Transmission Connected Solar Power Generation and Battery Storage Site Dynamic Modeling and Assessment

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ECE 44X

1. Overview

1.1 Executive Summary

The Transmission Connected Solar Power Generation and Battery Storage Site Dynamic Modeling and Assessment, henceforth shortened to Solar Power Generation and Battery Storage, developed with the interest to research, design, and verify a set of dynamic models that will be evaluated against the Electric Reliability Council of Texas (ERCOT) and California Independent System Operator (CAISO) Model Quality tests. The overall goal of the project is to reduce the knowledge gap between academia and industry. Within this, the additional usage and application of commonly used simulation software allows for an increased practical knowledge. The project is designed to give students practical knowledge in the power industry as well as create a usable simulation for a solar power generation site. The initial stage of the project is to research and confirm universal design principles of battery storage sites and the solar power generation sites. This will conclude in late november leading to the computer modeling stage.

1.2 Team Contracts and Protocols

Each team member is responsible for their communication with the group. For any required information not given a deadline when asked, the standard will be 48 hours. The main partner communication lead will be in charge of relaying any non-immediate questions and concerns to the project partner. If an individual member has an immediate question or concern that cannot wait for more than 48 hours, they should contact the project partner themselves.

Each member of the team will simulate models when applicable and all members are responsible for researching the system requirements. If a team member is unable to keep pace with research or simulation due to external influences, they must let the team know as soon as possible.

The Team lead will be in charge of keeping the team on track, making sure every assignment is completed and turned in by the due date, and ensure that group members are fulfilling their roles on the team

The Main Partner communicator will be the main point of contact with the project partner. They will be in charge of maintaining contact and setting up meetings with the project partner.

The PowerWorld and PS Cad simulators will be responsible for running a large part of the simulations. While the team member(s) will provide a large amount of the group simulation, every group member will do an equitable amount of simulation.

Table I
Team Protocols

Topic:	Protocol:	Standard:
On-time Deliverables and Team Collaboration	Drafts of all individuals' contributions to teamwork artifacts/submissions should be fully complete by set pre-deadline (such as the time/date of a team meeting to review the final submission) so that the team can look it over and make final revisions together.	Work judged as complete will include all necessary content and formatting requirements listed in Canvas and will be error-free.
Task Management	Team will use the google sheet for task assignment and record of completion.	During team meetings, the team will review tasks to be completed and assign out cards that represent these tasks on the google sheet. When a task is complete, individuals responsible will mark it as completed.
Project Communications	Team will communicate on a regular basis	Group Mates will respond within 24 hours to any questions.

Table II
Team Contact Information and Roles

Name:	Email:	Phone Number:	Primary Role
Austin Pearson	pearsoau@oregonstate.edu	971-280-3386	Team lead
Cole Ferguson	fergucol@oregonstate.edu	541-601-3917	PwrWrld simulation
Garrett Young	younggar@oregonstate.edu	541-588-2159	Main Partner Communication PwrWrld simulation
Michael Decosta	decostam@oregonstate.edu	925-234-3103	PSCAD Simulation

Will Dodge	will.dodge@shermco.com		Project Partner

1.3 Gap Analysis

The purpose of this project is to simulate and model a battery storage system for solar generated power. This includes a transmission system from the solar site to the battery storage system. The system must have a working dynamic model in 2 different softwares. The main components of the system that will need to be modeled include: Inverter, Transformer, Battery site, and Transmission system. Simulation will provide understanding about grid and system stability. This will provide important optimization results, what-if scenarios, and in depth understanding. Through extensive modeling and simulation using the current industry standard software, the engineering group will have important industry experience. We are assuming that the solar generation is the Bulk Electric Site.. This project must pass Texas (ERCOT) and California (CASIO) industry standards. The information and understanding learned from extensive simulation and modeling will be portrayed in an engineering report and operations and applications document. In this project, Jeff Whitt is the customer, and Will Dodge is the project partner.

1.4 Timeline/Proposed Timeline

Table III
Project Timeline

Week	Phase			
	Conception and Research	Planning and Modeling	Report	Presentation and Finalization
1	Project bidding			
2	Assemble and meet team			
3	Understand project needs and scope			
4	Initial research with provided documents			
5	Clarify project questions and definitions			

6	Download simulation softwares			
7	Learn simulation softwares			
8	Research site equipment			
9	Research site operation			
10	Research compliances			
11	Research compliances			
12	Research models			
13	Describe how models operate			
14		Data collection for model		
15		Approval of data collection		
16		Build model		
17		Acceptance of model build		
18		Model tuning		
19		Tuning acceptance		
20			Report drafting	
21			Report drafting	
22			Technical review	
23			Finalize report	
24				Presentation drafting
25				Continue presentation work
26				Presentation

				review
27				Finalize presentation
28				Presentation practice
29				Capstone expo
30				End project

1.5 References and File Links

     1.5.1 References (IEEE)

[1]   "EECS Project Portal," *Single Project*. [Online]. Available: https://eecs.oregonstate.edu/ capstone/submission/pages/viewSingleProject.php?id=057O91vsmFuh4Wuo. [Accessed: 14-Oct-2022].

     1.5.2 File Links

[1]   https://eecs.oregonstate.edu/capstone/submission/pages/viewSingleProject.php?id=057O91vsmFuh4Wuo

1.6 Revision Table

<div align="center">Table IV
Section 1 Revision Table</div>

10/14/2022	Austin Pearson: Created document, wrote executive summary, team contracts, revision table Michael Decosta: created gap analysis, references and file links Garrett Young: initiated timeline Cole Ferguson: modified timeline
11/3/2022	Cole Ferguson: Title page and table of contents creation, added table titles, removed boiler plate in sections 1.2 and 1.6, formatted references
11/18/2022	Cole Ferguson: Simplified project timeline Table 1.3 and added full thirty week plan Austin Pearson: Updated executive summary Michael Decosta: Updated gap analysis
5/7/2023	Cole Ferguson: Updated table formatting

2. Impacts and Risks

    2.1 Design Impact Statement

        2.1.1 Public Health, Safety, and Welfare Impacts

Our project is primarily simulation based on transferring solar energy and storing it to the grid. However, for this specific assignment we will consider the hypothetical where the system is being built. FLuke summarizes that, "Obviously, any site that is generating energy can be potentially dangerous. Solar sites are known to cause small electromagnetic fields, the latest research suggests these are not harmful to humans." [1] Solar sites are generally considered very safe. The biggest public safety threat is an electrical arc between two conductors that could potentially start a fire and cause millions of dollars of damage. The biggest danger of a solar site is electrical shock, which is primarily due to unsafe usage. By operating within the safety standards, the ERCOT and CASIO electrical shock should be very low risk.

Another potential risk to the public could be that the external site of the solar panels generates a lot of heat so they can get very hot, this is also very low risk because the public shouldn't be in the solar site without training or supervision. Transferring the solar energy to the grid has potential to be dangerous to the public, if it arcs and starts a fire.In the article "Solar Energy System and design" by N. K. Moluguri, necessary safety precautions are explained, "Relays and countermeasures are put in place to ensure safe usage of the transmission of solar energy systems." [2]. The negative risk to public safety is mostly likely negated in our case by the positive impacts, such as renewable energy, lower emissions, and a safer production to the public.

2.1.2 Cultural and Social Impacts

The planning, installation, and maintenance of solar generation sites creates many new jobs in the area where the project is established. Workers are needed to complete all of these stages and therefore helps to decrease the unemployment rate of the area [3].

On a smaller scale, if a business or home decides to install personal solar panels, not only will the cost to power their facilities be less, but will be paid by utility companies for the energy generated by the panels. The financial change will allow the households and businesses to spend more money, thus helping the local economy and social causes [3].

The fight against climate change is a major driver of renewable energy adoption. The push to utilize renewable energy has become a massive social cause as governmental entities continue to ignore the issue of climate change. Additionally, "corporate social responsibility" continues to grow as movements elaborate that companies need to not solely focus on profits, but to engage with the communities they serve and improve the society they are intertwined with [4].

There are several benefits of adopting solar power energy generation, however as noted by Jeremy Hsu in "Solar Power's Benefits Don't Shine Equally on Everyone," not everyone is able to take part in the movement. Studies have shown that despite the cost of solar panel installation has fallen significantly, fewer have been implemented in communities of color [5]. This inequality of access to solar energy is concerning, as even when removing income differences is taken into consideration, there are still more solar panels present in predominantly white communities. Initiatives and activists, such as Soulardarity, are making progress towards improving minority access to solar energy and state that "To us, [energy] is just another dimension of social justice challenges" [5]. Keeping lesser fortunate and underrepresented communities in mind is a vital consideration for including everyone in the adoption of solar energy.

Large scale solar generation sites occupy vast tracts of land and are typically located in empty, open, sunny areas near major cities with easy access to the power grid so that they can distribute the power created. In some cases, though, the land that solar sites are installed on are areas of cultural significance to local communities. An example of this is in the Mojave Desert outside of Las Vegas, where a 3000 acres solar farm is planned to be erected and also where several tribes regard the land as sacred. The Colorado River Indian Tribes filed a lawsuit against the government so that land grants given to solar companies might be delayed and so that the lands might not be desecrated or artifacts be destroyed [6]. This case further shows the importance of selecting solar generation sites carefully.

2.1.3 Environmental Impacts

The environmental uses of solar panels are widespread and mostly sustainable. The problem comes with the manufacturing and end of life of the photovoltaic cells. Specific types of panels are made using hazardous materials that may not necessarily be harmful to the environment while in use but can cause problems when they break down. This can require careful disposal and maintenance to

avoid any environmental damage. Other environmental impacts include land consumption, carbon reduction, and water pollution. [7]

The solar farms require a large amount of space for the energy collected to be viable for mass usage. The plants need to be removed which can lead to soil erosion due to the lack of anything holding down the soil. When cleared, the vegetation is often burned both increasing the amount of carbon released into the air and reducing the area's capability to absorb carbon dioxide and release oxygen. It also displaces animals, from smaller animals like bugs to large animals like foxes or deer. The displacement of animals is a big deal as it could displace endangered species. [8]

Carbon reduction can be seen by comparing the carbon emitted over the life of a system or per megawatt of energy generated. The carbon generated per MW will be much lower as it will only focus on while the solar system is in use while the lifespan will encompass all the carbon released during construction, usage, and disposal. In both cases the carbon emitted is lower than the carbon emitted in non renewable resources, but the carbon emitted over the lifespan will be much closer to the non renewable energy sources.

The use of solar energy generation also affects the water pollution as it does not require much water to run. The only water needed is to clean the panels as they can become covered in debris and reduce the effectiveness of the solar farm. Compared to the water required to run a coal or nuclear plant, the water used by solar power is inconsequential. [8] Overall the factors listed above make solar power generation one of the cleanest and most environmentally friendly ways to power our society.

2.1.4 Economic Factors

While solar farms have the tradeoff of taking up large amounts of space proportional to the area they are serving, they have the advantage of generating "free" energy from sunlight that can introduce more power to parts of the grid that they are connected to [9]. For the scope of our project, the solar site will be of average size and mostly serves to supplement the rest of the power grid as opposed to providing 100% of the energy. Of course, solar farms do not come without weaknesses. The most substantial is their low efficiency, which is partly the reason that so many are needed to be practical. Additionally, there is the issue of providing power at night, however this can be mitigated by batteries and as mentioned earlier, the solar panels are not the main source of power. The

combination of these factors is the driving force behind the economic costs and benefits of solar farms.

Since our project is more abstract than those based in hardware, our impact assessment mainly stems from the hypothetical situation in which the solar site that we are modeling is actually built. In this case, the first concern is the location of the solar site and its size. How many trees will need to be removed? Is the land in the area already flat enough? The choice of land depends on the parameters of the solar site, and in turn the cost to prepare the land, install the solar panels, and set up the infrastructure needed to connect them to the grid [10]. Most solar panels will be placed onto some sort of axis system, so they can angle towards the sun as needed. This demands additional costs and power associated with accommodating the complexity compared to static panels. Eventually, most solar farms will pay for themselves in a few years depending on their size. With proper maintenance a solar farm could last upwards of thirty years, so in most cases will not need frequent replacement. Overall, I do not think the economic impacts of our solar site would be too large, it depends greatly on the location our solar site was built, and how the introduction of a solar farm would affect that specific area.

2.2 Risks

Table V
Risk Assessment and Action Plans

Risk ID	Risk Description	Risk Category	Risk Probability	Risk Impact	Performance Indicator	Action Plan
R1	Software Download/Installation fails	Technical	Low	High	Error Message	Contact Support Upgrade OS
R2	Group Member is Late	Organizational	High	Low	Team member is late	Excuse first offense with further offenses being met with questioning and adapting if time constraints cause problems
R3	Simulation shows results	Safety	Low	High	Fire	Reanalyze System

	outside of expectations					Run additional tests
R4	Cannot meet with partner	Organizational	Med	Med	No Weekly Meeting	Develop questions for next meeting Spend extra time on previous agenda items
R5	Group member misses scheduled meeting	Organizational	Med	Low	Missed meeting	Analyze reason and change meeting times if needed
R6	Simulation slows to be unusable	Tenchical	Low	Low	30 second period where system has no visible change outside of calculation of simulation	Wait a minimum of 1 additional; minute before closing simulation software
R7	Simulation progress fall behind schedule	Organizational/technical	Med	High	Simulation progress for a specific group member falls behind	If a reason is given, the other group members will pick up slack if able. If no reason is given, group member will be given a chance to catch up. If simulation progress is not able to be made up by the group as a whole, the class instructor and project partner will be notified immediately.

R8	Group member drops out	Organizational	Low	High	Group member or instructor notifies the group that the group member will be dropping the class.	Contact the group member for a reason. Work with instructor and project partner to adapt constraints and requirements for a smaller group size.

2.3 References and File Links

2.3.1. References

[1]   Fluke, "Top 3 solar panel safety precautions," *Fluke*, 28-Sep-2022. [Online]. Available:https://www.fluke.com/en-us/learn/blog/renewable-energy/solar-power-safety. [Accessed: 04-Nov-2022].

[2]   N. K. Moluguri, C. R. Murthy, and V. Harshavardhan, "Solar Energy System and design review," Materials Today: Proceedings, 09-Dec-2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2214785316303807. [Accessed: 04-Nov-2022].

[3]   B. Heuberger, "Social impacts of solar energy," *Sciencing*, 02-Mar-2019. [Online]. Available: https://sciencing.com/social-impacts-of-solar-energy-12084229.html. [Accessed: 04-Nov-2022].

[4]   "Can going solar boost corporate social responsibility and revenue?," *Centrica Business Solutions*. [Online]. Available:https://www.centricabusinesssolutions.com/us/blogpost/ can-going-solar-boost-corporate-social-responsibility-and-revenue. [Accessed: 04-Nov-2022].

[5]   J. Hsu, "Solar Power's benefits don't shine equally on everyone," *Scientific American*, 04-Apr-2019. [Online]. Available:https://www.scientificamerican.com/article/ solar-powers-benefits-dont-shine-equally-on-everyone/. [Accessed: 04-Nov-2022].

