# Reliability Standards and Evaluation Methods for New Proposed High-VRE Integrated Energy Systems

Jessica Nicholson 12/23/2022


## Abstract

This report introduces a new procedure with associated methods to evaluate proposed integrated energy systems for facilities that will incorporate high levels of variable renewable energy (VRE). Since these facilities aim to incorporate greater renewable energy in their electric infrastructure, this report describes the purpose of this transition and how new and innovative systems can accomplish this while retaining reliability despite the additional challenges of variability. It describes the process taken to create standards based on system considerations related to reliability and details the evaluation steps necessary to determine whether a proposed system meets each standard. Ultimately, this report generates results on the reliability characteristics of a proposed high-VRE system to compare to measurable standards and determine the viability of this proposed system based on whether these standards are met. This report is a comprehensive guideline to ensure newly-proposed integrated systems perform as needed for their particular applications with minimal required known parameters and without the need for costly testing. It details the reliability considerations for proposed systems, the subsequent reliability evaluation procedure, supporting methods and calculations, and application of the procedure to an existing high-VRE system to validate the expected output results.

## Table of Contents

# 1. Introduction

1.1 Background:

Energy demand continues to grow on a global scale while the detrimental effects of climate change are becoming increasingly apparent. Due to this, implementing sustainable energy solutions is becoming increasingly critical to fulfill this energy demand while transitioning our energy infrastructure away from fossil fuels that perpetuate climate change. The long-term well-being of global communities and industry depends on our ability to make this transition while maintaining performance and reliability in addition to optimizing cost and resources. Additional renewable energy sources create additional challenges within the system, however, that must be managed. Renewable energy sources such as solar and wind power create system variability due to the uncontrolled resource inputs necessary to generate power, while fossil fuel sources have controllable generation that can be matched to load. Challenges such as these must be addressed to design effective high-VRE integrated systems with mechanisms that manage variability and ensure continuous service.

This energy transition requires that new integrated systems be conceptualized, constructed, and evaluated for use in existing facilities. Creating systems with high renewable energy implementation that are reliable requires solutions that account for several reliability considerations. These include the facility's relatively small system size, disconnect from the larger electrical grid, and more stringent service availability and general reliability requirements compared to residential applications. Due to the isolation, they will experience higher variability in the solar and wind resources they rely on. The several power generation methods and supporting storage methods of these integrated systems will control varied input power and reduce variability. Implementation of high-VRE systems is a new, necessary challenge that does not yet have established standards or evaluation methods to determine feasibility and compatibility with the needs of the facilities these systems will provide power to. This report provides a procedural set of evaluation methods that can guide this implementation, validate the reliability of high-VRE systems with wind and solar power, and optimize the system to ensure the system reaches its reliability standards while operating cost-effectively, efficiently, and with minimal excess power.

1.2 Problems to Address:

- What standards can new integrated systems adhere to in order to ensure reliability?
    - Reliability-based considerations of high-VRE integrated energy systems
    - Measurable standards based on these considerations or known system capabilities
    - Standards dependent on the characteristics or application of the proposed system
- Follow-up: What methods can be used to evaluate these new proposed systems and ensure they meet the identified reliability standards?

1.3 Applications and Impact of Project:

This project provides a framework for which to evaluate new proposed integrated systems. It will ensure that proposed energy grid projects with high-VRE inclusion are held to the standards that ensure reliability and advance high-VRE systems as valuable and sufficient replacements for fossil fuels. Maintaining performance is critical in the transition to sustainable integrated systems, so this project will validate the reliability of new integrated systems to be equal or greater than current non-variable systems. These new systems will reduce carbon footprint without compromising function or performance if they follow the guidelines of the explained procedure.

Potential applications of this project include specific locations, industries, and facilities with objectives to transition to high-VRE integrated systems. Each of these applications can significantly benefit from the methods this report provides to ensure reliability and optimize the systems proposed for these applications.

**Application Examples:**

- USACE facilities with critical systems and high service availability requirements
- Public, industrial, and residential facilities:
  - Currently using predominantly fossil fuels
- Energy grids at locations with high variability in:
  - Load
  - Ambient temperature
  - Direct normal solar irradiance, generated solar power
  - Wind speed, generated wind power

The larger impact of this project is to promote the reliable implementation of high-VRE systems to meet increasing electric demand over fossil fuel systems. Causes of increased electrical demand include growing use of electric vehicles, fabrication of hydrogen and other clean fuel, and increasing reliance on electrical mechanisms in our daily lives. Despite the growing electric demand, however, this project shows that it is possible to fulfill this demand using high-VRE energy systems given careful evaluation. This project demonstrates the capability of proposed high-VRE systems to be proven reliable and cost-effective through simulated results, assure viable implementation, and ease the apprehension surrounding the performance of VRE. Reliability results from the use of this evaluation will provide solutions that are reliable, cost-effective, and optimized, ultimately progressing the implementation of renewable energy in several types of grids and microgrids.

## 2. Objectives and Hypothesis

2.1 Objectives:

- **Identify** critical system considerations related to the reliability of a power system
- **Create** standards for each consideration based on existing standards and system capabilities to account for the additional challenges of high-VRE
- **Form** a procedure to evaluate proposed integrated systems for adherence to each standard
- **Determine** methods that the developed procedure follows to gather reliability results
- **Validate** that this procedure yields the numerical results expected

2.2 Hypothesis:

If effective standards are established for high-VRE integrated systems, the reliability of these implemented systems will meet or exceed that of current systems despite the additional challenges of new integrated systems. It is possible to accurately simulate the generated power of VRE sources and use this information—among related data—to gather valuable results about the reliability of high-VRE integrated systems and optimize system parameters to meet reliability standards.

## 3. Reliability Considerations and Standards

3.1 Known Proposed High-VRE System Parameters:

In order to evaluate proposed integrated systems for adherence to reliability standards, certain characteristics of these systems must be defined so they can be applied in the subsequent procedure to evaluate adherence to standards. These are the system characteristics that must be defined to apply this evaluation.

1. Power rate / installed capacity of each variable and non-variable power generation source
    a. Power rate / installed capacity
    b. Manufacturer and type
2. Total system size
    a. Total power rate from all systems
    b. Proportion of each power generation source in the full system
3. Each storage system included
    a. Manufacturer and type
    b. Instantaneous power capability (kW)
    c. Storage capacity (kWh)
4. Wind Turbine Parameters:
    a. Rated wind speed
    b. Rated power
    c. Number of blades
    d. Blade radius
    e. Altitude / height
    f. Air density associated with altitude
    g. Manufacturer power curve and $C_p$ curve of the wind turbine model
5. Solar Panel Parameters:
    a. Efficiency of DC/DC converter(s) used
    b. Temperature coefficient of solar panel brand
    c. Nominal operating cell temperature
6. Yearly load data from the proposed location taken at time intervals
    a. Includes associated average, peak, and minimum load
    b. Any time interval length can be used, but the shorter the time intervals, the more accurate the results will be
    c. The time interval length of this load data must match the time intervals used for other time-dependent variables in this evaluation to create corresponding data sets on the same time scale for calculation

3.2 System Reliability Considerations and Defined Standards:

This list describes each of the system considerations found relevant to reliability, the standards and/or guidelines defined for each consideration that this report recommends proposed systems follow, and justification of each consideration as well as background needed for subsequent sections that quantify these considerations based on their impact to system reliability. Proposed systems with a high proportion of variable renewable energy can be evaluated for adherence to each of these standards.

1. **Service Availability**

The percentage of time during a specified operational period that a system is meeting expectations by providing all of the demanded power. Failures and downtime contribute to a decrease in measured service availability. The system's minimum service availability percentage must meet or exceed current system standards for military installations or similar facilities. The service availability required of a system depends on the system's application, but for many critical systems, the minimum service availability is 99.999% to 99.9999%.

2. **VRE Penetration and Generated Power Variability**

Increasing the proportion of clean variable renewable energy is one of the most significant objectives of the proposed systems to be evaluated with these guidelines. The proposed system is therefore highly recommended to have high VRE penetration, defined as a minimum of 50% of the annual energy provided by the system with capability to provide up to 100% instantaneous power (Kroposki 1). A higher proportion of VRE leads to a higher overall system variability, however, in the generated power. Greater variability leads to more unpredictable power generation and decreased reliability. Due to the importance of integrating a significant portion of VRE, however, other considerations are a higher priority to maintain reliability despite this additional variability. These additional considerations are described below.

3. **Area Occupied and Varied VRE Types**

Spreading the VRE generation sources over a large land area can reduce the impact of natural resource inconsistency on generated power variability. "As you spread the VRE across an area, there is a marked decline in the system-wide variability" (Kroposki 3). Diverse methods of power generation within an integrated system also lower the expected variability of the system, as it therefore relies on several natural resources. One inconsistent source—such as solar or wind—is therefore not as impactful to the generation of the full system and is less likely to cause long periods of insufficient power generation that lead to failure.

4. **System Generated Power vs Load**

The generated power of a system cannot fall below the load for a significant amount of time. The greater the variability of the system in either power generation or load, the more likely load will exceed generated power and the higher the total system generated power must be compared to the load to ensure system reliability. As a numerical representation, the generated power of a system needed to ensure reliability will be a magnitude greater than 100% of the load the system provides power to at any given time. The greater the variability in the system, the larger this percentage must be to maintain service availability. Calculating generated power to compare to load data is explained in the Section 4 Evaluation Procedure.

5. **System storage capacity and instantaneous power output capability**

Storage capacity and power output capability must be sufficient to account for all time periods of load exceeding generated power. The storage capacity recommended to ensure reliability is dependent on variability. Larger variability, or greater variation between the total generated power and load over time, usually means that a larger storage capacity is needed relative to system size to maintain reliability. This also applies to instantaneous power output capability, as the storage system must be able to provide a minimum instantaneous power of the greatest disparity between load and power generation during a yearly trend.

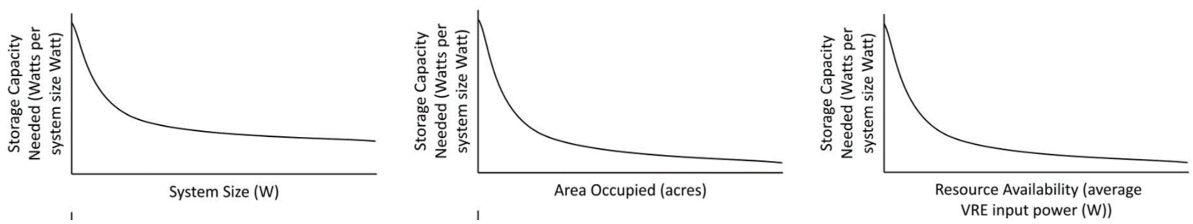


*Figure 1: Expected impact of system size, area occupied, and resource availability on storage capacity needed*

Each of these factors are components needed to calculate the predicted power generation of a proposed system. If this total power generation is calculated, it can be compared to load, used to calculate the predicted service availability of the system, and create a direct measure of how much storage is needed to make up for periods of power deficit. This storage capacity standard is therefore dependent on the calculated storage needed for the specific proposed system evaluated.

6. **Allowable Curtailment**

Curtailment occurs when generated power satisfies all load and input to storage sources to ensure a balanced system. Other factors such as transmission lines, voltage, interconnections, and stability may also impact curtailment as shown by Section 5.8. Assuming adequate capacity in these interconnected components, allowable voltage and stability, only system balancing needs to be considered in a curtailment decision. Whether or not these other factors have to be considered depends on the individual integrated system under evaluation.

## 4. Evaluation Procedure and System Optimization

This section describes a three-stage mathematical procedure to evaluate each proposed integrated system for adherence to the reliability standards defined in Section 3. The stages of this procedure calculate the predicted service availability of the proposed system, proportion of VRE generation, and optimal storage needed to ensure reliability by addressing each of the defined standards. Several of the methods mentioned in this procedure are explained in depth in Findings Section 5. The results of this procedure can be compared to the defined standards to evaluate reliability of the proposed system.

4.1 Standards 1 and 4: **The system's minimum service availability percentage must meet or exceed current system standards.**

1. Confirm that the system parameters listed in Section 3.1 are known, as they are necessary for this evaluation
2. Gather natural resource data
    a. Use the Global Solar Atlas (Solargis 2022) or a similar source to gather yearly direct normal irradiance data at the proposed location as shown by Figure 2 in the Findings section with the determined number of time steps
    b. Find yearly ambient temperature data for this proposed location
        i. Gather and record this data at the same time period and time intervals to correspond to irradiance data
    c. Gather annual wind speed data or create a simulated set of data
        i. Method 1: Gather known annual wind speed data
        ii. Method 2: If annual wind speed data is unknown, use the Global Wind Atlas to generate a plot of mean wind speed per area at the proposed location and use this plot to simulate a set of annual wind speed data. This method is described in the Findings Section 5.3.
3. Calculate generated wind power at every time step
    a. Method 1: Use the manufacturer power curve of each wind turbine model to create a set of generated power values that correspond to the wind speed data from step 2c. This method is explained in Findings Section 5.5.
    b. Method 2: Calculate wind power generation corresponding to each simulated wind speed, power coefficient and load time interval data point
4. Calculate generated solar power at each solar irradiance time step data point
5. Sum the calculated variable power generation data sets from steps 3 and 4 together into a data set to represent total system generated VRE power vs time
6. Create another data set of generated power including the non-variable generation components of the system
7. Create a set of data representing the difference between total generated power (for both non-variable generation included and excluded) and the corresponding load data points. This becomes a heat map where any values below 0 represent non-guaranteed reliability.
8. Calculate the proportion of heat map values above 0 for both the VRE-only scenario and full-system scenario, which represents the minimum projected service availability.

Equation 1: Minimum Projected Service Availability

$$S = N_{positive} / N_{total}$$

$N_{positive}$ refers to the number of data points greater than 0 while $N_{total}$ refers to the total number of data points in the set.

9. For the generated data sets in this calculation process using gaussian distribution parameters, the values of these sets will vary with each trial. Repeat this procedure for several trials to regenerate the gaussian data sets, recalculate the resulting service availability, and measure variation of these projected service availability results over several trials. The more trials taken—or projected service availability data points

collected—the more accurate the mean projected service availability will be as well as the variance of this data set. The data sets that may be generated from gaussian parameters (depending on the method used) are shown below.

a. Natural Resource Data (Step 2): Annual trends vary from year to year and are experiencing a larger long-term shift due to climate change, so using only one data set for these natural resource aspects would be unreliable to model long-term service availability.
    i. Wind speed
    ii. Solar irradiance
    iii. Ambient temperature
b. Annual Load Data (Step 1): With regular changes in population, electric demand, increased applications, and other factors that impact load, annual load trends often experience change over time so using one data set to represent annual load would be unreliable to model long-term service availability.

Variation in the projected service availability provides a view into the uncertainty of the model, which is caused by these gaussian distribution changing datasets and several other factors unique to the evaluated system. The lower the variance, the greater confidence that the model provides an accurate projected service availability. The mean service availability from the set of data points collected with each trial will be the true projected service availability used in subsequent analysis.

10. Evaluate this projected service availability of the proposed system's VRE components for adherence to the application-based service availability standard
    b. If this projected service availability is greater than the given service availability standard, the stand-alone VRE components of the system meet this standard
    c. If this service availability is not greater than the given service availability standard, the VRE system does not meet this standard and variability control systems such as storage or non-variable generation must be implemented in the system to ensure reliability.
    d. Section 4.3 of this procedure calculates the storage capacity and power needed to counteract low service availability and achieve a theoretical service availability of 100%. Existing storage and non-variable generation within the proposed system can be compared to these calculations to evaluate whether they ensure reliability.

4.2 Standard 2: **The system is recommended to have high VRE penetration, defined as a minimum of 50% of the annual energy provided by the system with capability to provide up to 100% instantaneous power**

The purpose of this overall evaluation is to ensure the reliability of high-VRE systems considering their additional challenges due to variability. Using the generated power of each source from the previous Section 4.1, this method can validate that the proposed system is a significantly high-VRE system that meets or exceeds 50% of its minimum annual energy provided by VRE sources.

1. Using the power generated vs load difference data set in Excel, the proportion of load supplied by VRE can be calculated corresponding to each data point. Equation 2 can be applied to each cell to do this. $P(w)_{diff}$ represents the data point from the generated power vs load difference data set while L represents the corresponding load data point.

Equation 2:

$$P_{VRE} = 1 - (COUNTIF(P(w)_{diff}, "<0") * ABS(P(w)_{diff})) / L$$

2. Once the proportion of load supplied by VRE for each corresponding data point is found, calculate the average proportion of load supplied by VRE. If this proportion is greater than 0.5, the recommendation is met.

3. The proportion of time that VRE generation supplies 100% of the load, or 100% instantaneous power, can also be calculated by applying Equation 3 to each cell of the previous data set. The variable "n" represents the number of $P_{VRE}$ data points, and $P_{VRE,1}$:$P_{VRE,n}$ spans the whole data set of size n. If this proportion is greater than 0, the recommendation is met for capability of instantaneous power, but it is still valuable to calculate this proportion to determine the expected proportion of the annual cycle that 100% of power will be provided by the VRE sources as well as when this is most / least likely to occur.

Equation 3:

$$P_{100\%} = COUNTIF(P_{VRE,1}: P_{VRE,n}, " = 1") / n$$

4.3 Standard 5: **System Storage Capacity and Power Output Capability must be Sufficient to Account for Time Periods of Load Exceeding Generated Power**

Based on the calculated service availability and the generated power vs load data table from Section 4.1 of the procedure, the total system storage capacity needed over the course of the annual cycle and the instantaneous power output capability needed to ensure reliability can be calculated. This procedure to calculate these parameters accounts for all periods of generated power shortage in comparison to load and increases the projected service availability of the system to a theoretical 100%. This assumes no considerations such as unplanned outages due to natural conditions that can be evaluated in a resiliency analysis. It does, however, ensure no theoretical cases of <100% service availability due to lack of reliability or power shortage.

1. Sum the magnitude of all the data points in the generated power vs load data table that fall below 0. For data points with hour-long time intervals, this is the total power shortage in watt-hours experienced over the cycle. The minimum storage capacity of the system in annual watt-hours corresponds to this value to overcome the insufficient service availability calculated for the stand-alone system and ensure reliability. If this procedure is run multiple times, the largest total power storage calculated determines the minimum storage capacity.

Equation 4: Minimum Annual Storage Capacity Needed in the System (Wh or kWh)

$$C_{min} = ABS(SUMIF(P(w)_{diff,1}: P(w)_{diff,n}, " < 0"))$$

2. Find the minimum power difference from the generated power vs load data table, as this corresponds to the maximum power shortage during the annual cycle. Equation 5 identifies this minimum in Excel and takes the absolute value to represent the minimum instantaneous power that the storage system must be capable of providing to the system to achieve 100% theoretical service availability. If this procedure is run multiple times, use the largest maximum power shortage calculated to determine the minimum instantaneous power capability.

Equation 5:

$$P_{min} = ABS(MIN(P(w)_{diff,1}: P(w)_{diff,n})$$

3. Among all the data points in the generated power vs load table greater than 0, find the total annual power surplus in watt-hours experienced over the annual cycle. This is the quantity of power generated in excess of the load that can be stored given adequate storage capacity. This must be significantly greater than the total power shortage over the annual cycle calculated in part 1 to be reasonably certain that the storage system will have sufficient stored power for the periods of greatest power shortage no matter when they occur. This is another condition that should be considered to achieve 100% theoretical service availability.

4. To ensure the generated power surplus provides sufficient power to storage for every period of shortage, calculate the running total of the chronological generated power vs load data set. If no points in this running total drop below zero, the power surplus is theoretically sufficient to provide stored power. This assumes that the charging rate of the implemented storage is high enough for all surplus to be stored, and inverter efficiency losses must also be considered. A conditional capped value should be added to the running total representing the proposed capacity or the minimum storage capacity calculated in step 1 so that this running total does not exceed storage capacity.

5. If total storage power and capacity are specified for the proposed system, compare these calculations to the specified storage power and capacity to evaluate whether this system is designed with sufficient power and capacity. If the specified values are lower than the calculated storage power and capacity needed, they must be raised to meet this minimum recommendation.

## 5. Supporting Findings and Methods

This section describes each of the findings that led to a procedural solution and provides detail on several of the methods needed to complete the calculations in the Section 4 procedure.

5.1 Calculating Generated Power of a PV Solar Source:

Equations 6, 7, and 8 make up a validated method to calculate generated solar power at a given time (El-Bidairi 2018). Solar irradiance is a resource that varies with time, while the efficiency representing loss due to temperature increase varies due to ambient temperature with time. Factoring the known values into each equation and applying the solar irradiance data as well as ambient temperature data will yield the calculated generated solar power at every time step.

Equation 6: PV Solar Generated Power

$$P_{PV} = C_{PV} S(t)\eta_{loss}(t)\eta_{DC/DC} \,/\, S_{STD}$$

Equation 7: Efficiency Representing Loss due to Temperature Increase

$$\eta_{loss}(t) = 1 - \lambda(T_{cell}(t) - 25)$$

Equation 8: Temperature of the PV Cell

$$T_{cell}(t) = T_a(t) - (S(t)/0.8)(T_{NOCT} - 20)$$

$C_{PV}$ = PV Rated Power (kW)

$S(t)$ = Solar Irradiance (kWh/m$^2$) vs Time

$\eta_{DC/DC}$ = Converter Efficiency

$S_{STD} = 1\ kW/m^2$ = Standard Solar Irradiance

$\lambda$ = Temperature coefficient of solar panel model

$T_a(t)$ = Ambient temperature (C) vs time

$T_{NOCT}$ = Nominal operating cell temperature (C)

Solar irradiance at the location of interest can be found from the Global Solar Atlas (Solargis 2022) in the format shown by Figure 2 of annual average hourly per month data points.

**Average hourly profiles**

Direct normal irradiation [Wh/m²]

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | | | | | | | | | | | | |
| 1 - 2 | | | | | | | | | | | | |
| 2 - 3 | | | | | | | | | | | | |
| 3 - 4 | | | | | | | | | | | | |
| 4 - 5 | | | | | | 4 | | | | | | |
| 5 - 6 | | | | 10 | 92 | 139 | 92 | 16 | | | | |
| 6 - 7 | | | 34 | 190 | 274 | 296 | 288 | 219 | 158 | 42 | | |
| 7 - 8 | 13 | 99 | 230 | 326 | 350 | 376 | 391 | 346 | 377 | 291 | 132 | 16 |
| 8 - 9 | 236 | 297 | 332 | 399 | 407 | 440 | 462 | 416 | 462 | 414 | 363 | 237 |
| 9 - 10 | 346 | 370 | 391 | 446 | 450 | 485 | 509 | 474 | 527 | 467 | 451 | 349 |
| 10 - 11 | 381 | 409 | 440 | 476 | 468 | 521 | 554 | 510 | 573 | 492 | 492 | 398 |
| 11 - 12 | 408 | 436 | 459 | 488 | 478 | 523 | 573 | 528 | 587 | 506 | 508 | 411 |
| 12 - 13 | 420 | 449 | 464 | 489 | 474 | 523 | 577 | 530 | 571 | 503 | 506 | 406 |
| 13 - 14 | 405 | 437 | 458 | 476 | 464 | 536 | 561 | 527 | 559 | 500 | 490 | 403 |
| 14 - 15 | 399 | 427 | 437 | 449 | 448 | 517 | 539 | 515 | 528 | 475 | 457 | 383 |
| 15 - 16 | 359 | 384 | 392 | 407 | 408 | 483 | 504 | 483 | 486 | 425 | 390 | 321 |
| 16 - 17 | 223 | 305 | 323 | 350 | 351 | 425 | 449 | 424 | 411 | 311 | 158 | 100 |
| 17 - 18 | | 90 | 208 | 265 | 283 | 351 | 372 | 332 | 251 | 37 | | |
| 18 - 19 | | | | 74 | 168 | 244 | 257 | 137 | | | | |
| 19 - 20 | | | | | | 48 | 41 | | | | | |
| 20 - 21 | | | | | | | | | | | | |
| 21 - 22 | | | | | | | | | | | | |
| 22 - 23 | | | | | | | | | | | | |
| 23 - 24 | | | | | | | | | | | | |
| Sum | 3190 | 3703 | 4169 | 4844 | 5117 | 5911 | 6170 | 5456 | 5490 | 4463 | 3947 | 3024 |

*Figure 2: Example of Solar Irradiance Data for a Specific Location (Maui) at Average Hourly/ Month Time Intervals Throughout the Year*

5.2 Temperature Coefficient for Solar Panel Power Calculations:

The temperature coefficient from Equation 7 represents the amount of efficiency loss that occurs with an increase in the surface temperature of the photovoltaic cell. This coefficient is defined for several solar panel models (Ost 2020).

5.3 Simulating Wind Speed Data from Location-Based Information:

In the absence of known time-based annual wind speed data, the Global Wind Atlas (Global 2022) provides a plot as shown by Figure 3 for the selected location of interest. This plot shows every mean wind speed throughout this selected location and the percentage of the selected area that corresponds to each mean wind speed. Data characteristics can be extracted from this plot to simulate a set of time-based wind speed data that is compatible to use in calculations of wind power generated.

