Alternative Power Source to Draw Underground Water

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Team 01

Final Report

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1. Fall 2012 CEMEX Project Summary

1.1 Introduction

Figure 1 is an aerial view of the CEMEX mining site located on Babbitt Ranches' land. With the large amount of machines and operations using water, there is a very high demand for water on the site. There is one generator, rated at 60 kilowatts (80 horsepower) that supplies power to the pump. The generator rating is more than adequate to meet the pump's power rating of 45 kilowatts (60 horsepower). This pump supplies water from a depth of 520 meters (1700 feet) below the surface at a flow rate of 0.2838 m^3/min (75 gallons per minute). On average, CEMEX is pumping 30,000 gallons of water per day. Because of the high amount of water being pumped, there is a resulting high usage of diesel fuel. The large amount of diesel fuel being purchased by CEMEX, allows for a lower than average price of $3.50 per gallon of fuel.

FIGURE 1: CEMEX SITE [COURTESY: NASA]

1.2 Needs Identification

On October 11, 2012 the team met with the client Billy Cordasco, President of Babbitt Ranches. Mr. Cordasco identified the combined need of CEMEX and Babbitt Ranches for a new means of providing energy to draw water from wells with depths beyond 800 feet at various well sites throughout Babbitt Ranches' land. The first priority for both Babbitt Ranches and CEMEX is to lower the operating costs of their water pumping systems. In addition, they have also expressed interest in mitigating their carbon emissions. Considering all wells on Babbitt Ranches' property, the well that is utilized by CEMEX is the most demanding design challenge and has the highest diesel fuel usage. Therefore, Mr. Cordasco would like a solution to be found for the CEMEX dedicated well, which then can be applied to other wells that are found throughout the ranch property.

Need Statement: The client is unsatisfied with the cost of fuel as well as the emission penalties required to draw 75 gallons of water per minute from 1700 feet below the surface.

Problem Statement: The client requests a solution that will draw water from 1700 feet while maintaining the current flow rate of 75 gal/min and reducing overall cost.

1.3 Constraints

The following is a list of constraints for the project:

1. The pump is required to pump water from 1700 feet.
2. The pump must operate at a flow rate of 75 gallons per minute.
3. The energy system must supply 50 kW of power to the pump.

1.4 Wind Energy

When considering wind turbines as an application for power generation, the average wind speed at a certain site is extremely important for determining the energy potential. This importance lies in the cubic relationship between wind speed and potential power. Figure 2 is a topographic map of the CO Bar Ranchlands where the CEMEX site is located. The boundaries of the CO Bar lie within the regions that contain the colored dots, which indicate watering holes. The map shows the average wind velocity (m/s) profiles that are present in the area. The CEMEX site is specified by the large yellow arrow. It can be seen from the map that the average wind velocity for the CEMEX location is 5.5 m/s, which is insufficient in terms of the standard for ideal power potential for wind turbine placement.