[6]   *Nature news*. [Online]. Available:https://www.nature.com/scitable/blog/eyes-on-environment/a_matter_of_scale_the/. [Accessed: 04-Nov-2022].

[7]   Clean Energy Ideas, "Environmental impacts of solar energy," *Clean Energy Ideas*, 01-Apr-2019. [Online]. Available: https://www.clean-energy-ideas.com/solar/solar-energy/environmental-impacts-of-solar-energy/. [Accessed: 04-Nov-2022].

[8]   Environmental impacts of solar power," *Union of Concerned Scientists*, 05-Mar-2013. [Online]. Available: https://www.ucsusa.org/resources/environmental-impacts-solar-power. [Accessed: 04-Nov-2022].

[9]   8MSolar, "The Economic & Environmental Impact of Solar Power," *8MSolar*, 29-Oct-2020. [Online]. Available:https://www.8msolar.com/the-economic-and-environmental-impacts-of-solar-energy-8msolar. [Accessed: 04-Nov-2022].

[10]   N. Vickery, "Initial steps for building a solar farm," Energy Central, 15-Nov-2017. [Online]. Available: https://energycentral.com/c/gn/initial-steps-building-solar-farm. [Accessed: 04-Nov-2022].

2.3.2 File Links

The following link contains the project partner materials that are used for research purposes.

https://drive.google.com/drive/folders/1v_hECWR-LaBee-0F87zcTxNGgHuvTdj_?usp=sharing

2.4 Revision Table

Table VI
Section 2 Revision Table

11/2/2022	Garrett Young: Initial formatting and section creation
11/4/2022	Garrett Young: Filled out risk assessment table
11/4/2022	Austin Pearson: Added file links and references.
11/18/2022	Austin Pearson: Update risk table Cole Ferguson: Fixed reference formatting
4/28/2023	Austin Pearson: Added the Design Impact Assessment statement
5/7/2023	Cole Ferguson: Updated table formatting

3. Top Level Architecture

3.1 Block Diagram
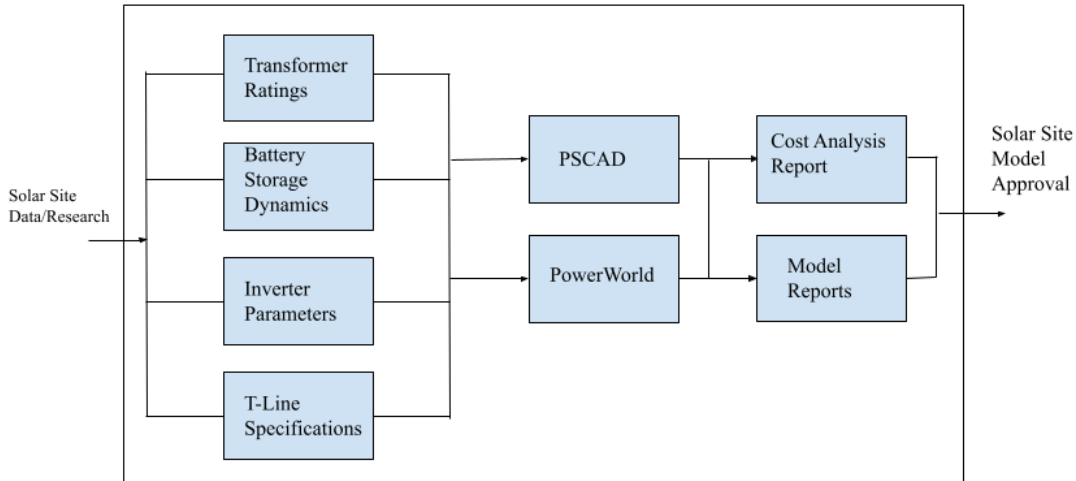
Diagram 1: Overall Block diagram
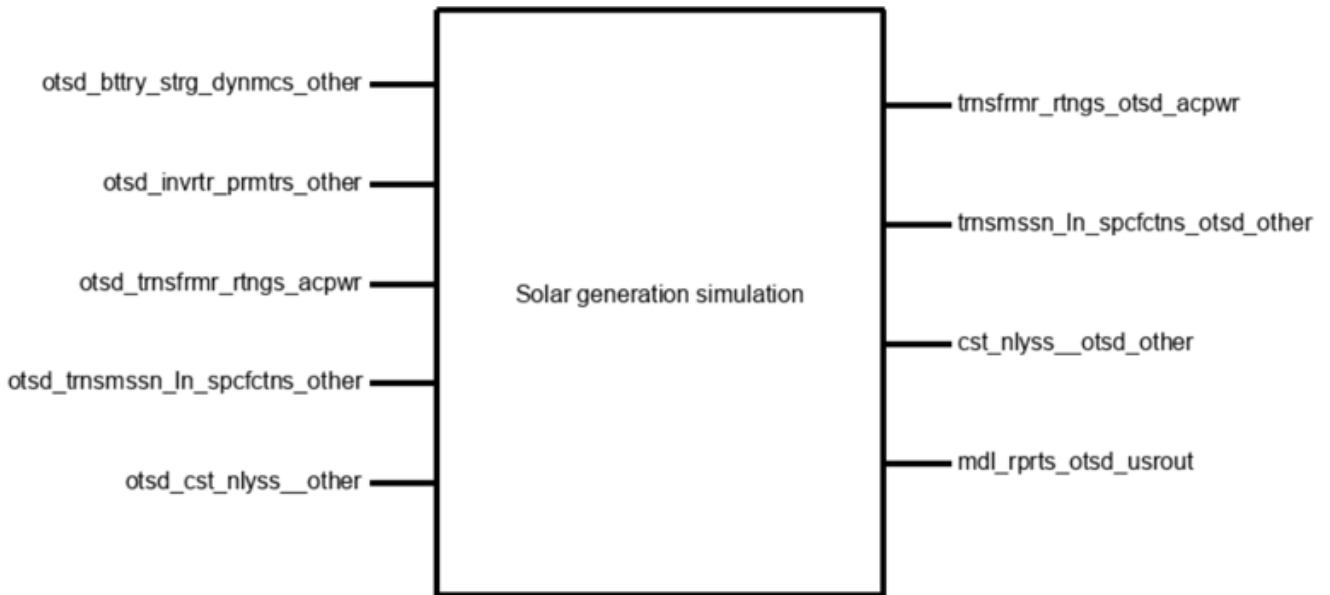
Diagram 2: Black Box Diagram

3.2 Block Descriptions

The Solar Power Generation and Battery Storage project is fairly complicated given its nature as a simulation based project. Diagram 1 shows the overall block diagram of the project, where the only outside input is the research to determine inputs for simulation in powerworld and PSCAD. The external output is the model reports and cost analysis report. The 4 parallelized blocks will take the research inputs shown in Diagram 2.

Block Champion: Cole Ferguson
Block Name: Battery Storage Dynamics
The purpose of the Battery Storage Dynamics block is to model the dynamics with which power is supplemented to the power grid in the event that the output of the solar array does not meet the amount of power demanded. Alternatively, when solar power generation is high or the power grid frequency and voltage is higher than required, the battery array will be recharged.

As stated, the main function of the battery storage block is to "pick up the slack" of the solar panel array. During periods where energy generation is disturbed and fails to produce required power level, the battery energy storage system injects its stored power. The addition of a readily available reserve of power during periods of lacking generation addresses the operational variability of solar power plants. The models will be tuned to match the response of the real life generation site through the modification of the REGC, REPC, and REEC characteristic values.

Block Name: Inverter Parameters
Block Champion: Austin Pearson
This block is the work required to collect, format and pass data to simulation software to model inverters in a solar site. This block will contain any relevant information required for inversion of power the system. For the 2 types of inverters, we used the datasheets from the Sungrow SG3150U and SC3150UD models as a reference for our hypothetical inverters. This aligns with the theme of our project wherein we are simulating our system and can use any physical components that fulfill the requirements. The inverters in our system must be able to convert from DC to AC, and from DC to AC and DC to AC respectively. The general point of the project is to ensure that a site meets requirements so it can be both built and connected to the grid, and this block contributes to fulfilling that requirement. The PSCAD and powerworld models are the accepted formats to prove that a site meets requirements. Outputs from the block will be entered into the models to generate values and analysis of the system. This block will specify any data needed to recreate the inverter connections to the system. Without the data collection that was acquired using the resources given by the project partner and datasheets, the dynamic models of the site including the inverters would be unable to perform simulations to prove acceptance of the CAISO and ERCOT standards. This requires careful consideration when selecting inverters as the use cases are extremely specific. The inverters used were defined in the site parameters given by the project partner. The inverters used in the photovoltaic section of the system use the Sungrow SG3150U inverters as a reference for simulation due to their connection and use in the North American 1500Vdc system. The inverters used in the energy storage system use the Sungrow

SC3150UD inverters as a reference. These models are used as a reference due to the close alignment with the required interfacing with each section of the site.

Block Name: Transformer Ratings
Block Champion: Garrett Young
Our system is meant to simulate a solar site that reacts to the needs of the power grid at any given moment. For instance, if the voltage of the power grid is dropping due to an increase in power demand or other such factors, the solar site will respond by outputting more reactive power from the solar farm and/or batteries. My block, the transformers, facilitate the delivery of voltage from the output at the inverters to the power grid, stepping it up at two separate locations to bring it the levels that are necessary. Due to the nature of our system every block is just as important as the others, however it is worth noting that the functionality of our system would not be possible without the inclusion of the transformers. The values of each of the components vary from site to site but the high and low voltages for each of the transformers are more or less the same.

Within the group I am modeling within PowerWorld, which is a simulation tool that primarily focuses on solving power flows, performing fault analysis, and plotting what-if scenarios. In PW, transformers exist as their own component and can have their values edited as needed. In our case, we are mainly interested in the high and low voltages however we could also change a variety of other values if the need arose.

Block Name: Transmission Line Specifications
Block Champion: Michael DeCosta
This block is the work it will take to create the detailed outline of the transmission line system. This block will contain any relevant information required for transmission of power along the system. Outputs from the block will be entered into the software simulation to generate values and analysis of the system. without proper transmission of energy the simulation will not work. The block will give the specifications necessary to model and simulate the transmission line system. The Input of this block is data collection and research. That is the research needed for the transmission line to function properly. The output of the system is a data collection sheet that will contain all necessary data to properly model the system in PSCAD and PowerWorld. Since the transmission line includes many different sections of the system, there will be varying voltages on the line, as well as varying impedances. To properly model this in the software, equivalent impedance is used. This must be included in the output "data collection sheet".

Block Name: Power World

Block Champion: Garrett Young

Our project will have simulations done in both PSCAD and PowerWorld, and this block represents the simulation done in PowerWorld. Based on our most recent block diagram, the input interfaces for this block are the main four blocks that we showed for the first checkoff. These represent the main components of the system and data that will be entered into PowerWorld in preparation for simulation/modeling. The interface properties for these inputs are the same, as they each represent the data being input into PW, rather than values such as voltage or current. The output interfaces are tied to the model report and cost analysis blocks, and following the same pattern as the input interfaces represent the outcome of the simulation rather than hardware or software. Once we have run the simulations and collected the plots and other pertinent data, we can write the reports and perform the cost analysis.

Block Name: PSCAD

Block Champion: Michael DeCosta

This block is the work it takes to set up a simulation and what if scenarios using dynamic models of the whole solar site. The output of this block will be a dynamic model including the transformers, inverters, batteries, and transmission line.

This block will also output a variety of plots. These plots will aid in writing the cost analysis report. PSCAD is where our data collection and research will tie together; using the data we gathered to enter via component parameters and the research to properly model the system in circuits. We can analyze the solar site changing different parameters to see which location could be the most profitable to implement a real solar site, this is just an example meant to give more understanding to how PSCAD will be used in our system.

Block Name: Model Reports

Block Champion: Cole Ferguson

This block represents the work done to produce reports that describe the functionality of both PSCAD and PowerWorld simulation softwares. This block will describe the operation of each system, performance during stability tests, and explain the control parameters used to model the response of the system. It will give a brief overview of how the inverters, batteries, and transformers are being used in the model, and some insight into how each of the components work together to produce power. The inputs are data and dynamic models from Power World and PSCAD. The output is a model report to the outside world. The model reports will be based on templates used by Shermco to do solar site consulting.

The reports are meant to serve as a summary given back to the client who needs solar site consultation and tuning. The model reports will be used and included into the project's final analysis report.

Block Name: Cost Analysis
Block Champion: Austin Pearson
Cost analysis is a deliverable report describing the actual usability of the system based on location data specified by the assigned standards, its goal is to give a deeper understanding and metrics about the costs and profits associated with operating a solar site. The analysis involves using the average cost of energy, average home energy draw, cost of components, dynamic models, and site data to give an accurate relative cost of installation and usability in the specified areas. For this cost analysis, we will hold the cost of components constant, or assume that the site is the same site in each different location. We will be observing how the location and cost of Kilowatt hour affects the profitability of a solar site. When completed, the cost analysis report will contain a detailed breakdown of the costs involved with the system along with the preferred installation location. The cost analysis report will be in 3 locations, Oregon, California, and Texas, this report will be a good piece of information to give to potential investors or a future group of engineering students taking over the project in the future.