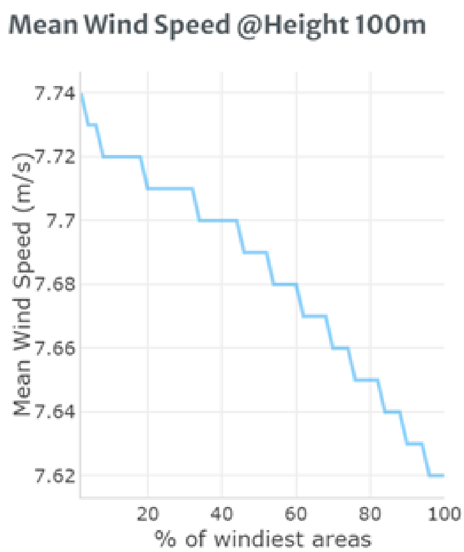


*Figure 3: Example of Mean Wind Speed Plot at a Specific Location (Flinders Island)*

Data can be extracted from this plot in Figure 3 as shown in Table 1 by treating the percentage of selected area corresponding to each mean wind speed as the quantity. This provides the information needed to calculate the true mean wind speed of the whole selected location and the standard deviation.

Table 1: Mean Wind Speed Values and Corresponding Quantities Found from Figure 3

| Mean Wind Speed (m/s) | Quantity (% of Selected Area) |
|---|---|
| 7.62 | 7 |
| 7.63 | 6 |
| 7.64 | 6 |
| 7.65 | 8 |
| 7.66 | 5 |
| 7.67 | 8 |
| 7.68 | 8 |
| 7.69 | 8 |
| 7.7 | 12 |
| 7.71 | 14 |
| 7.72 | 13 |
| 7.73 | 4 |
| 7.74 | 1 |
| **Total** | 100 |
| **Population Mean (m/s)** | 7.6814 |
| **Standard Deviation** | 0.033496866 |

Table 2 shows that a set of time-based wind speed data can be simulated by randomly generating a number for each data point within the normal distribution given the calculated parameters of mean and standard deviation from Table 1. The number of wind speed data points generated should equal the number of data points used for other time-based data sets in the procedure. If

Excel is used to create this simulated data set, Equation 9 can be applied to each cell to generate a random data point given the normal distribution parameters.

Equation 9: Formula to Simulate Wind Speed Data in Each Cell of Table 2

$$NORMINV(RAND(),\ MEAN,\ ST\ DEV)$$

Table 2: Simulated Wind Speed Data Set Using Normal Dist. Mean and Standard Deviation

| Hour | Wind Speed (m/s) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 7.71 | 7.71 | 7.69 | 7.68 | 7.70 | 7.69 | 7.60 | 7.66 | 7.70 | 7.72 | 7.70 | 7.67 |
| 1 | 7.63 | 7.71 | 7.67 | 7.75 | 7.73 | 7.64 | 7.63 | 7.70 | 7.76 | 7.69 | 7.75 | 7.64 |
| 2 | 7.67 | 7.66 | 7.66 | 7.66 | 7.67 | 7.72 | 7.66 | 7.65 | 7.73 | 7.70 | 7.66 | 7.69 |
| 3 | 7.73 | 7.66 | 7.65 | 7.69 | 7.67 | 7.67 | 7.72 | 7.73 | 7.72 | 7.67 | 7.71 | 7.65 |
| 4 | 7.64 | 7.67 | 7.68 | 7.69 | 7.66 | 7.68 | 7.73 | 7.72 | 7.70 | 7.71 | 7.66 | 7.62 |
| 5 | 7.72 | 7.69 | 7.69 | 7.60 | 7.66 | 7.69 | 7.71 | 7.67 | 7.70 | 7.63 | 7.73 | 7.64 |
| 6 | 7.70 | 7.71 | 7.71 | 7.70 | 7.72 | 7.71 | 7.69 | 7.70 | 7.70 | 7.68 | 7.74 | 7.66 |
| 7 | 7.71 | 7.70 | 7.61 | 7.65 | 7.64 | 7.62 | 7.69 | 7.70 | 7.64 | 7.66 | 7.66 | 7.62 |
| 8 | 7.64 | 7.76 | 7.67 | 7.66 | 7.71 | 7.71 | 7.66 | 7.71 | 7.67 | 7.66 | 7.65 | 7.72 |
| 9 | 7.68 | 7.69 | 7.69 | 7.71 | 7.68 | 7.71 | 7.69 | 7.64 | 7.75 | 7.70 | 7.69 | 7.66 |
| 10 | 7.70 | 7.68 | 7.62 | 7.69 | 7.68 | 7.70 | 7.66 | 7.63 | 7.65 | 7.67 | 7.64 | 7.67 |
| 11 | 7.71 | 7.64 | 7.69 | 7.71 | 7.68 | 7.69 | 7.68 | 7.70 | 7.66 | 7.68 | 7.74 | 7.73 |
| 12 | 7.68 | 7.70 | 7.70 | 7.67 | 7.70 | 7.71 | 7.65 | 7.69 | 7.64 | 7.67 | 7.65 | 7.66 |
| 13 | 7.64 | 7.71 | 7.65 | 7.70 | 7.67 | 7.70 | 7.70 | 7.71 | 7.68 | 7.66 | 7.65 | 7.69 |
| 14 | 7.67 | 7.69 | 7.68 | 7.68 | 7.65 | 7.66 | 7.68 | 7.67 | 7.69 | 7.64 | 7.68 | 7.66 |
| 15 | 7.69 | 7.66 | 7.64 | 7.69 | 7.71 | 7.66 | 7.68 | 7.69 | 7.70 | 7.68 | 7.70 | 7.68 |
| 16 | 7.71 | 7.67 | 7.69 | 7.68 | 7.67 | 7.63 | 7.72 | 7.69 | 7.72 | 7.68 | 7.73 | 7.66 |
| 17 | 7.65 | 7.70 | 7.68 | 7.65 | 7.73 | 7.70 | 7.69 | 7.67 | 7.68 | 7.64 | 7.71 | 7.70 |
| 18 | 7.73 | 7.67 | 7.68 | 7.71 | 7.70 | 7.65 | 7.67 | 7.63 | 7.73 | 7.67 | 7.62 | 7.76 |
| 19 | 7.71 | 7.62 | 7.72 | 7.61 | 7.66 | 7.70 | 7.67 | 7.67 | 7.75 | 7.71 | 7.71 | 7.71 |
| 20 | 7.65 | 7.63 | 7.73 | 7.67 | 7.63 | 7.71 | 7.67 | 7.68 | 7.67 | 7.69 | 7.69 | 7.71 |
| 21 | 7.65 | 7.60 | 7.69 | 7.65 | 7.68 | 7.70 | 7.73 | 7.68 | 7.67 | 7.64 | 7.66 | 7.72 |
| 22 | 7.66 | 7.70 | 7.72 | 7.67 | 7.72 | 7.69 | 7.69 | 7.65 | 7.65 | 7.70 | 7.70 | 7.72 |
| 23 | 7.65 | 7.65 | 7.69 | 7.69 | 7.70 | 7.63 | 7.66 | 7.65 | 7.65 | 7.72 | 7.71 | 7.70 |

<u>5.4 Calculating Generated Power from a Wind Turbine - Mathematically-Modeled Power Curve</u>:

Wind turbine manufacturers define power curves that plot the power generated by a turbine brand depending on wind speed conditions, and these charts also plot the power coefficient at different wind speeds. Figure 4 below shows an example of this power curve for the Enercon E-30 Turbine. The rated wind speed is the point at which the wind turbine reaches its maximum power generation capability, or the rated power of the turbine.

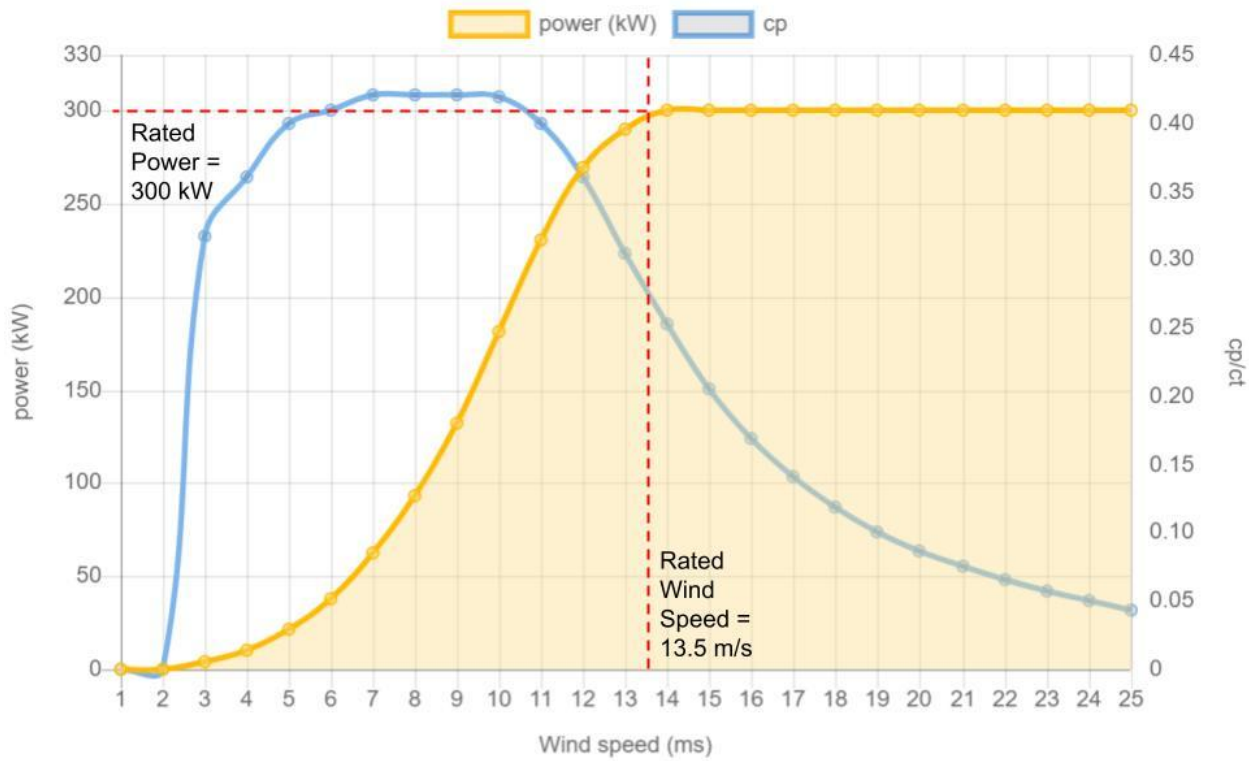


*Figure 4: Enercon E-30 Turbine Power Curve*

Because this curve provides the generated power of each wind turbine within the system at each wind speed, a data set of generated wind power for each turbine can be obtained directly from the wind speed data set. The generated power data sets for each turbine can then be summed into the total generated power at each time step. Despite recorded power data at only integers of wind speed, there are two ways to use a power curve to find the corresponding generated power to each wind speed data point. One is to linearly interpolate for non-integer wind speeds, and the other is to find a mathematical close-fit curve to the power curve that can be used to calculate power directly from a wind speed value.

Figure 6 details common mathematical models that have been tested for accurate fit to the shape of a wind turbine power curve. All of these models, however, are only fit to region 2, which occurs below rated wind speed and power as shown in Figure 5. These models do not closely fit the power curve after the inflection point, particularly when the slowing growth becomes visible as power draws near the turbine rated power. The error calculated for these models as well as correlation coefficients are shown in Figure 7 and Table 3. These models have been tested on several power curves, so the correlation coefficients represented in Table 3 express mean correlation coefficients for each model based on every power curve it has been fit-tested to.

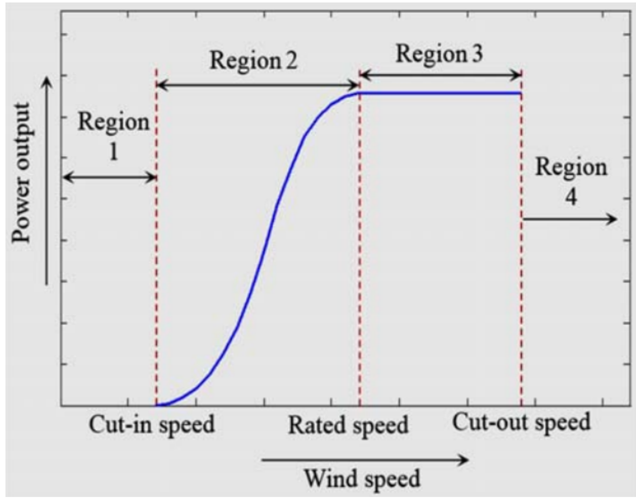


*Figure 5: Wind Turbine Power Curve Regions (Teyabeen 2019)*

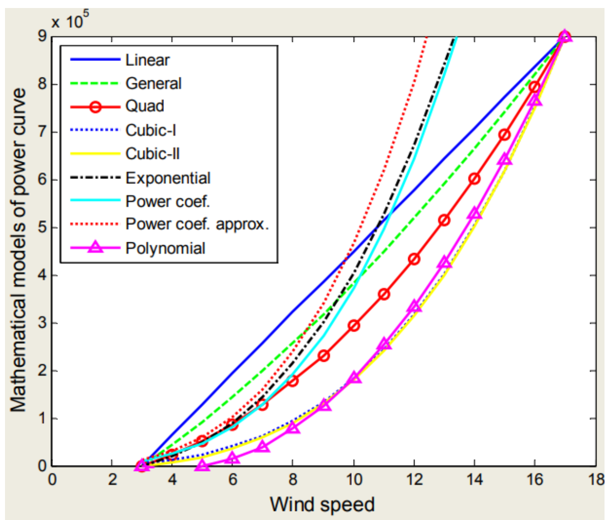


*Figure 6: Mathematical Models Used to Fit Power Curve Region 2 (Teyabeen 2019)*

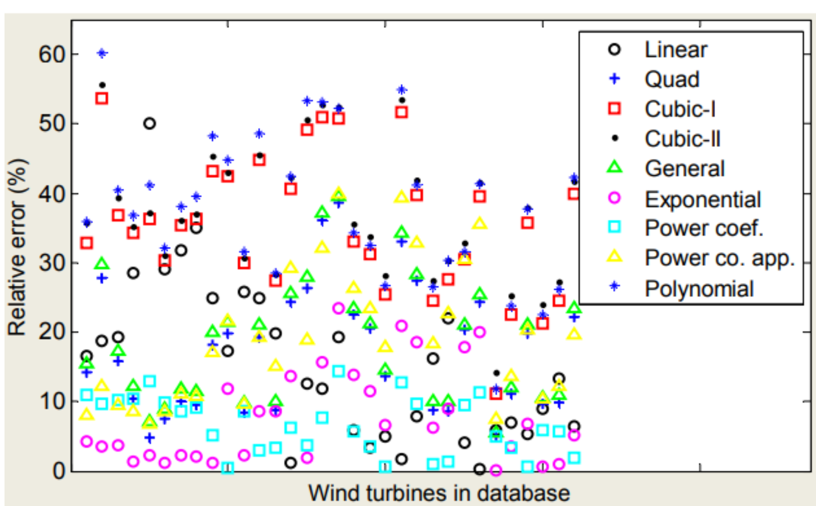


*Figure 7: Error Between Each Mathematical Model and Power Curve (Teyabeen 2019)*

Table 3: Average Correlation Coefficient of Each Mathematical Model (Teyabeen 2019)

| Mathematical model | Mean of correlation coefficient | Mean of MAPE | Rank |
|---|---|---|---|
| Linear | 0.9700 | 65.19 | 6 |
| Quadratic | 0.9718 | 29.76 | 2 |
| Cubic-I | 0.9408 | 42.67 | 3 |
| Cubic-II | 0.9408 | 45.99 | 4 |
| **General** | **0.9725** | **29.61** | **1** |
| Exponential | 0.9521 | 340.60 | 7 |
| Power Coeff. | 0.9408 | 405.21 | 8 |
| Appr. pow. Coef. | 0.9408 | 531.52 | 9 |
| polynomial | 0.9522 | 54.25 | 5 |

## 5.5 Calculating Generated Power from a Wind Turbine - Limited Growth Exponential Model:

While some correlation has been found in the mathematical models referenced in Section 5.4, the errors are too high to justify using one of these models to fit the full power curve rather than linear interpolation of the power curve. Another mathematical formula has been found to closely fit the shape of a power curve based on exponential limited growth. Equations 10 and 11 share this formula. The constant “c” is the carrying capacity, “k” is the growth rate, and “a” depends on the initial population $P_0$.

Equation 10:

$$P(t) = c \,/\, (1 + ae^{-kt})$$

Equation 11:

$$a = (c - P_0) \,/\, P_0$$

$$P(t) = population$$
$$c = carrying\ capacity$$
$$P_0 = initial\ population$$
$$k = growth\ rate$$
$$t = time$$

This exponential limited growth model is used for the unrelated application of limited population growth with time, however its formula structure with wind speed substituted in for time has proven to be a very close approximation of the power curve given the correct constants. Equation 12 below shows this new application of the exponential formula and Figure 8 shows this formula with demonstrated fit to the Enercon E-30 and E-44 power curves. The constant “a” and growth rate “k” were adjusted to accomplish this fit to both power curves, and the same can be done to fit this model to several other curves.

Equation 12:

$$P(w) = c \,/\, (1 + ae^{-kw})$$

$$P(w) = generated\ power\ (W\ or\ kW)$$
$$c = turbine\ rated\ power\ (W\ or\ kW)$$
$$k = rate\ of\ power\ growth\ with\ wind\ speed$$
$$w = wind\ speed\ (m/s)$$

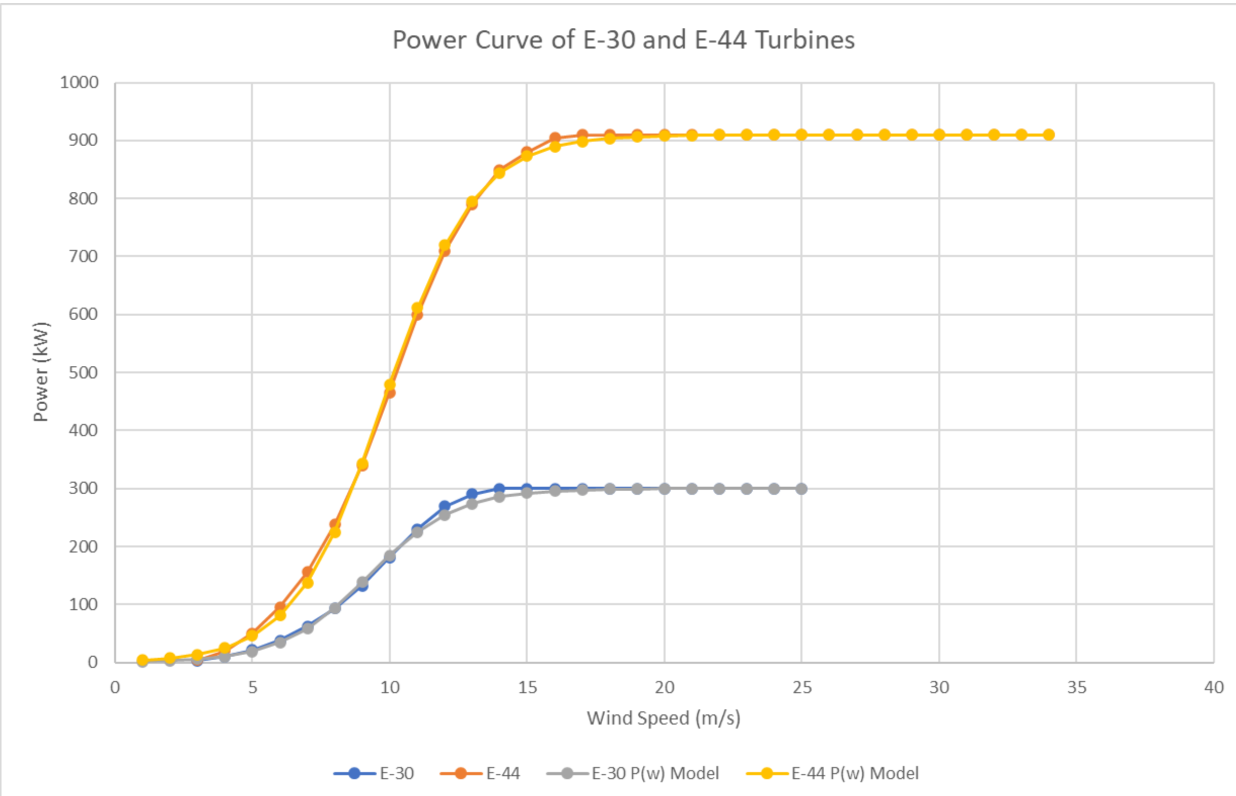


*Figure 8: Power Curves and P(w) Model Fit*

Table 4: Best-Fit P(w) Coefficients Used, r and $r^2$ Between P(w) Model and Power Curves

| Turbine | E-30 | E-44 |
|---|---|---|
| c | 300 | 910 |
| a | 340 | 400 |
| k | 0.63 | 0.61 |
| r | 0.999136 | 0.999781 |
| r^2 | 0.998273 | 0.999562 |

To confirm the accuracy of this model's fit to a power curve, three approaches have been used to evaluate its error. Figure 9 shows the percent error calculated between the power curve points and mathematical model, Figure 10 shows the magnitude of difference, and Table 4 shows the calculated correlation coefficient along with $r^2$ for the power curves in Figure 8. These results show that for properly chosen coefficients, fitting this mathematical model as closely as possible to a wind turbine power curve can yield less significant error than previously tested models. This error analysis should be repeated when fitting this particular model to other power curves to confirm low error at each wind speed.

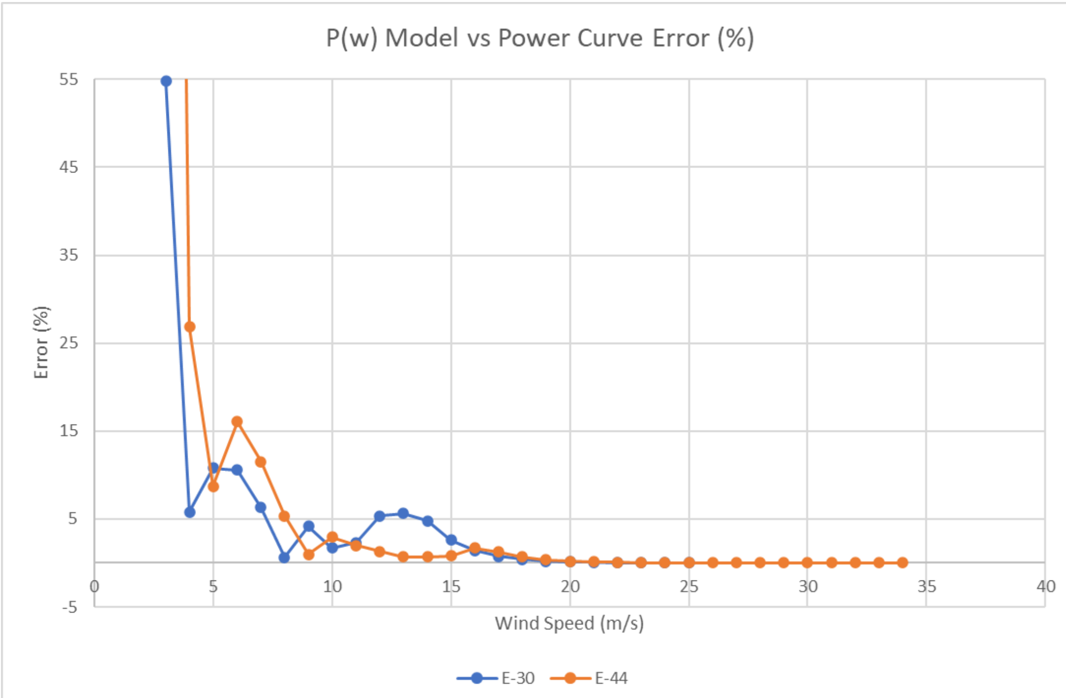


*Figure 9: Error (%) Between P(w) Mathematical Model and Power Curve*

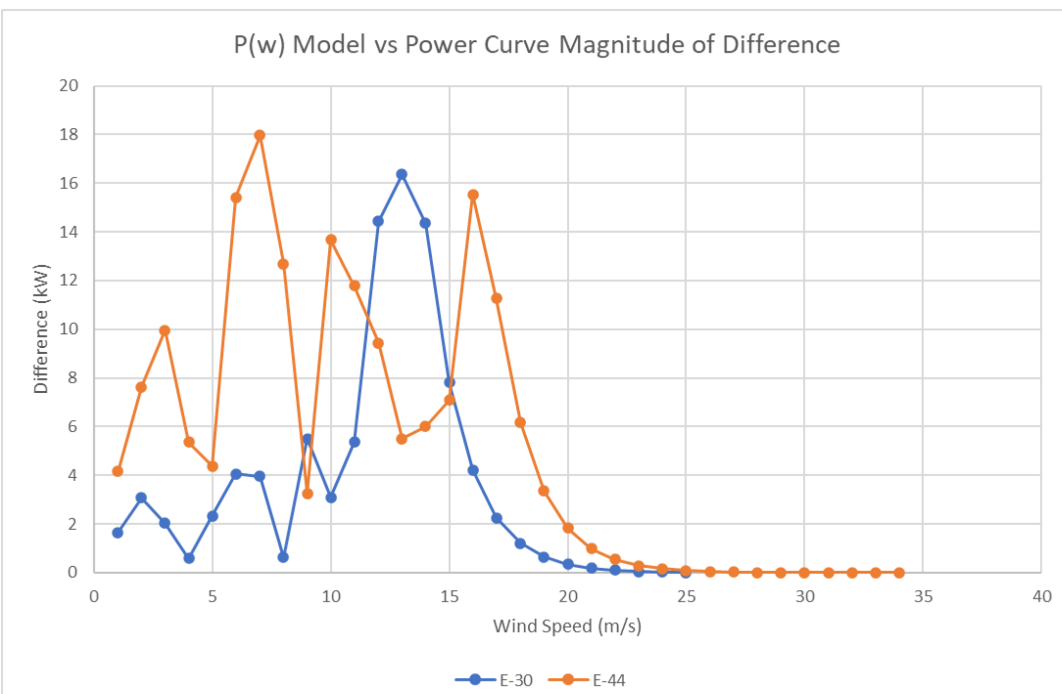


*Figure 10: Magnitude of Difference (kW) Between P(w) Mathematical Model and Power Curve*

5.6 Calculating Generated Power from a Wind Turbine - Power Coefficient Curve and Formula:

Equation 13 is a validated model to calculate the generated power of a wind turbine (El-Bidairi 2018). Calculating generated wind power at each data point using this equation requires the known power coefficient, air density, blade radius, and wind speed data. As well as generated power, manufacturer power curves define the power coefficient for each wind speed as shown by Figure 4. This curve can be used to create a set of power coefficient values that correspond to each wind speed data point. A close-fit mathematical model for this power coefficient curve has not been explored, but linear interpolation can be used to create the power coefficient data set corresponding to wind speed data.

