Analyzing Reliability of an off-grid PV System of a Reverse Osmosis Desalination Plant for Yabucoa, Puerto Rico

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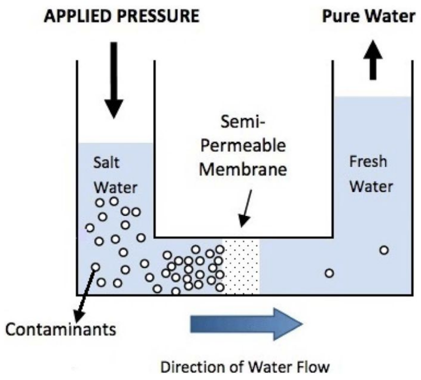
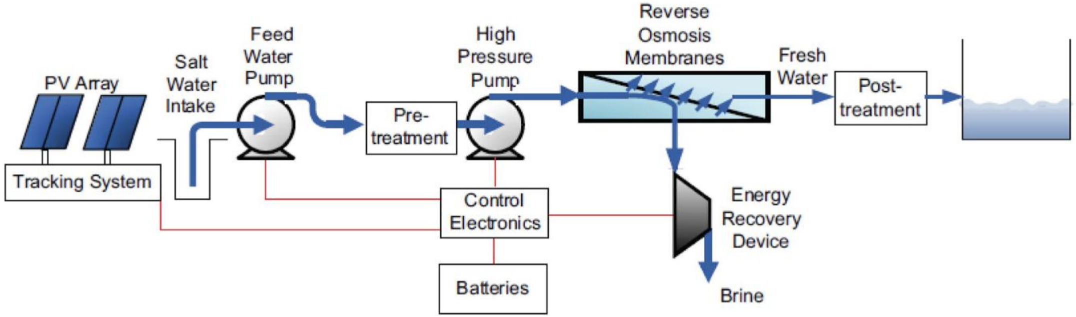
Motivation

- Seawater desalination is the removal of salt and impurities from seawater to produce fresh water
- Reverse Osmosis is a water purification process that uses a pump to push water through a membrane to filter out unwanted molecules and large particles
    - Only desalination process that can be powered with renewable energy





Background

- Journal- Investigation of off-grid photovoltaic systems for a reverse osmosis desalination system: A case study
- Highlights of Journal:
    - Off-grid PV system for a Reverse Osmosis Desalination system is investigated for Bushehr in Iran
    - HOMER and MATLAB Software were run for technical-economic feasibility
- Project Changes
    - Was unable to collect data from Iran
    - HOMER systems were not used
    - Performed analysis for Yabucoa, Puerto Rico
        - Need: After Hurricane Maria 2017, no freshwater for more than 6 months
            - Limited data analysis to during hurricane
        - Scope:
            - Off-grid PV system for Reverse Osmosis Desalination system
            - Used Schenker Modular 500
                - Used on boats - use case in high flooding and coastal areas
                - Models used by journal authors as well
            - Analyzed available cloud cover data and solar elevation data
            - Measured reliability using journal author equations
            - Generated reliability equations
            - Estimated system size according to population, infrastructure plan budget, human water need
            - Analyzed Reliability of system

Research Papers

- Understanding the process:
  - Process control in water desalination industry: an overview
  - Automation and process control of reverse osmosis plants using soft computing methodologies
- Energy Management focused:
  - Advanced control system for reverse osmosis optimization in water reuse system
  - Improvement of PV/T Based Reverse Osmosis Desalination Plant Performances Using Fuzzy Logic Controller
- Sizing the system by cost:
  - Optimal technical and economic configuration of photovoltaic powered reverse osmosis desalination systems operating in autonomous mode
- Assessing if a RO system can be solar powered:
  - Investigation of off-grid photovoltaic systems for a reverse osmosis desalination system: A case study (chosen)