3.3 Interface Definitions

3.3.1 Interface Table

Table VII
Interface Table

Name	Properties
otsd_bttry_strg_dynmcs_other	**Other:** Research Documents **Other:** Data Collection Sheet **Other:** Project Partner Approval
otsd_invrtr_prmtrs_other	**Other:** Inverter Research **Other:** SC3150UD Datasheet **Other:** Basic Inverter Research **Other:** SG3150U Datasheet
otsd_trnsfrmr_rtngs_acpwr	**Other:** Data Collection

	- **Vmax:** High Side Voltage of Collector: 345kV - **Vmax:** High Side Voltage of PMT: 34.5kV - **Vmin:** Low Side Voltage of Collector: 34.5kV - **Vmin:** Low Side Voltage of PMT: 690V
otsd_trnsmssn_ln_spcfctns_other	- **Other:** Research document, nameplate or datasheet - **Other:** research document, nameplate or datasheet - **Other:** data collection/ research
otsd_cst_nlyss__other	- **Other:** Research documents containing the cost of major components used in the system - **Other:** Research documents containing the average home energy draw in specified areas - **Other:** Research documents containing the average energy cost in specified areas
bttry_strg_dynmcs_pscd_other	- **Other:** Data collection sheet, Equivalent Generator Bus Voltage - **Other:** REEC control - **Other:** REPC control - **Other:** REGC control - **Other:** Data collection sheet, Equivalent Generator MVA
bttry_strg_dynmcs_pwrwrld_other	- **Other:** Data collection sheet, Equivalent Generator Bus Voltage - **Other:** REPC control - **Other:** REGC control - **Other:** Data collection sheet, Equivalent Generator MVA

	● **Other:** REEC control
invrtr_prmtrs_pscd_other	● **Other:** Data collection sheet, Equivalent Generator Bus Voltage ● **Other:** Data Collection document. ● **Other:** Data collection sheet, Equivalent Generator MVA
invrtr_prmtrs_pwrwrld_other	● **Other:** Data collection sheet, Equivalent Generator MVA ● **Other:** Model Acceptance ● **Other:** Data collection sheet, Equivalent Generator Bus Voltage
trnsfrmr_rtngs_otsd_acpwr	● **Other:** Approval from Project Partner that low side voltages are accurate ● **Other:** Approval from Project Partner that Data Collection is complete and accurate. ● **Other:** Approval from Project Partner that high side voltages are accurate
trnsfrmr_rtngs_pscd_other	● **Other:** Data collection sheet, transformer base MVA ● **Other:** Data collection sheet ● **Other:** Data collection sheet, PMT transformer
trnsfrmr_rtngs_pwrwrld_other	● **Other:** PW Model Draft ● **Other:** Data Collection ● **Other:** Model Acceptance
trnsmssn_ln_spcfctns_otsd_other	● **Other:** shows voltage on sheet ● **Other:** Data collection sheet ● **Other:** approved by Will Dodge

	• **Other:** shows impedance on data sheet
trnsmssn_ln_spcfctns_pscd_other	• **Other:** Data collection sheet, "MVA base for impedance calc" • **Other:** Data collection sheet • **Other:** Data collection sheet, equ impedance
trnsmssn_ln_spcfctns_pwrwrld_other	• **Other:** PW Model Draft • **Other:** Data Collection • **Other:** Model Acceptance
cst_nlyss__otsd_other	• **Other:** compares cost in 3 different areas: CA, OR, TX • **Other:** Compares variables in solar production • **Other:** Break even point for site
pscd_cst_nlyss__other	• **Other:** System Efficiency approved by project partner • **Other:** Maximum MVA • **Other:** Plot of system stability approved by project partner
pscd_mdl_rprts_other	• **Other:** Approval from Project Partner of Data Collection. • **Other:** PSCAD component model documents • **Other:** A .pscx PSCAD file that contains the simulation model
mdl_rprts_otsd_usrout	• **Other:** Model Reports, T-Line and Collector System • **Other:** Model Reports, Transformer • **Other:** Model Reports, Inverter and

	Battery
pwrwrld_cst_nlyss__other	• **Other:** System Efficiency approved by project partner • **Other:** Maximum MVA • **Other:** Plot of system stability approved by project partner
pwrwrld_mdl_rprts_other	• **Other:** Approval from Project Partner of Data Collection • **Other:** PowerWorld component model documents • **Other:** A .pwb PowerWorld file that contains the simulation model

3.4 References and File Links
    1.1.1.   References
    1.1.2.   File Links

The following link contains the project partner materials that are used for research purposes.
https://drive.google.com/drive/folders/1v_hECWR-LaBee-0F87zcTxNGgHuvTdj_?usp=sharing

3.5 Revision Table

Table VIII
Section 3 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
3/12/2023	Garrett Young: Added block diagram and black box images. Austin Pearson: Added interface table.
5/7/2023	Cole Ferguson: Updated table formatting

4. Block Validations

4.1 Battery Storage Dynamics

    4.1.1 Description

        The purpose of the Battery Storage Dynamics block is to model the dynamics with which power is supplemented to the power grid in the event that the output of the solar array does not meet the amount of power demanded. Alternatively, when solar power generation is high or the power grid frequency and voltage is higher than required, the battery array will be recharged. As stated, the main function of the battery storage block is to "pick up the slack" of the solar panel array. During periods where energy generation is disturbed and fails to produce required power level, the battery energy storage system injects its stored power. The addition of a readily available reserve of power during periods of lacking generation addresses the operational variability of solar power plants. The models will be tuned to match the response of the real life generation site through the modification of the REGC, REPC, and REECE characteristic values.

    4.1.2 Design

otsd_bttry_strg_dynmcs_other

Battery Storage Dynamics

bttry_strg_dynmcs_pscd_other
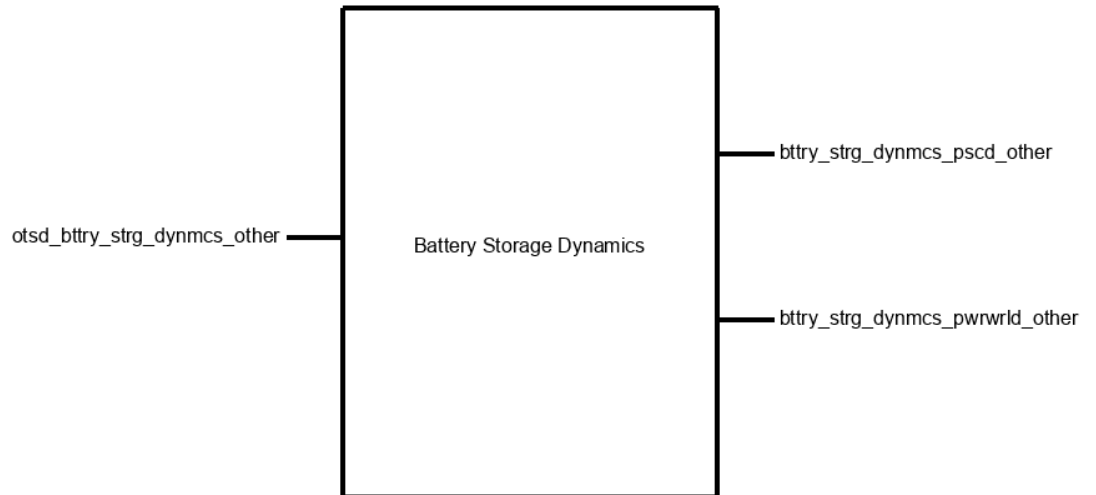
bttry_strg_dynmcs_pwrwrld_other

Figure 1 - Black Box Diagram

Figure one shows the black box diagram with all 3 interfaces

otsd_bttry_strg_dynmcs_other: This is the abstract inputs to the block.

bttry_strg_dynmcs_pscd_other: This is the dynamics and values that go to the PSCAD software.

bttry_strg_dynmcs_pwrwrld_other: This is the dynamics and values that go to the PowerWorld software.

The block represents an equivalent array of battery energy storage systems. For use in this project, it is much simpler and computationally easier to calculate the control dynamics during a power flow simulation to have a single, equivalent generator than to have the twenty eight individual battery storage systems modeled explicitly and connected together.

The outputs of the block are the control signals and base levels of the block for both PowerWorld and PSCAD. The first part of the output of the block is the control of the battery energy storage system. The control signals are processed and delegated to the rest of the power plant by the power plant controller. Using different control scheme models, plant behavior is monitored and changed so that production levels, revenue, compliance and grid stability are all taken into account during power plant operation. The three essential models are Renewable Energy Electrical Control (REEC), Renewable Energy Plant Control (REPC), and Renewable Energy Generation/Control (REGC). Specific control parameter characteristics are modified so that the project accurately models the generation site operation and response to external fluctuations.

The other part of the output of the block is the values that represent the power output of the battery energy storage system. The typical output voltage will be 630 volts, with ten percent variability during active charging and discharging periods. The SC3150U-MV Power Conversion System has a specific apparent power base that needs to be taken into account for calculations and equivalencing, as well as a maximum for how much real power can be handled by the equipment safely. These factors are important to modeling the battery array for power flow solutions and stability.

The input of the block are abstract requirements. The block must match the parameters specified in the various datasheets and site equipment nameplates referenced, which is compiled into the data collection sheet; the block will use research documents to convey the dynamics of a power generation site; and the block must be approved by the project partner. The approval of the project partner is an industry standard practice so that the

modeling of a site has been correctly modeled and validated by an authority.
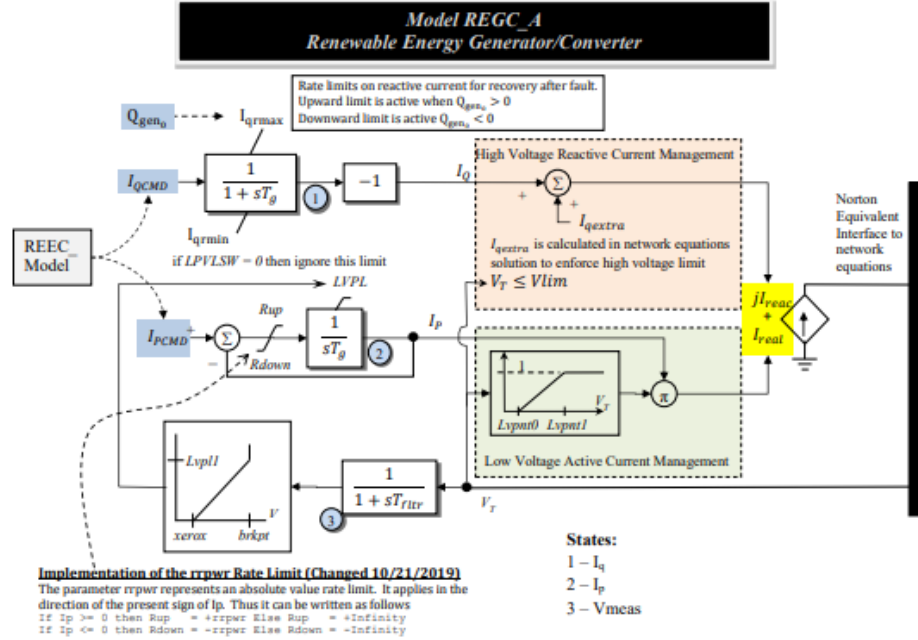
Machine Model REGC_A

Figure 2 - REGC Control Block Diagram

Plant Controller REPC_A and REPCA1 and REPCTA1
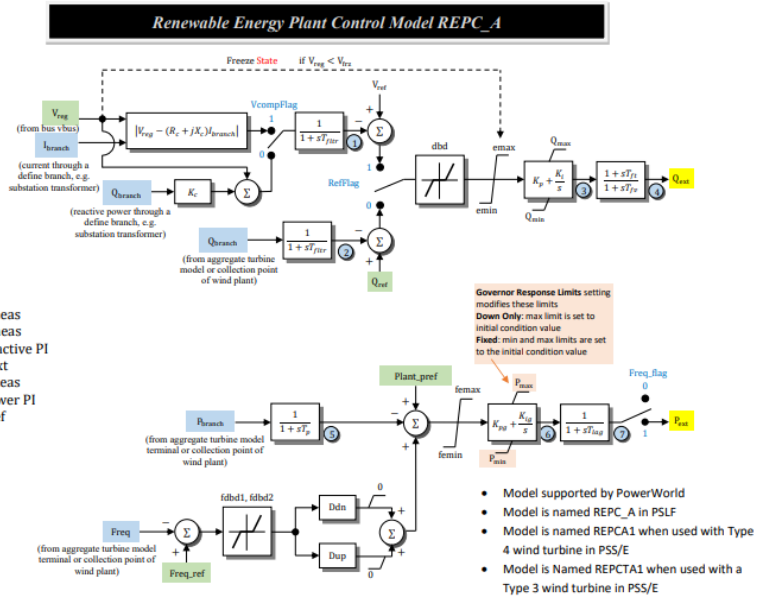
Figure 3 - REPC Control Block Diagram

Exciter REEC_A and REECA1
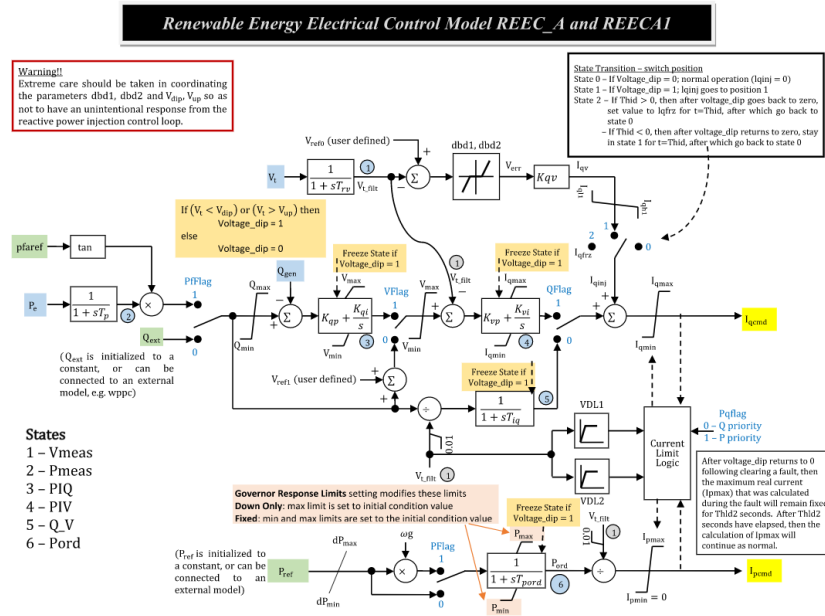
Figure 4 - REEC Control Block Diagram

Figure 2 shows the Renewable Energy Generator/Converter block diagram controls section of a plant controller, while Figure 3 shows the Renewable Energy Plant Controller block diagram controls section and Figure 4 shows the Renewable Energy Electrical Control block diagram controls section.

4.1.3 General Validation

This project is completely software based and as such not all blocks will be able to be tested and verified in isolation. This battery energy storage system specifically will not be able to be tested to all the required functionality without the full system present. This is because an external plant controller is informed of the frequency and voltage of the power grid and the rate of generation from the solar panel array generator to dictate how the battery array needs to be configured [1]. The plant controller decides if the battery array should source or sink reactive power to support grid voltage, increase or reduce interchange flow to assist in maintaining grid frequency, and when to store or discharge during predicted intervals [2]. All this is to say that the interface requirements listed are limited in this block validation so that they may actually be verified individually.

Battery energy storage systems are connected to the DC side of an inverter. The generation site configuration we are modeling is AC-coupled rather than DC-coupled, which means that the solar array and the battery array are connected through an AC-bus. The power supplied by the battery array will go through a DC-AC bidirectional converter to connect to connect to the same AC-bus as the solar array, rather than going through a DC/DC bidirectional converter that would then connect to the same DC-bus as the solar array, wherein both would enter a DC-AC inverter. The choice of this configuration requires different equipment and therefore different parameters. The bidirectional DC-AC converter hardware chosen for this project to model is the SC3150U-MV Power Conversion System, which was specified by our project partner because this is the device used on the actual power plant sites that they work on. This equipment comes with its own parameters, and as such dictate the outputs of the battery energy storage system. The values indicated below are based upon the DC-side inputs of this converter [3].