This power coefficient data set can then be substituted into Equation 13 to calculate generated wind power at every wind speed data point. This method is more accurate compared to modeling the manufacturer power curve when the air density assumed in generating the power curve is not accurate to the actual air density of the turbine location.

Equation 13: Wind Generated Mechanical Power

$$P_{mech} = 0.5\rho C_p v(t)^3 \pi r^2$$

$\rho$ = Air density (kg/m$^3$)

$C_p$ = Power coefficient corresponding to wind speed

$v(t)$ = Wind speed (m/s) vs time

$r$ = Blade radius

5.7 Generating a Load Data Set in the Absence of Annual Load Data:

In some cases, detailed load data with data points across a significant time period is unavailable. This section describes a method to generate load data that can be used for this evaluation when detailed load data is unavailable. The parameters that must still be known, however, are peak, minimum, and mean load. Trends of monthly load per year and hourly load per day can also be used to apply weighted factors to the mean load depending on the time of day and time of year that this data point falls on. Load experiences a pattern of change throughout the day with peak hours and minimum hours that depend on operations, schedule and demand. Load over a yearly period also has peak and minimum load periods due to several conditions that change the demand depending on time of year. For each yearly period and each time of day, a multiplication factor can be created that expresses the load at its time period as a proportion of the mean load for the full annual cycle. Table 6 in the Flinders Island Analysis Section 6 shows how these multiplication factors represent trends and create a nominal load data set.

While a set of data based on larger trends provides an expected annual load profile, natural variation occurs in the actual load within a system. The known maximum and minimum load provide a view of how significantly load can spike or dip in outlier moments during the annual time period. These values can be used to model the expected variation from nominal trends, and a random number generator formula can be added to the nominal value of each data point to create slight variations in each data point representative of natural factors causing deviation from expected demand. Table 7 in Section 6 represents a data set with Equation 14 showing the noise added to the trend-based expected values in Table 6.

Equation 14: Load Profile with Added Randomized Noise

$$L = (L_{avg} * D) + (2 * (RAND() - 0.5) * (L_{peak} - L_{expected}))$$

$$L_{avg} = Monthly\ Average\ Load$$
$$D = Hourly\ Demand\ Factor$$
$$RAND() = Random\ Number\ between\ 0\ and\ 1$$
$$L_{peak} = Peak\ Load$$
$$L_{expected} = Highest\ Expected\ Load\ from\ Table\ ()$$

The deviation from expected load is most likely not uniform, however, but rather has a higher probability of being relatively small. The additional noise model shown below adds a normally distributed value to the expected load data given a standard deviation representative of the amount of variation. These results are shown in Table 8 from Section 6.

Equation 15: Load Profile with Added Normally Distributed Noise

$$L = (L_{avg} * D) + NORMINV(RAND(), 0, S)$$

$$S = Standard\ Deviation$$
$$NORMINV() = Normally\ Distributed\ Value\ from\ Probability,\ Mean,\ and\ S$$

5.8 Curtailment:

An intentional shut-off of power generation systems to control input power. In the event that input power exceeds load enough to overwhelm storage and other input power control systems, curtailment may be necessary. Several factors influence the decision to curtail power (Bird 2014). Particularly in wind applications, one of the greatest reasons for curtailment is transmission constraints. When the development of additional renewable energy sources outpaces the development of transmission lines to transport the generated energy, curtailment is implemented to protect this transmission. System balancing may also be a challenge that requires curtailment in the scenario that input power exceeds load, storage sources, and other power routes. Voltage, interconnection, and stability issues are also prevalent causes of curtailment. Defining curtailment standards for new integrated systems based on these factors may ensure that it is implemented properly to ensure reliability.

Wind turbines have a limit to the wind speed they can operate under due to stress constraints. Manufacturer power curves specify a cut-in and cut-out wind speed for which power generation cannot occur beyond this range. Next Steps Section 8.2 describes how this curtailment can be designed into the procedure to ensure that wind speeds outside of the cut-in to cut-out range yield a wind turbine generated power of 0 for further analysis.

## 6. Procedure Validation with Existing High-VRE System

To demonstrate the capability of the reliability evaluation procedure described in Section 4, the procedure has been applied to the known Flinders Island power grid. This is a successful isolated system with a high proportion of VRE and service availability. Available information on Flinders Island such as its approximate load profile, system parameters, and natural wind and solar resources have been used to apply this procedure. The results from this procedure shown in the sections below include service availability of the stand-alone VRE components, proportion of VRE power generation, and recommended storage capacity and power for Flinders Island to maintain service availability.

<u>6.1 Standards 1 and 4</u>: **The system's minimum service availability percentage must meet or exceed current system standards.**

1. Table 5 summarizes the known parameters of the Flinders Island System needed for this analysis.

Table 5: Flinders Island System Generation Sources (El-Bidairi 2018)

<table>
<tr><th colspan="6">Wind Turbines</th></tr>
<tr><td>Manufacturer / Type</td><td># of Blades</td><td>Rotor Diameter [m]</td><td>Tower Height [m]</td><td>Air Density [kg/m^3]</td><td>Power Rate [kW]</td></tr>
<tr><td>Enercron AERO E-30</td><td>3</td><td>29.6</td><td>50</td><td>1.225</td><td>300</td></tr>
<tr><td>Enercron AERO E-44</td><td>3</td><td>44</td><td>55</td><td>1.225</td><td>900</td></tr>
<tr><th colspan="6">Solar Panel(s)</th></tr>
<tr><td>Manufacturer / Type</td><td colspan="2">Temperature Coefficient [C^-1]</td><td>Nominal Operating Temp. [C]</td><td>DC/DC Converter Efficiency</td><td>Power Rate (kW)</td></tr>
<tr><td>N/A</td><td colspan="2">0.00485</td><td>45</td><td>0.8</td><td>175</td></tr>
<tr><th colspan="2">Diesel Generator(s) (Backup)</th><th colspan="3">Storage</th><th rowspan="2">Total VRE Power Rate (kW)</th></tr>
<tr><td>Manufacturer / Type</td><td>Power Rate (kW)</td><td>Source</td><td>Manufacturer / Type</td><td>Power Rate (kW)</td></tr>
<tr><td>Caterpillar</td><td>728</td><td>Battery</td><td>Toshiba Lithium-Ion</td><td>500</td><td>1375</td></tr>
<tr><td>Caterpillar</td><td>728</td><th colspan="3">Load (kW)</th><th rowspan="2">Total Power Rate (kW)</th></tr>
<tr><td>Caterpillar</td><td>360</td><td>Minimum</td><td>Mean</td><td>Maximum</td></tr>
<tr><td>Caterpillar</td><td>1200</td><td>55</td><td>422.85</td><td>1024</td><td>4391</td></tr>
</table>

Flinders Island load data is unavailable for this analysis, so a simulated set of load data vs time is provided using a normal distribution formula that randomly outputs values per time step using the available maximum, minimum, and average load. For cases such as this with an absence of periodic load data, the data simulation models shown here can be applied given some known information. These models are explained in depth in Section 5.7.

Table 6: Simulated Load Data with No Noise

| Monthly Avg. Load (kW) | | 423 | 413 | 438 | 447 | 452 | 467 | 487 | 472 | 387 | 387 | 377 | 367 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hourly Demand Factor (Proportion of Monthly Average Load) | Hour of Day | Load (kW) - Noise-Free Model | | | | | | | | | | | |
| | | January | February | March | April | May | June | July | August | September | October | November | December |
| 0.775 | 0 | 327.83 | 320.08 | 339.45 | 346.43 | 350.30 | 361.93 | 377.43 | 365.80 | 299.93 | 299.93 | 292.18 | 284.43 |
| 0.775 | 1 | 327.83 | 320.08 | 339.45 | 346.43 | 350.30 | 361.93 | 377.43 | 365.80 | 299.93 | 299.93 | 292.18 | 284.43 |
| 0.750 | 2 | 317.25 | 309.75 | 328.50 | 335.25 | 339.00 | 350.25 | 365.25 | 354.00 | 290.25 | 290.25 | 282.75 | 275.25 |
| 0.750 | 3 | 317.25 | 309.75 | 328.50 | 335.25 | 339.00 | 350.25 | 365.25 | 354.00 | 290.25 | 290.25 | 282.75 | 275.25 |
| 0.750 | 4 | 317.25 | 309.75 | 328.50 | 335.25 | 339.00 | 350.25 | 365.25 | 354.00 | 290.25 | 290.25 | 282.75 | 275.25 |
| 0.775 | 5 | 327.83 | 320.08 | 339.45 | 346.43 | 350.30 | 361.93 | 377.43 | 365.80 | 299.93 | 299.93 | 292.18 | 284.43 |
| 0.775 | 6 | 327.83 | 320.08 | 339.45 | 346.43 | 350.30 | 361.93 | 377.43 | 365.80 | 299.93 | 299.93 | 292.18 | 284.43 |
| 0.800 | 7 | 338.40 | 330.40 | 350.40 | 357.60 | 361.60 | 373.60 | 389.60 | 377.60 | 309.60 | 309.60 | 301.60 | 293.60 |
| 0.850 | 8 | 359.55 | 351.05 | 372.30 | 379.95 | 384.20 | 396.95 | 413.95 | 401.20 | 328.95 | 328.95 | 320.45 | 311.95 |
| 0.900 | 9 | 380.70 | 371.70 | 394.20 | 402.30 | 406.80 | 420.30 | 438.30 | 424.80 | 348.30 | 348.30 | 339.30 | 330.30 |
| 0.975 | 10 | 412.43 | 402.68 | 427.05 | 435.83 | 440.70 | 455.33 | 474.83 | 460.20 | 377.33 | 377.33 | 367.58 | 357.83 |
| 1.100 | 11 | 465.30 | 454.30 | 481.80 | 491.70 | 497.20 | 513.70 | 535.70 | 519.20 | 425.70 | 425.70 | 414.70 | 403.70 |
| 1.200 | 12 | 507.60 | 495.60 | 525.60 | 536.40 | 542.40 | 560.40 | 584.40 | 566.40 | 464.40 | 464.40 | 452.40 | 440.40 |
| 1.300 | 13 | 549.90 | 536.90 | 569.40 | 581.10 | 587.60 | 607.10 | 633.10 | 613.60 | 503.10 | 503.10 | 490.10 | 477.10 |
| 1.500 | 14 | 634.50 | 619.50 | 657.00 | 670.50 | 678.00 | 700.50 | 730.50 | 708.00 | 580.50 | 580.50 | 565.50 | 550.50 |
| 1.500 | 15 | 634.50 | 619.50 | 657.00 | 670.50 | 678.00 | 700.50 | 730.50 | 708.00 | 580.50 | 580.50 | 565.50 | 550.50 |
| 1.500 | 16 | 634.50 | 619.50 | 657.00 | 670.50 | 678.00 | 700.50 | 730.50 | 708.00 | 580.50 | 580.50 | 565.50 | 550.50 |
| 1.300 | 17 | 549.90 | 536.90 | 569.40 | 581.10 | 587.60 | 607.10 | 633.10 | 613.60 | 503.10 | 503.10 | 490.10 | 477.10 |
| 1.200 | 18 | 507.60 | 495.60 | 525.60 | 536.40 | 542.40 | 560.40 | 584.40 | 566.40 | 464.40 | 464.40 | 452.40 | 440.40 |
| 1.100 | 19 | 465.30 | 454.30 | 481.80 | 491.70 | 497.20 | 513.70 | 535.70 | 519.20 | 425.70 | 425.70 | 414.70 | 403.70 |
| 0.975 | 20 | 412.43 | 402.68 | 427.05 | 435.83 | 440.70 | 455.33 | 474.83 | 460.20 | 377.33 | 377.33 | 367.58 | 357.83 |
| 0.900 | 21 | 380.70 | 371.70 | 394.20 | 402.30 | 406.80 | 420.30 | 438.30 | 424.80 | 348.30 | 348.30 | 339.30 | 330.30 |
| 0.850 | 22 | 359.55 | 351.05 | 372.30 | 379.95 | 384.20 | 396.95 | 413.95 | 401.20 | 328.95 | 328.95 | 320.45 | 311.95 |
| 0.800 | 23 | 338.40 | 330.40 | 350.40 | 357.60 | 361.60 | 373.60 | 389.60 | 377.60 | 309.60 | 309.60 | 301.60 | 293.60 |

Table 7: Simulated Load Data with Randomized Noise

| Monthly Avg. Load (kW) | | 423 | 413 | 438 | 447 | 452 | 467 | 487 | 472 | 387 | 387 | 377 | 367 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hourly Demand Factor (Proportion of Monthly Average Load) | Hour of Day | Load (kW) - Randomized Noise Model | | | | | | | | | | | |
| | | January | February | March | April | May | June | July | August | September | October | November | December |
| 0.775 | 0 | 364.27 | 194.10 | 172.22 | 182.83 | 351.12 | 582.19 | 263.63 | 361.90 | 268.31 | 447.11 | 280.36 | 131.57 |
| 0.775 | 1 | 308.49 | 371.11 | 536.86 | 566.62 | 462.01 | 296.83 | 360.70 | 391.36 | 414.26 | 261.97 | 311.73 | 186.45 |
| 0.750 | 2 | 507.27 | 529.46 | 109.03 | 469.58 | 553.27 | 409.56 | 272.09 | 217.42 | 134.34 | 108.42 | 201.55 | 294.71 |
| 0.750 | 3 | 161.29 | 112.32 | 377.28 | 462.71 | 435.45 | 407.16 | 579.13 | 356.37 | 223.58 | 157.63 | 203.91 | 449.71 |
| 0.750 | 4 | 109.51 | 526.44 | 515.67 | 524.68 | 226.63 | 296.86 | 524.90 | 240.63 | 381.92 | 498.05 | 200.27 | 401.97 |
| 0.775 | 5 | 321.24 | 531.22 | 141.19 | 312.81 | 229.72 | 322.32 | 358.06 | 519.04 | 150.68 | 349.03 | 351.75 | 408.65 |
| 0.775 | 6 | 223.93 | 166.31 | 369.27 | 290.05 | 251.23 | 200.52 | 248.28 | 433.97 | 484.80 | 388.25 | 352.15 | 69.49 |
| 0.800 | 7 | 400.91 | 512.76 | 450.48 | 154.10 | 426.93 | 152.31 | 312.85 | 277.19 | 468.39 | 138.12 | 184.81 | 197.41 |
| 0.850 | 8 | 265.89 | 332.46 | 453.03 | 166.91 | 565.88 | 302.50 | 418.74 | 531.75 | 360.81 | 463.77 | 435.43 | 174.19 |
| 0.900 | 9 | 377.69 | 474.52 | 373.68 | 578.51 | 610.24 | 540.24 | 501.29 | 349.61 | 256.66 | 552.31 | 332.44 | 231.63 |
| 0.975 | 10 | 522.12 | 220.13 | 528.29 | 604.06 | 572.93 | 613.91 | 596.50 | 600.74 | 527.91 | 364.64 | 264.53 | 183.40 |
| 1.100 | 11 | 359.23 | 502.02 | 337.42 | 462.17 | 592.54 | 534.16 | 582.70 | 479.07 | 573.54 | 645.68 | 492.34 | 628.59 |
| 1.200 | 12 | 537.82 | 634.34 | 739.20 | 527.92 | 459.35 | 438.28 | 787.73 | 429.05 | 271.18 | 579.40 | 270.47 | 485.28 |
| 1.300 | 13 | 592.35 | 582.70 | 634.65 | 408.97 | 527.55 | 798.55 | 454.46 | 658.35 | 702.85 | 600.21 | 641.08 | 562.38 |
| 1.500 | 14 | 772.81 | 421.15 | 620.26 | 705.17 | 615.03 | 723.39 | 860.05 | 899.06 | 427.32 | 762.83 | 567.28 | 419.71 |
| 1.500 | 15 | 557.21 | 582.55 | 665.10 | 787.85 | 603.20 | 661.84 | 840.50 | 644.42 | 455.19 | 654.99 | 545.78 | 329.58 |
| 1.500 | 16 | 484.67 | 797.56 | 867.37 | 450.51 | 526.64 | 482.50 | 585.23 | 662.42 | 467.12 | 565.76 | 726.38 | 386.32 |
| 1.300 | 17 | 383.86 | 592.88 | 551.41 | 526.30 | 390.28 | 647.01 | 805.91 | 733.81 | 581.40 | 323.18 | 355.63 | 351.74 |
| 1.200 | 18 | 721.86 | 444.13 | 403.61 | 366.97 | 404.28 | 440.42 | 610.14 | 760.70 | 594.35 | 318.87 | 252.27 | 312.85 |
| 1.100 | 19 | 332.82 | 359.83 | 604.60 | 465.74 | 342.05 | 565.57 | 374.27 | 403.63 | 565.46 | 239.15 | 632.67 | 608.71 |
| 0.975 | 20 | 489.76 | 507.65 | 502.74 | 515.92 | 600.29 | 313.10 | 596.94 | 597.04 | 267.12 | 198.44 | 487.60 | 455.12 |
| 0.900 | 21 | 473.84 | 562.05 | 200.11 | 320.98 | 491.98 | 323.27 | 319.64 | 482.78 | 197.12 | 155.43 | 305.13 | 307.55 |
| 0.850 | 22 | 398.47 | 348.17 | 214.02 | 390.10 | 592.92 | 222.62 | 475.98 | 295.84 | 215.53 | 287.39 | 414.42 | 468.78 |
| 0.800 | 23 | 226.22 | 437.45 | 519.75 | 236.53 | 517.87 | 378.37 | 484.32 | 585.36 | 116.24 | 350.28 | 452.05 | 198.23 |

Table 8: Simulated Load Data with Normally Distributed Noise

| Monthly Avg. Load (kW) | | 423 | 413 | 438 | 447 | 452 | 467 | 487 | 472 | 387 | 387 | 377 | 367 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hourly Demand Factor (Proportion of Monthly Average Load) | Hour of Day | Load (kW) - Normal Distribution Noise Model | | | | | | | | | | | |
| | | January | February | March | April | May | June | July | August | September | October | November | December |
| 0.775 | 0 | 537.49 | 353.76 | 319.40 | 284.25 | 369.79 | 248.51 | 173.83 | 402.31 | 319.00 | 309.07 | 189.57 | 228.05 |
| 0.775 | 1 | 278.81 | 251.18 | 364.82 | 453.34 | 297.94 | 303.85 | 415.29 | 410.62 | 351.43 | 319.13 | 313.80 | 308.05 |
| 0.750 | 2 | 204.56 | 247.77 | 214.31 | 349.36 | 273.19 | 420.80 | 511.99 | 445.92 | 358.84 | 283.93 | 263.30 | 169.50 |
| 0.750 | 3 | 340.64 | 308.79 | 181.81 | 343.02 | 545.43 | 387.46 | 401.27 | 355.23 | 307.63 | 358.25 | 246.29 | 277.00 |
| 0.750 | 4 | 319.93 | 265.46 | 431.66 | 218.53 | 340.96 | 404.57 | 273.02 | 190.03 | 267.19 | 234.21 | 358.63 | 80.59 |
| 0.775 | 5 | 307.43 | 249.06 | 369.95 | 400.77 | 444.09 | 387.20 | 328.31 | 357.69 | 245.65 | 363.38 | 297.89 | 362.92 |
| 0.775 | 6 | 346.00 | 235.47 | 368.86 | 326.70 | 210.38 | 279.57 | 194.62 | 362.24 | 376.15 | 169.11 | 248.12 | 296.73 |
| 0.800 | 7 | 350.31 | 392.50 | 373.37 | 379.27 | 367.78 | 515.78 | 304.43 | 522.43 | 184.71 | 342.21 | 246.89 | 369.70 |
| 0.850 | 8 | 375.76 | 309.27 | 338.97 | 272.42 | 440.75 | 342.30 | 431.25 | 436.96 | 423.90 | 386.10 | 439.06 | 297.11 |
| 0.900 | 9 | 389.14 | 338.77 | 467.56 | 443.47 | 336.36 | 284.99 | 493.15 | 288.35 | 423.66 | 268.53 | 290.47 | 366.71 |
| 0.975 | 10 | 467.59 | 469.80 | 457.68 | 476.20 | 376.06 | 551.98 | 453.52 | 657.25 | 343.60 | 318.74 | 195.88 | 337.28 |
| 1.100 | 11 | 386.73 | 458.80 | 474.36 | 411.34 | 413.89 | 528.47 | 645.65 | 433.25 | 380.91 | 452.35 | 555.21 | 400.60 |
| 1.200 | 12 | 483.62 | 334.05 | 403.26 | 657.64 | 575.93 | 517.60 | 681.12 | 454.72 | 304.63 | 513.02 | 427.39 | 410.43 |
| 1.300 | 13 | 557.81 | 500.74 | 529.04 | 611.87 | 763.94 | 618.92 | 524.34 | 713.80 | 324.53 | 484.37 | 514.24 | 539.42 |
| 1.500 | 14 | 545.68 | 740.09 | 566.52 | 630.85 | 807.28 | 770.77 | 781.30 | 786.50 | 573.64 | 586.40 | 540.80 | 576.58 |
| 1.500 | 15 | 522.24 | 699.34 | 631.68 | 655.00 | 548.34 | 722.68 | 701.33 | 649.75 | 475.80 | 516.75 | 645.49 | 587.92 |
| 1.500 | 16 | 847.99 | 741.67 | 704.75 | 616.03 | 772.55 | 611.44 | 737.24 | 651.41 | 596.05 | 505.87 | 657.07 | 593.71 |
| 1.300 | 17 | 566.57 | 607.72 | 613.05 | 604.92 | 648.16 | 547.12 | 573.99 | 425.01 | 504.59 | 563.02 | 531.78 | 460.48 |
| 1.200 | 18 | 478.06 | 388.77 | 414.43 | 469.00 | 573.25 | 723.43 | 670.46 | 550.50 | 445.82 | 614.49 | 364.60 | 384.16 |
| 1.100 | 19 | 458.68 | 434.02 | 352.13 | 579.43 | 505.36 | 540.50 | 380.91 | 448.81 | 510.22 | 345.18 | 468.55 | 458.59 |
| 0.975 | 20 | 494.57 | 418.79 | 397.53 | 531.12 | 541.33 | 478.41 | 388.03 | 342.09 | 400.78 | 249.60 | 305.26 | 342.38 |
| 0.900 | 21 | 362.59 | 544.51 | 395.17 | 499.14 | 360.20 | 491.30 | 284.33 | 481.26 | 324.30 | 336.16 | 419.08 | 301.02 |
| 0.850 | 22 | 249.02 | 352.71 | 392.67 | 364.14 | 207.17 | 331.46 | 346.69 | 460.65 | 510.69 | 271.07 | 182.32 | 117.01 |
| 0.800 | 23 | 180.55 | 415.08 | 510.01 | 319.38 | 386.86 | 334.05 | 505.05 | 492.65 | 392.36 | 350.15 | 294.91 | 360.30 |

2. This step shows the data gathered for each of the natural resources at the Flinders Island location to use in subsequent calculations.

