clear, in the absence of the solar array, the system is unable to match the demand of load; this indicates that the solar and hydro plant have been sized reasonably (as alternatively, if the hydro plant alone could meet demand, there would be no need for expensive solar panels at all). However it is also clear that the objective of grid-autonomy is no longer maintained; daily draws of over 200 kW are made from the grid, for a weekly total of roughly 4300 kWh. While the degree to which autonomy is important to the local community should play a role in making such a decision, for the purposes of this report, it was determined that this scenario should not be permitted to drive sizing, as it is comparatively unlikely and would dramatically increase system-costs.

2 Economic Analysis

In this section is offered a rough estimate of the cost of creating the designed system.

2.1 Capital Cost Breakdown

The principal costs of concern are the capital costs. In particular, we consider the costs of the hydropower installation, the solar panels and associated MPPTs, and the batteries.

Item	Estimated Unit Capacity Cost	Installed Capacity	Total Capital Cost	Percent of Total Capital Cost
Hydropower Installation	4287 USD/kW	484 kW	USD 2,074,908	49.0%
Solar Panel Modules	320 USD/module	461 kWp (1376 modules)	USD 440,320	10.4%
Solar MPPT Units	700 USD/unit	39 units	USD 27,300	0.6%
Batteries	1638 USD/kWh (usable)	1033 kWh (usable)	USD 1,692,054	40.0%
Total			USD 4,234,582	100.0%

Item	Estimated Unit O&M Cost	Installed Capacity	Total O&M Cost	Percent of Total O&M Cost
Hydropower Installation	43.78 USD/kW	484 kW	2119 USD/y	57.7%
Solar PV + Storage Installation	33.67 USD/kW	461 kWp	1552 USD/y	42.3%
Total			3671 USD/y	100.0%

The unit cost of hydropower is estimated using that of the nearby Oahe dam, adjusted for inflation. It is worth noting that the system was designed iteratively to adequately meet design objectives - economic optimisation was not (and in the authors' opinion, due to their imprecision, should not be) performed on the preliminary cost estimates here.

2.2 O&M Cost Estimation

Operation and Maintenance (O&M) Costs are estimated per unit of capacity based on data from [**STATISTA Report**]. This report provides data for 'solar PV with storage', which was used to estimate the combined O&M costs of the solar PV and battery system. Overall, the estimated annual costs of the system are less than 0.1% of the estimated capital costs.

2.3 Levelised Cost of Electricty

The so-called 'Levelised Cost of Electricity' (LCOE) is a standard metric for measuring the amortised cost of the production of a single unit of electricity [**LAZARD LCOE**]. For simplicity, in calculating the LCOE, we neglect the ongoing costs. We assume the system lifetime to be 25 years, roughly in line with the warranty of the solar modules [**LG NEON MANUAL**], with the acknowledgement that some parts of the system, especially the hydro installation may last much longer, while others, such as the batteries, may degrade more rapidly, making this a rough approximation.

Further, the LCOE here presented is the 'overnight' cost of the system - it excludes the costs of installation, construction, and obtenance of capital (not due to lack of importance, but because they exceed the scope of this report). This said, this 'overnight' LCOE is then simply the total energy generated divided by the system cost:

$$\mathrm{LCOE}_{\mathrm{overnight}} = \frac{\mathrm{Cost}_{\mathrm{system}}}{E_{\mathrm{lifetime}}} = 45.07\ \mathrm{USD/MWh}$$

For an overnight LCOE of roughly 45 USD / MWh. This is roughly double what the average European consumer pays after taxes [**Europe energy**] - though this is not unreasonable given that utility-scale installations are able to benefit from economies-of-scale.