4.1.4 Interface Validation

Table IX

4.1 Interface Table

otsd_bttry_strg_dynmcs_other : Input

Other: Project Partner Approval	The project partner will confirm that the values accurately represent real-world values.	The values collected are based on the real-world site's equipments' datasheets.
Other: Research Documents	Documents that explain how different parameters are used and manipulate the response of the system, as well as how the power flow of the system develops.	The research documents are used to learn how the dynamics of a generation site are managed and controlled.
Other: Data Collection Sheet	It is a required document for site simulation that must be approved by the proposing entity.	Matches the generation site equipment specifications to accurately represent the site.

bttry_strg_dynmcs_pscd_other : Output

Other: REGC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	Renewable energy power plants all have a plant controller that decides how much energy is

		sourced or sinked [1].
Other: Data collection sheet, Equivalent Generator MVA	The block represents 28 battery energy storage systems, each with a base MVA of 3.15. So 28*3.15=88.2 and is used in power flow calculations.	To be an equivalent generator for 28 instances, the single base MVA of 3.15, from the data datasheet [3], needs to be scaled up.
Other: Data collection sheet, Equivalent Generator Bus Voltage	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	The SC3150U-MV datasheet specifies this value [3].
Other: REEC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	Renewable energy power plants all have a plant controller that decides how much energy is sourced or sinked [1].
Other: REPC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	Renewable energy power plants all have a plant controller that decides how much energy is sourced or sinked [1].

bttry_strg_dynmcs_pwrwrld_other : Output

Other: Data collection sheet, Equivalent Generator MVA	The block represents 28 battery energy storage systems, each with a base MVA of 3.15. So 28*3.15=88.2 and is used in power flow calculations.	To be an equivalent generator for 28 instances, the single base MVA of 3.15, from the data datasheet [3], needs to be scaled up.
Other: REEC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	Renewable energy power plants all have a plant controller that decides how much energy is sourced or sinked [1].
Other: Data collection sheet, Equivalent Generator Bus Voltage	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	The SC3150U-MV datasheet specifies this value [3].
Other: REPC control	In order to fully operate as a	Renewable energy power plants

	dynamic model the block must be controlled by the plant controller.	all have a plant controller that decides how much energy is sourced or sinked [1].
Other: REGC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	Renewable energy power plants all have a plant controller that decides how much energy is sourced or sinked [1].

4.1.5 Verification Process

Required Tools:
1. Laptop
2. Powerworld
3. PSCAD
4. Project Drive
5. Project Partner Approval Email
6. Data Collection Spreadsheet

otsd_bttry_strg_dynmcs_other
1. Open email from Project Partner, Will Dodge, stating that the block has been approved.
2. Open Project Drive
3. Open "Model Data Collection"
4. Verify that the data has been approved
5. Open "Research Documents" folder
6. Verify that documents in folder exist

bttry_strg_dynmcs_pwrwrld_other
1. Open Powerworld model
2. Select Battery Storage generator symbol
3. Select "Stability" tab
4. In "Machine Models" verify that "Type" is "Active - REGC_A"
5. In "Other Models" verify that "Type" is "Active - REPC_A (Plant Controller)"
6. In "Exciters" verify that "Type" is "Active - REEC_A"
7. Select "Power and Voltage Control"
8. Verify that "SetPoint Voltage" value matches "Equivalent Generator Bus Voltage" on the data collection spreadsheet (88.2)
9. Verify that "Generator MVA Base" value matches "Equivalent Generator MVA" on the data collection spreadsheet (630)
10. Select Solar PV generator symbol

11. Repeat steps 3 through 9

bttry_strg_dynmcs_pscd_other
1. Open PSCAD project document folder
2. Select "Multimeter" symbol
3. Select "Configuration" tab
4. Verify that "Base MVA" is "3.15"
5. Verify that "Base Voltage" is "0.63"
6. Select Inverter module
7. Select "Control" module
8. Select "Control" tab
9. Verify that control parameters are set

4.1.6 References and File Links

[1] "Handbook on Battery Energy Storage System," Asian Development Bank, Dec-2018. [Online]. Available: https://www.adb.org/sites/default/files/publication/479891/handbook-battery-energy-storage-system.pdf. [Accessed: 20-Jan-2023].

[2] "Battery Energy Storage Systems and Hybrid Power Plants," NERC Inverter-Based Resource Performance Working Group Informational Webinar, 15-Jul-2021. [Online]. Available: https://www.nerc.com/comm/PC/IRPTF_Webinars_DL/2021_07_-_IRPWG_BESS_Hybrid_Webinar.pdf. [Accessed: 20-Jan-2023].

[3] "SUNGROW SG3150U-MV 1500V central inverter," ACES Atlantic Clean Energy Supply Official Site. [Online]. Available: https://atlanticces.com/sungrow-sg3150u-mv-1500v-central-inverter/. [Accessed: 20-Jan-2023].

4.1.7 Revision Table

Table X
Section 4.1 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
3/12/2023	Cole Ferguson: Populated sections
5/7/2023	Cole Ferguson: Updated table formatting

4.2 Inverter Parameters

4.2.1 Description

This block is the work required to collect, format and pass data to simulation software to model inverters in a solar site. This block will contain any relevant information required for inversion of power the system. For the 2 types of inverters, we used the datasheets from the Sungrow SG3150U and SC3150UD models as a reference for our hypothetical inverters. This aligns with the theme of our project wherein we are simulating our system and can use any physical components that fulfill the requirements. The inverters in our system must be able to convert from DC to AC, and from DC to AC and DC to AC respectively. The general point of the project is to ensure that a site meets requirements so it can be both built and connected to the grid, and this block contributes to fulfilling that requirement. The PSCAD and powerworld models are the accepted formats to prove that a site meets requirements. Outputs from the block will be entered into the models to generate values and analysis of the system. This block will specify any data needed to recreate the inverter connections to the system. Without the data collection that was acquired using the resources given by the project partner and datasheets, the dynamic models of the site including the inverters would be unable to perform simulations to prove acceptance of the CAISO and ERCOT standards. This requires careful consideration when selecting inverters as the use cases are extremely specific. The inverters used were defined in the site parameters given by the project partner. The inverters used in the photovoltaic section of the system use the Sungrow SG3150U inverters as a reference for simulation due to their connection and use in the North American 1500Vdc system. The inverters used in the energy storage system use the Sungrow SC3150UD inverters as a reference. These models are used as a reference due to the close alignment with the required interfacing with each section of the site.

4.2.2 Design

The design includes all the specifications that will be utilized for the inverters to function correctly. The inverters have possibly the most important job in a solar site. Without the ability to convert from AC to DC and vice versa, the efficiency of the system decreases to a point that makes the site useless to maintain. The input is an outside set of research documents dedicated to understanding and clarifying inverter characteristics. The outputs are the parameters passed to the simulation softwares, PSCAD and powerworld. This is shown in figure 1, detailing the most updated block interconnections and labels. The main output to

both softwares is the data collection document. Using the data collection document, all the data needed to simulate is gathered from Inverter Parameters input and formatted in a way that can be easily input into the simulations. The data collection document does not solely contain the Inverter Parameters data. It contains all the data from each of the parallel blocks shown in section 3.2 needed to simulate.
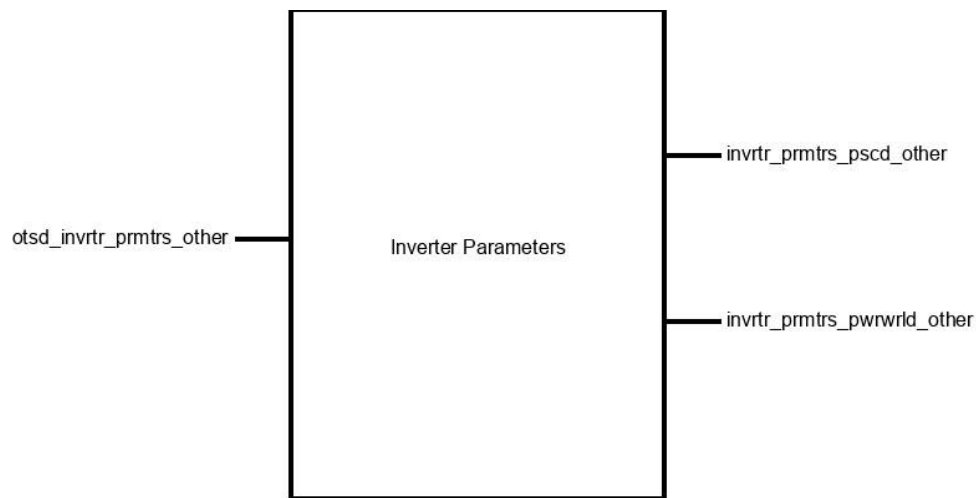

Figure 1: Inverter Parameters Block Diagram.

4.2.3 General Validation

The block is responsible for the data related to the inversion of energy received from the site and batteries. By including the specifications of the specific models of the inverters, we can create a block that is easier to understand and easier to validate. Due to the time and cost constraints building a real solar site is out of the question so by simulation we can still work with the related topics. This block contains all the data related to the specific inverters that are required to simulate a solar site. The inputs will be the inverter research and documents while output is the data collection document that contains the needed information to simulate and model. The best solution to prove that our block works is by defining the properties as documents that have been approved by our project partner. Will Dodge is the project partner for our group and project and his approval is well valued. He is experienced in the software simulation of solar sights and has been doing it professionally for 3 years. Having Will's approval of our data means that we did it correctly and have all the necessary information and specifications for the inverter.. This block is basically a research block that outputs a clean, organized sheet of data that contains everything required to model the actual solar site in software. The information that is

here will be uploaded into the simulation and used to prove our project's feasibility.

4.2.4 Interface Validation

The block is responsible for the inversion of energy from the photovoltaic site and batteries to the preferred energy format to be accepted by the power grid. By including the specifications, we can create a block that is easier to understand and easier to validate. Due to the time and cost constraints building a real solar site is out of the question so by simulation we can still work with the related topics. This block takes input from outside research, such as basic inverter documents to solidify knowledge and datasheets to determine the validity and usability of certain inverters. This gives an overall knowledge of the inverters and their properties that are used to develop and complete the data collection document. The data collection assigned by the project partner is what is generally used to determine the interconnections and properties of the interfaces. The outputs will be the data collection document. The issue with our system is that it is very hard to prove that it works due to the fact that we have to use software to simulate the entire system. With this, our software requires we enter the input and output of the inverter. Instead of complicating validation and verification we simplify it by creating specification blocks that determine how certain sections of the model will act. With this we are able to show that the simulation works as a whole and prove the system works.

Table XI

Section 4.2 Interface Table

Otsd_invrtr_prmtrs_usrin: Input

Other: Inverter Research	In order to accurately model our solar system in PSCAD and PowerWorld, our project partner sent me this document to add overall knowledge on the inverters.	The design details meet the property as the document was used in general research on the system and how it works. This includes best practices and reasonings related directly to the inverters.
Other: SC3150UD Datasheet	Inverters will be based on 2 different models. This is the datasheet for one inverter used for reference, the SC3150UD.	The design details meet the property as the document was used as a reference for verifying data the inverter uses. This includes voltage and power levels that will be verified against the data collection document.

Other: SG3150U Datasheet	Inverters will be based on 2 different models. This is the datasheet for one inverter used for reference, the SG3150U.	The design details meet the property as the document was used as a reference for verifying data the inverter uses. This includes voltage and power levels that will be verified against the data collection document.
Other: Basic Inverter Research	In order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the inverters that are being used. Research Doc 1 is based around general inverter research for solar power.	The design of the block calls for general knowledge and specific knowledge of inverters. The basic inverter research property is the general knowledge used to learn about inverters.

Invtr_prmtrs_pscad_other: Output

Other: Data collection sheet, Equivalent Generator MVA	The block represents 28 battery energy storage systems, each with a base MVA of 3.15. So 28*3.15=88.2 and is used in power flow calculations.	To be an equivalent generator for 28 instances, the single base MVA of 3.15, from the data datasheet, needs to be scaled up.
Other: Data collection sheet, Equivalent Generator Bus Voltage	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	The SC3150U-MV datasheet specifies this value.
Other: Data collection Document	This document is the overall data collected from individual and project	This is the document containing the data from multiple blocks that is needed to simulate the solar site. The document contains very few

	partner assigned research that is used to populate the PSCAD model.	inputs specifically from the inverters but what is used is vital.

Invtr_prmtrs_pwrwrld_other: Output

Other: Data collection sheet, Equivalent Generator MVA	The block represents 28 battery energy storage systems, each with a base MVA of 3.15. So 28*3.15=88.2 and is used in power flow calculations.	To be an equivalent generator for 28 instances, the single base MVA of 3.15, from the data datasheet, needs to be scaled up.
Other: Data collection sheet, Equivalent Generator Bus Voltage	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	The SC3150U-MV datasheet specifies this value.
Other: Model Acceptance	This document is the overall data collected from individual and project partner assigned research that is used to populate the powerworld model.	This is the document containing the data from multiple blocks that is needed to simulate the solar site. The document contains very few inputs specifically from the inverters but what is used is vital.

4.2.5 Verification Process

Input: Inverter Research

Compile at least 3 documents that assisted in data collection.

Highlight at least 1 specific item in each document that assisted in filling out the data collection sheet.

Display documentation on inverters and use of documents in regards to the system and project.

Input: Data collection sheet

System specifications can be verified through the inverter research input as the research directly determines the usable power and voltage requirements.

Research documents will be pulled up in parallel with the data collection document to show the correct data correlation between the selected inverter datasheets and the values used.

4.2.6 References and File Links

References:

[1]"404.aspx | SUNGROW," *br.sungrowpower.com*. https://br.sungrowpower.com/upload/file/20210512/DS_20210322_SC2750%203150%203450UD-MV%20Datasheet_V1.1.2_EN.pdf (accessed Feb. 11, 2023).

[2] "DS SG3150U-MV Datasheet v1.2 en - sungrow power," Sungrow Power, https://en.sungrowpower.com/upload/file/20201216/DS_SG3150U-MV%20Datasheet_V1.2_EN.pdf.pdf (accessed May 15, 2023).

File Links:

Project Partner Files

Inverter Parameter Research Documents

4.2.7 Revision Table

Table XII
Section 4.2 Revision Table

1/20/2023	Austin Pearson: Started Draft
2/11/2023	Austin Pearson: Redid interface properties, Updated Description, Changed design section, Updated general validation, added a more complete verification plan, Added references used when formulating, updated reversion table, added revision statement.
3/10/2023	Austin Pearson: Populated sections on project document
5/7/2023	Cole Ferguson: Updated table formatting
5/14/2023	Austin Pearson: Fixed description and verified references.

4.3 Transformer Ratings

    4.3.1 Description

        Our system is meant to simulate a solar site that reacts to the needs of the power grid at any given moment. For instance, if the voltage of the power grid is dropping due to an increase in power demand or other such factors, the solar site will respond by outputting more reactive power from the solar farm and/or batteries. My block, the transformers, facilitate the delivery of voltage from the output at the inverters to the power grid, stepping it up at two separate locations to bring it the levels that are necessary. Due to the nature of our system every block is just as important as the others, however it is worth noting that the functionality of our system would not be possible without the inclusion of the transformers. The values of each of the components vary from site to site but the high and low voltages for each of the transformers are more or less the same.

        Within the group I am modeling within PowerWorld, which is a simulation tool that primarily focuses on solving power flows, performing fault analysis, and plotting what-if scenarios. In PW, transformers exist as their own component and can have their values edited as needed. In our case, we are mainly interested in the high and low voltages however we could also change a variety of other values if the need arose.