Table 9: Flinders Island Location Annual Solar Direct Normal Irradiance Data

| Hour | Solar DNI (Wh/m^2) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 137 | 182 |
| 6 | 284 | 188 | 64 | 0 | 0 | 0 | 0 | 0 | 58 | 244 | 269 | 314 |
| 7 | 364 | 324 | 310 | 202 | 65 | 28 | 35 | 154 | 295 | 341 | 319 | 380 |
| 8 | 422 | 367 | 367 | 345 | 299 | 277 | 282 | 343 | 369 | 381 | 364 | 420 |
| 9 | 461 | 383 | 383 | 360 | 352 | 357 | 366 | 381 | 388 | 379 | 394 | 455 |
| 10 | 479 | 382 | 362 | 356 | 362 | 354 | 370 | 386 | 402 | 406 | 383 | 449 |
| 11 | 492 | 387 | 359 | 357 | 365 | 356 | 371 | 387 | 409 | 419 | 405 | 473 |
| 12 | 518 | 389 | 363 | 357 | 358 | 352 | 362 | 367 | 400 | 430 | 415 | 495 |
| 13 | 512 | 393 | 372 | 361 | 346 | 334 | 364 | 356 | 397 | 431 | 406 | 477 |
| 14 | 505 | 368 | 359 | 344 | 325 | 327 | 337 | 345 | 369 | 405 | 403 | 459 |
| 15 | 502 | 373 | 351 | 322 | 294 | 285 | 314 | 338 | 357 | 400 | 400 | 459 |
| 16 | 462 | 376 | 338 | 269 | 107 | 54 | 119 | 250 | 318 | 370 | 380 | 432 |
| 17 | 398 | 330 | 214 | 0 | 0 | 0 | 0 | 0 | 59 | 211 | 313 | 373 |
| 18 | 283 | 121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 215 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Daily** | 5752 | 4381 | 3842 | 3273 | 2873 | 2724 | 2920 | 3307 | 3821 | 4447 | 4648 | 5583 |

Table 10: Flinders Island Location Annual Ambient Temperature Data (Flinders 2022)

| **Monthly Mean** | | 17.9 | 18.25 | 17.05 | 14.8 | 12.6 | 10.6 | 9.9 | 10.2 | 11.4 | 12.8 | 14.5 | 16.1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hourly deviation factor** | **Hour of Day** | **Ambient Temperature (C)** | | | | | | | | | | | |
| | | January | February | March | April | May | June | July | August | September | October | November | December |
| 0.75 | 0 | 11.3947 | 14.97567 | 5.42115 | 24.68433 | -5.13417 | 11.90358 | 10.18024 | 10.4913 | 12.48077 | 19.59983 | 8.019897 | 14.10423 |
| 0.75 | 1 | 10.64793 | 18.5217 | 11.3643 | -1.48243 | 9.606093 | 10.18651 | 13.22882 | 5.204139 | -1.22548 | 18.18706 | 11.32123 | 7.247243 |
| 0.8 | 2 | 13.95836 | 10.5584 | 4.570086 | 3.26 | 6.111466 | 3.488406 | 23.39329 | 4.471964 | 13.75439 | 7.392953 | 2.92597 | 8.101375 |
| 0.8 | 3 | 8.56399 | 12.92851 | 15.01466 | 19.77755 | 19.32902 | 6.238074 | 7.709778 | 19.81041 | 11.80797 | 5.045828 | 0.776615 | 18.08232 |
| 0.9 | 4 | 12.67006 | 21.59439 | 6.887103 | 5.990158 | -3.06578 | 5.010148 | 2.178486 | 13.71876 | 3.073158 | 18.35755 | 6.914094 | 13.48196 |
| 1 | 5 | 20.29012 | 23.60368 | 18.32695 | 5.43198 | 13.02831 | 3.669576 | 2.974472 | 23.47244 | 7.178153 | 15.35587 | 21.53378 | 25.523 |
| 1 | 6 | 6.017623 | 23.73248 | 27.12878 | 7.389208 | 10.56317 | 7.892582 | 17.4646 | 14.36383 | 21.13123 | 14.11666 | 9.719752 | 18.00785 |
| 1 | 7 | 28.10621 | 10.07303 | 7.865285 | 9.316819 | 16.59769 | 7.446646 | 7.791928 | 25.49571 | 13.42393 | 21.64953 | 15.96349 | 10.97637 |
| 1.1 | 8 | 22.88049 | 17.91069 | 6.846411 | 27.99457 | 24.22149 | 17.05683 | 16.17222 | 6.928134 | 10.71609 | 17.77123 | 4.016972 | 25.30341 |
| 1.2 | 9 | 27.61181 | 9.638928 | 24.30049 | 13.24893 | 22.68322 | 9.868558 | 23.01279 | 6.169271 | 17.07343 | 10.06391 | 16.06643 | 20.72099 |
| 1.2 | 10 | 20.35882 | 21.51772 | 28.12983 | 15.39673 | 19.56641 | 8.324339 | 3.76297 | -0.487627 | 8.121868 | 23.46201 | 18.56887 | 16.77802 |
| 1.25 | 11 | 20.87476 | 23.41726 | 20.11839 | 19.09939 | 14.11605 | 19.03201 | 12.08308 | 29.5472 | 8.799177 | 14.73173 | 16.0719 | 26.05378 |
| 1.25 | 12 | 23.4973 | 32.5272 | 11.38155 | 17.47581 | 6.376946 | 9.351132 | 10.2929 | 2.352409 | 21.82779 | 23.76039 | 20.75612 | 21.60808 |
| 1.25 | 13 | 5.410819 | 20.20794 | 27.85481 | 11.47068 | 9.579741 | 23.52404 | 15.60918 | 8.481448 | 10.84167 | 0.965121 | 19.47599 | 25.05028 |
| 1.2 | 14 | 8.655163 | 30.85099 | 28.40194 | 22.96885 | 6.938939 | -0.416189 | 13.59437 | 23.35877 | 16.64431 | 21.38263 | 16.2389 | 20.72129 |
| 1.2 | 15 | 33.14557 | 23.5809 | 25.72967 | 14.17777 | 15.02851 | 18.2195 | 14.4321 | 7.027354 | 14.87737 | 4.727198 | 12.77352 | 4.338874 |
| 1.1 | 16 | 38.29492 | 22.58929 | 8.533994 | 6.160906 | 1.690069 | 7.729843 | 7.337147 | 14.29934 | 4.741132 | 9.012424 | 16.2372 | 12.37007 |
| 1 | 17 | 20.90883 | 6.46058 | 15.6832 | 18.12192 | 27.4967 | 19.58942 | -3.663591 | 5.541549 | 1.161544 | 16.04321 | 14.65901 | 14.53006 |
| 1 | 18 | 10.94211 | 17.57557 | 21.38563 | 7.418209 | 3.564391 | 12.8492 | 25.43423 | 17.8661 | 16.0305 | 22.33424 | 14.31773 | 17.45752 |
| 1 | 19 | 22.89222 | 14.98724 | 17.08767 | 11.01154 | 7.089892 | 10.8357 | 12.15595 | 5.240216 | 17.47647 | 21.28144 | 7.188797 | 24.33639 |
| 0.9 | 20 | 5.616975 | 17.58683 | 20.20232 | 14.20961 | -1.83397 | 13.5623 | 10.83111 | 0.997728 | 8.321264 | 22.94064 | 9.632819 | 10.32755 |
| 0.8 | 21 | 32.38782 | 7.650298 | 18.38811 | 15.05911 | -1.0318 | 5.912579 | 13.17914 | 12.8728 | 7.357208 | 20.84469 | 3.071288 | 17.98856 |
| 0.8 | 22 | 4.344888 | 16.8225 | 18.71257 | 8.198111 | 12.33279 | -9.542173 | 6.048553 | 9.282569 | 15.81969 | 8.374971 | 20.29246 | 11.9949 |
| 0.75 | 23 | 9.195452 | 13.59756 | 12.72139 | 9.599724 | 10.4064 | 9.213301 | -6.684511 | 16.73915 | 7.347538 | 6.303232 | 11.39848 | -4.26902 |
| | **Daily Avg** | 17.44446 | 18.03789 | 16.75235 | 12.74915 | 10.21923 | 9.622747 | 10.77164 | 11.80187 | 11.19921 | 15.15435 | 12.41422 | 15.86813 |

A plot of wind speed over an annual period of time at the Flinders Island location is shown in Figure 11, however the numerical data used to generate this plot is not available. Table 11 therefore shows simulated annual wind speed data from randomly generated normal values given the approximate mean and standard deviation of the plotted data. It is expected, however, that numerical data for wind speed over an annual period will be available for the use of this analysis on proposed systems. If no data is available, the method in Section 5.5 can be used to generate a set of wind speed data.

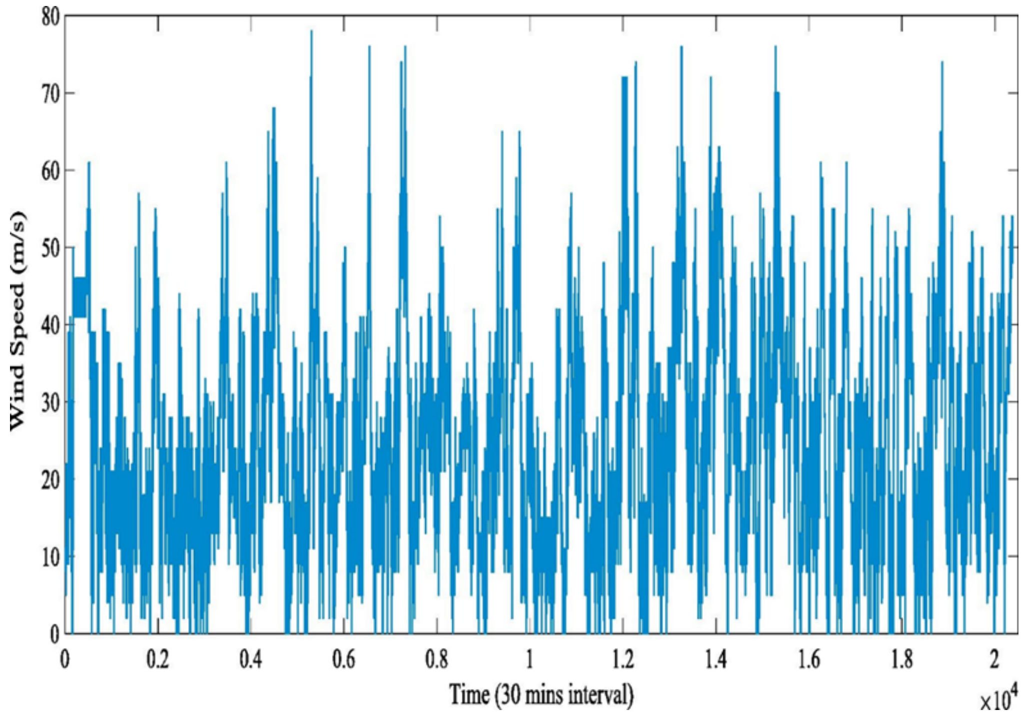


*Figure 11: Wind Speed vs Time at Flinders Island (El-Bidairi 2018)*

Because this wind speed profile has significant variation with several instantaneous peaks and minimum values, the standard deviation chosen to generate the wind speed data in Table 11 must be large enough to represent the highest wind speed peaks and ensure that the evaluation considers the implications of these high wind speed scenarios on the resulting service availability and generated power vs load difference map. High wind speeds may be larger than the cut-off wind speed of several wind turbines, however, so the calculated power generation from these values in the simulated wind speed data Table 11 should be 0 as explained in Section 8.2 describing curtailment.

Table 11: Flinders Island Location Simulated Annual Wind Speed Data

| Hour | Wind Speed (m/s) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 13.60 | 20.39 | 15.83 | 18.22 | 15.18 | 20.27 | 6.10 | 16.73 | 7.60 | 20.70 | 18.10 | 16.53 |
| 1 | 11.41 | 21.21 | 24.21 | 16.55 | 15.57 | 9.74 | 13.46 | 16.88 | 16.96 | 21.41 | 14.42 | 20.85 |
| 2 | 7.88 | 14.88 | 2.87 | 15.25 | 14.81 | 14.01 | 13.71 | 12.23 | 13.75 | 1.61 | 11.14 | 11.80 |
| 3 | 12.86 | 9.18 | 15.75 | 9.47 | 8.20 | 19.55 | 9.01 | 11.50 | 23.47 | 12.62 | 27.01 | 13.27 |
| 4 | 5.60 | 13.55 | 8.62 | 13.76 | 15.92 | 15.08 | 10.10 | 16.36 | 5.29 | 14.30 | 9.54 | 11.11 |
| 5 | 18.88 | 11.96 | 12.37 | 18.48 | 14.61 | 8.83 | 6.66 | 6.52 | 19.43 | 11.66 | 10.97 | 18.34 |
| 6 | 17.78 | 14.57 | 14.65 | 18.63 | 18.43 | 18.64 | 5.95 | 9.01 | 16.57 | 9.77 | 15.67 | 4.52 |
| 7 | 13.23 | 18.81 | 15.10 | 13.46 | 15.91 | 10.20 | 10.44 | 14.59 | 26.01 | 19.93 | 16.53 | 12.98 |
| 8 | 9.36 | 14.71 | 13.99 | 6.85 | 12.49 | 23.37 | 13.63 | 14.62 | 18.88 | 18.39 | 9.15 | 14.93 |
| 9 | 15.62 | 17.48 | 11.59 | 18.57 | 8.97 | 14.68 | 16.74 | 18.14 | 10.93 | 13.14 | 9.10 | 17.88 |
| 10 | 9.32 | 5.34 | 12.19 | 12.85 | 14.18 | 13.90 | 18.46 | 5.30 | 15.48 | 8.85 | 25.72 | 10.44 |
| 11 | 13.02 | 18.30 | 14.69 | 12.23 | 8.85 | 5.07 | 11.51 | 16.16 | 13.89 | 8.29 | 15.81 | 16.69 |
| 12 | 8.50 | 6.64 | 14.06 | 12.33 | 18.96 | 10.01 | 10.08 | 19.45 | 16.38 | 7.23 | 11.44 | 14.06 |
| 13 | 16.87 | 15.26 | 14.01 | 13.16 | 7.00 | 13.72 | 12.70 | 3.67 | 17.21 | 12.80 | 15.09 | 20.36 |
| 14 | 8.33 | 19.46 | 12.16 | 10.19 | 10.68 | 12.34 | 3.62 | 16.81 | 16.95 | 10.60 | 15.97 | 26.81 |
| 15 | 14.62 | 13.38 | 13.69 | 22.91 | 13.89 | 19.71 | 23.49 | 8.02 | 16.02 | 16.90 | 9.80 | 16.51 |
| 16 | 10.27 | 15.39 | 15.60 | 16.38 | 17.39 | 12.60 | 10.63 | 11.31 | 20.43 | 17.57 | 6.80 | 9.69 |
| 17 | 11.31 | 6.48 | 4.21 | 8.35 | 21.01 | 12.64 | 15.31 | 22.07 | 11.63 | 14.22 | 9.46 | 12.63 |
| 18 | 13.78 | 11.69 | 12.20 | 13.10 | 10.56 | 13.94 | 5.98 | 17.70 | 13.10 | 14.07 | 7.67 | 13.74 |
| 19 | 12.15 | 20.06 | 4.42 | 15.11 | 19.17 | 19.62 | 13.63 | 14.97 | 7.69 | 18.28 | 10.68 | 14.80 |
| 20 | 11.54 | 12.21 | 11.41 | 15.82 | 23.23 | 20.69 | 19.64 | 12.55 | 19.64 | 20.04 | 23.63 | 14.96 |
| 21 | 14.86 | 21.74 | 13.73 | 13.82 | 21.64 | 14.60 | 11.57 | 22.60 | 14.65 | 17.72 | 17.79 | 12.15 |
| 22 | 13.47 | 18.33 | 12.17 | 15.85 | 15.33 | 9.01 | 17.63 | 23.81 | 14.89 | 15.41 | 11.88 | 23.03 |
| 23 | 8.27 | 10.25 | 18.78 | 15.30 | 20.31 | 16.12 | 10.89 | 16.41 | 12.97 | 9.66 | 17.89 | 14.40 |
| **Daily Avg** | 12.19 | 14.64 | 12.85 | 14.44 | 15.10 | 14.51 | 12.12 | 14.48 | 15.41 | 13.97 | 14.22 | 15.10 |

3. The power curves given as examples in the procedure are for the Enercon E-30 and E-44 turbines used in the Flinders Island system. Section 5.5 details the mathematical model used to calculate generated wind power and its coefficients as well as error calculations that validate this model. Tables 12 and 13 below show the results for wind power generated by each Flinders Island turbine using the mathematical model.

Table 12: Generated Wind Power from the E-30 Turbine

| Hour | Wind Power Generated E-30 (kW) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 291.78 | 157.61 | 195.97 | 254.72 | 102.39 | 298.18 | 299.79 | 167.97 | 36.01 | 222.25 | 279.28 | 299.64 |
| 1 | 300.00 | 293.92 | 251.92 | 299.06 | 292.49 | 299.90 | 7.79 | 298.97 | 226.19 | 294.97 | 300.00 | 284.98 |
| 2 | 273.80 | 106.22 | 287.62 | 266.25 | 0.06 | 223.75 | 261.32 | 299.97 | 274.41 | 299.56 | 292.55 | 171.46 |
| 3 | 83.86 | 299.73 | 250.16 | 298.69 | 296.45 | 135.28 | 300.00 | 295.86 | 3.69 | 292.61 | 299.22 | 295.96 |
| 4 | 299.30 | 200.48 | 299.85 | 283.75 | 298.41 | 299.99 | 299.90 | 292.18 | 0.33 | 299.70 | 296.23 | 278.90 |
| 5 | 293.52 | 295.47 | 272.14 | 299.21 | 241.13 | 48.09 | 299.87 | 299.99 | 127.19 | 299.93 | 300.00 | 280.49 |
| 6 | 300.00 | 129.55 | 299.64 | 299.94 | 296.54 | 8.48 | 205.13 | 299.06 | 125.79 | 300.00 | 293.66 | 16.60 |
| 7 | 299.93 | 18.33 | 281.30 | 299.43 | 298.72 | 296.54 | 282.41 | 267.48 | 63.74 | 294.35 | 293.84 | 299.46 |
| 8 | 144.71 | 281.46 | 138.56 | 113.93 | 294.97 | 282.65 | 298.95 | 254.54 | 288.66 | 297.89 | 79.38 | 299.54 |
| 9 | 287.88 | 289.35 | 299.92 | 178.63 | 299.87 | 11.19 | 299.87 | 32.00 | 296.31 | 40.72 | 299.60 | 288.23 |
| 10 | 181.89 | 279.93 | 212.51 | 299.24 | 292.89 | 42.35 | 299.96 | 157.67 | 161.15 | 258.26 | 299.94 | 272.16 |
| 11 | 300.00 | 90.57 | 283.48 | 299.94 | 283.86 | 282.01 | 299.87 | 241.79 | 299.91 | 135.91 | 299.98 | 178.74 |
| 12 | 215.75 | 248.25 | 291.64 | 90.14 | 298.72 | 277.73 | 178.03 | 296.72 | 288.86 | 298.98 | 277.33 | 290.50 |
| 13 | 299.77 | 299.47 | 242.02 | 296.79 | 271.62 | 288.57 | 272.31 | 299.89 | 265.88 | 277.11 | 283.93 | 268.80 |
| 14 | 291.43 | 196.76 | 299.45 | 299.88 | 48.79 | 204.24 | 299.06 | 299.15 | 298.46 | 189.41 | 299.98 | 291.46 |
| 15 | 212.14 | 299.62 | 246.31 | 191.59 | 295.58 | 281.79 | 38.27 | 269.42 | 299.78 | 280.56 | 91.93 | 299.97 |
| 16 | 270.42 | 0.76 | 299.00 | 17.54 | 297.28 | 212.57 | 222.25 | 291.22 | 34.17 | 300.00 | 202.01 | 159.33 |
| 17 | 299.66 | 299.70 | 264.04 | 300.00 | 234.96 | 9.70 | 299.98 | 292.37 | 155.78 | 299.96 | 290.88 | 240.99 |
| 18 | 299.00 | 290.35 | 299.94 | 296.91 | 299.96 | 298.61 | 299.74 | 279.63 | 112.11 | 299.93 | 101.92 | 299.78 |
| 19 | 252.68 | 299.12 | 37.85 | 296.92 | 127.95 | 299.64 | 264.55 | 1.58 | 288.02 | 28.80 | 173.45 | 292.69 |
| 20 | 298.89 | 299.97 | 284.59 | 299.52 | 229.84 | 296.70 | 257.61 | 275.36 | 273.53 | 299.77 | 299.80 | 107.00 |
| 21 | 188.63 | 299.83 | 297.10 | 226.86 | 297.76 | 285.01 | 264.41 | 299.64 | 234.06 | 300.00 | 298.06 | 296.99 |
| 22 | 300.00 | 145.72 | 65.46 | 241.15 | 275.42 | 289.56 | 281.32 | 299.68 | 278.84 | 127.71 | 175.47 | 295.57 |
| 23 | 36.68 | 296.56 | 21.20 | 298.33 | 216.78 | 299.77 | 299.90 | 288.20 | 299.95 | 286.88 | 297.84 | 2.80 |
| **Daily kWh** | 6021.70 | 5418.72 | 5721.69 | 6048.41 | 5892.43 | 5272.29 | 6132.30 | 6100.33 | 4732.82 | 6025.25 | 6126.26 | 5812.04 |

Table 13: Generated Wind Power from the E-44 Turbine

| Hour | Wind Power Generated E-44 (kW) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 851.7761 | 382.3301 | 486.4891 | 680.4739 | 248.3145 | 893.7794 | 907.4883 | 409.3077 | 96.07524 | 566.4505 | 785.6991 | 905.9422 |
| 1 | 909.9512 | 864.7805 | 669.7547 | 900.8001 | 856.0165 | 908.7295 | 25.37023 | 900.0126 | 579.2387 | 871.448 | 909.9204 | 814.2354 |
| 2 | 760.1087 | 257.2269 | 828.2576 | 727.0787 | 0.401695 | 571.2856 | 706.6469 | 909.5577 | 762.8855 | 905.2519 | 856.3869 | 418.5684 |
| 3 | 205.7009 | 906.828 | 663.0992 | 897.7921 | 881.2724 | 326.4597 | 909.9704 | 877.3404 | 13.309 | 856.7606 | 902.147 | 877.982 |
| 4 | 902.8522 | 499.6087 | 908.1393 | 807.8854 | 895.55 | 909.8784 | 908.6581 | 854.1556 | 1.626632 | 906.5325 | 879.8239 | 783.8984 |
| 5 | 862.3063 | 874.7085 | 752.6175 | 902.078 | 630.1741 | 124.1377 | 908.2883 | 909.7889 | 306.8349 | 909.0611 | 909.9811 | 791.5875 |
| 6 | 909.9276 | 312.5289 | 905.9578 | 909.1676 | 881.9249 | 27.30082 | 513.4104 | 900.7705 | 303.4791 | 909.9278 | 863.1321 | 48.85602 |
| 7 | 908.9698 | 53.25383 | 795.5878 | 904.0075 | 897.9837 | 881.9114 | 801.1297 | 732.2955 | 159.895 | 867.4762 | 864.2921 | 904.2669 |
| 8 | 349.6981 | 796.3989 | 334.4885 | 275.2817 | 871.4299 | 802.3315 | 899.845 | 679.7671 | 833.9605 | 891.5895 | 195.4777 | 905.0242 |
| 9 | 829.7053 | 837.8111 | 908.8906 | 437.8747 | 908.3676 | 34.70727 | 908.3782 | 86.60425 | 880.3731 | 107.0935 | 905.6329 | 831.5765 |
| 10 | 446.818 | 788.8567 | 535.8037 | 902.3508 | 858.4533 | 110.867 | 909.4392 | 382.4933 | 391.4515 | 694.3324 | 909.0861 | 752.7299 |
| 11 | 909.956 | 221.0644 | 806.5373 | 909.0978 | 808.4776 | 799.1047 | 908.3022 | 632.5055 | 908.7582 | 327.9787 | 909.6927 | 438.1852 |
| 12 | 545.8359 | 655.9845 | 850.9899 | 220.0851 | 898.0187 | 778.3184 | 436.2476 | 883.1981 | 835.0972 | 900.1182 | 776.4253 | 844.3457 |
| 13 | 907.2488 | 904.3568 | 633.3225 | 883.6316 | 750.3204 | 833.4658 | 753.4059 | 908.5136 | 725.4905 | 775.3772 | 808.8105 | 737.9671 |
| 14 | 849.7238 | 488.7621 | 904.2218 | 908.4232 | 125.7546 | 510.7351 | 900.818 | 901.5565 | 895.9268 | 467.7783 | 909.6602 | 849.9122 |
| 15 | 534.6445 | 905.7752 | 648.8434 | 473.9462 | 875.4669 | 798.0014 | 101.3849 | 740.6496 | 907.4229 | 791.9276 | 224.1802 | 909.5603 |
| 16 | 745.006 | 3.37647 | 900.3107 | 51.25045 | 887.0994 | 535.9628 | 566.4638 | 848.515 | 91.7373 | 909.9725 | 504.1205 | 386.7558 |
| 17 | 906.2059 | 906.5575 | 717.8122 | 909.9498 | 608.6372 | 30.66718 | 909.6849 | 855.3019 | 377.6413 | 909.3961 | 846.5267 | 629.6877 |
| 18 | 900.3046 | 843.4821 | 909.14 | 884.4879 | 909.3458 | 897.1492 | 906.9353 | 787.3954 | 271.0195 | 909.0714 | 247.2223 | 907.388 |
| 19 | 672.6467 | 901.3154 | 100.3867 | 884.5633 | 308.6777 | 905.9723 | 719.9264 | 6.370751 | 830.4456 | 78.97293 | 423.8874 | 857.2098 |
| 20 | 899.4096 | 909.5857 | 812.2236 | 904.855 | 591.3168 | 883.0097 | 691.7645 | 767.2561 | 758.876 | 907.2501 | 907.6255 | 259.0448 |
| 21 | 465.5688 | 907.9305 | 885.8702 | 581.4346 | 890.5942 | 814.3778 | 719.3346 | 905.9336 | 605.5781 | 909.9485 | 892.8795 | 885.0759 |
| 22 | 909.945 | 352.2345 | 163.8169 | 630.2274 | 767.5048 | 838.989 | 795.6765 | 906.4099 | 783.6202 | 308.0957 | 429.3226 | 875.3561 |
| 23 | 97.65741 | 882.0606 | 60.44348 | 894.9554 | 549.055 | 907.261 | 908.6398 | 831.4319 | 909.286 | 824.267 | 891.1859 | 10.48946 |
| **Daily kWh** | 17281.97 | 15456.82 | 16183 | 17481.7 | 16900.16 | 15124.4 | 17717.21 | 17617.13 | 13230.03 | 17506.08 | 17753.12 | 16625.65 |

4. The solar power generated at Flinders Island given location-based solar irradiance data and ambient temperature data is shown in Table 14 below.