My Approach

- Iran Data was not available
- HOMER systems was not available
- Assessed the natural reliability of the electricity production using solar data containing indices of “Cloud Cover” and “Solar Elevation Angle”
  - Cloud Cover is dual of Clearness Index
  - Solar Elevation Angle used to calculate Solar Radiation
  - Period 16 September 2017 - 2 October 2017 (Hurricane Maria)
- Used MATLAB to perform analysis
- Analysed using model: Schenker - Modular 500 Naval desalination system
  - Other plants unreliable due to hurricane damage, flooding, landslides
  - This plant is meant to be in water
- Analyzed reliability using author provided fuzzy time function
  - Simple time function used in HOMER was not provided - unable to compare
- Performed technical-economic analysis using local population and local budget provided by US Infrastructure Plan for Puerto Rico

Research Paper Approach

- Authors assessed the natural reliability of the electricity production using solar data containing indices of “Clearness Index” and “Daily Solar Radiation”
  - Period 16 years: 2000 - 2016
  - 9 districts of Bushehr Province in Iran
- HOMER and Excel were used for technical-economic feasibility of the proposed systems
  - HOMER systems have own analysis tools the authors used
- Analysed using model: Schenker - BWRO-2S-130/75 desalination system
- Analyzed reliability using fuzzy time function rather than simple method in HOMER toolbox
- Performed technical-economic analysis using local energy, installation, maintenance costs

System Reliability Equations

- Shortage of annual electricity produced from photovoltaic system designed on the basis of sunshine hours

$$LOL_i = \sum_{j=1}^{12} D_j (w_j - w_{ij})$$

- Reliability of accessibility to electricity is achieved based on daily sunshine hours in the ith month

$$R_i = 1 - \frac{LOL_i}{W_y}$$

- Ranking function is implemented which projects fuzzy numbers on real numbers status

$$\text{R}: F(R) \to R$$

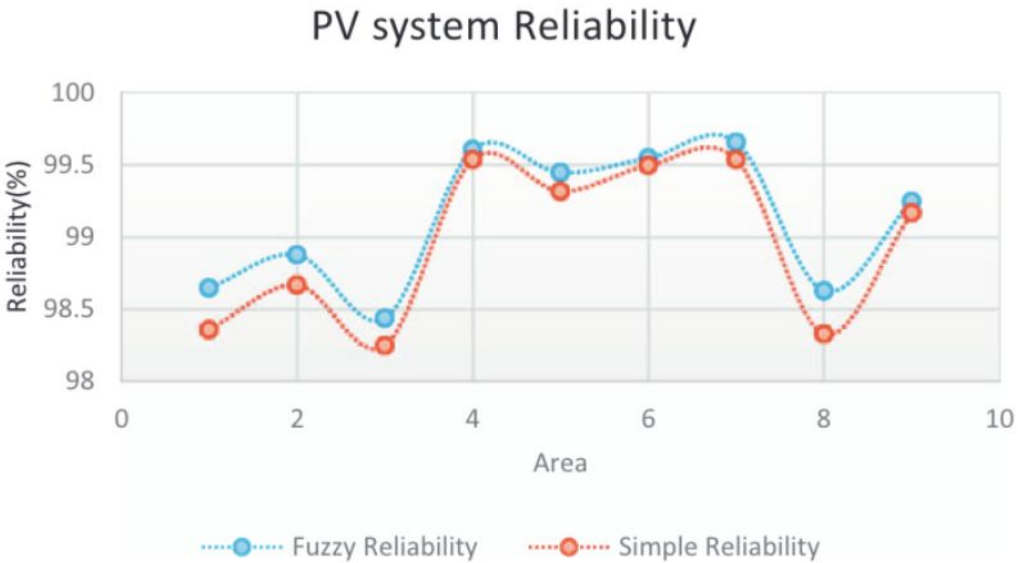
$$R(\tilde{a}_j) = \frac{(a_j - m_j) + 2a_j + (a_j + n_j)}{4} \cong \frac{a^1 + a^u}{2} \qquad \forall\ \tilde{a}_j(a_j, m_j, n_j)$$