    4.3.2 Design

        The design of our system is quite rigid as the entire project is meant to mimic the process that we would go through if we had a real client that wanted to construct a solar site. It would be our responsibility to request the proper information, review it, and then enter it into the simulation software so we could test for fail conditions and whether the proposed parameters would work or not. As a result, there are little to no creative liberties that we are employing in our project as we must adhere to the data provided by our project partner. The first step of the process in the creation of our simulation is to do research for our block, collect the information for that block and then clarify anything that we cannot find on our own or do not understand. Afterwards, we will combine this data for the final system which we then simulate using PowerWorld and PSCAD, comparing the two to see if our outputs match. The image of the PowerWorld circuit below is an example of how our system can be set up in simulation, excluding the battery branch in this specific case.

Figure 1: Black box diagram, both transformers are simplified into one.
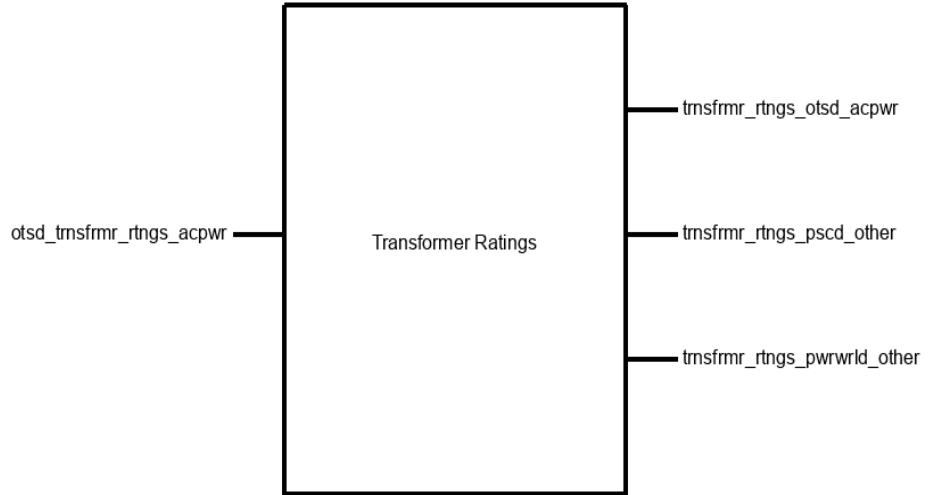
The image below shows an example of how our system looks in PowerWorld. Note that in PW, we are modeling the power grid as a slack generator for the sake of simplicity. In addition, the other generator represents the power output of the solar farm after the output has been converted from AC to DC power. We also choose to exclude the battery branch in this iteration, however it could be represented as another generator if we wanted to include it. In the majority of cases the batteries will not serve any role in the system, as the solar panel output should be sufficient most of the time. If this is not true, the batteries can supplement the solar farm so that the power grid can remain stable.

Figure 2: Transformers as they appear in PowerWorld.
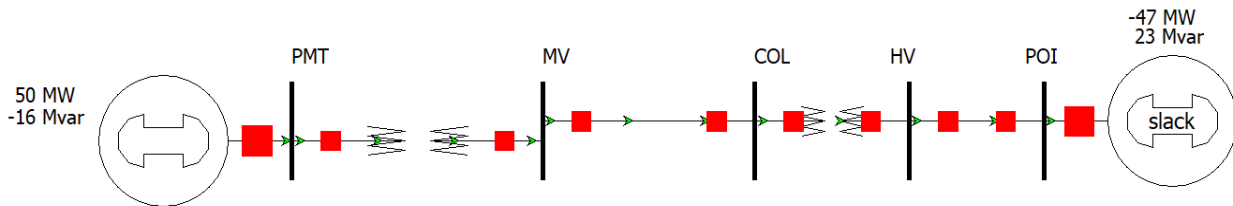
4.3.3 General Validation

Our system is based entirely on the site parameters, and as such the transformers will behave according to what has been defined. The needs of the system dictate that the transformers step up the voltage to very precise numbers as mentioned previously, but due to the nature of the simulation

this is set by the values that are entered by the user and do not fluctuate afterward.

Since our project is based on simulations, costs, obtaining parts, hardware performance and other such categories for assessment are not applicable to our specific project. Our main method of validation will be comparing our results to the standards that real solar sites must adhere to (such as CASIO or ERCOT). Furthermore, we will also compare the differences between the PSCAD and PowerWorld outputs to ensure that they fall within acceptable levels of each other. The main set of limits that we face are imposed by our project partner. Since they are acting like the client in this project, we must adhere to their specifications, component choices, and other such parameters. As mentioned previously our research and simulation will undergo analysis by our project partner for approval.

There is not really any alternative block that could be substituted for the transformers as they are required for the circuit to work in the expected way. Technically speaking there are many different kinds of transformers that could be used for a solar site. In terms of solar sites the specific transformers that are used are not that important as long as they can meet the needs of the system. However, as discussed in section 1, since we are mimicking the real process for developing solar sites the transformer that would be used is the one provided by the client, which in this case is our project partner. Since the rest of the system is designed around this specific model of transformer, changing it would compromise the simulation results. In short, while we theoretically could use a different set of transformers, doing so would be outside the scope of the project.

4.3.4 Interface Validation

Since the previous iteration of this block for the first set of checkoffs, the interfaces and properties have changed substantially. There is now only one input that represents the data collection for the transformers. Additional outputs have been added due to the overall changes to the system block diagram, and their properties reflect project partner approval, research, and other such documents as they did in the previous version but they have been refined for the updated blocks.

Tables in Section 3.3.1

4.3.5 Verification Process

Since my block does not involve any standard components like PCBs, software, microcontrollers, or circuits the process of verification is a bit unorthodox compared to other projects. As described in previous sections, the entire verification process relies on approval from our project partner so in some ways it is not really possible to replicate the process as this would require the research documentation to achieve. My interfaces are not tangible as well, so this makes it difficult to write a plan that someone outside of the project could follow. Nevertheless, I think that this plan explains the process we are following fairly well.

1. Research and complete data collection from
2. Acquire approval from client (project partner)
3. Input approved data into simulation, compile with other blocks
4. Run simulations with dynamic models and analyze results
5. Compare the outputs to project standards, and seek affirmation from project partner

4.3.6 References and File Links

4.3.7 Revision Table

Table XIII
Section 4.3 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
5/7/2023	Cole Ferguson: Updated table formatting

4.4 Transmission Lines Specifications

4.4.1 Description

This block is the work it will take to create the detailed outline of the transmission line system. This block will contain any relevant information required for transmission of power along the system. Outputs from the block will be entered into the software simulation to generate values and analysis of the system. without proper transmission of energy the simulation will not work. The block will give the specifications necessary to model and simulate the transmission line system. The Input of this block is data collection and research. That is the research needed for the

transmission line to function properly. The output of the system is a data collection sheet that will contain all necessary data to properly model the system in PSCAD and PowerWorld. Since the transmission line includes many different sections of the system, there will be varying voltages on the line, as well as varying impedances. To properly model this in the software, equivalent impedance is used. This must be included in the output "data collection sheet". The voltage must be shown in the data collection sheet in MVA. The general background information about how this block fits into the system and why research/data collection input is so vital is following. The transmission system will be responsible for carrying energy from one component of the system to the next. The entire project contains inverters, transformers, and batteries that manipulate the energy on the line. The t line must have an impedance that can correspond to the voltage on the line in order to have adequate transmission of energy. So, the research being done as an input is reading through data sheets, looking through schematics, and examining nameplates. Then finding out the proper calculations and conversions to get usable data that can be inputted into PSCAD and PowerWorld so that we can simulate.

4.4.2 Design
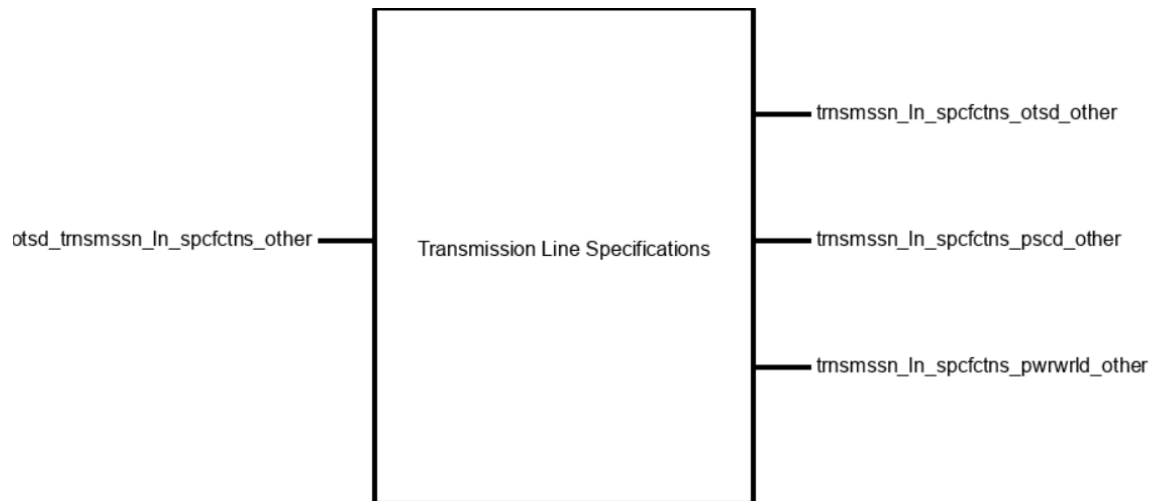
The design includes all the necessary technical specifications that will be required for the transmission line to function correctly and to accurately model in the software. Since the loss of the transmission line will affect the amount of energy produced the loss of the transmission line is important. The impedance of the transmission line will be an output that is discovered through research. The input of the block will be research, which includes going through documents and understanding how the system functions. The solar site, this will be simulated through software since we do not have a real solar site. The output of the block is a data

collection sheet. The data collection sheet is required to show the equivalent impedance and the different voltages throughout the line. The data collection sheet is required to have the project partner's approval, this is Michael Decosta Group 19 to ensure that the data collected is correct. By having the correct data and parameters we can accurately model the system in software. The role of this block is to give the specs of voltage and impedance that is required for software simulation. The T line is responsible for moving energy from one block to another.

4.4.3 General Validation

The block is supposed to be responsible for the transmission of energy from the inverters and batteries to the transformers which go to the electrical grid. By including the specifications, we can create a block that is easier to understand and easier to validate. Due to the time and cost constraints building a real solar site is out of the question so by simulation we can still work with the related topics. This block is important because it allows us to move energy through the system and is necessary for simulation. An alternative solution could be to just make a T line block and have input as power from the inverters and batteries and have it output power to the transformer. The issue with this is it is very hard to prove that it works, since using our software we enter the input and output of the T line. The best solution to prove that our block works is by defining the properties as approval or check off by the project partner. He is experienced in the software simulation of solar sights and has been doing it professionally for 3 years. Having will approve our data means that we did it correctly and have all the necessary information and specifications for the transmission line. This block is basically a research block that outputs a clean, organized sheet of data that contains everything required to model the actual solar site in software.

4.4.4 Interface Validation

The block is supposed to be responsible for the transmission of energy from the inverters and batteries to the transformers which go to the electrical grid. By including the specifications, we can create a block that is easier to understand and easier to validate. The block is supposed to be responsible for the transmission of energy from the inverters and batteries to the transformers which go to the electrical grid. By including the specifications, we can create a block that is easier to understand and easier to validate.

<div align="center">

Table XIV

Section 4.4 Interface Table

</div>

otsd_trnsmssn_ln_spcfctns_other : Input

Other: Research document, nameplate or datasheet	In order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.
Other: research document, nameplate or datasheet	in order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.
Other: data collection/ research	in order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.

otsd_trnsmssn_ln_spcfctns_other : Input

Other: Research document, nameplate or datasheet	In order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.

Other: research document, nameplate or datasheet	In order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.
Other: data collection/ research	In order to accurately model our solar system in PSCAD and PowerWorld we must have input parameters that are "gathered" from the solar site, as well as specs from data sheets about the specific transformers and inverters that are being used.	The design details meet the property because the property is showing the research/ data collection documents that we reviewed to get our answers on the data collection sheet.

trnsmssn_ln_spcfctns_otsd_other : Output

Other: shows impedance on sheet	Impedance or equivalent impedance is what allows energy to flow down a transmission line, including this value will allow the software to model the transmission line of the system.	Without knowing the equ impedance the software can't model the system. This is important because without being able to model the transmission line, energy cant move from one block to another.
Other: Data collection sheet	The data collection sheet shows all the necessary values that correspond to the solar site; those values will be entered into the parameters of the model in the software.	The data that is entered into the data sheet is what we will use to develop and accurate model that will allow us to do simulations on the system.
Other: approved by Will Dodge	To have a useful model it must be correctly modeling, so if we do not have correct data to input into the software, we will not get useful	Will Dodge is an EE at Shermco and has working experience not only doing the simulation part of our project, but also real on site

	results. By having the PE, or an expert, to double check the values we can be confident they are correct.	data collection as well. By meeting his approval we know that we have learned how to do data collection, or synthesize important site parameters and understand what parameters are necessary to accurately model and run simulation on a solar system,
Other: shows voltage on data sheet	The voltage is constantly being stepped up and stepped down, by showing the different steps in voltages along the site, we can properly model in the software. The voltage on the line is important because the impedance of the line must be matched to it to have transmission of energy.	The data collection sheet has a lot of voltage values that need to be specified. The changing voltage needs to be kept track of

trnsmssn_ln_spcfctns_pscd_other : Output

Other: Data collection sheet, "MVA base for impedance calc"	The MVA base is required to make sure each transformer is functioning as it should.	We know that this is good because it is approved by the project partner, by signing his initials on the data collection sheet.
Other: Data collection sheet	To make sure the calculations that were made were correct and to make sure we are accurately modeling the site data correctly.	It is approved by a project partner with 5+ years working experience.
Other: Data collection sheet, equ impedance	The equ impedance is how pscad models the segments of transmission lines between components.	The equ impedance calculations are correct and right, it gives the equations used in the references in the data sheet and is approved by project partner.

trnsmssn_ln_spcfctns_pwrwrld_other : Output

Other: PW Model Draft	To make sure what is being used in power world is accurately	This draft is talked over and agreed upon with the group and project

	modeling the system.	partner, and serves as a draft to create the model in Power World.
Other: Data Collection	To make sure the calculations that were made were correct and to make sure we are accurately modeling the site data correctly.	It is approved by a project partner with 5+ years working experience.
Other: Model Acceptance	To make sure that the parameters that were gathered from the data collection sheet were accurately put into the software, without error.	The model acceptance document is completed and sent to project partner for review and approval. This ensures that the correct values are used and makes sure the simulation is correct.

4.4.5 Verification Process

Inputs: Research/data collection

1. Compile at least 3 documents that assisted in data collection.

2. Highlight at least 1 specific item in each document that assisted in filling out the data collection sheet.

Outputs: Data collection sheet

1. Fill out the value column of the data collection sheet.

2. Email data collection sheet as a PDF to project Partner (Will Dodge)

3. Get approval for correct data collection values.

4. Show approved data collection sheet.

4.4.6 References and File Links

[1] "Transmission line specifications block validation," Electrical Engineering and Computer Science. [Online]. Available: https://eecs.engineering.oregonstate.edu/capstone/ece/student/reports/bloc kvalidationt emplate.php?blockid=5654. [Accessed: 20-Jan-2023].