Table 14: Generated Solar Power

| Hour | Solar Power Generated (kW) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 10.13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.42 | 19.90 | 26.12 |
| 6 | 45.13 | 27.23 | 8.95 | 0 | 0 | 0 | 0 | 0 | 8.34 | 37.23 | 41.99 | 47.54 |
| 7 | 53.00 | 50.87 | 49.05 | 31.30 | 9.56 | 4.27 | 5.33 | 22.01 | 45.47 | 50.98 | 48.78 | 59.88 |
| 8 | 63.47 | 56.00 | 58.76 | 50.12 | 43.92 | 41.90 | 42.86 | 54.73 | 58.13 | 58.29 | 58.96 | 62.46 |
| 9 | 68.23 | 60.73 | 56.91 | 56.02 | 52.46 | 56.35 | 54.58 | 61.29 | 59.60 | 59.95 | 60.84 | 69.41 |
| 10 | 73.44 | 57.48 | 52.69 | 54.85 | 54.80 | 56.23 | 60.04 | 63.88 | 64.32 | 60.76 | 58.41 | 69.64 |
| 11 | 75.39 | 57.77 | 54.18 | 54.11 | 56.62 | 53.97 | 58.11 | 56.16 | 65.31 | 65.31 | 62.64 | 70.63 |
| 12 | 78.74 | 55.68 | 56.97 | 54.51 | 57.37 | 55.65 | 57.08 | 59.88 | 60.26 | 64.49 | 62.95 | 75.64 |
| 13 | 84.05 | 59.58 | 54.30 | 56.62 | 54.60 | 49.46 | 56.09 | 56.52 | 62.74 | 71.32 | 61.86 | 71.59 |
| 14 | 81.72 | 52.93 | 52.17 | 51.15 | 51.73 | 53.69 | 52.20 | 51.21 | 56.64 | 61.18 | 62.26 | 70.06 |
| 15 | 72.85 | 55.53 | 51.58 | 49.65 | 44.98 | 42.94 | 48.31 | 53.87 | 55.14 | 64.90 | 62.72 | 75.17 |
| 16 | 65.04 | 56.26 | 53.52 | 42.64 | 16.92 | 8.26 | 18.39 | 38.14 | 51.04 | 58.72 | 58.52 | 68.14 |
| 17 | 60.19 | 52.66 | 32.29 | 0 | 0 | 0 | 0 | 0 | 9.29 | 31.77 | 48.10 | 57.82 |
| 18 | 44.02 | 17.86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.91 | 32.18 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Daily kWh** | 875.40 | 660.59 | 581.37 | 500.97 | 442.96 | 422.72 | 452.98 | 517.70 | 596.27 | 689.30 | 716.83 | 856.30 |

5. Table 15 sums the generated power data for each of the solar and wind sources to represent the total power generated by the VRE of the system.

Table 15: Total Power Generated by VRE Sources

| Hour | Total VRE Power Generated (kW) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 1143.55 | 539.94 | 682.46 | 935.19 | 350.70 | 1191.96 | 1207.28 | 577.28 | 132.08 | 788.70 | 1064.97 | 1205.58 |
| 1 | 1209.95 | 1158.70 | 921.68 | 1199.86 | 1148.51 | 1208.63 | 33.16 | 1198.98 | 805.43 | 1166.42 | 1209.92 | 1099.21 |
| 2 | 1033.91 | 363.45 | 1115.87 | 993.33 | 0.47 | 795.03 | 967.97 | 1209.53 | 1037.30 | 1204.82 | 1148.94 | 590.03 |
| 3 | 289.56 | 1206.55 | 913.26 | 1196.49 | 1177.72 | 461.74 | 1209.97 | 1173.21 | 17.00 | 1149.37 | 1201.36 | 1173.94 |
| 4 | 1202.15 | 700.08 | 1207.99 | 1091.63 | 1193.96 | 1209.87 | 1208.56 | 1146.33 | 1.95 | 1206.23 | 1176.06 | 1062.80 |
| 5 | 1165.96 | 1170.18 | 1024.75 | 1201.29 | 871.31 | 172.23 | 1208.15 | 1209.78 | 434.02 | 1213.41 | 1229.88 | 1098.19 |
| 6 | 1255.06 | 469.31 | 1214.55 | 1209.11 | 1178.46 | 35.78 | 718.55 | 1199.83 | 437.61 | 1247.15 | 1198.77 | 113.00 |
| 7 | 1261.90 | 122.46 | 1125.93 | 1234.73 | 1206.26 | 1182.72 | 1088.88 | 1021.79 | 269.10 | 1212.81 | 1206.91 | 1263.61 |
| 8 | 557.87 | 1133.87 | 531.81 | 439.33 | 1210.31 | 1126.89 | 1241.65 | 989.03 | 1180.75 | 1247.77 | 333.81 | 1267.02 |
| 9 | 1185.82 | 1187.89 | 1265.72 | 672.52 | 1260.70 | 102.25 | 1262.83 | 179.90 | 1236.29 | 207.77 | 1266.08 | 1189.22 |
| 10 | 702.15 | 1126.26 | 801.01 | 1256.44 | 1206.14 | 209.44 | 1269.44 | 604.05 | 616.91 | 1013.35 | 1267.43 | 1094.53 |
| 11 | 1285.35 | 369.41 | 1144.21 | 1263.15 | 1148.97 | 1135.09 | 1266.28 | 930.46 | 1273.97 | 529.19 | 1272.31 | 687.55 |
| 12 | 840.33 | 959.92 | 1199.61 | 364.74 | 1254.11 | 1111.70 | 671.35 | 1239.80 | 1184.22 | 1263.58 | 1116.70 | 1210.49 |
| 13 | 1291.07 | 1263.40 | 929.63 | 1237.04 | 1076.54 | 1171.50 | 1081.81 | 1264.92 | 1054.11 | 1123.80 | 1154.60 | 1078.36 |
| 14 | 1222.87 | 738.45 | 1255.84 | 1259.45 | 226.28 | 768.67 | 1252.08 | 1251.92 | 1251.03 | 718.37 | 1271.90 | 1211.44 |
| 15 | 819.63 | 1260.93 | 946.74 | 715.18 | 1216.03 | 1122.72 | 187.96 | 1063.94 | 1262.35 | 1137.39 | 378.82 | 1284.70 |
| 16 | 1080.46 | 60.39 | 1252.84 | 111.43 | 1201.29 | 756.78 | 807.11 | 1177.88 | 176.94 | 1268.69 | 764.65 | 614.23 |
| 17 | 1266.06 | 1258.92 | 1014.14 | 1209.95 | 843.59 | 40.37 | 1209.67 | 1147.67 | 542.71 | 1241.12 | 1185.50 | 928.51 |
| 18 | 1243.33 | 1151.69 | 1209.08 | 1181.40 | 1209.30 | 1195.76 | 1206.67 | 1067.02 | 383.13 | 1209.01 | 358.05 | 1239.35 |
| 19 | 925.33 | 1200.44 | 138.23 | 1181.48 | 436.63 | 1205.61 | 984.48 | 7.95 | 1118.46 | 107.78 | 597.34 | 1149.90 |
| 20 | 1198.30 | 1209.56 | 1096.81 | 1204.38 | 821.15 | 1179.71 | 949.37 | 1042.62 | 1032.40 | 1207.02 | 1207.43 | 366.04 |
| 21 | 654.20 | 1207.76 | 1182.97 | 808.29 | 1188.35 | 1099.38 | 983.74 | 1205.57 | 839.64 | 1209.95 | 1190.94 | 1182.07 |
| 22 | 1209.94 | 497.96 | 229.28 | 871.37 | 1042.92 | 1128.55 | 1077.00 | 1206.09 | 1062.46 | 435.81 | 604.79 | 1170.92 |
| 23 | 134.34 | 1178.62 | 81.65 | 1193.29 | 765.83 | 1207.03 | 1208.54 | 1119.63 | 1209.24 | 1111.15 | 1189.02 | 13.29 |
| **Daily kWh** | 24179.07 | 21536.13 | 22486.07 | 24031.07 | 23235.54 | 20819.41 | 24302.49 | 24235.16 | 18559.12 | 24220.63 | 24596.21 | 23293.99 |

6. The power generated by the non-VRE diesel generators is added to Table 15 to create Table 16, the total power generated by the system as time-based data.

Table 16: Total Power Generated from All Sources

| Hour | Total Power with Generators (kW) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 4159.55 | 3555.94 | 3698.46 | 3951.19 | 3366.70 | 4207.96 | 4223.28 | 3593.28 | 3148.08 | 3804.70 | 4080.97 | 4221.58 |
| 1 | 4225.95 | 4174.70 | 3937.68 | 4215.86 | 4164.51 | 4224.63 | 3049.16 | 4214.98 | 3821.43 | 4182.42 | 4225.92 | 4115.21 |
| 2 | 4049.91 | 3379.45 | 4131.87 | 4009.33 | 3016.47 | 3811.03 | 3983.97 | 4225.53 | 4053.30 | 4220.82 | 4164.94 | 3606.03 |
| 3 | 3305.56 | 4222.55 | 3929.26 | 4212.49 | 4193.72 | 3477.74 | 4225.97 | 4189.21 | 3033.00 | 4165.37 | 4217.36 | 4189.94 |
| 4 | 4218.15 | 3716.08 | 4223.99 | 4107.63 | 4209.96 | 4225.87 | 4224.56 | 4162.33 | 3017.95 | 4222.23 | 4192.06 | 4078.80 |
| 5 | 4181.96 | 4186.18 | 4040.75 | 4217.29 | 3887.31 | 3188.23 | 4224.15 | 4225.78 | 3450.02 | 4229.41 | 4245.88 | 4114.19 |
| 6 | 4271.06 | 3485.31 | 4230.55 | 4225.11 | 4194.46 | 3051.78 | 3734.55 | 4215.83 | 3453.61 | 4263.15 | 4214.77 | 3129.00 |
| 7 | 4277.90 | 3138.46 | 4141.93 | 4250.73 | 4222.26 | 4198.72 | 4104.88 | 4037.79 | 3285.10 | 4228.81 | 4222.91 | 4279.61 |
| 8 | 3573.87 | 4149.87 | 3547.81 | 3455.33 | 4226.31 | 4142.89 | 4257.65 | 4005.03 | 4196.75 | 4263.77 | 3349.81 | 4283.02 |
| 9 | 4201.82 | 4203.89 | 4281.72 | 3688.52 | 4276.70 | 3118.25 | 4278.83 | 3195.90 | 4252.29 | 3223.77 | 4282.08 | 4205.22 |
| 10 | 3718.15 | 4142.26 | 3817.01 | 4272.44 | 4222.14 | 3225.44 | 4285.44 | 3620.05 | 3632.91 | 4029.35 | 4283.43 | 4110.53 |
| 11 | 4301.35 | 3385.41 | 4160.21 | 4279.15 | 4164.97 | 4151.09 | 4282.28 | 3946.46 | 4289.97 | 3545.19 | 4288.31 | 3703.55 |
| 12 | 3856.33 | 3975.92 | 4215.61 | 3380.74 | 4270.11 | 4127.70 | 3687.35 | 4255.80 | 4200.22 | 4279.58 | 4132.70 | 4226.49 |
| 13 | 4307.07 | 4279.40 | 3945.63 | 4253.04 | 4092.54 | 4187.50 | 4097.81 | 4280.92 | 4070.11 | 4139.80 | 4170.60 | 4094.36 |
| 14 | 4238.87 | 3754.45 | 4271.84 | 4275.45 | 3242.28 | 3784.67 | 4268.08 | 4267.92 | 4267.03 | 3734.37 | 4287.90 | 4227.44 |
| 15 | 3835.63 | 4276.93 | 3962.74 | 3731.18 | 4232.03 | 4138.72 | 3203.96 | 4079.94 | 4278.35 | 4153.39 | 3394.82 | 4300.70 |
| 16 | 4096.46 | 3076.39 | 4268.84 | 3127.43 | 4217.29 | 3772.78 | 3823.11 | 4193.88 | 3192.94 | 4284.69 | 3780.65 | 3630.23 |
| 17 | 4282.06 | 4274.92 | 4030.14 | 4225.95 | 3859.59 | 3056.37 | 4225.67 | 4163.67 | 3558.71 | 4257.12 | 4201.50 | 3944.51 |
| 18 | 4259.33 | 4167.69 | 4225.08 | 4197.40 | 4225.30 | 4211.76 | 4222.67 | 4083.02 | 3399.13 | 4225.01 | 3374.05 | 4255.35 |
| 19 | 3941.33 | 4216.44 | 3154.23 | 4197.48 | 3452.63 | 4221.61 | 4000.48 | 3023.95 | 4134.46 | 3123.78 | 3613.34 | 4165.90 |
| 20 | 4214.30 | 4225.56 | 4112.81 | 4220.38 | 3837.15 | 4195.71 | 3965.37 | 4058.62 | 4048.40 | 4223.02 | 4223.43 | 3382.04 |
| 21 | 3670.20 | 4223.76 | 4198.97 | 3824.29 | 4204.35 | 4115.38 | 3999.74 | 4221.57 | 3855.64 | 4225.95 | 4206.94 | 4198.07 |
| 22 | 4225.94 | 3513.96 | 3245.28 | 3887.37 | 4058.92 | 4144.55 | 4093.00 | 4222.09 | 4078.46 | 3451.81 | 3620.79 | 4186.92 |
| 23 | 3150.34 | 4194.62 | 3097.65 | 4209.29 | 3781.83 | 4223.03 | 4224.54 | 4135.63 | 4225.24 | 4127.15 | 4205.02 | 3029.29 |
| **Daily kWh** | 96563.07 | 93920.13 | 94870.07 | 96415.07 | 95619.54 | 93203.41 | 96686.49 | 96619.16 | 90943.12 | 96604.63 | 96980.21 | 95677.99 |

7. The total generated power at each time step is subtracted by the load for each of the three load scenarios at the corresponding time step to create a heat map of the difference. Positive values represent a generated power surplus while negative values represent a generated power shortage.

Table 17: Power Generated / Load Difference - VRE Only Noise-Free Load Model

| Hour | Difference Between Power Generated and Load | | | | VRE-Only, Noise-Free Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 815.73 | 219.87 | 343.01 | 588.77 | 0.40 | 830.04 | 829.85 | 211.48 | -167.84 | 488.78 | 772.80 | 921.15 |
| 1 | 882.12 | 838.63 | 582.23 | 853.44 | 798.21 | 846.71 | -344.27 | 833.18 | 505.50 | 866.49 | 917.74 | 814.79 |
| 2 | 716.66 | 53.70 | 787.37 | 658.08 | -338.53 | 444.78 | 602.72 | 855.53 | 747.05 | 914.57 | 866.19 | 314.78 |
| 3 | -27.69 | 896.80 | 584.76 | 861.24 | 838.72 | 111.49 | 844.72 | 819.21 | -273.25 | 859.12 | 918.61 | 898.69 |
| 4 | 884.90 | 390.33 | 879.49 | 756.38 | 854.96 | 859.62 | 843.31 | 792.33 | -288.30 | 915.98 | 893.31 | 787.55 |
| 5 | 838.13 | 850.10 | 685.30 | 854.86 | 521.01 | -189.70 | 830.73 | 843.98 | 134.10 | 913.48 | 937.71 | 813.77 |
| 6 | 927.23 | 149.23 | 875.10 | 862.68 | 828.16 | -326.15 | 341.12 | 834.03 | 137.69 | 947.23 | 906.60 | -171.43 |
| 7 | 923.50 | -207.94 | 775.53 | 877.13 | 844.66 | 809.12 | 699.28 | 644.19 | -40.50 | 903.21 | 905.31 | 970.01 |
| 8 | 198.32 | 782.82 | 159.51 | 59.38 | 826.11 | 729.94 | 827.70 | 587.83 | 851.80 | 918.82 | 13.36 | 955.07 |
| 9 | 805.12 | 816.19 | 871.52 | 270.22 | 853.90 | -318.05 | 824.53 | -244.90 | 887.99 | -140.53 | 926.78 | 858.92 |
| 10 | 289.72 | 723.59 | 373.96 | 820.62 | 765.44 | -245.89 | 794.62 | 143.85 | 239.59 | 636.03 | 899.85 | 736.71 |
| 11 | 820.05 | -84.89 | 662.41 | 771.45 | 651.77 | 621.39 | 730.58 | 411.26 | 848.27 | 103.49 | 857.61 | 283.85 |
| 12 | 332.73 | 464.32 | 674.01 | -171.66 | 711.71 | 551.30 | 86.95 | 673.40 | 719.82 | 799.18 | 664.30 | 770.09 |
| 13 | 741.17 | 726.50 | 360.23 | 655.94 | 488.94 | 564.40 | 448.71 | 651.32 | 551.01 | 620.70 | 664.50 | 601.26 |
| 14 | 588.37 | 118.95 | 598.84 | 588.95 | -451.72 | 68.17 | 521.58 | 543.92 | 670.53 | 137.87 | 706.40 | 660.94 |
| 15 | 185.13 | 641.43 | 289.74 | 44.68 | 538.03 | 422.22 | -542.54 | 355.94 | 681.85 | 556.89 | -186.68 | 734.20 |
| 16 | 445.96 | -559.11 | 595.84 | -559.07 | 523.29 | 56.28 | 76.61 | 469.88 | -403.56 | 688.19 | 199.15 | 63.73 |
| 17 | 716.16 | 722.02 | 444.74 | 628.85 | 255.99 | -566.73 | 576.57 | 534.07 | 39.61 | 738.02 | 695.40 | 451.41 |
| 18 | 735.73 | 656.09 | 683.48 | 645.00 | 666.90 | 635.36 | 622.27 | 500.62 | -81.27 | 744.61 | -94.35 | 798.95 |
| 19 | 460.03 | 746.14 | -343.57 | 689.78 | -60.57 | 691.91 | 448.78 | -511.25 | 692.76 | -317.92 | 182.64 | 746.20 |
| 20 | 785.88 | 806.88 | 669.76 | 768.55 | 380.45 | 724.38 | 474.55 | 582.42 | 655.08 | 829.69 | 839.85 | 8.22 |
| 21 | 273.50 | 836.06 | 788.77 | 405.99 | 781.55 | 679.08 | 545.44 | 780.77 | 491.34 | 861.65 | 851.64 | 851.77 |
| 22 | 850.39 | 146.91 | -143.02 | 491.42 | 658.72 | 731.60 | 663.05 | 804.89 | 733.51 | 106.86 | 284.34 | 858.97 |
| 23 | -204.06 | 848.22 | -268.75 | 835.69 | 404.23 | 833.43 | 818.94 | 742.03 | 899.64 | 801.55 | 887.42 | -280.31 |

Table 18: Power Generated / Load Difference - VRE Only Randomized Noise Load Model

| Hour | Difference Between Power Generated and Load | | | | VRE-Only, Randomized Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 779.28 | 345.84 | 510.24 | 752.36 | -0.42 | 609.77 | 943.65 | 215.38 | -136.22 | 341.60 | 784.62 | 1074.01 |
| 1 | 901.46 | 787.59 | 384.82 | 633.24 | 686.49 | 911.81 | -327.54 | 807.61 | 391.16 | 904.44 | 898.19 | 912.77 |
| 2 | 526.64 | -166.02 | 1006.85 | 523.75 | -552.81 | 385.47 | 695.88 | 992.11 | 902.95 | 1096.40 | 947.38 | 295.32 |
| 3 | 128.27 | 1094.24 | 535.97 | 733.77 | 742.26 | 54.58 | 630.84 | 816.83 | -206.58 | 991.75 | 997.45 | 724.23 |
| 4 | 1092.64 | 173.65 | 692.32 | 566.95 | 967.33 | 913.02 | 683.65 | 905.70 | -379.97 | 708.18 | 975.79 | 660.83 |
| 5 | 844.72 | 638.96 | 883.56 | 888.48 | 641.58 | -150.09 | 850.09 | 690.73 | 283.35 | 864.38 | 878.13 | 689.55 |
| 6 | 1031.13 | 303.00 | 845.28 | 919.06 | 927.23 | -164.74 | 470.26 | 765.85 | -47.19 | 858.90 | 846.62 | 43.50 |
| 7 | 860.99 | -390.30 | 675.46 | 1080.64 | 779.33 | 1030.41 | 776.03 | 744.60 | -199.29 | 1074.69 | 1022.10 | 1066.20 |
| 8 | 291.98 | 801.40 | 78.78 | 272.43 | 644.43 | 824.39 | 822.91 | 457.28 | 819.94 | 784.00 | -101.62 | 1092.83 |
| 9 | 808.13 | 713.37 | 892.04 | 94.01 | 650.46 | -437.99 | 761.54 | -169.72 | 979.63 | -344.55 | 933.64 | 957.58 |
| 10 | 180.03 | 906.14 | 272.72 | 652.38 | 633.22 | -404.47 | 672.94 | 3.31 | 89.00 | 648.71 | 1002.90 | 911.14 |
| 11 | 926.12 | -132.61 | 806.79 | 800.98 | 556.43 | 600.93 | 683.59 | 451.39 | 700.44 | -116.49 | 779.97 | 58.96 |
| 12 | 302.50 | 325.58 | 460.40 | -163.18 | 794.76 | 673.41 | -116.38 | 810.75 | 913.04 | 684.18 | 846.24 | 725.20 |
| 13 | 698.72 | 680.70 | 294.98 | 828.07 | 548.99 | 372.95 | 627.36 | 606.58 | 351.26 | 523.59 | 513.52 | 515.98 |
| 14 | 450.06 | 317.30 | 635.58 | 554.28 | -388.76 | 45.28 | 392.03 | 352.86 | 823.70 | -44.46 | 704.62 | 791.72 |
| 15 | 262.42 | 678.37 | 281.64 | -72.67 | 612.84 | 460.88 | -652.53 | 419.52 | 807.16 | 482.40 | -166.96 | 955.13 |
| 16 | 595.79 | -737.17 | 385.47 | -339.08 | 674.65 | 274.28 | 221.87 | 515.46 | -290.17 | 702.94 | 38.28 | 227.91 |
| 17 | 882.20 | 666.04 | 462.73 | 683.65 | 453.32 | -606.64 | 403.75 | 413.86 | -38.68 | 917.94 | 829.87 | 576.76 |
| 18 | 521.47 | 707.57 | 805.47 | 814.43 | 805.02 | 755.34 | 596.53 | 306.32 | -211.22 | 890.14 | 105.77 | 926.50 |
| 19 | 592.50 | 840.61 | -466.37 | 715.74 | 94.58 | 640.04 | 610.21 | -395.68 | 553.00 | -131.37 | -35.33 | 541.19 |
| 20 | 708.54 | 701.91 | 594.08 | 688.45 | 220.87 | 866.61 | 352.43 | 445.58 | 765.29 | 1008.57 | 719.83 | -89.07 |
| 21 | 180.36 | 645.71 | 982.86 | 487.31 | 696.37 | 776.12 | 664.11 | 722.79 | 642.52 | 1054.52 | 885.81 | 874.52 |
| 22 | 811.47 | 149.79 | 15.26 | 481.27 | 450.00 | 905.92 | 601.01 | 910.25 | 846.94 | 148.41 | 190.37 | 702.15 |
| 23 | -91.88 | 741.17 | -438.10 | 956.76 | 247.96 | 828.66 | 724.22 | 534.27 | 1093.00 | 760.87 | 736.97 | -184.94 |