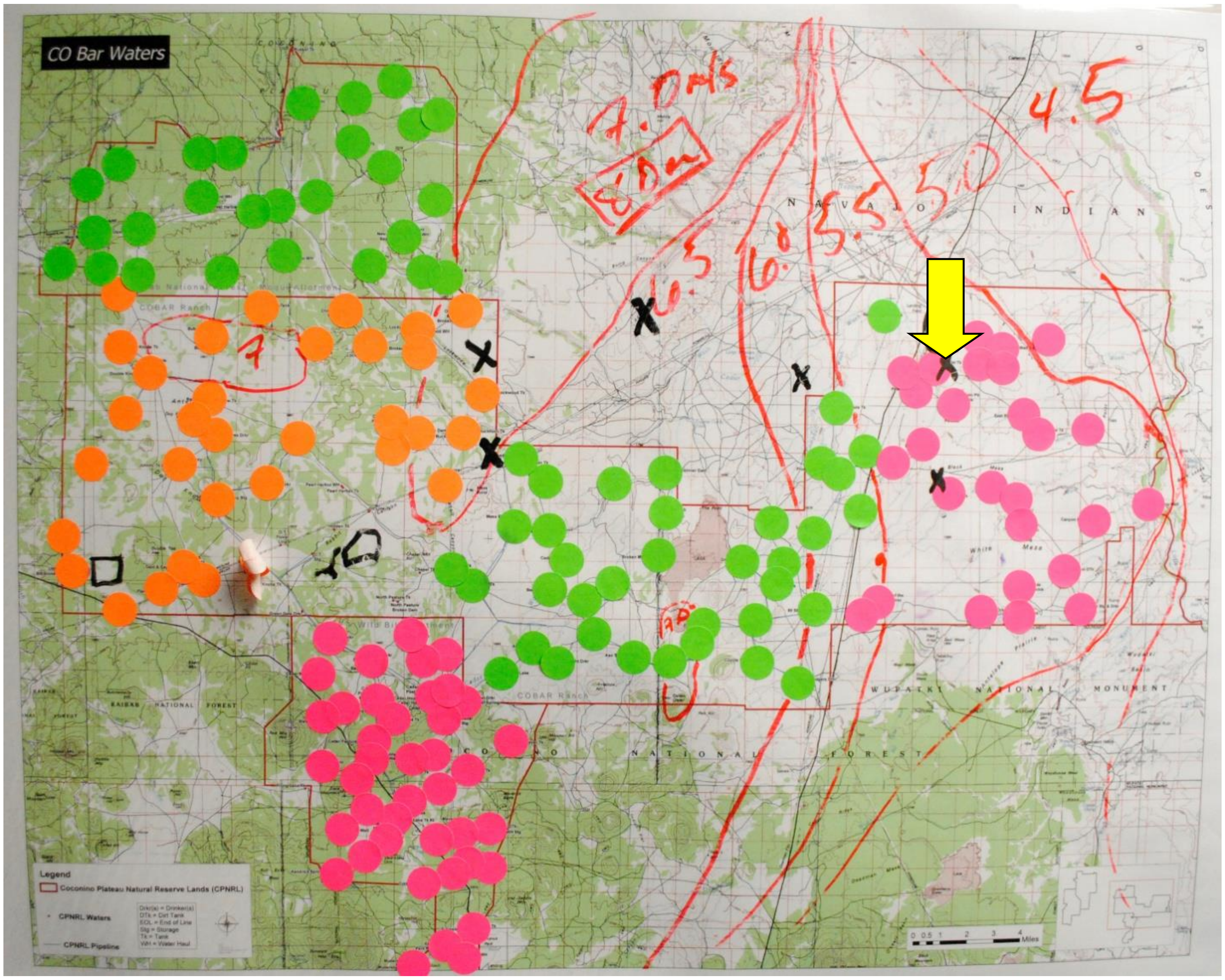


FIGURE 2: TOPOGRAPHICAL MAP OF CO BAR RANCHLANDS [COURTESY: DAVID WILLY]

The average wind speed of 5.5 m/s is helpful for determining a wind turbine(s) that would be required to be able to fully operate the water pump. However, wind turbines are not able to run on minimal amounts of wind speeds. For example, the wind turbine being considered in subsequent analysis to meet the energy requirements is only able to operate on wind speeds greater than 4.5 m/s. Thus, a MATLAB code was written to plot a Raleigh distribution based on an average wind speed of 5.5 m/s. Figure 3 is one result of that code. It displays how the frequency of wind speeds may vary throughout a typical day with an average of 5.5 m/s. Figure 3 illustrates that there would be a large percentage of wind velocities that are less than 4.5m/s, which would be unusable for this operation.