4.4.7 Revision Table

Table XV
Section 4.4 Revision Table

1/18/2023	Michael Decosta: Initial formatting and section creation
1/19/2023	Michael Decosta: created template and worked on blocks
1/20/2023	Michael Decosta: completed block, added interfaces, and finished block

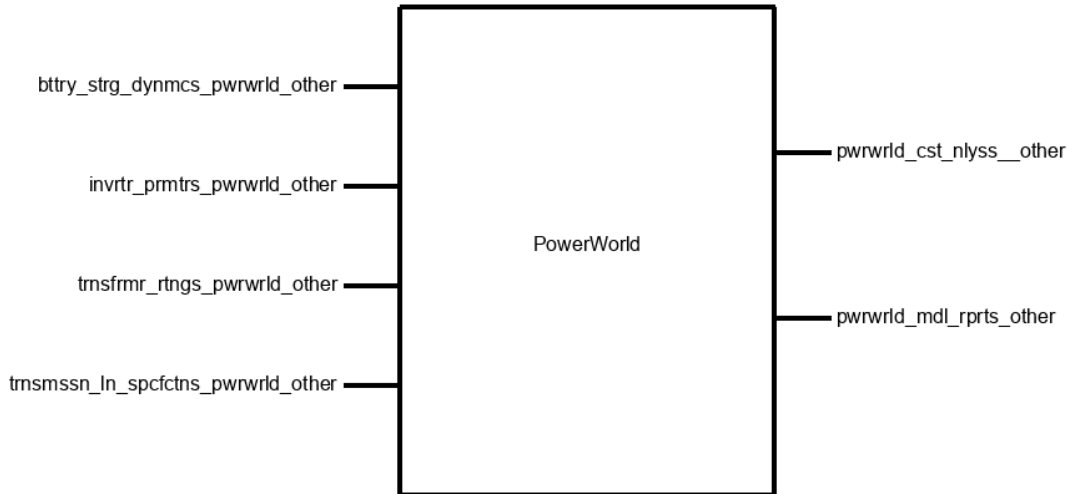|	
	validation template, updated student portal.
2/11/2023	Michael Decosta: finished proofreading, and submitted. Fixed margins, fixed organization, cleaned up based on Rachel's media comment.
3/12/2023	Michael Decosta: Added validation to project document.
5/7/2023	Cole Ferguson: Updated table formatting

4.5 PowerWorld

4.5.1 Description

Our project will have simulations done in both PSCAD and PowerWorld, and this block represents the simulation done in PowerWorld. Based on our most recent block diagram, the input interfaces for this block are the main four blocks that we showed for the first checkoff. These represent the main components of the system and data that will be entered into PowerWorld in preparation for simulation/modeling. The interface properties for these inputs are the same, as they each represent the data being input into PW, rather than values such as voltage or current. The output interfaces are tied to the model report and cost analysis blocks, and following the same pattern as the input interfaces represent the outcome of the simulation rather than hardware or software. Once we have run the simulations and collected the plots and other pertinent data, we can write the reports and perform the cost analysis.

4.5.2 Design

This block represents the simulation of the system in PowerWorld, which will later be compared to the outputs from PSCAD. In our current block diagram the inputs to the PW block originate from the blocks that we checked off first, which represent the data for each of the core components of the system. These connections are not meant to show interactions between blocks such as voltage or current, but rather data collection, research, project partner approval, etc. The outputs show the relationship between PW and the report part of the project, namely the cost analysis and organization of the plots and simulation results.

Input labels (left side):
- bttry_strg_dynmcs_pwrwrld_other
- invrtr_prmtrs_pwrwrld_other
- trnsfrmr_rtngs_pwrwrld_other
- trnsmssn_ln_spcfctns_pwrwrld_other

Block: PowerWorld

Output labels (right side):
- pwrwrld_cst_nlyss__other
- pwrwrld_mdl_rprts_other

4.5.3 General Validation

This block fulfills half of the simulation engineering requirement, since we need PowerWorld and PSCAD results for the final reports. As with the rest of the project, this block does not have any physical components such as PCBs. I suppose that an alternative to this block would be PSCAD since they have accomplished the same goal.

4.5.4 Interface Validation

The input interfaces of the PW block are from the component blocks that we devised for the first check off. These blocks represent the research/data that goes into each of these components, and the corresponding approval from our project partner that shows this information is correct. The outputs are the results from the PW simulation that will be used to write the reports and ultimately determine if our solar site meets the standards listed in the deliverables of our project.

Tables in Section 3.3.1

4.5.5 Verification Process

1. Collect data from input blocks
2. Create draft of model in PW with necessary components
3. Ensure data and dynamics models are loaded correctly
4. Produce plots and results
5. Verify that results match standards

4.5.6 References and File Links

Federal Energy Regulatory Commission. [Online]. Available: https://www.ferc.gov/sites/default/files/2020-04/reliability-primer_1.pdf. [Accessed: 20-Jan-2023].

4.5.7 Revision Table

Table XVI
Section 4.5 Revision Table

|	
3/10/2023	Austin Pearson: Initial formatting and section creation
5/7/2023	Cole Ferguson: Updated table formatting

4.6 PSCAD

4.6.1 Description

This block is the work it takes to set up a simulation and what if scenarios using dynamic models of the whole solar site. The output of this block will be a dynamic model including the transformers, inverters, batteries, and transmission line.

This block will also output a variety of plots. These plots will aid in writing the cost analysis report. PSCAD is where our data collection and research will tie together; using the data we gathered to enter via component parameters and the research to properly model the system in circuits. We can analyze the solar site changing different parameters to see which location could be the most profitable to implement a real solar site, this is just an example meant to give more understanding to how PSCAD will be used in our system.

4.6.2 Design
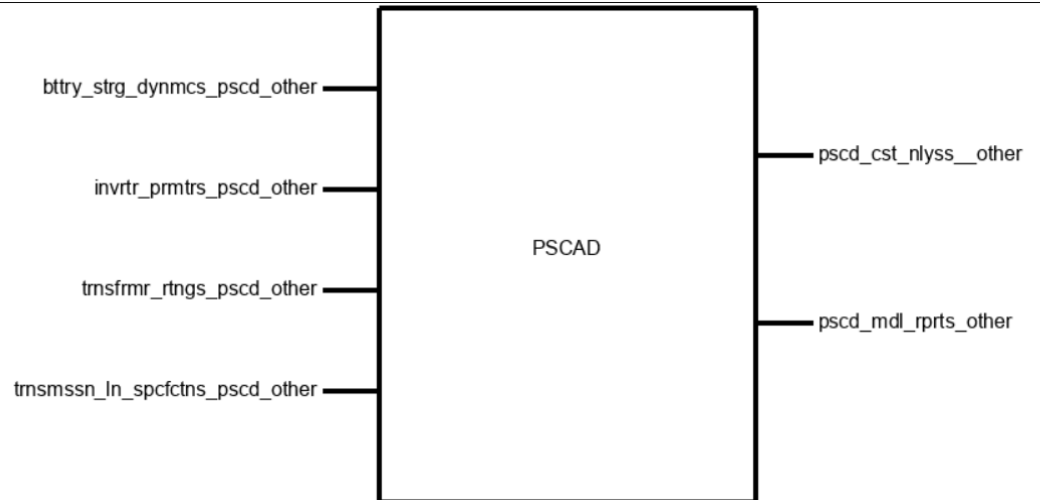
The design of this block is made up of the required parameters and components to run a simulation.The block's inputs are "site parameters" that'll come from the data collection sheet and are inputted into our software to model and simulate the solar site. The block outputs graphs of frequency, MVA, voltage as well as fault analysis. These graphs will give important insight and understanding for how the model needs to be tuned to meet the ERCOT and NERC standards (MOD 25 and MOD 26). The block will also output a .pscx file, that will be a dynamic model, meaning that will be a working file that can be edited and changed and continue to be modified and re-run to give what if scenarios of the site. Taking a deeper look at the contents of the block, the solar site is modeled using an SG135 and SC135 file that is generated and standardized across the PSCAD software and produced and distributed by PSCAD to users.These files are modified to properly model the site by adding buses, transformers, batteries, and collector systems. Then connecting the system to the grid we can see how it would function real time, and how well the solar site is protected and how it reacts to faults in correspondence with the grid.

4.6.3 General Validation

This block is necessary because it can be expensive, dangerous, and less practical to do analysis of a solar site in person. Due to the power electronics involved and specifically the very fast switching speed of the inverters of the power electronics, a high power software is needed to accurately analyze the system. This solar site could be producing a high magnitude of power which can be dangerous, it is also connected to the grid, because of this it must be properly protected, and produce the amount of power it is estimated to produce, this is needed to have a stable grid. The best way to prove that this block works is to show the .pcsx file as

well as the simulation running with output plots. This block is extremely important to the project because without the simulation we can't adhere to the standards, we can't properly tune and study the system, or generate post simulation model reports or cost analysis.

4.6.4 Interface Validation

Due to the time and cost constraints building a real solar site is out of the question so by simulation we can still work with the related topics. This block draws its inputs from the transformer ratings block, the tline specifications block, the inverter parameters, and the dynamic battery storage block; they are neatly compiled via the "data collection document". It has an output of dynamic models, data, and "model acceptance document". All outputs are needed for the reports that need to be written, with data being in the form of 2-5 graphs that demonstrate core important attributes/behavior of the system. Similar to other blocks the model acceptance document will be approved by the project partner, guaranteeing its correctness. The dynamic model will be shown via 1 .pscx file that can be saved, edited, and re opened, proving its a dynamic model. An alternative solution could be only doing the simulation of the solar site in just Power world, and although this would be significantly easier, it would not properly model the system accurately enough, since Power world cant account for the fast switching of the inverters inside the power electronics. The work that this block does is accurately modeling the solar site in PSCAD software and running analysis of it to produce data, a dynamic model, and a model acceptance document.

Table XVII

Section 4.6 Interface Table

bttry_strg_dynmcs_pscd_other : Input

Other: Data collection sheet, Equivalent Generator Bus Voltage	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	The values collected are based on the real-world site's equipments' datasheets.
Other: REEC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	The research documents are used to learn how the dynamics of a generation site are managed and controlled.

Other: REPC control	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	The research documents are used to learn how the dynamics of a generation site are managed and controlled.
Other: REGC control	The SC3150U-MV expects and accepts this voltage as an input, with some slight variance due to operation mode.	Matches the generation site equipment specifications to accurately represent the site.
Other: Data collection sheet, Equivalent Generator MVA	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	The values collected are based on the real-world site's equipments' datasheets.

invrtr_prmtrs_pscd_other : Input

Other: Data collection sheet, Equivalent Generator Bus Voltage	The block represents 28 battery energy storage systems, each with a base MVA of 3.15. So 28*3.15=88.2 and is used in power flow calculations.	The values collected are based on the real-world site's equipments' datasheets.
Other: Data Collection document.	The data collection sheet shows all the necessary values that correspond to the solar site, those values will be entered into the	The data that is entered into the data sheet is what we will use to develop an accurate model that will allow us to do simulations on the system.
Other: Data collection sheet, Equivalent Generator MVA	In order to fully operate as a dynamic model the block must be controlled by the plant controller.	The research documents are used to learn how the dynamics of a generation site are managed and controlled.

trnsfrmr_rtngs_pscd_other : Input

Other: Data collection sheet, transformer base MVA	To make sure the correct transformer is where they should be. In transformers the parameter in the software that we change to make it a pad mount vs a main	Our project must clear our data collection form before we are permitted to continue with the simulations, to continue that our simulations are done with the

	power transformer is the mva base.	proper values and will not produce inaccurate results
Other: Data collection sheet	The data collection sheet shows all the necessary values that correspond to the solar site, those values will be entered into the parameters of the model in the software.	The data that is entered into the data sheet is what we will use to develop an accurate model that will allow us to do simulations on the system.
Other: Data collection sheet, PMT transformer	To make sure the correct transformer is where they should be. In transformers the parameter in the software that we change to make it a pad mount vs a main power transformer is the mva base	Our project must clear our data collection form before we are permitted to continue with the simulations, to continue that our simulations are done with the proper values and will not produce inaccurate results.

trnsmssn_ln_spcfctns_pscd_other : Input

Other: Data collection sheet, "MVA base for impedance calc"	The MVA base is required to make sure each transformer is functioning as it should.	The MVA base for the section of line connecting the transformer and the impedance of the line is needed to do the calculation for the reactance and resistance of the line per unit length, this is the form it is in when entered in PSCAD.
Other: Data collection sheet	The data collection sheet shows all the necessary values that correspond to the solar site, those values will be entered into the	The data that is entered into the data sheet is what we will use to develop an accurate model that will allow us to do simulations on the system.
Other: Data collection sheet, equ impedance	The equ impedance is how pscad models the segments of transmission lines between components.	The equ impedance calculations are correct and right, it gives the equations used in the references in the data sheet and is approved by project partner.

pscd_cst_nlyss__other : Output

Other: System Efficiency approved by project partner	To make sure our cost analysis is meaningful we must have an efficient system, it produces more energy than it uses.	By having an efficient system that means it will produce more energy than it utilizes, by having our starting point for cost analysis set there we can see how much more money can be generated in each location.
Other: Maximum MVA	Using the maximum MVA output to the grid, the price of power sold can be calculated.	Normally the cost analysis would need to include a section calculating the power output to the grid. Maximum MVA is apparent power seen at the grid interface. Apparent power is much more helpful as it takes the reactive power into account.
Other: Plot of system stability approved by project partner	In order to do a proper cost analysis the system must be stable or it can not meet standards and be approved to function. By ensuring system stability we can make sure our cost analysis is meaningful.	If a system is not stable it can't have longevity and it can't bounce back from faults, meaning that it could malfunction in a dangerous way, or not produce energy, skewing the results of cost analysis. The cost analysis takes into account the energy being produced over time and the price per kilowatt hour in the corresponding location.

pscd_mdl_rprts_other : Output

Other: Approval from Project Partner of Data Collection.	To make sure that we used the correct data to build our models with.	This is the process through which EE work with PSCAD and engineering consulting on solar sites. The information is correct because it is reviewed and approved by a professional.
Other: PSCAD component model documents	The user guide to modeling each component in PSCAD is needed to create a model report that	The standardized documents are provided by the seller when buying power electronics for solar

	summarizes how the components function and work together to generate solar power to the grid.	sites. These work like a data sheet and give you the name for the PSCAD library that is needed to model the components.
Other: A .pscx PSCAD file that contains the simulation model	In order to meet the system engineer requirement of a dynamic model. This file can be opened and edited, and can be passed along as a good starting point to a group after us.	It is a dynamic model because it can be opened, edited, and resaved. Multiple iterations can occur and this 1 file contains all the information regarding our solar site.