Table 19: Power Generated / Load Difference-VRE Only Normal Distribution Noise Load Model

| Hour | Difference Between Power Generated and Load | | | | | VRE-Only, Normal Distribution Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 606.06 | 186.18 | 363.05 | 650.94 | -19.09 | 943.45 | 1033.45 | 174.97 | -186.92 | 479.63 | 875.40 | 977.53 |
| 1 | 931.14 | 907.53 | 556.86 | 746.52 | 850.57 | 904.78 | -382.13 | 788.36 | 454.00 | 847.29 | 896.12 | 791.16 |
| 2 | 829.35 | 115.68 | 901.56 | 643.97 | -272.73 | 374.24 | 455.98 | 763.61 | 678.46 | 920.89 | 885.64 | 420.53 |
| 3 | -51.09 | 897.77 | 731.45 | 853.47 | 632.29 | 74.29 | 808.70 | 817.97 | -290.63 | 791.12 | 955.07 | 896.94 |
| 4 | 882.22 | 434.63 | 776.34 | 873.10 | 853.00 | 805.30 | 935.54 | 956.31 | -265.24 | 972.02 | 817.43 | 982.21 |
| 5 | 858.53 | 921.12 | 654.81 | 800.52 | 427.22 | -214.97 | 879.84 | 852.09 | 188.37 | 850.03 | 931.99 | 735.27 |
| 6 | 909.05 | 233.84 | 845.69 | 882.41 | 968.08 | -243.79 | 523.92 | 837.59 | 61.46 | 1078.04 | 950.66 | -183.74 |
| 7 | 911.59 | -270.05 | 752.56 | 855.47 | 838.48 | 666.94 | 784.45 | 499.36 | 84.39 | 870.60 | 960.02 | 893.91 |
| 8 | 182.12 | 824.60 | 192.84 | 166.91 | 769.56 | 784.58 | 810.40 | 552.07 | 756.85 | 861.67 | -105.25 | 969.91 |
| 9 | 796.69 | 849.12 | 798.16 | 229.05 | 924.35 | -182.74 | 769.67 | -108.45 | 812.63 | -60.76 | 975.61 | 822.51 |
| 10 | 234.56 | 656.46 | 343.33 | 780.24 | 830.08 | -342.54 | 815.92 | -53.20 | 273.31 | 694.61 | 1071.54 | 757.25 |
| 11 | 898.62 | -89.39 | 669.85 | 851.81 | 735.08 | 606.61 | 620.64 | 497.20 | 893.06 | 76.84 | 717.10 | 286.96 |
| 12 | 356.70 | 625.86 | 796.35 | -292.90 | 678.18 | 594.09 | -9.76 | 785.08 | 879.59 | 750.56 | 689.31 | 800.05 |
| 13 | 733.26 | 762.66 | 400.60 | 625.17 | 312.60 | 552.58 | 557.47 | 551.12 | 729.58 | 639.43 | 640.36 | 538.94 |
| 14 | 677.19 | -1.64 | 689.32 | 628.60 | -581.00 | -2.11 | 470.78 | 465.42 | 677.39 | 131.96 | 731.11 | 634.86 |
| 15 | 297.39 | 561.59 | 315.05 | 60.19 | 667.70 | 400.04 | -513.36 | 414.18 | 786.55 | 620.64 | -266.67 | 696.79 |
| 16 | 232.47 | -681.28 | 548.09 | -504.60 | 428.74 | 145.34 | 69.86 | 526.47 | -419.11 | 762.82 | 107.58 | 20.52 |
| 17 | 699.48 | 651.20 | 401.09 | 605.03 | 195.44 | -506.76 | 635.68 | 722.66 | 38.12 | 678.11 | 653.73 | 468.02 |
| 18 | 765.27 | 762.92 | 794.65 | 712.39 | 636.06 | 472.33 | 536.21 | 516.52 | -62.69 | 594.52 | -6.55 | 855.19 |
| 19 | 466.65 | 766.41 | -213.89 | 602.05 | -68.73 | 665.11 | 603.57 | -440.86 | 608.25 | -237.40 | 128.79 | 691.30 |
| 20 | 703.73 | 790.77 | 699.28 | 673.26 | 279.83 | 701.30 | 561.34 | 700.53 | 631.63 | 957.41 | 902.17 | 23.66 |
| 21 | 291.61 | 663.26 | 787.81 | 309.15 | 828.15 | 608.08 | 699.42 | 724.31 | 515.34 | 873.79 | 771.86 | 881.05 |
| 22 | 960.92 | 145.25 | -163.39 | 507.23 | 835.75 | 797.08 | 730.31 | 745.44 | 551.78 | 164.74 | 422.48 | 1053.91 |
| 23 | -46.21 | 763.54 | -428.36 | 873.91 | 378.97 | 872.98 | 703.49 | 626.98 | 816.87 | 761.00 | 894.11 | -347.01 |

The remainder of this analysis requires only the VRE Only difference heat map, so the total generated power vs load difference data tables are in the Appendix Section 9.2.

8. The minimum projected service availability of this system found for each of the three load models is summarized in Table 26.

9. This particular analysis uses simulated load data, wind speed data and ambient temperature data that create different scenarios based on the randomized factors of these inputs each time a new trial is run. Due to this, the service availability result experiences variation between trials.

10. The calculated service availability of this system given each load scenario is shown in Table 26.

<u>6.2 Standard 2</u>: **The system is recommended to have high VRE penetration, defined as a minimum of 50% of the annual energy provided by the system with capability to provide up to 100% instantaneous power**

1. Equation 2 is applied to the load vs power generation Tables 17, 18 and 19 to calculate the proportion of the load that is supplied by VRE at each time step. Tables 20, 21, and 22 show these results for each load scenario.

Table 20: Proportion of Load Supplied by VRE - Noise-Free Load Model

| Hour | Proportion of Load Supplied by VRE Generation | | | | | Noise-Free Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.440391 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.087858 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0.001376 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 0.912715 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.05858 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.006726 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 0.475868 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 0.09886 | 1 | 1 | 1 | 1 | 1 | 0.397286 |
| 7 | 1 | 0.370629 | 1 | 1 | 1 | 1 | 1 | 1 | 0.869178 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 0.243275 | 1 | 0.423484 | 1 | 0.596516 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 0.459979 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 1 | 0.813139 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 0.679972 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 1 | 1 | 1 | 1 | 0.333739 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 1 | 1 | 1 | 1 | 1 | 1 | 0.257309 | 1 | 1 | 1 | 0.669893 | 1 |
| 16 | 1 | 0.097479 | 1 | 0.166184 | 1 | 1 | 1 | 1 | 0.304815 | 1 | 1 | 1 |
| 17 | 1 | 1 | 1 | 1 | 1 | 0.066489 | 1 | 1 | 1 | 1 | 1 | 1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.825008 | 1 | 0.791444 | 1 |
| 19 | 1 | 1 | 0.286911 | 1 | 0.878179 | 1 | 1 | 0.015306 | 1 | 0.253176 | 1 | 1 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 22 | 1 | 1 | 0.615842 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | 0.396986 | 1 | 0.233011 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.045281 |

Table 21: Proportion of Load Supplied by VRE - Randomized Noise Load Model

| Hour | Proportion of Load Supplied by VRE Generation | | | | | Randomized Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 1 | 1 | 1 | 1 | 0.998799 | 1 | 1 | 1 | 0.492289 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.091932 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0.68644 | 1 | 1 | 0.000843 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.076049 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.005112 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 0.534341 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 0.178431 | 1 | 1 | 0.902665 | 1 | 1 | 1 |
| 7 | 1 | 0.238818 | 1 | 1 | 1 | 1 | 1 | 1 | 0.574521 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.766619 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 0.189265 | 1 | 0.514556 | 1 | 0.376175 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 0.341155 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 1 | 0.735849 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.819591 | 1 | 1 |
| 12 | 1 | 1 | 1 | 0.690893 | 1 | 1 | 0.852257 | 1 | 1 | 1 | 1 | 1 |
| 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 1 | 1 | 1 | 1 | 0.367909 | 1 | 1 | 1 | 1 | 0.941719 | 1 | 1 |
| 15 | 1 | 1 | 1 | 0.907765 | 1 | 1 | 0.223635 | 1 | 1 | 1 | 0.694097 | 1 |
| 16 | 1 | 0.075716 | 1 | 0.247335 | 1 | 1 | 1 | 1 | 0.378802 | 1 | 1 | 1 |
| 17 | 1 | 1 | 1 | 1 | 1 | 0.062388 | 1 | 1 | 0.933464 | 1 | 1 | 1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.644628 | 1 | 1 | 1 |
| 19 | 1 | 1 | 0.228637 | 1 | 1 | 1 | 1 | 0.019688 | 1 | 0.450673 | 0.944151 | 1 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.804284 |
| 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | 0.593838 | 1 | 0.15709 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.067064 |

Table 22: Proportion of Load Supplied by VRE - Normal Distribution Noise Load Model

| Hour | **Proportion of Load Supplied by VRE Generation** | | | | | Normal Distribution Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 1 | 1 | 1 | 1 | 0.948375 | 1 | 1 | 1 | 0.414058 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.079847 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0.001708 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 0.850031 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.055271 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.007306 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 0.444806 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 0.127983 | 1 | 1 | 1 | 1 | 1 | 0.380807 |
| 7 | 1 | 0.311988 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.760283 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 0.358781 | 1 | 0.623887 | 1 | 0.773726 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 0.379435 | 1 | 0.919057 | 1 | 1 | 1 | 1 |
| 11 | 1 | 0.805159 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 0.554616 | 1 | 1 | 0.985664 | 1 | 1 | 1 | 1 | 1 |
| 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 1 | 0.997785 | 1 | 1 | 0.280295 | 0.997268 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 1 | 1 | 1 | 1 | 1 | 1 | 0.268011 | 1 | 1 | 1 | 0.586875 | 1 |
| 16 | 1 | 0.081422 | 1 | 0.180879 | 1 | 1 | 1 | 1 | 0.296862 | 1 | 1 | 1 |
| 17 | 1 | 1 | 1 | 1 | 1 | 0.073778 | 1 | 1 | 1 | 1 | 1 | 1 |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.859382 | 1 | 0.982028 | 1 |
| 19 | 1 | 1 | 0.39257 | 1 | 0.863999 | 1 | 1 | 0.017706 | 1 | 0.312234 | 1 | 1 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 22 | 1 | 1 | 0.583892 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 | 0.744056 | 1 | 0.16009 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.036898 |

2. The average proportion of load supplied by VRE for each load scenario is summarized in Table 26.

3. The proportion of time that VRE generation supplies 100% of the load for each load scenario is summarized in Table 26.

6.3 - Standard 5: **System Storage Capacity and Power Output Capability must be Sufficient to Account for Time Periods of Load Exceeding Generated Power**

1. The total power shortage in watt-hours experienced over the annual cycle is calculated and summarized in Table 26. This represents the annual capacity the storage system is recommended to have.

2. The maximum power shortage during the annual cycle, which corresponds to the minimum storage power capability, is calculated and summarized in Table 26.

3. The total annual power surplus experienced over the annual cycle is calculated and summarized in Table 26. This value is recommended to be significantly larger than the total annual power shortage.

4. Tables 23, 24, and 25 show the running total of the generated power vs load difference data set to represent the current stored power. A capacity cap on the running total was not implemented, but this is recommended in future applications to yield an accurate running

total. Time steps of a negative value can then be identified as moments of insufficient stored power to maintain reliability. This result for the Flinders Island analysis is summarized in Table 26.

Table 23: Current Stored Power Running Total - Noise-Free Load Model

| Hour | Current Stored Power (kWh, No capacity cap) | | | | VRE-Only, Noise-Free Load Model | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 867.6 | 12500.6 | 27504.0 | 42964.8 | 55944.7 | 68309.4 | 80196.7 | 88191.6 | 99922.2 | 111500.4 | 123523.6 | 137233.9 |
| 1 | 1386.9 | 13386.4 | 28359.6 | 42662.8 | 56733.0 | 69037.6 | 81019.4 | 89029.9 | 100244.9 | 112131.2 | 124284.6 | 138148.5 |
| 2 | 2266.6 | 14269.9 | 29080.1 | 43536.7 | 57504.6 | 69570.3 | 81856.8 | 89883.7 | 101153.9 | 113050.5 | 125209.2 | 139069.8 |
| 3 | 1983.7 | 15107.8 | 29899.5 | 44339.8 | 58105.1 | 70423.9 | 82674.5 | 90710.9 | 102072.5 | 113949.0 | 125175.2 | 139990.9 |
| 4 | 2473.0 | 15427.6 | 30777.5 | 45210.6 | 58020.2 | 71203.8 | 82448.3 | 90883.3 | 102981.2 | 114509.4 | 126065.6 | 140828.7 |
| 5 | 3365.9 | 15736.8 | 31237.6 | 46074.1 | 58593.5 | 72026.6 | 83275.5 | 90601.6 | 103891.0 | 115149.8 | 126993.6 | 141131.5 |
| 6 | 3080.5 | 16654.0 | 32115.1 | 46836.7 | 59398.0 | 72873.2 | 82909.1 | 91169.7 | 104456.3 | 114907.3 | 127869.4 | 141862.3 |
| 7 | 3667.6 | 17437.5 | 32917.3 | 46689.8 | 60239.2 | 73709.6 | 83343.0 | 92026.1 | 105400.2 | 115859.3 | 128793.5 | 142509.1 |
| 8 | 3716.9 | 18336.6 | 33270.8 | 46489.9 | 59918.4 | 74539.9 | 83085.7 | 92856.1 | 106334.2 | 116781.5 | 129732.4 | 142852.2 |
| 9 | 3473.9 | 19226.9 | 34142.2 | 47239.7 | 60770.2 | 75381.6 | 83309.5 | 93690.7 | 107256.7 | 116730.0 | 129731.9 | 143411.2 |
| 10 | 4085.9 | 19086.2 | 34979.3 | 47553.3 | 60606.1 | 76122.9 | 84100.5 | 94263.8 | 108112.9 | 117568.3 | 130343.9 | 144105.1 |
| 11 | 4506.3 | 19881.1 | 35745.4 | 48286.4 | 61309.5 | 76162.4 | 83862.1 | 95006.3 | 107762.5 | 117234.0 | 130498.5 | 144004.9 |
| 12 | 4817.6 | 20461.6 | 36465.8 | 48885.1 | 61413.7 | 76866.2 | 84060.5 | 95704.6 | 108571.2 | 118044.2 | 130639.5 | 144846.3 |
| 13 | 5450.5 | 21190.4 | 37164.4 | 48958.2 | 61804.9 | 77515.6 | 84631.3 | 95843.4 | 109096.2 | 118803.0 | 131419.5 | 145648.6 |
| 14 | 6101.2 | 21837.1 | 36863.6 | 49547.3 | 62376.6 | 76893.0 | 84862.2 | 95198.2 | 108897.1 | 119366.8 | 132125.4 | 146361.5 |
| 15 | 6722.8 | 22477.3 | 37470.1 | 50086.9 | 62705.9 | 76426.9 | 84193.1 | 95325.0 | 108420.4 | 120048.7 | 132831.4 | 146842.4 |
| 16 | 7198.8 | 23122.6 | 38065.0 | 50637.4 | 63228.5 | 76909.7 | 83633.5 | 95843.4 | 107907.8 | 120243.6 | 132862.5 | 147458.3 |
| 17 | 7812.6 | 23669.7 | 37983.0 | 51177.3 | 63825.1 | 76310.4 | 83867.3 | 95312.9 | 108543.3 | 119794.8 | 133212.1 | 148240.5 |
| 18 | 8544.5 | 23229.8 | 38665.2 | 51824.7 | 64491.9 | 76383.5 | 84492.6 | 95912.8 | 108377.5 | 120424.0 | 133114.1 | 147916.0 |
| 19 | 9254.7 | 23890.6 | 39200.8 | 52518.9 | 64889.2 | 77042.0 | 85083.9 | 96266.0 | 108498.6 | 120471.4 | 133745.3 | 148714.5 |
| 20 | 9705.7 | 24538.6 | 39920.1 | 53234.1 | 65615.5 | 77736.6 | 85522.9 | 97009.8 | 109024.9 | 121298.3 | 134579.3 | 149566.2 |
| 21 | 10528.4 | 25326.9 | 40732.8 | 54041.8 | 66399.5 | 78519.6 | 86293.5 | 97781.6 | 109034.8 | 121979.0 | 134523.9 | 149296.3 |
| 22 | 10826.0 | 26185.8 | 41547.4 | 54832.3 | 66680.9 | 79332.5 | 87074.9 | 98520.5 | 109825.4 | 121715.9 | 135408.8 | 150137.2 |
| 23 | 11662.0 | 26637.6 | 42103.0 | 55672.8 | 67481.4 | 79552.8 | 87557.8 | 99352.5 | 110716.8 | 122615.0 | 136311.8 | 150888.6 |

Table 24: Current Stored Power Running Total - Randomized Noise Load Model

| Hour | Current Stored Power (kWh, No capacity cap) | | | | VRE-Only, Randomized Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 743.7 | 11147.2 | 25156.6 | 40653.7 | 53320.8 | 66673.9 | 78212.0 | 86732.3 | 97670.8 | 110438.6 | 123307.1 | 136426.8 |
| 1 | 1325.7 | 11852.9 | 26149.3 | 40408.1 | 54094.8 | 67451.0 | 79141.5 | 87744.0 | 98169.3 | 111260.3 | 124012.7 | 137512.1 |
| 2 | 1982.9 | 12553.4 | 26687.8 | 41491.4 | 54964.7 | 67849.3 | 80192.0 | 88418.3 | 99149.8 | 112035.6 | 125078.3 | 138548.6 |
| 3 | 1758.0 | 13392.5 | 27455.4 | 42113.6 | 55501.2 | 68672.1 | 81129.6 | 89188.1 | 100110.6 | 113154.9 | 124863.0 | 139313.9 |
| 4 | 2430.1 | 13761.9 | 28209.5 | 43088.5 | 55353.0 | 69459.3 | 80915.9 | 89238.6 | 100909.7 | 113559.7 | 125532.8 | 140291.4 |
| 5 | 3293.2 | 14070.3 | 28632.4 | 43959.5 | 56112.3 | 70286.2 | 81949.7 | 88974.8 | 102023.0 | 114016.9 | 126583.5 | 140816.8 |
| 6 | 3028.2 | 14946.5 | 29617.8 | 44539.0 | 57081.7 | 71018.0 | 81659.2 | 89320.4 | 102540.6 | 113748.6 | 127332.4 | 141704.4 |
| 7 | 3402.7 | 15542.7 | 30507.0 | 44207.5 | 57874.1 | 71730.7 | 81939.7 | 89993.8 | 103523.8 | 114692.7 | 128394.2 | 142499.3 |
| 8 | 3367.4 | 16377.8 | 30794.9 | 43820.4 | 57500.0 | 72460.8 | 81713.9 | 90629.2 | 104654.9 | 115831.3 | 129483.5 | 142617.5 |
| 9 | 3063.9 | 17073.3 | 31742.5 | 44622.9 | 58457.3 | 73196.5 | 82034.7 | 91256.4 | 105771.4 | 115827.9 | 129336.0 | 143099.0 |
| 10 | 3470.4 | 16759.6 | 32396.4 | 44754.3 | 58365.5 | 74010.5 | 83005.6 | 91796.5 | 106572.0 | 116824.2 | 129766.8 | 143873.8 |
| 11 | 4086.2 | 17768.5 | 33294.6 | 45431.2 | 59084.1 | 74009.8 | 82628.4 | 92566.3 | 106436.5 | 116395.1 | 129926.0 | 143902.7 |
| 12 | 4295.3 | 18444.5 | 33971.5 | 45992.6 | 59392.4 | 74672.0 | 82879.5 | 93203.9 | 107047.7 | 117402.2 | 129869.4 | 144815.1 |
| 13 | 4837.8 | 19347.9 | 34605.4 | 46003.4 | 59806.8 | 75294.8 | 83602.4 | 93139.5 | 107458.8 | 118287.8 | 130613.1 | 145716.0 |
| 14 | 5700.1 | 20003.9 | 34398.4 | 46612.8 | 60261.6 | 74556.3 | 83810.7 | 92536.2 | 107419.4 | 118955.4 | 131389.5 | 146376.7 |
| 15 | 6351.0 | 20540.1 | 35000.8 | 46983.8 | 60518.6 | 73977.7 | 83128.2 | 92799.3 | 106968.6 | 119822.0 | 132057.5 | 146687.9 |
| 16 | 6828.3 | 21209.7 | 35751.9 | 47582.5 | 61202.5 | 74649.6 | 82565.3 | 93500.1 | 106524.3 | 119819.7 | 132134.0 | 147361.9 |
| 17 | 7310.5 | 21532.3 | 35663.7 | 48223.9 | 61900.2 | 74122.0 | 82612.8 | 92973.2 | 107126.8 | 119441.1 | 132467.8 | 148219.9 |
| 18 | 7978.9 | 21209.5 | 36565.2 | 48801.0 | 62546.4 | 74305.9 | 83293.1 | 93718.4 | 107023.3 | 120135.5 | 132331.1 | 148020.4 |
| 19 | 8482.5 | 21913.6 | 36915.4 | 49539.4 | 63079.1 | 74896.9 | 83847.9 | 94036.9 | 107134.2 | 120396.7 | 132803.1 | 148879.8 |
| 20 | 8832.8 | 22572.4 | 37615.4 | 50291.9 | 63968.8 | 75443.5 | 84358.2 | 94958.4 | 107461.1 | 121029.5 | 133641.3 | 149910.4 |
| 21 | 9461.9 | 23302.9 | 38374.2 | 51170.4 | 64822.7 | 76280.0 | 85224.3 | 95526.9 | 107651.5 | 121711.5 | 133456.4 | 149458.4 |
| 22 | 9623.0 | 24143.6 | 39221.4 | 51963.1 | 65305.5 | 77237.1 | 85933.5 | 96155.4 | 108467.5 | 121395.4 | 134430.9 | 150113.3 |
| 23 | 10405.6 | 24383.2 | 39747.3 | 52832.7 | 65901.1 | 77375.6 | 86251.4 | 97066.8 | 109499.8 | 122348.6 | 135539.7 | 150873.7 |

Table 25: Current Stored Power Running Total - Normal Distribution Noise Load Model

| Hour | Current Stored Power (kWh, No capacity cap) | | | | VRE-Only, Normal Distribution Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 915.6 | 11894.4 | 27335.3 | 43114.0 | 55229.9 | 66920.0 | 78415.0 | 86484.0 | 98221.4 | 109538.2 | 121773.7 | 135512.1 |
| 1 | 1403.8 | 12865.4 | 28098.5 | 42588.8 | 56006.0 | 67546.4 | 79182.8 | 87441.4 | 98454.8 | 110178.4 | 122662.5 | 136289.6 |
| 2 | 2284.2 | 13671.6 | 28868.4 | 43566.6 | 56793.2 | 67988.8 | 79859.4 | 88128.2 | 99352.9 | 111026.6 | 123583.8 | 137195.7 |
| 3 | 2002.8 | 14555.5 | 29758.1 | 44379.1 | 57393.1 | 68940.5 | 80767.6 | 89042.9 | 100187.7 | 111979.4 | 123516.6 | 138124.1 |
| 4 | 2601.0 | 14875.0 | 30765.1 | 45242.7 | 57428.3 | 69926.0 | 80561.7 | 89316.0 | 101090.3 | 112470.2 | 124366.7 | 139042.0 |
| 5 | 3348.5 | 15413.7 | 31179.3 | 45921.3 | 58018.1 | 70637.2 | 81556.8 | 89059.3 | 102040.9 | 113065.4 | 125268.9 | 139177.9 |
| 6 | 3100.1 | 16211.6 | 31951.9 | 46618.7 | 58672.2 | 71573.6 | 81131.5 | 89580.8 | 102607.9 | 112885.6 | 126096.2 | 139899.1 |
| 7 | 3713.6 | 17062.6 | 32688.9 | 46464.7 | 59573.4 | 72451.1 | 81470.0 | 90435.6 | 103532.3 | 113865.0 | 127002.8 | 140576.7 |
| 8 | 3651.2 | 18120.5 | 33140.5 | 46216.2 | 59135.1 | 73251.3 | 81399.8 | 91225.0 | 104503.0 | 114730.4 | 127856.8 | 140757.2 |
| 9 | 3282.6 | 18919.9 | 34000.8 | 47030.8 | 59968.8 | 74176.9 | 81651.6 | 91987.3 | 105302.0 | 114734.0 | 127847.8 | 141186.9 |
| 10 | 3885.4 | 18749.5 | 34886.7 | 47389.9 | 59660.9 | 74909.6 | 82516.0 | 92638.8 | 106133.4 | 115553.4 | 128556.6 | 141945.8 |
| 11 | 4221.7 | 19632.1 | 35778.6 | 48070.2 | 60359.6 | 75030.4 | 82403.9 | 93425.0 | 105766.2 | 115349.0 | 128809.7 | 142069.3 |
| 12 | 4462.7 | 20279.6 | 36416.8 | 48596.9 | 60278.5 | 75788.8 | 82538.2 | 94006.9 | 106552.7 | 116197.9 | 128949.0 | 142744.2 |
| 13 | 5007.9 | 21106.1 | 37092.4 | 48630.7 | 60667.6 | 76254.3 | 82971.2 | 94043.1 | 107112.5 | 116899.9 | 129759.9 | 143541.8 |
| 14 | 5514.1 | 21753.8 | 36822.3 | 49100.8 | 61150.7 | 75619.9 | 83115.0 | 93443.3 | 106993.9 | 117470.6 | 130566.7 | 144195.6 |
| 15 | 6214.0 | 22466.2 | 37442.6 | 49712.1 | 61534.3 | 75102.8 | 82485.4 | 93618.9 | 106410.7 | 118193.6 | 131386.1 | 144618.4 |
| 16 | 6660.0 | 23173.2 | 38073.8 | 50196.9 | 61956.3 | 75636.5 | 82081.9 | 94072.3 | 105914.5 | 118255.9 | 131473.0 | 145209.9 |
| 17 | 7360.6 | 23608.0 | 38030.2 | 50692.6 | 62562.0 | 74962.6 | 82414.7 | 93413.6 | 106582.5 | 117981.9 | 131822.2 | 145959.1 |
| 18 | 8070.6 | 23160.4 | 38748.6 | 51370.0 | 63224.3 | 74951.1 | 83024.2 | 94128.7 | 106389.2 | 118624.7 | 131760.9 | 145581.3 |
| 19 | 8886.4 | 23716.6 | 39455.3 | 52034.3 | 63636.0 | 75475.0 | 83462.3 | 94577.3 | 106485.2 | 118642.7 | 132391.1 | 146341.1 |
| 20 | 9359.2 | 24356.0 | 40162.7 | 52792.3 | 64382.4 | 76047.7 | 83802.3 | 95319.1 | 107069.8 | 119436.9 | 132963.6 | 147096.5 |
| 21 | 10052.6 | 25151.6 | 40907.0 | 53465.4 | 64980.7 | 76862.0 | 84645.4 | 96174.7 | 107181.8 | 120141.3 | 132841.8 | 146774.1 |
| 22 | 10392.1 | 26033.4 | 41696.9 | 54258.9 | 65225.6 | 77519.9 | 85444.8 | 96884.5 | 107924.4 | 119860.1 | 133789.3 | 147642.5 |
| 23 | 11141.7 | 26482.7 | 42371.8 | 55037.3 | 66124.8 | 77668.8 | 85873.4 | 97581.7 | 108886.8 | 120786.2 | 134664.8 | 148403.0 |