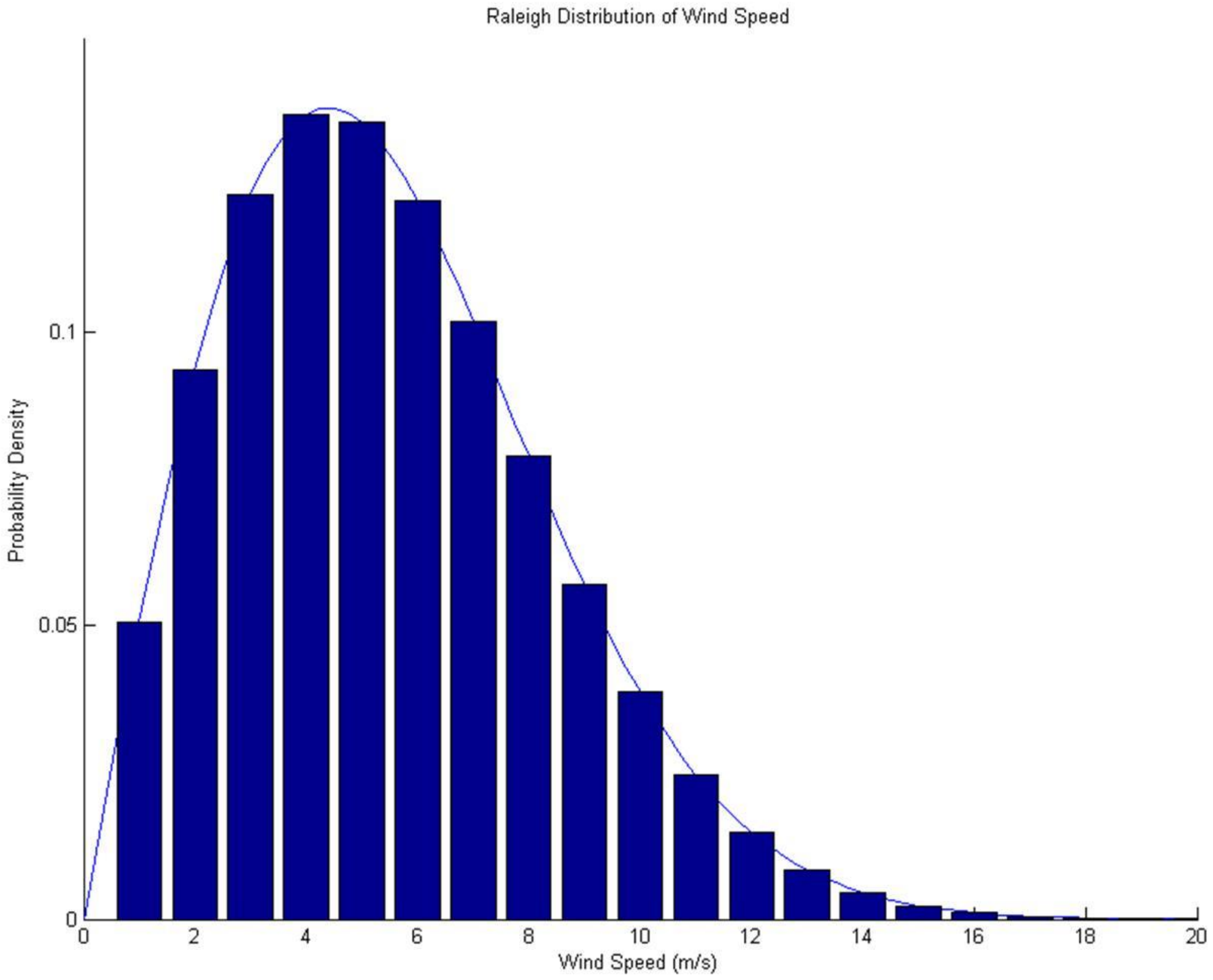


FIGURE 3: RALEIGH DISTRIBUTION BASED ON AVERAGE WIND SPEED

Calculations were then performed to determine the properties of the usable wind that the CEMEX site would experience. These showed that the site would receive usable wind speed (above 4.5 m/s) 64.29% of the time.

A wind turbine's cut in speed is defined as the wind speed that is necessary to provide enough torque to turn the turbine and generate power. For most turbines cut in speed is approximately 4.5 m/s. Additionally, wind turbines do not produce power at their designated power rating until wind speeds reach approximately 14m/s. Figure 4 below shows an idealized power curve for a wind turbine with a 30 m rotor diameter. It shows the amount of power that this particular turbine would output based on the wind speed available. It shows again that the poor average wind speed would provide very low amounts of power comparable to how much power the turbine can actually produce. This would mean that purchasing a turbine would be far overpaying for the turbine's power potential, when only much lower amounts of power are needed.

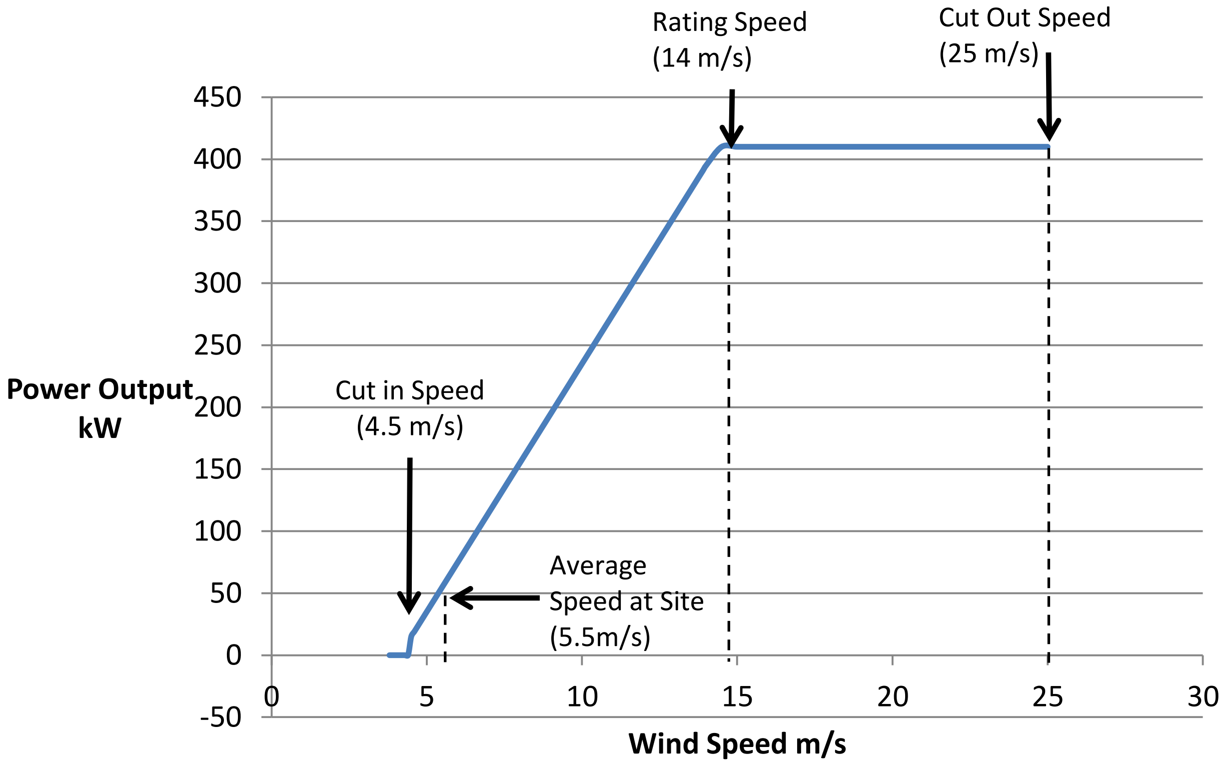


FIGURE 4: IDEALIZED POWER CURVE - 30M ROTOR DIAMETER

1.5 Wind Power Cost

Assuming a turbine of specifications previously discussed and a given average wind speed of 5.5m/s that will meet the energy demands of the client, a cost analysis was performed. The associated cost of a wind turbine of this scale is illustrated in Table 1 which includes a subsidy (30% of installation cost) by the Federal Government for renewable energy projects.