System Reliability using Fuzzy Rank Function

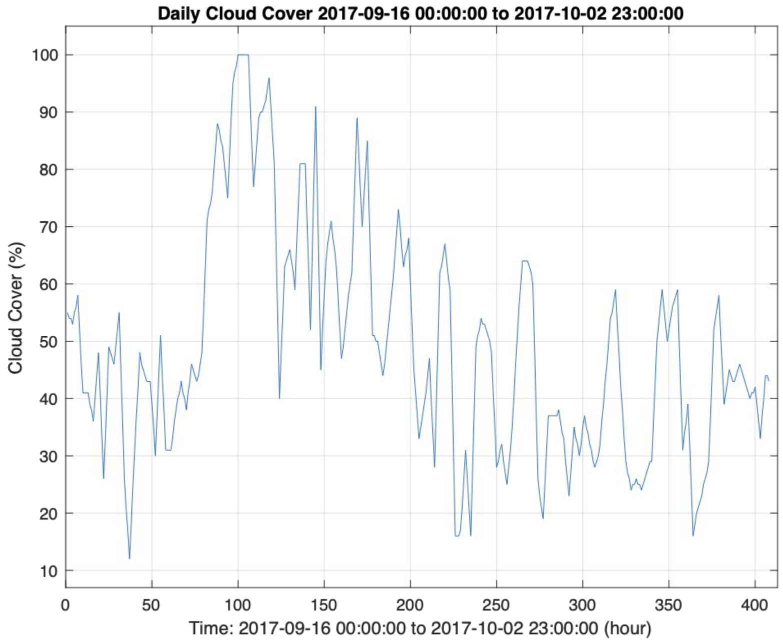
Table 4
Reliability of the PV system for each area using Fuzzy Rank Function.

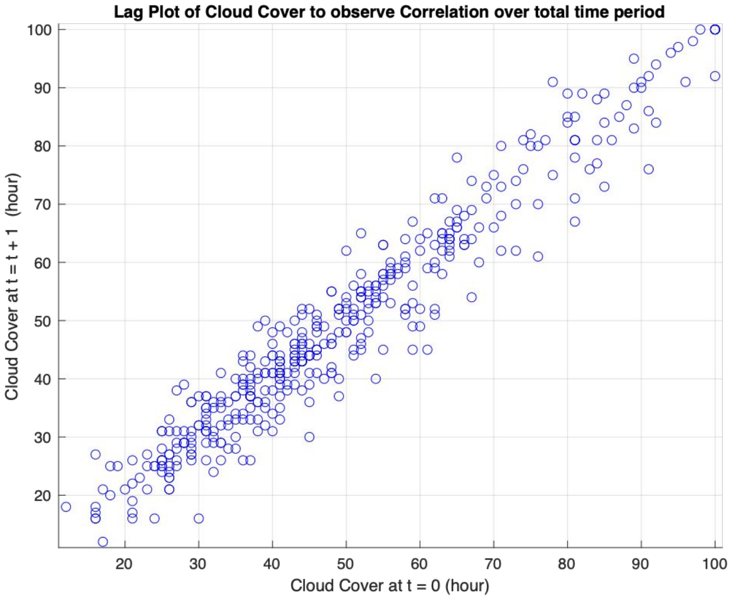
	Reliability (%)								
	Bushehr	Deylam port	Dayyer port	Delvar	Ganaveh port	Asaluyeh	Kangan port	Rig port	Siraf port
Jan.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Feb.	97.66	97.79	98.94	99.07	98.90	98.56	99.23	97.58	92.07
Mar.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Apr.	98.37	98.57	99.37	99.79	99.63	99.39	99.66	98.34	100
May	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Jul.	98.37	98.57	99.37	99.79	99.63	99.39	99.66	98.34	100
Jun.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Aug.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Sep.	98.37	98.57	99.37	99.79	99.63	99.39	99.66	98.34	100
Oct.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Nov.	98.37	98.57	99.37	99.79	99.63	99.39	99.66	98.34	100
Dec.	98.96	99.21	98.83	99.58	99.42	99.77	99.72	98.95	99.85
Ann.	98.65	98.88	98.44	99.61	99.45	99.55	99.66	98.63	99.25