4.6.5 Verification Process
Inputs: data collection sheet
1. Compile at least 3 documents that assisted in data collection.
2. Highlight at least 1 specific item in each document that assisted in filling out the data collection sheet.
3. Repeat for each of the 4 components (tline, inverter, battery, transformer)
Outputs: Dynamic .pscx file (a) Model acceptance document (b) Data (c)
1a. Open dynamic .pscx file in PSCAD
2a. Change any parameter and save and re open, showing it updates.

3b. Show model acceptance document
4c. Show graph templates (incomplete graphs) that data will be on.

4.6.6 References and File Links
4.6.7 Revision Table

Table XVIII
Section 4.6 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
5/7/2023	Cole Ferguson: Updated table formatting

4.7 Model Reports

    4.7.1 Description

        This block represents the work done to produce reports that describe the functionality of both PSCAD and PowerWorld simulation softwares. This block will describe the operation of each system, performance during stability tests, and explain the control parameters used to model the response of the system. It will give a brief overview of how the inverters, batteries, and transformers are being used in the model, and some insight into how each of the components work together to produce power. The model reports will be used and included into the project's final analysis report.
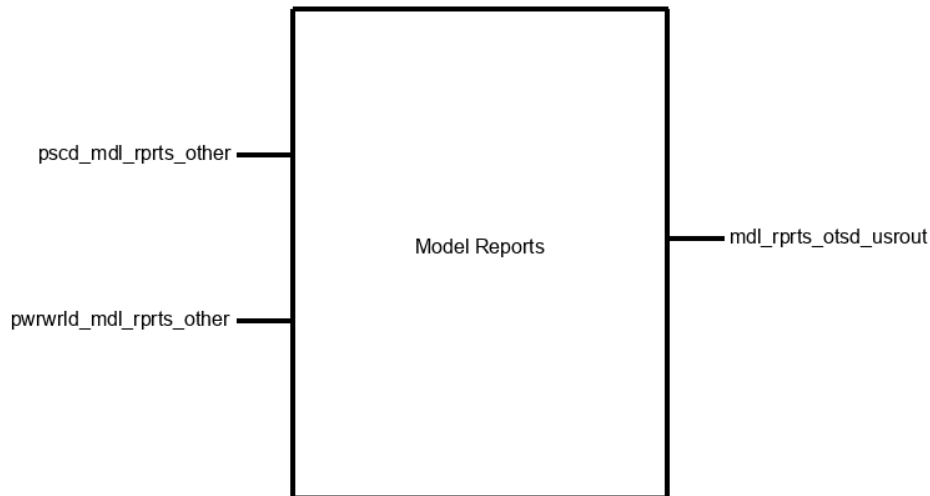
    4.7.2 Design

Figure 1 - Black Box Diagram

Figure one shows the black box diagram with all 3 interfaces

pscd_mdl_rprts_other: This is the PSCAD model file used to reference and create the reports.

pwrwrld_mdl_rprts_other: This is the PowerWorld model file used to reference and create the reports.

mdl_rprts_otsd_usrout: This is the completed model reports.

The block represents the work done to write the reports describing the operation of both of the simulation softwares and the models used and the compliance with

various standards.

4.7.3 General Validation

One of the project requirements for this project was to produce a final report that describes the operation of each system including outlining the models used. Using professional templates provided by the project partner, reports for the different components of the system will be written. These reports will cover NERC MOD-026 and MOD-027 [1,2] compliance, as well as CAISO compliance [3], and explain the inner workings of both simulations and model pieces.

4.7.4 Interface Validation

Table XIX

Section 4.7 Interface Table

pscd_mdl_rprts_other : Input

Other: A .pscx PSCAD file that contains the simulation model	In order to write a report describing the PSCAD model, a working dynamic model must first exist.	The dynamic model can be modified and iterated to be an accurate representation of the site.
Other: Approval from Project Partner of Data Collection.	The model must be approved by the project partner so that there is certainty that the site is being modeled correctly.	The site is approved as a representation of the site. The information is correct because it has been approved by a professional.
Other: PSCAD component model documents	Documents that are used to describe how to set up and operate certain components.	The documents are standardized descriptions from the producer about how to work with the components and function in simulation [4].

mdl_rprts_otsd_usrout : Output

Other: Model Reports, NERC Compliance Report	The completed reports that describe the function of the different components and simulations.	A project requirement was to produce a set of reports that describe the components within both simulations. Using professional templates, the reports will be thorough.
Other: Model Reports, CAISO Compliance Report	The completed reports that describe the function of the different components and	A project requirement was to produce a set of reports that describe the components within

	simulations.	both simulations. Using professional templates, the reports will be thorough.
Other: Model Reports, Component Reports	The completed reports that describe the function of the different components and simulations.	A project requirement was to produce a set of reports that describe the components within both simulations. Using professional templates, the reports will be thorough.

pwrwrld_mdl_rprts_other : Input

Other: A .pwb PowerWorld file that contains the simulation model	In order to write a report describing the PowerWorld model, a model must first exist to describe.	The dynamic model can be modified and iterated to be an accurate representation of the site.
Other: Approval from Project Partner of Data Collection	The model must be approved by the project partner so that there is certainty that the site is being modeled correctly.	The site is approved as a representation of the site. The information is correct because it has been approved by a professional.
Other: PowerWorld component model documents	Documents that are used to describe how to set up and operate certain components.	The documents are standardized descriptions from the producer about how to work with the components and function in simulation.

4.7.5 Verification Process
Required Tools:
1. Laptop
2. PowerWorld
3. PowerWorld model file
4. PSCAD
5. PSCAD model file
6. Project Partner Approval Email
7. Project Drive

pscd_mdl_rprts_other:
1. Launch PSCAD

2. Open the project PSCAD model .pscx file
3. Verify that the file opens.
4. Open email from Project Partner, Will Dodge
5. Confirm that the data collection spreadsheet has been approved.
6. Open PSCAD project document folder
7. Verify that documents in folder exist and pertain to PSCAD

pwrwrld_mdl_rprts_other
1. Launch PowerWorld
2. Open the project PowerWorld model .pwb file
3. Verify that the file opens.
4. Open email from Project Partner, Will Dodge
5. Confirm that the data collection spreadsheet has been approved.
6. Open PowerWorld project document folder
7. Verify that documents in folder exist and pertain to PowerWorld

mdl_rprts_otsd_usrout:
1. Open "Project Model Reports" folder
2. Verify that CAISO compliance report exist
3. Verify that NERC compliance report exist
4. Verify that Component reports exists

4.7.6 References and File Links

[1] "Standard MOD-026-1 — Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions." [Online]. Available: https://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-026-1.pdf. [Accessed: 13-Mar-2023].

[2] "Standard MOD-027-1 — Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions." [Online]. Available: https://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-027-1.pdf. [Accessed: 13-Mar-2023].

[3] "Electromagnetic transient modeling requirements - caiso.com," 21-Oct-2020. [Online]. Available: https://www.caiso.com/Documents/Presentation-ElectromagneticTransient

ModelSubmissionsRequirement-Oct212020.pdf. [Accessed: 13-Mar-2023].

[4] "National Renewable Energy Laboratory (NREL) home page | NREL." [Online]. Available: https://www.nrel.gov/docs/fy15osti/62053.pdf. [Accessed: 12-Mar-2023].

4.7.7 Revision Table

Table XX
Section 4.7 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
3/12/2023	Cole Ferguson: Populated sections
5/7/2023	Cole Ferguson: Updated table formatting

4.8 Cost Analysis
4.8.1 Description

Cost analysis is a deliverable report describing the actual usability of the system based on location data specified by the assigned standards. The analysis involves using the average cost of energy, average home energy draw, estimated cost of components, dynamic models, and site data to give an accurate relative cost of installation and usability in the specified areas. The Cost Analysis uses the cost of energy and home draw to give an approximate cost for the average home in specified areas. From there the dynamic models are used to obtain an estimated power output to the grid. With this, the analysis shows the potential revenue that could be generated by selling the given power to the grid and homeowners. This is compared with an estimated price for components and installation costs to give an estimated break even date. The break even date will be the best reference in where to locate our site as the general idea of the site is to both make money by selling power and to decrease carbon emissions by moving a larger percentage of the population over to renewable energy.

4.8.2 Design
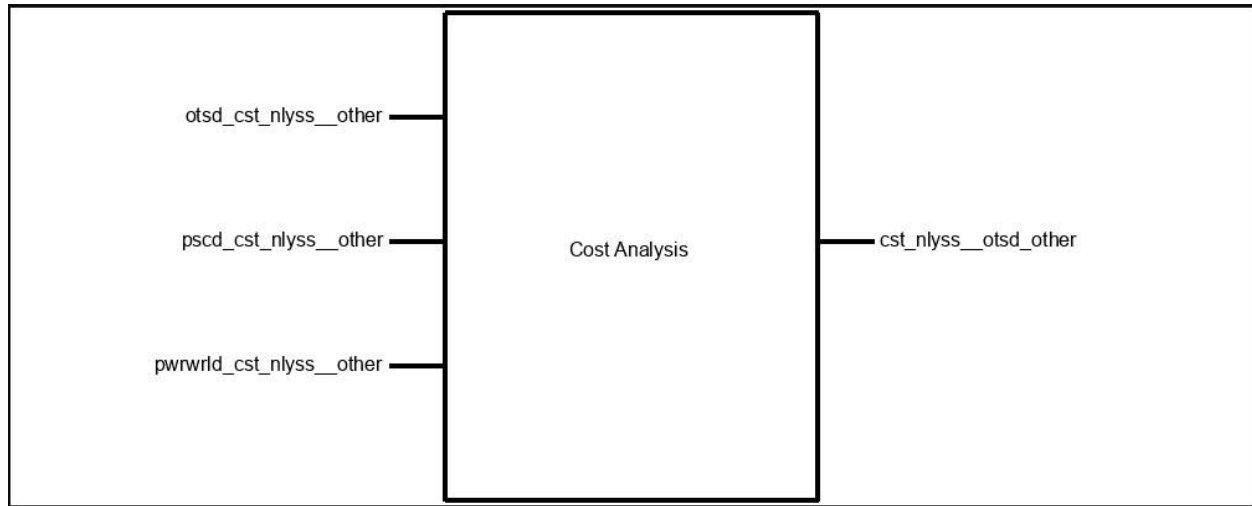
4.8.3 General Validation

This block is important to the project because it is putting all the work from the project into a professional document that gives a concise overview of the analysis done relating to implementing a solar site in any of the 3 states. We chose to do a cost analysis to act as a summary and give more in depth analysis of pros and cons of developing a solar site in the future. Due to the huge financial compensation and longevity of a solar site, having an in-depth cost analysis would be the first thing that potential investors would like to see. A cost analysis report gives a very broad breakdown of how expenses and profits would compare using the same solar pans and system, just in a different location. Since this cost analysis could be so complex and time consuming, we simplified it to the most important changing variables, Intensity of light to hit the solar panel, the duration of light to hit the solar panel, and the average price per Kwh. Locations play a key role in all 3 of these metrics.

4.8.4 Interface Validation

Table XXI

Section 4.8 Interface Table

otsd_cst_nlyss__other : Input

Other: Research documents containing the cost of major components used in the system	In order to accurately assess the system the price for each component of the system must be standardized throughout the cost analysis and accurate.	So that the cost analysis is correct and simple for a non electrical engineer to read and understand.

Other: Research documents containing the average home energy draw in specified areas	To accurately assess the system and how much money it is generating, the average home draw can indicate which states use the most energy.	So that the cost analysis is correct and makes sense it must be tailored to the area of generations price per kwh. Ideally the documents will encapsulate data for all states in one document.
Other: Research documents containing the average energy cost in specified areas	To accurately assess the system and how much money it is generating, the buy back rate per Kwh must be correct and accurate.	So that the cost analysis is correct and makes sense it must be tailored to the area of generations price per kwh. Ideally the documents will encapsulate data for all states in one document.

cst_nlyss__otsd_other : Output

Other: compares cost in 3 different areas: CA, OR, TX	The three standards we are adhering to are ERCOT, NERC, and CASIO, these standards correlate to the three states. By knowing all the standards we have more options of solar site consultation, and gain valuable experience with all standards.	Meeting these standards are necessary for implementation. To get approval from the corresponding utility companies that are in charge of the grid, a system must comply with either the ERCOT, CASIO, or NERC.
Other: Compares variables in solar production	The peak sun hours of the areas that are to be compared is used in calculations of the breakeven point.	Peak sun hours is the best variable to use that is both uniform across states while being different per state.
Other: Break even point for site	The breakeven point is where the total cost and total profit are equal, so by ensuring that the system operates above that point, it guarantees the system will be at least profitable.	By including a breakeven point in the cost analysis, we have hard tangible evidence to show, using a visual that is easy for someone without knowledge of the system to understand. The breakeven point will be distinguishable in the cost analysis.

pscd_cst_nlyss__other : Input

Other: System Efficiency approved by project partner	In order to have a system that makes money it must produce more power than it consumes.	The system being efficient implies that it doesn't waste power. The system efficiency will be approved by the project partner to ensure it is giving a proper analysis of the entire system and taking into account necessary parameters.
Other: Maximum MVA	Using the maximum MVA output to the grid, the price of power sold can be calculated.	Normally the cost analysis would need to include a section calculating the power output to the grid. Maximum MVA is apparent power seen at the grid interface. Apparent power is much more helpful as it takes the reactive power into account. Using the models provides us with a more reliable and proven value.
Other: Plot of system stability approved by project partner	In order to do a proper cost analysis the system must be stable or it can not meet standards and be approved to function. By ensuring system stability we can make sure our cost analysis is meaningful.	If a system is not stable or cannot stabilize, it can cause problems that involve taking the site offline for an extended period of time. Meaning that it could malfunction in a dangerous way, or not produce energy, skewing the results of cost analysis.

pwrwrld_cst_nlyss__other : Input

Other: System Efficiency approved by project partner	To make sure our cost analysis is meaningful we must have an efficient system, it produces more energy than it uses.	By having an efficient system that means it will produce more energy than it utilizes, by having our starting point for cost analysis set there we can see how much more money can be generated in each location.

Other: Maximum MVA	Using the maximum MVA output to the grid, the price of power sold can be calculated.	Normally the cost analysis would need to include a section calculating the power output to the grid. Maximum MVA is apparent power seen at the grid interface. Apparent power is much more helpful as it takes the reactive power into account. Using the models provides us with a more reliable and proven value.
Other: Plot of system stability approved by project partner	In order to do a proper cost analysis the system must be stable or it can not meet standards and be approved to function. By ensuring system stability we can make sure our cost analysis is meaningful.	If a system is not stable or cannot stabilize, it can cause problems that involve taking the site offline for an extended period of time. Meaning that it could malfunction in a dangerous way, or not produce energy, skewing the results of cost analysis.

4.8.5 Verification Process

1. Show cost analysis report
2. Highlight where all 3 states are included.
3. Show model and approval for power world and PSCAD where project partner has approved model.
4. Show data from research for price per Kwh in each state.
5. Show system stability is above 50%.