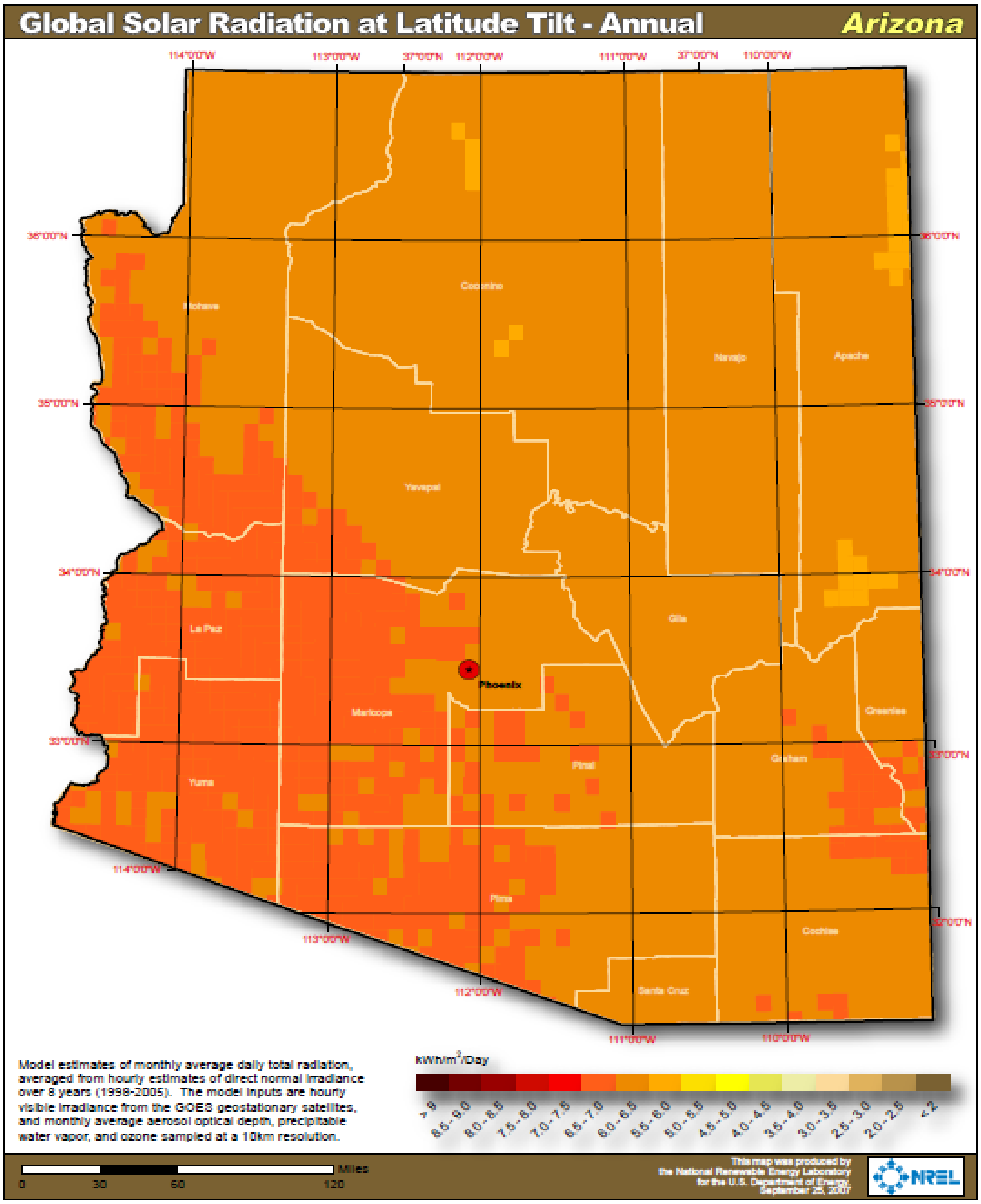
TABLE 1: WIND POWER COST

Estimated Cost	Amount	Units
Average cost of single Turbine	1,250,000.00	$
Installation Cost of Turbine Array	1,250,000.00	$
Federal Tax Credit	375,000.00	$
Net Cost	875,000.00	$

The average wind speed at the location is approximately 5.5 m/s. The relatively poor wind speed requires that the wind turbine be oversized to compensate, increasing the cost of installation. Additionally another large problem with a wind turbine would be that a standard diesel generator would have to be fully available, at full cost of fuel and ownership, to meet the power needs of the client if the turbine production was suboptimal. This requirement coupled with the poor average wind speed may prevent the installation of a wind driven power generation system and the associated large capital investment. The team recommends that a wind power resource no longer be considered to meet the needs of the client.

1.6 Solar Energy

Arizona is well known for having an extremely high percentage of days with full sun. Figure 5 shows the average sun resource for Arizona in kWh/m^2/day. The CEMEX site experiences 6.0-6.5 kWh/m^2/day, which is more than adequate for the consideration of solar installation. These values alone indicate that solar may be a highly optimal resource for this application.