6.4 Flinders Island Results Summary:

Table 26: Flinders Island Results Summary

| | Load Model | | | |
|---|---|---|---|---|
| **SYSTEM RESULTS** | Noise-Free | Random Noise | Normal Dist. | Standard |
| Stand-Alone VRE Service Availability (%) | 85.42 | 84.03 | 85.42 | System-based |
| Average Proportion of Load Supplied by VRE | 0.91 | 0.91 | 0.91 | >0.5 |
| Proportion of Time 100% Instantaneous Power is Supplied by VRE | 0.85 | 0.84 | 0.85 | >0 |
| Current Instantaneous Storage Power Capability (kW) | 500.00 | 500.00 | 500.00 | >minimum |
| Minimum Instantaneous Storage Power Capability Needed (kW)* | 669.09 | 738.53 | 673.87 | N/A |
| Total Annual Power Surplus (kWh) | 163271.2 | 163832.4 | 160906.8 | N/A |
| Total Annual Power Shortage / Minimum Storage Capacity (kWh) | 12382.62 | 12958.71 | 12503.71 | N/A |
| Ratio of Surplus to Shortage | 13.19 | 12.64 | 12.87 | >5 |
| Time Steps of Insufficient Stored Power | 0 | 0 | 0 | "=0" |

Given known system information, these results show that this procedure is capable of calculating several factors relevant to the reliability of the system. It determines the service availability of the stand-alone VRE components of the system, validates the proportion of load supplied by these VRE components, ensures no insufficient stored power, and recommends the storage capacity and instantaneous power capability needed to maintain constant service availability.

## 7. Conclusion

This project defines a set of reliability standards that newly-proposed high-VRE systems are recommended to follow and are possible to evaluate. Using the procedure built based on these standards, proposed integrated systems can be thoroughly evaluated to ensure the system is designed to be reliable and cost-effective through optimized service availability and storage. This evaluation is a critical step before implementation that can determine the success of a proposed integrated system. Some of the standards proposed systems are recommended to meet are measurable, while others vary by application and have to be chosen depending on the type of system evaluated. Regardless, this procedure and its associated methods provide the calculated reliability parameters to compare to associated standards, whether they are defined or dependent on the system. The reliability evaluation methods provided by this report can solve significant modern energy challenges as described in Section 1.3 and the results are applicable to several circumstances. Despite the additional challenges that high-VRE systems face, and given a thorough evaluation using this report, implementation of high-VRE integrated systems can maintain reliability and be cost-effective while reducing environmental impact for more sustainable operations.

## 8. Next Steps

8.1 Reliability Standards:

- Minimum service availability standards are dependent on the application of a proposed energy system. The proposed system will likely have an associated service availability target, but **common service availability standards for several applications can be defined in the event that no target or standard is specified.** The appropriate standard can then be chosen and compared to the service availability results of this evaluation.

8.2 Adjust Generated Power Formulas to Account for Curtailment:

- Wind turbines have a cut-in wind speed at which power generation begins and a cut-out wind speed due to limits on the operational stress they can endure. The current method of modeling the power curve to calculate generated wind power from wind speed data does not account for the cut-in and cut-out speed, so **the model can be redesigned as a piecewise function that returns a generated power value of zero for wind speeds past the cut-in to cut-out range.** This will ensure that the model does not overestimate the power generated by the wind turbine sources of the system, particularly in systems at locations with frequent wind speeds above or below the cut-in to cut-out range.
- The current calculation model for generated solar power does not consider solar panel curtailment, so factors that cause curtailment can be identified and designed into the mathematical model.
- Overload of generated power compared to load must be prevented. Determine how excess power generation will be filtered out of the proposed system.

8.3 Reduce Uncertainty and Improve Accuracy of this Evaluation:

- The data used in the Flinders Island Analysis to demonstrate the procedure is not representative of the chronological data and fidelity recommended for this evaluation. Data in this analysis—as it is for demonstration purposes—is representative of the average hourly value per month, while data used to evaluate a proposed system should be at chronological time steps rather than average values over periods of time.
- Determine the data fidelity required to yield accurate results from this analysis, or the recommended maximum size of time intervals chosen between chronological data points. Load and wind speed often experience instantaneous spikes that may not be captured by sampled load data over a time period, no matter how small the time intervals are. The smaller the time intervals, the more likely load spikes are to be captured. If the highest instantaneous load values are not captured in the sampled set, these values should be added to the data set so that these high-load scenarios are considered.
- In conditions of rapid wind speed change or variability, wind turbine inertia causes the calculated—or predicted—power generation to be less accurate to the actual power generated. This contributes to some uncertainty in the procedure results. To increase the accuracy of calculated wind power generation, the next step is to define turbine inertia depending on the turbine model and find a method to integrate this factor into the generated wind power formula.
- Add a capacity cap to the running total calculated in Procedure Section 4.3 step 4. This can ensure that the storage capacity is not exceeded and the stored power at each time step is accurately simulated. The excess power cut off by the cap is filtered out of the system, and this capacity cap is based on the minimum storage capacity calculated in Section 4.3 step 1.
- This procedure determines the total annual generated power shortage (kWh) corresponding to the minimum storage capacity needed to maintain service availability and the total annual power surplus (kWh). The greater the ratio of annual power surplus

to shortage as shown in Table 26, the more certainty that stored power will be available for every period of power shortage regardless of length. Proposed high-VRE systems are expected to have a high ratio due to variability in power generation and design for minimal shortage, however this ratio can have a defined minimum to ensure adequate stored power during shortages, particularly long ones such as the daily solar shortage.

- The load, wind speed, solar irradiance, and ambient temperature variables used in this evaluation will not experience the same trends long-term due to population growth, electric demand changes, the progression of climate change and other factors. For this evaluation to remain accurate in predicting long-term reliability factors, a time-based growth factor can be developed and applied to each of these data sets depending on predictive models for the change these variables will experience. Several existing projections of future global average temperature are accurate (Buis 2021) and can be used to create this growth factor for ambient temperature. Location-based projections on future load, wind speed, and solar irradiance may also be available—or possible to develop—to create associated growth factors.

<u>8.4 Perform Additional Validation of this Evaluation</u>:

- Find known Flinders Island data to compare to the Flinders Island evaluation results and calculate error to approximate the accuracy of the evaluation.
- Apply this evaluation to existing USACE facility energy microgrids and compare the evaluation results to actual data from the operating system. Calculate error between these results and the data to approximate the accuracy of the evaluation.

<u>8.5 Build Additional Clean and/or Renewable Sources Into this Analysis</u>:

- This procedure has the potential to be expanded to evaluate proposed energy systems with clean and/or renewable sources other than solar panels and turbine-based wind power.
    - Controllable or Semi-Controllable:
        - Hydropower
        - Geothermal energy
        - Biomass energy
    - Variable:
        - Non-turbine based wind power
        - Wave energy collectors

# 9. Appendices

9.1 Current High-VRE Systems Comparison:

Figure 12 and the table below summarize a comparison between the critical qualities of several existing systems that are highly isolated and high-VRE. This data provides an understanding of the capabilities of current systems; a benchmark to construct models and create measurable standards that are ambitious yet reasonable based on system needs as well as current system capabilities. While it was not possible to gather significant data on many of the existing high-VRE systems found, this helped identify some of the system parameters that must be known and evaluated in order to determine reliability in terms of load, power generated, service availability, and storage power / capacity needed to ensure service availability.

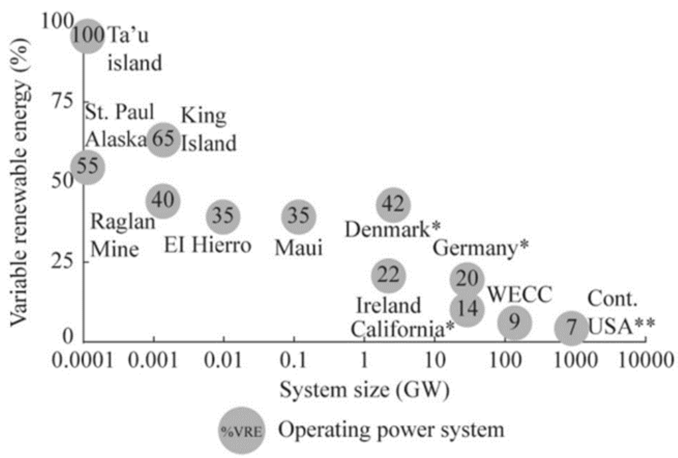


*Figure 12: System Size vs VRE % Plot of Current Systems ()*

Table 27: Comparative Characteristics of Current High-VRE Isolated Systems

| | System Specifications | | | | | | | | | Reliability Factors | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| System / Location | System Size (MW) | System Distribution | | | VRE % | Average Load (MW) | Peak Load (MW) | Storage Type(s) | Storage Capacity (kW) | Service Availability (%) | Failures |
| Island of Maui | 1019 | 1019 MW Solar | | | 35 | 80 | 200 | | | 99.98 | |
| King Island | 6 | 470 kW Solar | 2.45 MW Wind | Diesel | 65 | 1.37 | 2.5 | Battery, Flywheels, dynamic resistors | 4500 + 1 MVA | | |
| St. Paul, Alaska | 1.2 | 900 kW Wind | 300 kW Diesel | | 55 | 0.07 | | Flywheel | | | |
| Kodiak Island, Alaska | 28 | 20% Wind | 80% Hydro | | 95 | 18 | 25 (min 11) | Battery | 3000 | | |
| Raglan Mine, Northern Canada | 4.6 | 3 MW Wind | 1.6 MW Diesel | | 40 | 1.4 | | 200 kW flywheel, 200 kW Li-Ion battery, 200 kW PEM fuel cell | 600 | 97.3 | |
| El Hierro, Canary Islands | 7 | 7 MW Wind | | | 35 | 4 | 7.5 | Pump hydro storage | 7200 MWh for 100% wind system | | February 18th and 19th, 18-month test |
| Ireland | | | | | 22 | 5500 | 6500 | | | | |
| Flinders Island | 3 | 200 kW Solar | 900 kW Wind | Diesel | 60 | 0.765 | 1.3 | Battery, flywheel, dynamic resistor | 2250 + 850 kVA | | |
| Ta'u Island, American Samoa | 1.4 | 1.4 MW PV Solar | | | 100 | 0.08 | | 6 MWh battery | | | |
| Coober Pedy | 3.9 | 1 MW Solar | 4 MW Wind | Diesel | 70 | 1.48 | 3 | | 4500 + 1.7 MVA | | |
| Rottnest Island | 1.2 | 600 kW Solar | 600 kW Wind | Diesel | 45 | 0.57 | 1.1 | | | | |
| CAISO | | 0.4 GW Solar | 2.8 GW Wind | | 10.9 | 34246.6 | | | | | |
| EEX | | 30.8 GW Solar | 30.7 GW Wind | | 26.5 | | | | | | |
| IESO | 38079 | 1.5 GW Wind | | | 24.7 | 15278.5 | 22986 | | | | |

## 9.2 Additional Generated Power / Load Difference Charts and Diagrams for Flinders Island

Table 28: Power Generated / Load Difference - Noise-Free Load Model

| Hour | Difference Between Power Generated and Load | | | | | Non-VRE Included, Noise-Free Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 3831.73 | 3235.87 | 3359.01 | 3604.77 | 3016.40 | 3846.04 | 3845.85 | 3227.48 | 2848.16 | 3504.78 | 3788.80 | 3937.15 |
| 1 | 3898.12 | 3854.63 | 3598.23 | 3869.44 | 3814.21 | 3862.71 | 2671.73 | 3849.18 | 3521.50 | 3882.49 | 3933.74 | 3830.79 |
| 2 | 3732.66 | 3069.70 | 3803.37 | 3674.08 | 2677.47 | 3460.78 | 3618.72 | 3871.53 | 3763.05 | 3930.57 | 3882.19 | 3330.78 |
| 3 | 2988.31 | 3912.80 | 3600.76 | 3877.24 | 3854.72 | 3127.49 | 3860.72 | 3835.21 | 2742.75 | 3875.12 | 3934.61 | 3914.69 |
| 4 | 3900.90 | 3406.33 | 3895.49 | 3772.38 | 3870.96 | 3875.62 | 3859.31 | 3808.33 | 2727.70 | 3931.98 | 3909.31 | 3803.55 |
| 5 | 3854.13 | 3866.10 | 3701.30 | 3870.86 | 3537.01 | 2826.30 | 3846.73 | 3859.98 | 3150.10 | 3929.48 | 3953.71 | 3829.77 |
| 6 | 3943.23 | 3165.23 | 3891.10 | 3878.68 | 3844.16 | 2689.85 | 3357.12 | 3850.03 | 3153.69 | 3963.23 | 3922.60 | 2844.57 |
| 7 | 3939.50 | 2808.06 | 3791.53 | 3893.13 | 3860.66 | 3825.12 | 3715.28 | 3660.19 | 2975.50 | 3919.21 | 3921.31 | 3986.01 |
| 8 | 3214.32 | 3798.82 | 3175.51 | 3075.38 | 3842.11 | 3745.94 | 3843.70 | 3603.83 | 3867.80 | 3934.82 | 3029.36 | 3971.07 |
| 9 | 3821.12 | 3832.19 | 3887.52 | 3286.22 | 3869.90 | 2697.95 | 3840.53 | 2771.10 | 3903.99 | 2875.47 | 3942.78 | 3874.92 |
| 10 | 3305.72 | 3739.59 | 3389.96 | 3836.62 | 3781.44 | 2770.11 | 3810.62 | 3159.85 | 3255.59 | 3652.03 | 3915.85 | 3752.71 |
| 11 | 3836.05 | 2931.11 | 3678.41 | 3787.45 | 3667.77 | 3637.39 | 3746.58 | 3427.26 | 3864.27 | 3119.49 | 3873.61 | 3299.85 |
| 12 | 3348.73 | 3480.32 | 3690.01 | 2844.34 | 3727.71 | 3567.30 | 3102.95 | 3689.40 | 3735.82 | 3815.18 | 3680.30 | 3786.09 |
| 13 | 3757.17 | 3742.50 | 3376.23 | 3671.94 | 3504.94 | 3580.40 | 3464.71 | 3667.32 | 3567.01 | 3636.70 | 3680.50 | 3617.26 |
| 14 | 3604.37 | 3134.95 | 3614.84 | 3604.95 | 2564.28 | 3084.17 | 3537.58 | 3559.92 | 3686.53 | 3153.87 | 3722.40 | 3676.94 |
| 15 | 3201.13 | 3657.43 | 3305.74 | 3060.68 | 3554.03 | 3438.22 | 2473.46 | 3371.94 | 3697.85 | 3572.89 | 2829.32 | 3750.20 |
| 16 | 3461.96 | 2456.89 | 3611.84 | 2456.93 | 3539.29 | 3072.28 | 3092.61 | 3485.88 | 2612.44 | 3704.19 | 3215.15 | 3079.73 |
| 17 | 3732.16 | 3738.02 | 3460.74 | 3644.85 | 3271.99 | 2449.27 | 3592.57 | 3550.07 | 3055.61 | 3754.02 | 3711.40 | 3467.41 |
| 18 | 3751.73 | 3672.09 | 3699.48 | 3661.00 | 3682.90 | 3651.36 | 3638.27 | 3516.62 | 2934.73 | 3760.61 | 2921.65 | 3814.95 |
| 19 | 3476.03 | 3762.14 | 2672.43 | 3705.78 | 2955.43 | 3707.91 | 3464.78 | 2504.75 | 3708.76 | 2698.08 | 3198.64 | 3762.20 |
| 20 | 3801.88 | 3822.88 | 3685.76 | 3784.55 | 3396.45 | 3740.38 | 3490.55 | 3598.42 | 3671.08 | 3845.69 | 3855.85 | 3024.22 |
| 21 | 3289.50 | 3852.06 | 3804.77 | 3421.99 | 3797.55 | 3695.08 | 3561.44 | 3796.77 | 3507.34 | 3877.65 | 3867.64 | 3867.77 |
| 22 | 3866.39 | 3162.91 | 2872.98 | 3507.42 | 3674.72 | 3747.60 | 3679.05 | 3820.89 | 3749.51 | 3122.86 | 3300.34 | 3874.97 |
| 23 | 2811.94 | 3864.22 | 2747.25 | 3851.69 | 3420.23 | 3849.43 | 3834.94 | 3758.03 | 3915.64 | 3817.55 | 3903.42 | 2735.69 |

Table 29: Power Generated / Load Difference - Randomized Noise Load Model

| Hour | Difference Between Power Generated and Load | | | | | Non-VRE Included, Randomized Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 3795.28 | 3361.84 | 3526.24 | 3768.36 | 3015.58 | 3625.77 | 3959.65 | 3231.38 | 2879.78 | 3357.60 | 3800.62 | 4090.01 |
| 1 | 3917.46 | 3803.59 | 3400.82 | 3649.24 | 3702.49 | 3927.81 | 2688.46 | 3823.61 | 3407.16 | 3920.44 | 3914.19 | 3928.77 |
| 2 | 3542.64 | 2849.98 | 4022.85 | 3539.75 | 2463.19 | 3401.47 | 3711.88 | 4008.11 | 3918.95 | 4112.40 | 3963.38 | 3311.32 |
| 3 | 3144.27 | 4110.24 | 3551.97 | 3749.77 | 3758.26 | 3070.58 | 3646.84 | 3832.83 | 2809.42 | 4007.75 | 4013.45 | 3740.23 |
| 4 | 4108.64 | 3189.65 | 3708.32 | 3582.95 | 3983.33 | 3929.02 | 3699.65 | 3921.70 | 2636.03 | 3724.18 | 3991.79 | 3676.83 |
| 5 | 3860.72 | 3654.96 | 3899.56 | 3904.48 | 3657.58 | 2865.91 | 3866.09 | 3706.73 | 3299.35 | 3880.38 | 3894.13 | 3705.55 |
| 6 | 4047.13 | 3319.00 | 3861.28 | 3935.06 | 3943.23 | 2851.26 | 3486.26 | 3781.85 | 2968.81 | 3874.90 | 3862.62 | 3059.50 |
| 7 | 3876.99 | 2625.70 | 3691.46 | 4096.64 | 3795.33 | 4046.41 | 3792.03 | 3760.60 | 2816.71 | 4090.69 | 4038.10 | 4082.20 |
| 8 | 3307.98 | 3817.40 | 3094.78 | 3288.43 | 3660.43 | 3840.39 | 3838.91 | 3473.28 | 3835.94 | 3800.00 | 2914.38 | 4108.83 |
| 9 | 3824.13 | 3729.37 | 3908.04 | 3110.01 | 3666.46 | 2578.01 | 3777.54 | 2846.28 | 3995.63 | 2671.45 | 3949.64 | 3973.58 |
| 10 | 3196.03 | 3922.14 | 3288.72 | 3668.38 | 3649.22 | 2611.53 | 3688.94 | 3019.31 | 3105.00 | 3664.71 | 4018.90 | 3927.14 |
| 11 | 3942.12 | 2883.39 | 3822.79 | 3816.98 | 3572.43 | 3616.93 | 3699.59 | 3467.39 | 3716.44 | 2899.51 | 3795.97 | 3074.96 |
| 12 | 3318.50 | 3341.58 | 3476.40 | 2852.82 | 3810.76 | 3689.41 | 2899.62 | 3826.75 | 3929.04 | 3700.18 | 3862.24 | 3741.20 |
| 13 | 3714.72 | 3696.70 | 3310.98 | 3844.07 | 3564.99 | 3388.95 | 3643.36 | 3622.58 | 3367.26 | 3539.59 | 3529.52 | 3531.98 |
| 14 | 3466.06 | 3333.30 | 3651.58 | 3570.28 | 2627.24 | 3061.28 | 3408.03 | 3368.86 | 3839.70 | 2971.54 | 3720.62 | 3807.72 |
| 15 | 3278.42 | 3694.37 | 3297.64 | 2943.33 | 3628.84 | 3476.88 | 2363.47 | 3435.52 | 3823.16 | 3498.40 | 2849.04 | 3971.13 |
| 16 | 3611.79 | 2278.83 | 3401.47 | 2676.92 | 3690.65 | 3290.28 | 3237.87 | 3531.46 | 2725.83 | 3718.94 | 3054.28 | 3243.91 |
| 17 | 3898.20 | 3682.04 | 3478.73 | 3699.65 | 3469.32 | 2409.36 | 3419.75 | 3429.86 | 2977.32 | 3933.94 | 3845.87 | 3592.76 |
| 18 | 3537.47 | 3723.57 | 3821.47 | 3830.43 | 3821.02 | 3771.34 | 3612.53 | 3322.32 | 2804.78 | 3906.14 | 3121.77 | 3942.50 |
| 19 | 3608.50 | 3856.61 | 2549.63 | 3731.74 | 3110.58 | 3656.04 | 3626.21 | 2620.32 | 3569.00 | 2884.63 | 2980.67 | 3557.19 |
| 20 | 3724.54 | 3717.91 | 3610.08 | 3704.45 | 3236.87 | 3882.61 | 3368.43 | 3461.58 | 3781.29 | 4024.57 | 3735.83 | 2926.93 |
| 21 | 3196.36 | 3661.71 | 3998.86 | 3503.31 | 3712.37 | 3792.12 | 3680.11 | 3738.79 | 3658.52 | 4070.52 | 3901.81 | 3890.52 |
| 22 | 3827.47 | 3165.79 | 3031.26 | 3497.27 | 3466.00 | 3921.92 | 3617.01 | 3926.25 | 3862.94 | 3164.41 | 3206.37 | 3718.15 |
| 23 | 2924.12 | 3757.17 | 2577.90 | 3972.76 | 3263.96 | 3844.66 | 3740.22 | 3550.27 | 4109.00 | 3776.87 | 3752.97 | 2831.06 |