4.8.6 References and File Links

[1] V. Ramasamy, "U.S. solar photovoltaic system and energy storage cost benchmarks with minimum sustainable price analysis: Q1 2022," Q1-2022 U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks With Minimum Sustainable Price Analysis Data File | NREL Data Catalog, https://data.nrel.gov/submissions/202 (accessed May 1, 2023).

[2] "Sun hours map: How many sun hours do you get?," Unbound Solar, https://unboundsolar.com/solar-information/sun-hours-us-map (accessed May 1, 2023).

[3] "Average Revenue Per Kilowatt-hour, 2019" American Public Power, http://www.smks.info/uploads/2/7/3/7/27372311/67_2020_u.s._rates_per_kwh_report_10-27-20.pdf (accessed May 1, 2023)

[4] "2021 Average Monthly Bill- Residential" Energy Information Administration, https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf (accessed May 1, 2023)

4.8.7 Revision Table

Table XXII
Section 4.8 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation
5/7/2023	Cole Ferguson: Updated table formatting
5/7/2023	Austin Pearson: Updated the description
5/14/2023	Austin Pearson: Updated the interface descriptions and verified references.

5. Systems Verification Evidence

5.1 Universal Constraints

5.1.1 The system may not include a breadboard.

Due to our project being primarily software and simulation based, this constraint is met, because our project does not utilize a breadboard.

5.1.2 The final system must include a student designed PCB.

Due to our project being primarily software and simulation based, this constraint does NOT apply to our project.

5.1.3 All connections to PCBs must use connectors.

Since our project does not require a PCB or utilize a PCB, this constraint does NOT apply to our project.

5.1.4 All power supplies in the system must be at least 65% efficient.

This system does not require any power supplies, since it is simulation based. This constraint does not apply to the project.

5.1.5 The system may be no more than 50% built from purchased 'modules.'

The system is entirely "built". There are some standardized PSCAD inverter and converter files, but even those were modified to properly model our system, making them built.

5.2 Requirements

5.2.1 Comparisons

5.2.1.1 Project partner requirement:
Compare models built on various platforms and understand the benefits and limitations of each.

5.2.1.2 Engineering Requirement:
The project will compare results of each simulation system for the "voltage and frequency instability tests" and the results will be within 5% of each other.

5.2.1.3 Verification process
1. Show side by side comparisons of the flat-run graphs from PSCAD and PowerWorld.
      1a. Show MW vs Time graph
      1b. Show MVAR vs Time graph
      1c. Show Voltage vs Time graph

5.2.1.4 Testing evidence
This will be shown in person using this folder. The goal of our flat run outputs was to show that the PSCAD and PowerWorld plots were within 5% of each other. This 5% is somewhat arbitrary as we wrote the requirement long before we got the final output plots, though our plots still fall within this restriction. The MVAR plot is deceiving due to the way that we normalized the data between PSCAD and PowerWorld, to fit them on the same plot. The values are closer than they appear on the plot for this reason. The plots of Vpu, or voltage per unit, show that the voltage is stable, and is further proved by the MVAR vs time plot. MVAR are controlled by voltage, and since the MVAR are stable then the voltage must be stable. Those two plots prove that it is stable during the "voltage instability test" as per the engineering requirement. The "frequency instability test" proof is in the MW vs time plot. The MW are controlled by frequency, and since the MW are stable, then the frequency must be stable, proving that it passes the "frequency instability test".

5.2.2 Costs

5.2.2.1 Project partner requirement:

The cost of running the solar site will be within an acceptable level.

5.2.2.2 Engineering Requirement:
The project will provide a cost analysis of the cost of the solar site compared to the energy standards and average energy cost in 3 or more of the areas related to the standard's application.

5.2.2.3 Verification process
Our cost analysis report will be linked below.

5.2.2.4 Testing evidence
[Cost Analysis Document](#)
For our cost analysis we chose to evaluate the costs of solar sites in Texas, Oregon, and California, and determine the amount of time it would take for the solar site to pay for itself. This is shown by break even point on the table. The formula used for calculation can be seen on the analysis and is easily repeatable for other states if needed.

5.2.3 Dynamic Models

5.2.3.1 Project partner requirement:
Will contain working dynamic models in PSCAD and PowerWorld.

5.2.3.2 Engineering Requirement:
The project will produce a set of dynamic models in both PowerWorld and PSCAD that are approved by the Project Partner including a transient response model.

5.2.3.3 Verification process
1. PSCAD
   a. Open PSCAD and load the dynamic model file (will be a .pscx file)
   b. Change a parameter's value, or add a "mock" component.
   c. Save PSCAD file
   d. Re-Open PSCAD file and show the changed updated value or component.
2. Powerworld
   a. Open Powerworld
   b. Load the dynamic model files (will be a .PWB and a .pwd file)
   c. Change a parameter's value, or add a "mock" component.

       d. Save Powerworld files

       e. Re-Open Powerworld files and show the changed updated value or component.

5.2.3.4 Testing evidence

This will be shown in person using this [folder](#). The files in this folder cannot be opened directly, but need to be opened through the respective software. Verification of this requirement is done when the PSCAD and PW models are shown to be dynamic by way of changes being preserved between versions. As for the transient response model, both PW and PSCAD's modeling is transient by nature, so by using the respective softwares the models designed satisfy that part of the engineering requirement.

5.2.4 Model Reports

5.2.4.1 Project partner requirement:

Provide a description of what each model does and how it works.

5.2.4.2 Engineering Requirement:

The project will produce a final report that describes the operation of each system including outlining the models used and is approved by the project partner.

5.2.4.3 Verification process

1. Present model reports
2. Show project partner approval on model reports.

5.2.4.4 Testing evidence

This will be shown in person using this [folder](#). These reports outline the parameters used in our models and the outputs they produced, and show that these results were approved by our project partner, thus acting as approval of the final versions of our models in PSCAD and PowerWorld.

5.2.5 Site Parameters

5.2.5.1 Project partner requirement:

The site parameters are correctly modeled.

5.2.5.2 Engineering Requirement:

The project will accurately match the parameters of the site being modeled through data collection forms with approval by the project partner.

5.2.5.3 Verification process

1. Present data collection sheet and model acceptance sheet.

2. Show project partner approval for the corresponding data collection sheet and model acceptance sheet.

5.2.5.4 Testing evidence

This will be shown in person using this [folder](#). These two forms show the process of data collection and entering that data into the models, and then being approved by our project partner. This approval is indicated by the initial in the tables within the document as well as an email.

5.2.6 Softwares

5.2.6.1 Project partner requirement:

System will use multiple simulation softwares.

5.2.6.2 Engineering Requirement:

The system will include models designed and simulated in PSCAD and PowerWorld that will be verified by project partner.

5.2.6.3 Verification process

1. Show designed model in PSCAD and Power World
2. Show results from simulation in PSCAD
3. Show results from simulation in Power World
4. Show project partners approval of accurate and correct models and simulation.

5.2.6.4 Testing evidence

This will be shown in person using this [folder](#). Inspecting the folder shows all the different verification steps: both the system models from both the softwares are present, the resulting simulation plots from both softwares are present and the parallel data demonstrates that they are modeled similarly and correctly, which is also verified through the project partner email of approval.

5.2.7 Stability Analysis

5.2.7.1 Project partner requirement:

The models will perform at an acceptable level even during extreme cases.

5.2.7.2 Engineering Requirement:

The system simulations will return to a steady state condition response to stability testing and is approved by project partner.

5.2.7.3 Verification process

1. Ensure dynamic models and data are entered correctly in software.

2. Show simulation and stability analyses results.
3. Determine if output plots meet expectations, by approval by project partner.

5.2.7.4 Testing evidence

This will be shown in person using this [folder](). The goal of our stability analysis tests were to determine if our models would recover from faults or not. The plots in the folder show that for both PSCAD and PowerWorld, our models recover from the faults, and return to a steady-state condition in a reasonable amount of time.

5.2.8 Standards

5.2.8.1 Project partner requirement:
System will pass ERCOT/CASIO standards.

5.2.8.2 Engineering Requirement:
The system will pass ERCOT/CASIO standards. ERCOT, mod. 26, 27, and for CAISO compare between positive sequence (pwrldwrld) and emt (PSCAD) and show they do the same thing.

5.2.8.3 Verification process
1. Show relevant model reports, pertaining to CASIO and ERCOT standards.
2. Present graph from PSCAD and Power World to cement that they are doing the same thing.

5.2.8.4 Testing evidence

This will be shown in person using this [folder](). Since our solar site is not real, the passing of the standards was determined by our project partner, whereas a real solar site would be submitted for evaluation. The presence of the ERCOT, CAISO, and Mod 26/27 documents and the corresponding approval from our project partner show that our models/system met these standards.The emt model report pertains to PSCAD and the "positive sequence" model report pertains to PW.

5.3 Reference and File Links

[1] V. Ramasamy, "U.S. solar photovoltaic system and energy storage cost benchmarks with minimum sustainable price analysis: Q1 2022," Q1-2022 U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks With Minimum Sustainable Price Analysis Data File | NREL Data Catalog, https://data.nrel.gov/submissions/202 [accessed May 1, 2023]

[2] "Sun hours map: How many sun hours do you get?" [Online].
Available: https://unboundsolar.com/solar-information/sun-hours-us-map
[accessed May 1, 2023]

[3] "Average Revenue Per Kilowatt-hour, 2019" [Online]. Available:
http://www.smks.info/uploads/2/7/3/7/27372311/67_2020_u.s._rates_per_
kwh_report_10-27-20.pdf [accessed May 1, 2023]

[4] "2021 Average Monthly Bill- Residential" [Online]. Available:
https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf
[accessed May 1, 2023]

[5] "California iso - prices, today's outlook" [Online]. Available:
https://www.caiso.com/TodaysOutlook/Pages/prices.html [accessed May
6, 2023]

[6] "Real-time settlement point prices display" [Online]. Available:
https://www.ercot.com/content/cdr/html/20230506_real_time_spp.html
[accessed May 6, 2023]

[7] "Standard MOD-026-1 — Verification of Models and Data for
Generator Excitation Control System or Plant Volt/Var Control
Functions." [Online]. Available:
https://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-026-1.pdf.
[Accessed: 13-Mar-2023].

[8] "Standard MOD-027-1 — Verification of Models and Data for
Turbine/Governor and Load Control or Active Power/Frequency Control
Functions." [Online]. Available:
https://www.nerc.com/pa/Stand/Reliability%20Standards/MOD-027-1.pdf.
[Accessed: 13-Mar-2023].

[9] "Electromagnetic transient modeling requirements - caiso.com,"
21-Oct-2020. [Online]. Available:
https://www.caiso.com/Documents/Presentation-ElectromagneticTransient
ModelSubmissionsRequirement-Oct212020.pdf. [Accessed:
13-Mar-2023].

[10] "National Renewable Energy Laboratory (NREL) home page | NREL." [Online]. Available: https://www.nrel.gov/docs/fy15osti/62053.pdf. [Accessed: 12-Mar-2023].

System Verification Documentation

5.4 Revision Table

Table XXIII
Section 5.4 Revision Table

3/10/2023	Austin Pearson: Initial formatting and section creation Michael DeCosta: Updated universal constraints
3/12/2023	Austin Pearson: Finished initial formatting. added Project Partner Requirements, Engineering Requirements, Verification Process, and Testing evidence.
5/7/2023	Cole Ferguson: Updated table formatting
5/11/2023	Austin Pearson: Confirmed engineering requirements and updated references.

6. Project Closing

6.1 Future Recommendations

6.1.1 Technical Recommendations

If at all possible, avoid using the free version PSCAD. We ran into a multitude of issues when dealing with this version of the software. The technical support is hardly responsive and took forever to correspond back with us when our program incurred errors.

When tuning the model, attempting to perfectly match the real world response is not possible. There is far too much noise in the sample data. Instead it is far easier and acceptable to follow the trend or average values of the sample and to track through the oscillations, as they are caused by real-world factors.

Estimating a cost analysis is difficult when the exact prices of inverters is ambiguous. We tried contacting the inverter manufacturer's sales department on multiple occasions and we were unsuccessful in acquiring an estimate of the price of the units to use as a reference for the inverter price in the cost analysis. Aside from the PV array itself, the inverters are

the most costly part of the entire site as the sheer number of them pushes the price past the cost of the transformers. Due to the complications involved with acquiring specific pricing, the cost analysis covers the site as a whole using government data, rather than a price for our specific system. In the future, a cost analysis document is not worth the work and the time can be better spent debugging or fault protection analysis.

Conduct research thoroughly to ensure no details are missed. Our project partner was invaluable during the research phase due to his training and knowledge to point us in the right direction for each topic. Utilizing the expertise that our project partner has acquired through his experience, the research could be streamlined with more coordination.

6.1.2 Global Impact Recommendations

Gaining experience using the programs gives valuable understanding and expectations for how an industry position might look. An impact of this project was teaching us how to use common industry power system programs so that we may have an exposure to them and be better equipped for a professional job that uses them. Having a thorough experience in these softwares is appealing to recruiters.

A complete model gives clients a good starting point in how the dynamics of a solar generation site might look, but there are plenty more in-depth processes that can be done to even more precisely model the site. An impact of this project is that it is providing our project partner with dynamic models of their proposed site, but we are only scratching the surface of everything that can be done in these softwares.

6.1.3 Teamwork Recommendations

A recommendation for a more successful project would be to have more frequent meeting times. This would make members more accountable, informed of progress, and cause progress to be achieved more timely. It would also allow teammates to more easily help each other when setbacks are encountered.

Scheduling meeting days and times two weeks in advance would reduce miscommunication and ensure availability. Creating a spreadsheet weekly with meeting days and times would be beneficial so that everyone can check it throughout the week and more easily work with each other instead of simply hoping that someone is available.

Establishing a consistent meeting place or zoom meeting link is also a simple suggestion. There was a period with our group where we had multiple meeting links floating around due to various reasons, which caused confusion within our group. Having a concrete meeting place would reduce confusion.

6.2 Project Artifact Summary

Data Collection
https://docs.google.com/document/d/1klN-JFKLDh9NiAqcUfkqiTzkKs_mQ64-/edit?usp=sharing&ouid=113358165243930705286&rtpof=true&sd=true

Model Acceptance
https://docs.google.com/document/d/1sS1_KOtWJzPi16hpTRvxyv5H7j0M4-ym/edit?usp=sharing&ouid=113358165243930705286&rtpof=true&sd=true

MV Schedule
https://docs.google.com/spreadsheets/d/1h_1WWqVbSiP0lrZiPlFgoIu6lRvcW7WdrZ7TjpitB7I/edit?usp=sharing

Site Data
https://drive.google.com/drive/folders/1TNBNSyQ_GjpfDSrZ11Esn2WtSCA49Yc3?usp=share_link

6.3 Presentation Materials

Overall Project Showcase site:
https://eecs.engineering.oregonstate.edu/capstone/ece/student/index.php

Requirements:
https://eecs.engineering.oregonstate.edu/capstone/ece/student/requirements.php

Block Diagram:
https://eecs.engineering.oregonstate.edu/capstone/ece/student/blockdiagram.php