Model estimates of monthly average daily total radiation, averaged from hourly estimates of direct normal irradiance over 8 years (1998-2005). The model inputs are hourly visible irradiance from the GOES geostationary satellites, and monthly average aerosol optical depth, precipitable water vapor, and ozone sampled at a 10km resolution.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. September 25, 2007

FIGURE 5: SOLAR RESOURCE FOR ARIZONA [COURTESY: NREL]

1.7 Photovoltaic System with Battery Array Cost Analysis

One main idea of how to utilize the resource of the sun was to use a photovoltaic panel (PV) array with a corresponding battery array. The PV panels would capture energy from the sun and either send it to the pump or store it into the batteries for future use. Research has shown that six days of autonomous function are required for systems that are not grid tied. This means that the battery array would need to provide six full days of power when there is no solar resource available for the PV array, such as during long stormy weather. For this to be possible, 384 batteries would be required to match the demand. A wholesale cost estimate of this is $1,300,000 which is comparable to the cost of the entire PV array itself. Additionally, these batteries have a maximum 11 year maximum life. Cost analysis found that there would be an 18 year time period for the batteries to pay back their cost in diesel fuel savings. This shows that it would payback period is greater than the useful life of the batteries. As a result, the team recommends that a solar array with battery backup no longer be considered to meet the needs of the client.

1.8 Photovoltaic System with Diesel Backup Cost Analysis

Various metrics were calculated to understand the performance of a solar array as compared with the current diesel generator system. The following shows the results of calculating cumulative cash flow at the optimum system size. The system was optimized to provide 100% of the pump's energy requirements given perfect weather conditions. To ensure that the pump could deliver 30000 gallons of water per day, the system was oversized to account for the changing angle of the sun. However, cloud cover may dictate that the system is unable to produce the power the pump requires and thus the pump would have to rely on the diesel generator. Various assumptions were made in calculating the performance of the system (Table 2). One assumption that must be noted is the annual increase in fuel price is 2.5%. The team's research indicates that this is a conservative annual fuel price increase.

TABLE 2: ASSUMPTIONS

Assumptions	
Factor	Assumption
Solar Resources	Assumed solar irradiance value of 900 watts per square meter
Panel Contamination	Cleaned frequently: 98% sunlight transmission
Temperature	System operates at average temperature of 25C
Orientation	South facing array: Tilted at optimal angle for given latitude
Shading	Array can provide power for 80% of available hours per year
Energy Delivered	Various system losses: Delivery is 81%
Fuel Price	Diesel fuel will rise 2.5% annually
Diesel Generator	Generator must be available to ensure power demands are met

The cumulative cash flow for the project can be seen in Figure 6. The project will have a payback period of greater than 20 years. With an annual fuel price increase of 2.5% the fuel savings are not sufficient to offset the project cost.

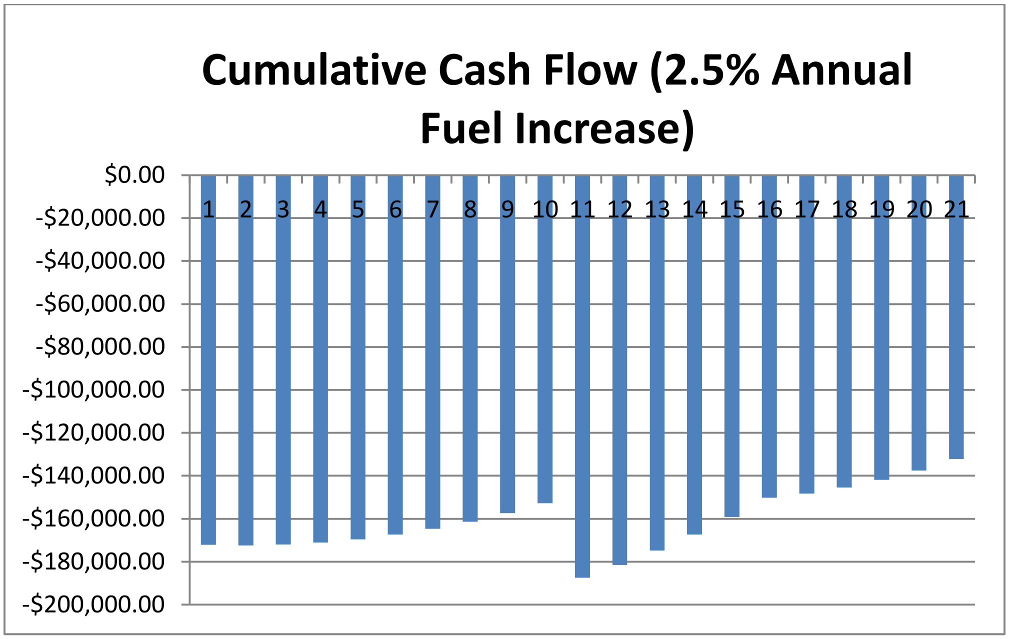


FIGURE 6: CULUMLATIVE CASH FLOW

The payback period for the previous iteration of the project was found to be suboptimal. The team discovered that an annual fuel price increase of 4.5% brought the project payback period into a reasonable timeframe. The team's reevaluation of assumptions is illustrated in Table 3.