Table 30: Power Generated / Load Difference - Normal Distribution Noise Load Model

| Hour | **Difference Between Power Generated and Load** | | | | | Non-VRE Included, Normal Distribution Noise Load Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| 0 | 3622.06 | 3202.18 | 3379.05 | 3666.94 | 2996.91 | 3959.45 | 4049.45 | 3190.97 | 2829.08 | 3495.63 | 3891.40 | 3993.53 |
| 1 | 3947.14 | 3923.53 | 3572.86 | 3762.52 | 3866.57 | 3920.78 | 2633.87 | 3804.36 | 3470.00 | 3863.29 | 3912.12 | 3807.16 |
| 2 | 3845.35 | 3131.68 | 3917.56 | 3659.97 | 2743.27 | 3390.24 | 3471.98 | 3779.61 | 3694.46 | 3936.89 | 3901.64 | 3436.53 |
| 3 | 2964.91 | 3913.77 | 3747.45 | 3869.47 | 3648.29 | 3090.29 | 3824.70 | 3833.97 | 2725.37 | 3807.12 | 3971.07 | 3912.94 |
| 4 | 3898.22 | 3450.63 | 3792.34 | 3889.10 | 3869.00 | 3821.30 | 3951.54 | 3972.31 | 2750.76 | 3988.02 | 3833.43 | 3998.21 |
| 5 | 3874.53 | 3937.12 | 3670.81 | 3816.52 | 3443.22 | 2801.03 | 3895.84 | 3868.09 | 3204.37 | 3866.03 | 3947.99 | 3751.27 |
| 6 | 3925.05 | 3249.84 | 3861.69 | 3898.41 | 3984.08 | 2772.21 | 3539.92 | 3853.59 | 3077.46 | 4094.04 | 3966.66 | 2832.26 |
| 7 | 3927.59 | 2745.95 | 3768.56 | 3871.47 | 3854.48 | 3682.94 | 3800.45 | 3515.36 | 3100.39 | 3886.60 | 3976.02 | 3909.91 |
| 8 | 3198.12 | 3840.60 | 3208.84 | 3182.91 | 3785.56 | 3800.58 | 3826.40 | 3568.07 | 3772.85 | 3877.67 | 2910.75 | 3985.91 |
| 9 | 3812.69 | 3865.12 | 3814.16 | 3245.05 | 3940.35 | 2833.26 | 3785.67 | 2907.55 | 3828.63 | 2955.24 | 3991.61 | 3838.51 |
| 10 | 3250.56 | 3672.46 | 3359.33 | 3796.24 | 3846.08 | 2673.46 | 3831.92 | 2962.80 | 3289.31 | 3710.61 | 4087.54 | 3773.25 |
| 11 | 3914.62 | 2926.61 | 3685.85 | 3867.81 | 3751.08 | 3622.61 | 3636.64 | 3513.20 | 3909.06 | 3092.84 | 3733.10 | 3302.96 |
| 12 | 3372.70 | 3641.86 | 3812.35 | 2723.10 | 3694.18 | 3610.09 | 3006.24 | 3801.08 | 3895.59 | 3766.56 | 3705.31 | 3816.05 |
| 13 | 3749.26 | 3778.66 | 3416.60 | 3641.17 | 3328.60 | 3568.58 | 3573.47 | 3567.12 | 3745.58 | 3655.43 | 3656.36 | 3554.94 |
| 14 | 3693.19 | 3014.36 | 3705.32 | 3644.60 | 2435.00 | 3013.89 | 3486.78 | 3481.42 | 3693.39 | 3147.96 | 3747.11 | 3650.86 |
| 15 | 3313.39 | 3577.59 | 3331.05 | 3076.19 | 3683.70 | 3416.04 | 2502.64 | 3430.18 | 3802.55 | 3636.64 | 2749.33 | 3712.79 |
| 16 | 3248.47 | 2334.72 | 3564.09 | 2511.40 | 3444.74 | 3161.34 | 3085.86 | 3542.47 | 2596.89 | 3778.82 | 3123.58 | 3036.52 |
| 17 | 3715.48 | 3667.20 | 3417.09 | 3621.03 | 3211.44 | 2509.24 | 3651.68 | 3738.66 | 3054.12 | 3694.11 | 3669.73 | 3484.02 |
| 18 | 3781.27 | 3778.92 | 3810.65 | 3728.39 | 3652.06 | 3488.33 | 3552.21 | 3532.52 | 2953.31 | 3610.52 | 3009.45 | 3871.19 |
| 19 | 3482.65 | 3782.41 | 2802.11 | 3618.05 | 2947.27 | 3681.11 | 3619.57 | 2575.14 | 3624.25 | 2778.60 | 3144.79 | 3707.30 |
| 20 | 3719.73 | 3806.77 | 3715.28 | 3689.26 | 3295.83 | 3717.30 | 3577.34 | 3716.53 | 3647.63 | 3973.41 | 3918.17 | 3039.66 |
| 21 | 3307.61 | 3679.26 | 3803.81 | 3325.15 | 3844.15 | 3624.08 | 3715.42 | 3740.31 | 3531.34 | 3889.79 | 3787.86 | 3897.05 |
| 22 | 3976.92 | 3161.25 | 2852.61 | 3523.23 | 3851.75 | 3813.08 | 3746.31 | 3761.44 | 3567.78 | 3180.74 | 3438.48 | 4069.91 |
| 23 | 2969.79 | 3779.54 | 2587.64 | 3889.91 | 3394.97 | 3888.98 | 3719.49 | 3642.98 | 3832.87 | 3777.00 | 3910.11 | 2668.99 |

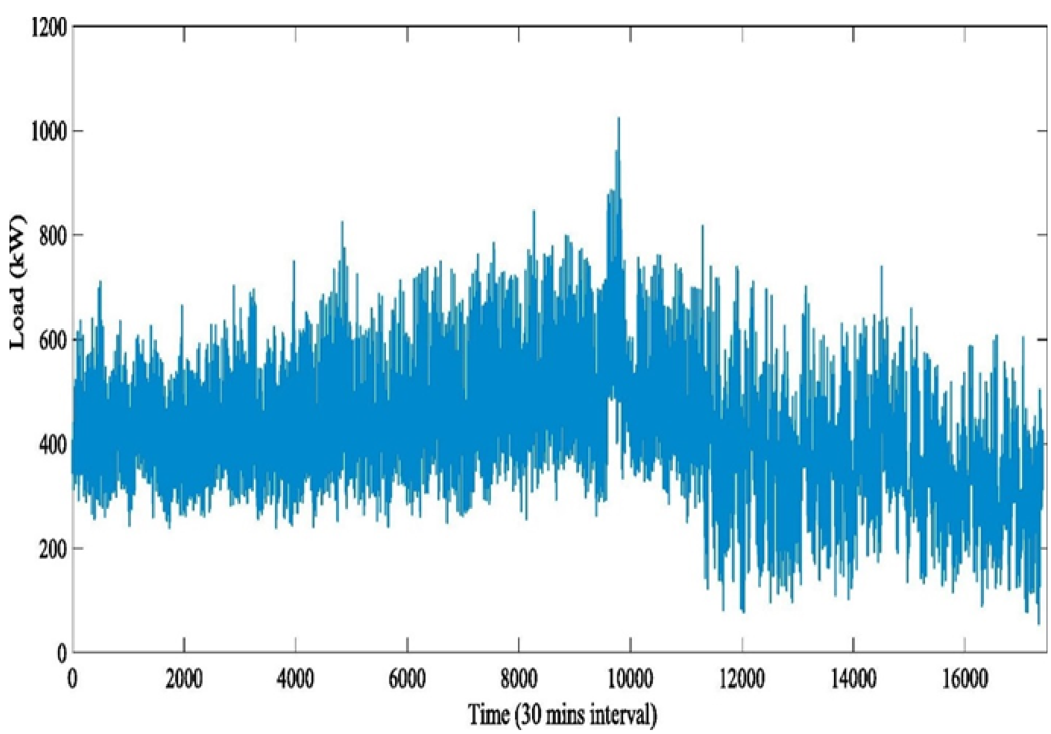


*Figure 13: Flinders Island Annual Load Profile (El-Bidairi 2018)*

Table 31: Additional Wind Turbine Specifications (El-Bidairi 2018)

| Wind turbine type | Cut-in wind speed (m/s) | Rated wind speed (m/s) | Cut-out wind speed (m/s) | Survival wind speed (m/s) | Rotor diameter (m) | No. of blades | Max. rotor speed (U/min) | Swept area ($m^2$) | Tower hub height (m) |
|---|---|---|---|---|---|---|---|---|---|
| E-44 | 3 | 16.5 | 34 | 59.5 | 44 m | 3 | 34 | 1521 $m^2$ | 55 |
| E-30 | 2.5 | 13.5 | 25 | 70 | 29.6 | 3 | 48 | 876 | 50 |

9.3 Proposed System Forecasting Accuracy Recommendation:

NRMSE, or Normalized Root Mean Square Error, is a measure of error that can be used to determine the accuracy of a forecasting system (Zhang 61). This calculation can be used to evaluate the accuracy of any forecasting method given that you know the predicted power input and the actual power input after the time horizon has passed. The lower the NRMSE, the less error between predicted and actual power input and the more accurate the system is.

Equations 16 and 17: Normalized Root Mean Square Error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{n}} \qquad NRMSE = \frac{RMSE}{\bar{y}}$$

Here is an example of several forecasting methods evaluated using NRMSE (Zhang 2017).

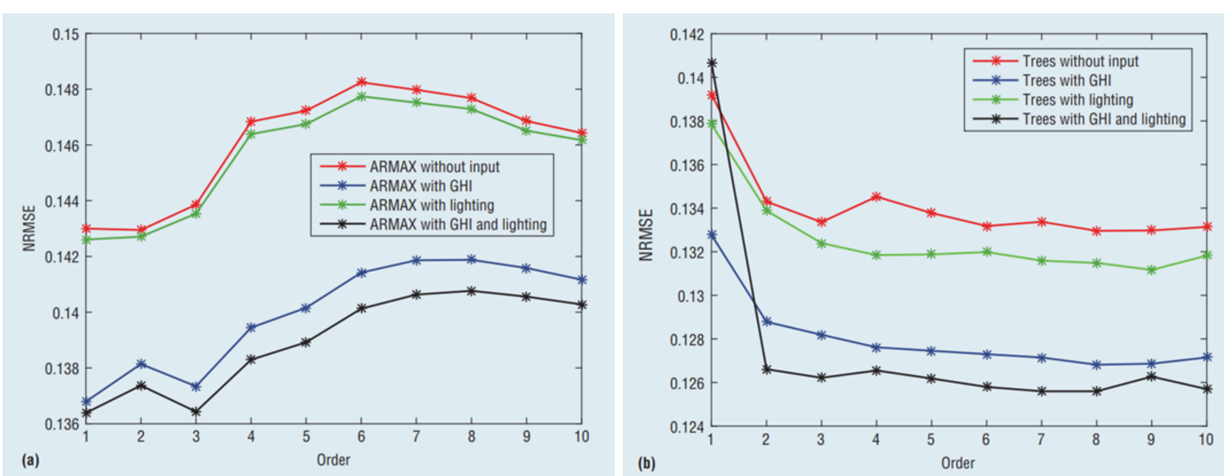


*Figure 14: NRMSE of Several Forecasting Systems based on ODE Order*

Good forecasting accuracy leads to a reduction in voltage violations for several applications, as shown in Figure 15 (Zhang 2017).

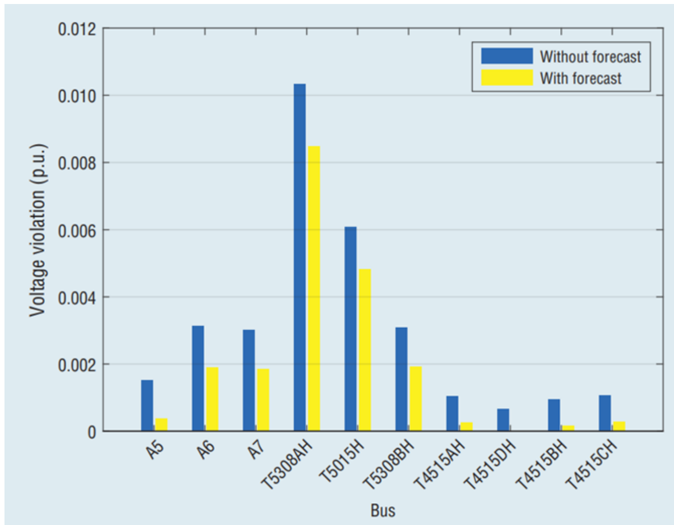


*Figure 15: Voltage Violation With vs Without Forecasting for Different Systems*

Accurate generated power forecasting improves a system's ability to respond to load and generated power changes, reducing voltage violations and decreasing chance of failure. It is recommended that the accuracy of this short-term forecasting does not exceed a specified maximum normalized root-mean square error (NRMSE) as calculated by Equations 16 and 17. The lowest NRMSE a system can reach depends on length of the time horizon—or period of time forecasted ahead—chosen for the proposed integrated system. A NRMSE maximum standard has been developed based on current forecasting system accuracy capabilities shown by existing data.

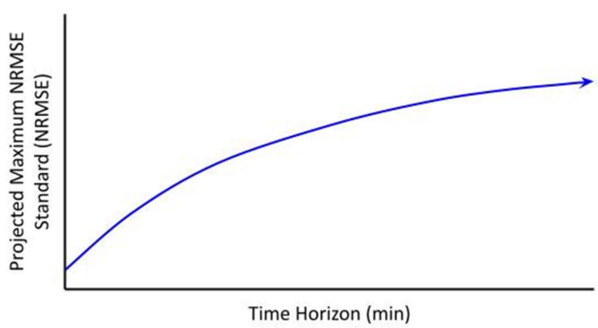


*Figure 16: Predicted Trend in Current System NRMSE Values and NRMSE Maximum Standard as Time Horizon Changes*

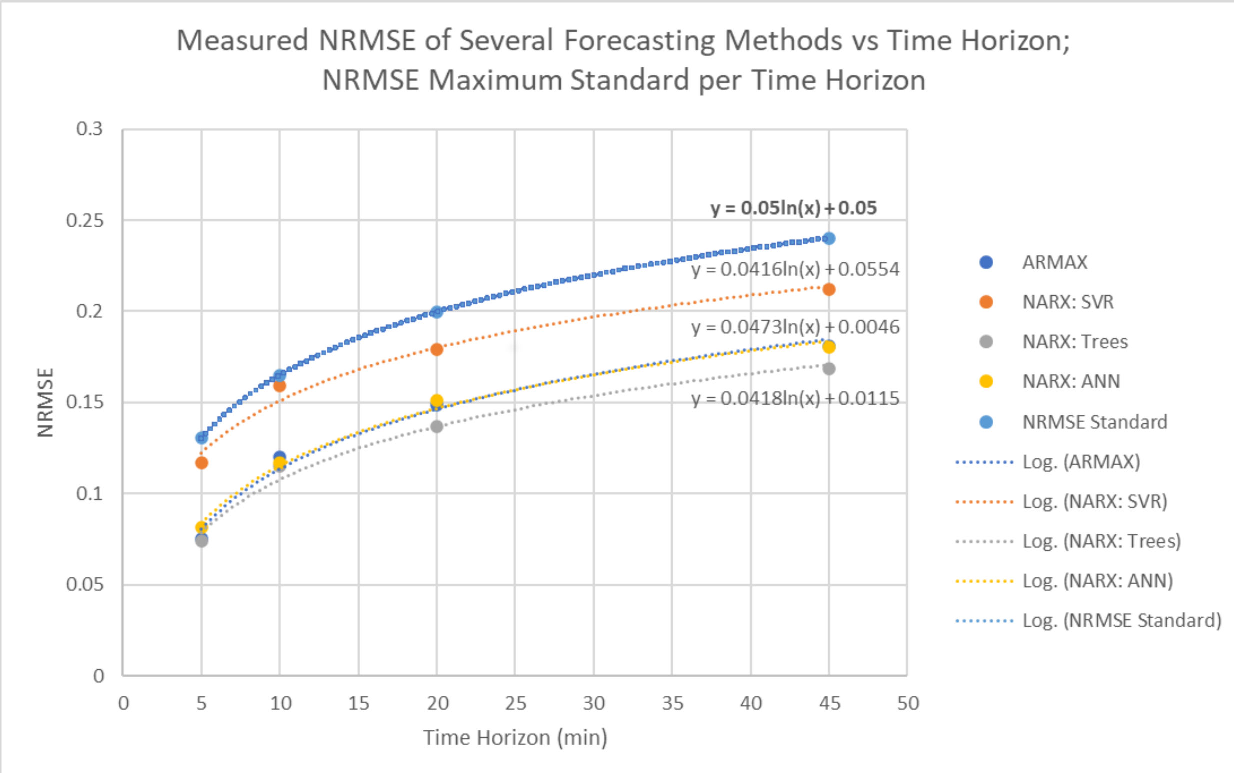


*Figure 17*

This plot of measured NRMSE data from current forecasting systems shows that the predicted trend in Figure 16 is accurate, and the change in NRMSE with time horizon for each forecasting method closely matches a logarithmic function. This means that other forecasting systems will likely follow a similar trend and the NRMSE maximum standard can also be dependent on the time horizon by a logarithmic function. For proposed integrated systems, NRMSE should be as low as possible but not unreasonably low as to surpass current system accuracy capabilities. To achieve this, a model is shown by the bolded blue line in the plot above. Equation 18 from the plot represents the recommended maximum NRMSE that any proposed system's short-term forecasting method should have based on its time horizon.

Equation 18:

$$NRMSE = 0.05ln(t) + 0.05$$

$$t = Time\ Horizon\ (min)$$

<u>9.4 Project Technical Approach, Process and Milestones</u>:

1. Define reliability and robustness characteristics

Use existing knowledge and sources on reliability and robustness in electrical systems to create a set of system characteristics that encapsulate both reliability and robustness. These will be the characteristics with developed measurable standards that will be evaluated in new integrated systems.

2. Determine needed conditions and variables, parameters of proposed integrated systems

Each proposed integrated system has several known or defined characteristics in order to be evaluated with the listed methods and procedure, so this step lays out these characteristics. It also gives an overview of the system's evaluated parameters.

3. Conduct research and comparative analysis into existing high-VRE electric systems

Current isolated high-VRE electric systems can show me a lot in terms of current system capabilities and the reliability and robustness potential of a high-VRE system, based on the variability of the system among other factors. This step encompasses in-depth research on these current systems and a comparative analysis that can be used to set standards for newly developed and proposed systems.

4. Create measurable standards

Using results from the analysis of existing systems, existing standards and differences in high-VRE systems, create measurable standards for each of the evaluated parameters of new integrated systems. These standards may be universal to all proposed systems or dependent on known system characteristics.

5. Determine methods of evaluation for new integrated systems

New integrated systems can be evaluated for these standards, so this section will determine which methods of evaluation to use to evaluate these systems.

6. Create recommendations and next steps to expand on work

In the event of any incomplete standards or testing methods, this section creates recommendations on how to continue this work and create a complete set of guidelines for evaluation of integrated systems.

7. Write final report detailing the standards and evaluation methods needed to validate proposed high-VRE integrated energy systems

<u>Schedule & Milestones:</u>

| Task | 2-21 | 2-28 | 3-7 | 3-14 | 3-21 | 3-28 | 4-4 | 4-11 | 4-18 | 4-25 | 5-2 | 5-9 | 5-16 | 5-23 | 5-30 | 6-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | |

## References


Al‑Quraan, A., Al‑Masri, H., Al‑Mahmodi, M., & Radaideh, A. (2021). Power curve modelling of wind turbines‑ a comparison study. *IET Renewable Power Generation*, *16*(2), 362–374. https://doi.org/10.1049/rpg2.12329

Bauer, L. (n.d.). *Wind Turbines Database*. Wind turbines database. Retrieved November 22, 2022, from https://en.wind-turbine-models.com/turbines

Bird, L., Cochran, J., & Wang, X. (2014). Wind and solar energy curtailment: Experience and practices in the United States. https://doi.org/10.2172/1126842

Buis, A. (2021, January 26). *Study confirms climate models are getting future warming projections right – climate change: Vital signs of the planet*. NASA. Retrieved December 23, 2022, from https://climate.nasa.gov/news/2943/study-confirms-climate-models-are-getting-future-warming-projections-right/

Cho, Y., Hur, K., Kang, Y., & Muljadi, E. (2017). Impedance-based stability analysis in grid interconnection impact study owing to the increased adoption of converter-interfaced generators. *Energies*, *10*(9), 1355. https://doi.org/10.3390/en10091355

*Concentrating solar power*. NREL.gov. (n.d.). Retrieved June 7, 2022, from https://www.nrel.gov/csp/

Department of Defense (DoD) (2013, January 7). *UFC 3-401-01 mechanical engineering, with change 1*. WBDG. Retrieved June 7, 2022, from https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-401-01

Department of Defense (DoD) (2015, January 7). *UFC 3-440-01 facility-scale renewable energy systems*. WBDG. Retrieved June 7, 2022, from https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-440-01

El-Bidairi, K. S., Nguyen, H. D., Jayasinghe, S. D. G., Mahmoud, T. S., & Penesis, I. (2018, September 5). *A hybrid energy management and battery size optimization for standalone microgrids: A case study for Flinders Island, Australia*. Energy Conversion and Management. Retrieved October 18, 2022, from https://www.sciencedirect.com/science/article/pii/S0196890418309415#b0260

*Flinders island long-term averages. Flinders Island climate, averages and extreme weather records. (n.d.). Retrieved December 21, 2022, from https://www.farmonlineweather.com.au/climate/station.jsp?lt=site&lc=99005*

*Global wind atlas*. Global Wind Atlas. (n.d.). Retrieved June 7, 2022, from https://globalwindatlas.info/

Gouvernement du Canada. (2022, June 1). *Government of Canada*. Natural Resources Canada. Retrieved June 8, 2022, from https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/21146

*Grid modernization*. NREL.gov. (n.d.). Retrieved June 7, 2022, from https://www.nrel.gov/grid/

*How to normalize the RMSE*. Marine Data Science. (n.d.). Retrieved June 7, 2022, from https://www.marinedatascience.co/blog/2019/01/07/normalizing-the-rmse/

Hybrid Energy Solutions Success stories. (n.d.). Retrieved June 7, 2022, from https://www.hydro.com.au/clean-energy/hybrid-energy-solutions/success-stories

*Independent evaluation of the El Hierro Wind & Pumped Hydro System*. Energy Matters. (2018, April 15). Retrieved June 8, 2022, from http://euanmearns.com/an-independent-evaluation-of-the-el-hierro-wind-pumped-hydro-system/

Kroposki, B. D. (2017). Integrating high levels of variable renewable energy into Electric Power Systems. https://doi.org/10.2172/1374134

Liu, L., Wang, Z., Wang, Y., Wang, J., Chang, R., He, G., Tang, W., Gao, Z., Li, J., Liu, C., Zhao, L., Qin, D., & Li, S. (2020). Optimizing Wind/solar combinations at finer scales to mitigate renewable energy variability in China. *Renewable and Sustainable Energy Reviews*, *132*, 110151. https://doi.org/10.1016/j.rser.2020.110151

*Media*. Overview. (n.d.). Retrieved June 7, 2022, from https://www.ieso.ca/en/Corporate-IESO/Media/Overview

*Ost, I. (2020, April 20). Does solar panel temperature coefficient matter? Solar.com. Retrieved December 21, 2022, from https://www.solar.com/learn/does-solar-panel-temperature-coefficient-matter/#:~:text=Most%20solar%20panels%20have%20a,decrease%20in%20efficiency%20by%200.37%25*

*Project profile hybrid CHP system St. Paul Island, AK*. (n.d.). Retrieved June 7, 2022, from https://chptap.lbl.gov/profile/318/StPaulIsland-Project_Profile.pdf

Renewables 100 Policy Institute. (2015, April 12). *Kodiak Island - 99.5% locally owned Renewable Power*. Go 100% Renewable Energy : Kodiak Island - 99.5% Locally Owned Renewable power. Retrieved June 7, 2022, from http://www.go100percent.org/cms/index.php?id=77&tx_ttnews%5Btt_news%5D=403&cHash=15b2517ace5c2b357949ac1270be2166#:~:text=Kodiak%20Island%2C%20located%20on%20the,3%20MW%20battery%20storage%20system.

*Rottnest Island Water and renewable energy nexus project - hydro tasmania*. (n.d.). Retrieved June 8, 2022, from https://www.hydro.com.au/docs/default-source/clean-energy/hybrid-energy-solutions/rottnest_island.pdf?sfvrsn=f2ad4828_2

Simard, S., Fytas, K., Paraszczak, J., Laflamme, M., & Agbossou, K. (2017). Wind power opportunities for remote mine sites in the Canadian North. *Renewable Energy and Power Quality Journal*, *1*(15), 173–178. https://doi.org/10.24084/repqj15.262

*Sohoni, V., Gupta, S. C., & Nema, R. K. (2016). A critical review on wind turbine power curve modelling techniques and their applications in wind based Energy Systems. Journal of Energy, 2016, 1–18. https://doi.org/10.1155/2016/8519785*

*Solar Resource Maps and Data*. NREL.gov. (n.d.). Retrieved June 7, 2022, from https://www.nrel.gov/gis/solar-resource-maps.html

*Solar Resource Maps of World*. Solargis. (n.d.). Retrieved June 7, 2022, from https://solargis.com/maps-and-gis-data/download/world

*Solargis. (n.d.). Global solar atlas. Global Solar Atlas. Retrieved August 20, 2022, from https://globalsolaratlas.info/*

*Sustainability report*. Hawaiian Electric. (n.d.). Retrieved June 8, 2022, from https://www.hawaiianelectric.com/clean-energy-hawaii/sustainability-report

Teyabeen, A., Akkari, F., & Jwaid, A. (2019). Mathematical modelling of wind turbine power curve. *International Journal of Simulation: Systems, Science & Technology*. https://doi.org/10.5013/ijssst.a.19.05.15

Virginia Smith. (n.d.). Retrieved June 7, 2022, from https://cs.cmu.edu/~smithv

Zhang, Y., Yang, R., Zhang, K., Jiang, H., & Zhang, J. J. (2017). Consumption behavior analytics-aided energy forecasting and dispatch. *IEEE Intelligent Systems*, *32*(4), 59–63. https://doi.org/10.1109/mis.2017.3121551