Results - System Reliability Improvement

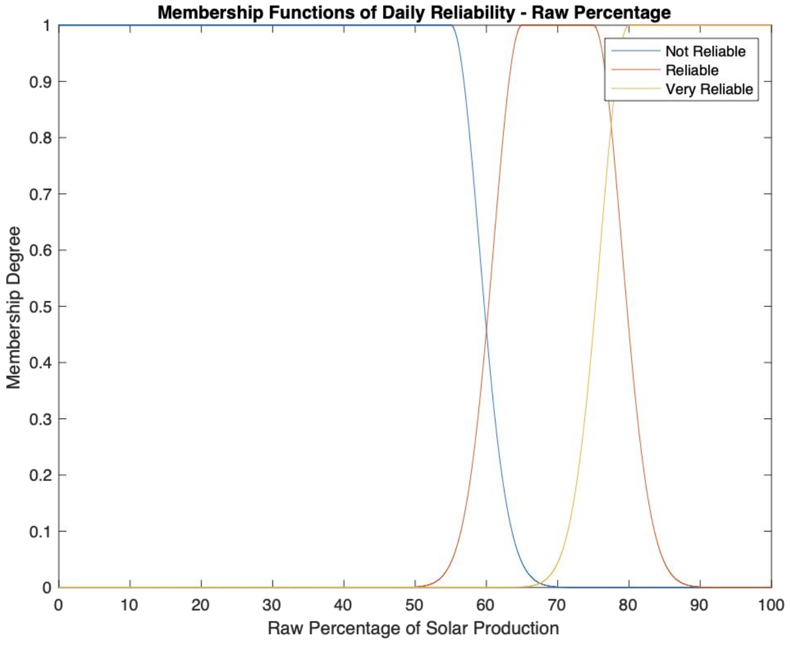


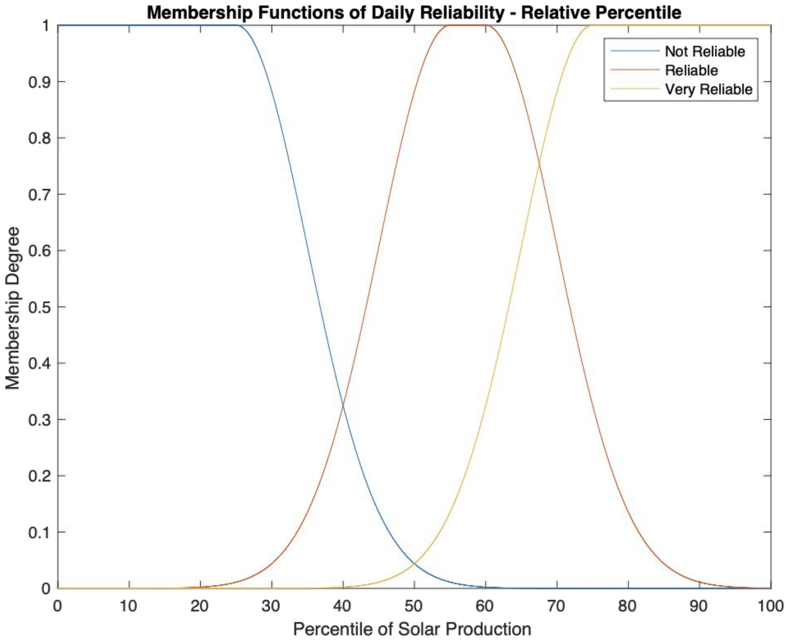
Cloud Cover Data during Hurricane Maria





Membership Functions for Natural Reliability based on Solar Availability





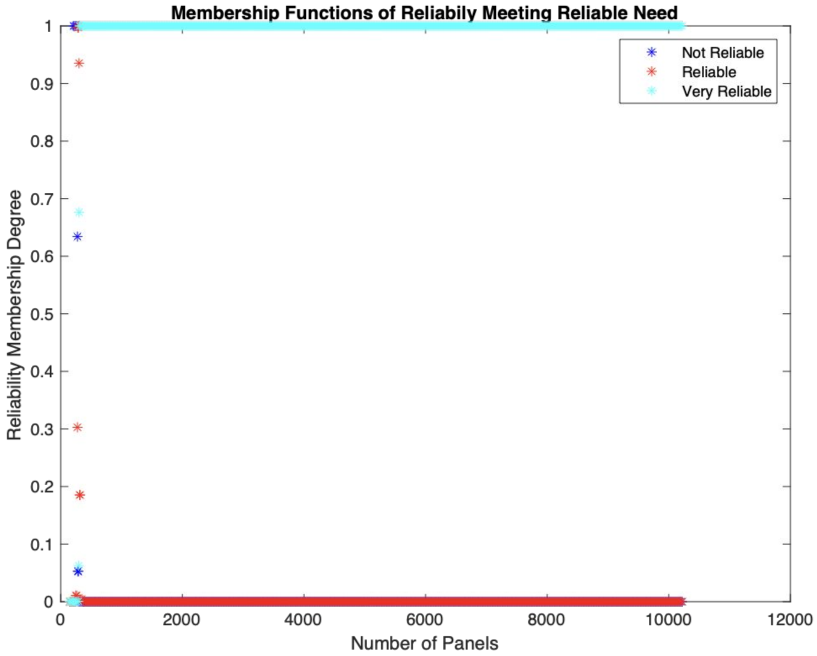
System Reliability using Paper Fuzzy Rank Function vs. Fuzzy Rules

1 Hurricane Day	2 Reliability
1	0.9999
2	0.9999
3	0.9999
4	0
5	0
6	0
7	6.0874e-13
8	0.0650
9	0.9581
10	0.9999
11	0.9999
12	0.9999
13	0.9999
14	0.9999
15	0.6754
16	0.9999
17	0.9999

1 Hurricane Day	2 Not Reliable	3 Somewhat Reliable	4 Reliable	5 Very Reliable
1	0.0100	0.2604	0.2608	0.0131
2	0.0100	0.0100	0.0562	0.9500
3	0.0100	0.2692	0.4670	0.8246
4	0.9500	0.0100	0.0100	0.0100
5	0.9500	0.0100	0.0100	0.0100
6	0.9500	0.0100	0.0100	0.0100
7	0.9500	0.0100	0.0100	0.0100
8	0.9350	0.0100	0.0100	0.0100
9	0.0437	0.0511	0.0503	0.0100
10	0.0100	0.0209	0.1250	0.9500
11	0.0100	0.0820	0.2537	0.9500
12	0.0100	0.3041	0.4928	0.7658
13	0.0100	0.0165	0.1118	0.9500
14	0.0100	0.4664	0.5707	0.3950
15	0.3247	0.0100	0.0100	0.0100
16	0.0100	0.0100	0.0526	0.9500
17	0.0100	0.4393	0.4565	0.0712

Analyzing System Reliability Based on - How Reliably Water Need is Met

- Number of Panels?
  - From Data on Right:
    - Reliable - 296 panels
    - Very Reliable - 313 panels
- Yabucoa Population = 33000
- Schenker Desal Plant Spec
  - desal_output_hour = 132 gals/hour
  - desal_energy_consumption = 3.5 kWh
- Reliable Water Need = 0.5 gallons/day
- Reliable Water Need Population = Yabucoa Population * Reliable Water Need
- Water Budget per person = ($455 million / 5 / 3.5 million) * Yabucoa Population
- Plants within budget = 11



Further Research Ideas

- Simulate Hurricanes using AutoRegressive process since high correlation
- Analyze post Hurricane Reliability
- Optimize system size based on cost and production
- Include Battery Storage

Fuzzy Rules

- Rule 1: if x is not reliable and y is not reliable then z is not reliable
- Rule 2: if x is reliable and y is not reliable then z is not reliable
- Rule 3: if x is not reliable and y is reliable then z is somewhat reliable
- Rule 4: if x is not reliable and y is very reliable then z is somewhat
- reliable
- Rule 5: if x is reliable and y is reliable then z is reliable
- Rule 6: if x is very reliable and y is reliable then z is reliable
- Rule 7: if x is reliable and y is very reliable then z is reliable
- Rule 8: if x is very reliable and y is very reliable then z is very reliable

Fuzzy Output Membership Function