TABLE 3: ASSUMPTION REEVALUATION

Assumptions	
Factor	Assumption
Solar Resources	Assumed solar irradiance value of 900 watts per square meter
Panel Contamination	Cleaned frequently: 98% sunlight transmission
Temperature	System operates at average temperature of 25C
Orientation	South facing array: Tilted at optimal angle for given latitude
Shading	Array can provide power for 80% of available hours per year
Energy Delivered	Various system losses: Delivery is 81%
Fuel Price	Diesel fuel will rise 4.5% annually
Diesel Generator	Generator must be available to ensure power demands are met

The associated system configuration necessary to meet the power demands of the pump can be seen in Table 4.

TABLE 4: ESTIMATED SYSTEM SIZE

Estimated System Size	
Solar Rating Northern Arizona (Watts-per-square meter)	900
Panel Efficiency	15%
System Efficiency	81%
Number of Panels	420
Equivalent Area Required (square meters)	504
System Power Delivered (kilowatts AC)	55.34

The team created a MATLAB program which would take these inputs, as well as local weather and sun conditions, to create a plot of the total energy the PV panels are able to output as a function of the hour of the day. This plot is shown below in Figure 7.

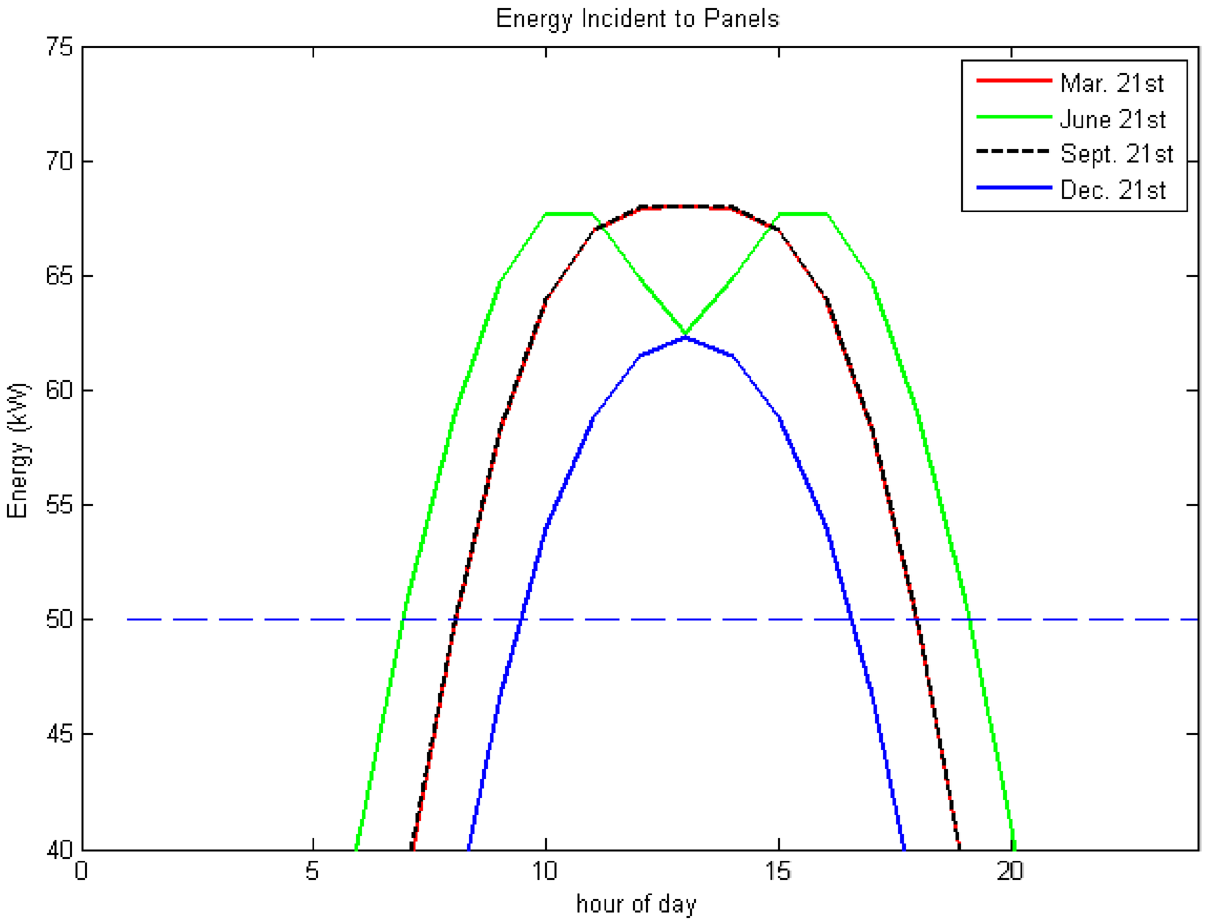


FIGURE 7: ENERGY AVAILABLE TO PV ARRAY VERSUS HOUR OF DAY

The estimated system cost is based upon average system a cost of similar size is shown in Table 5.

TABLE 5: ESTIMATED SYSTEM COST

Estimated System Cost	
Average Cost per Watt (AC):	$7.00
System Installation Gross Cost	$387,368.81

Financial Incentives at the time of installation are shown in Table 6. Refer to Cumulative Cash Flow in Table 8 to see incentives span the life cycle of the array of 20 years. A number of incentives for renewable energy installations exist. The few listed are applicable for an off-grid installation in Arizona of the rated size.

TABLE 6: FINANCIAL INCENTIVES

Financial Incentives	
Federal Tax Credit (30% of cost)	$116,210.64
State Credits corporate (10% of gross cost)	$38,736.88
Utility Credits APS Utility rebate ($1.35 per Watt AC)	$74,706.84
AZ solar energy production tax credit ($0.01 per kilowatt-hr)	$25,566.34
ESTIMATED NET COST	$132,148.10

Figure 8 is the summary of the cumulative cash flow the installation can expect over time. The annual net cash flow is the total cash after all costs are summed with all incentives, fuel savings, and tax effects. Cash Flow breakeven is where the chart crosses the $0 point. The chart illustrates that the project will have a payback period of approximately 19.5 years (column 1 represents cash flows at installation i.e. year zero, therefore column 20 is representative of year 19).

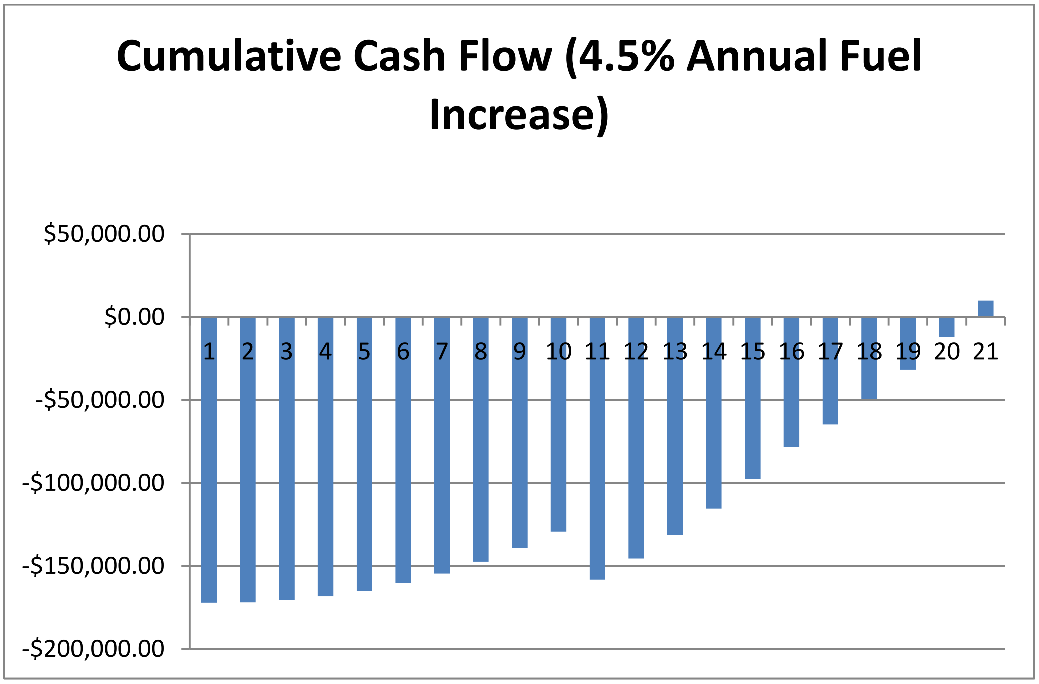


FIGURE 8: CUMULATIVE CASH FLOW

Financial and environmental benefits of the solar array are listed in Table 7.

TABLE 7: SAVINGS AND BENEFITS

Savings And Benefits	
Average Monthly Fuel Savings (20 year life)	$3,797.16
Average Annual Fuel Savings (20 year life)	$45,565.94
20 Year Fuel Savings	$911,318.75
Levelized cost of Solar Energy for Installation ($/(kW-hr))	0.49
CO2 Saved over lifetime of array (Tons CO2)	1,628.19

Cash flow and cumulative cash flow by year is illustrated in Table 8. The current year's value of cumulative cash flow is the sum of the previous year's cumulative cash flow and the current year's annual cash flow.

TABLE 8: CUMULATIVE CASH FLOW BY YEAR

Year Of Operation	At Installation	1	2	3	4	5	6	7	8	9
Gross Installation Cost	-$387,368.81	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$116,210.64	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$25,566.34	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$38,736.88	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$74,706.84	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$0.00	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38
Diesel Fuel Savings per Year	$0.00	$29,049.33	$30,356.55	$31,722.59	$33,150.11	$34,641.86	$36,200.75	$37,829.78	$39,532.12	$41,311.07
Annual System Maintenance	$0.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	$0.00	-$6,550.34	-$6,845.10	-$7,153.13	-$7,475.02	-$7,811.40	-$8,162.91	-$8,530.24	-$8,914.11	-$9,315.24
Generator Purchase (10 year life)	-$35,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	-$5,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	-$172,148.10	$246.37	$1,258.82	$2,316.84	$3,422.46	$4,577.84	$5,785.21	$7,046.91	$8,365.39	$9,743.20
Cumulative Cash Flow	-$172,148.10	-$171,901.74	-$170,642.92	-$168,326.08	-$164,903.62	-$160,325.78	-$154,540.57	-$147,493.66	-$139,128.27	-$129,385.06

Year Of Operation	10	11	12	13	14
Gross Installation Cost	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38
Diesel Fuel Savings per Year	$43,170.07	$45,112.72	$47,142.79	$49,264.22	$51,481.11
Annual System Maintenance	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	-$9,734.43	-$10,172.48	-$10,630.24	-$11,108.60	-$11,608.48
Generator Purchase (10 year life)	-$35,000.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	-$5,000.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	-$28,816.99	$12,687.62	$14,259.93	$15,902.99	$17,620.00
Cumulative Cash Flow	-$158,202.05	-$145,514.43	-$131,254.50	-$115,351.51	-$97,731.51

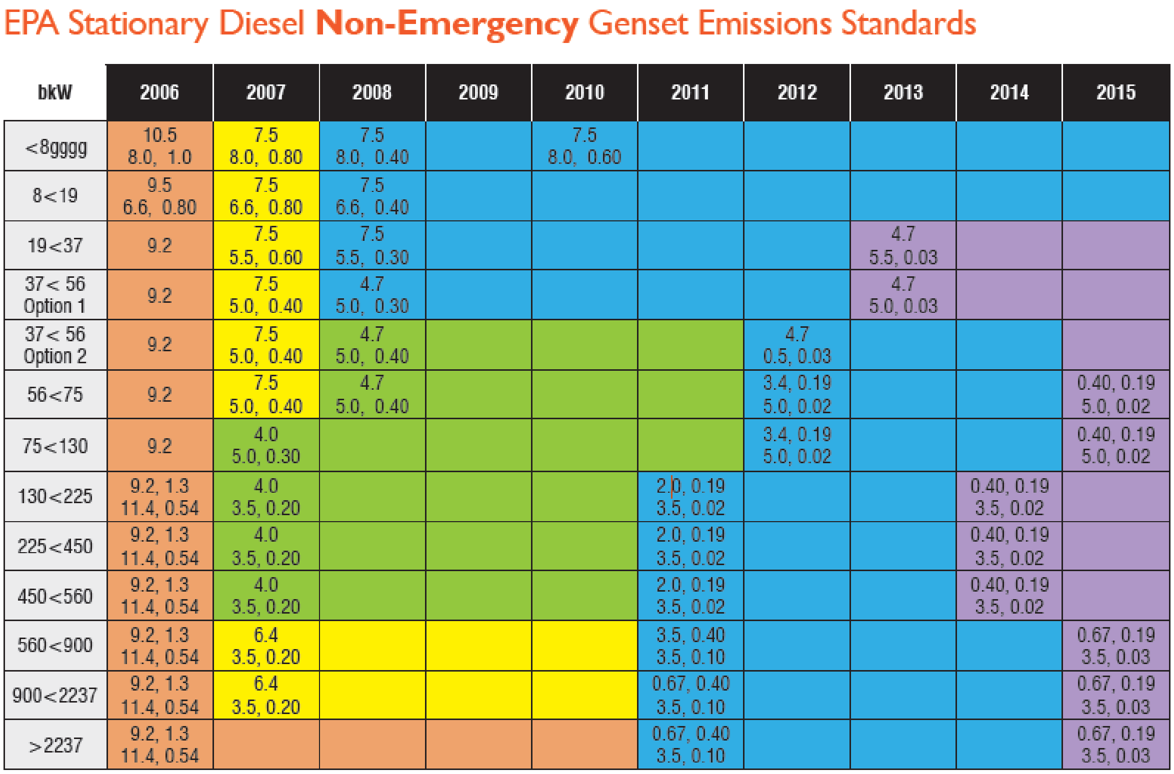
Year Of Operation	15	16	17	18	19	20
Gross Installation Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$7,747.38	$0.00	$0.00	$0.00	$0.00	$0.00
Diesel Fuel Savings per Year	$53,797.76	$56,218.65	$58,748.49	$61,392.18	$64,154.82	$67,041.79
Annual System Maintenance	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	-$12,130.87	-$12,676.76	-$13,247.21	-$13,843.33	-$14,466.28	-$15,117.27
Generator Purchase (10 year life)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	$19,414.27	$13,541.90	$15,501.28	$17,548.84	$19,688.54	$21,924.52
Cumulative Cash Flow	-$78,317.24	-$64,775.34	-$49,274.06	-$31,725.22	-$12,036.68	$9,887.85

The previous analysis shows the high sensitivity of the payback period to the percentage rise in fuel price. The volatility of fuel prices makes it difficult to make an accurate forecast of future prices. Given a modest annual fuel price increase of 2.5% the installation payback period is much greater than 20 years. At a 4.5% annual fuel price increase the payback period approaches an appropriate timeframe for a project of this scale.

1.9 Diesel Generator Analysis

One of the clients' main concerns is the purchase of a new diesel generator to conform to new EPA standards. This factor directly relates to why they are considering alternative energy as means of drawing water before the new emission standards take effect. If an alternative energy system could be designed to draw the water and fulfill the flow requirements of the client, there would be no need to purchase a new generator and potentially, a huge savings on the cost of diesel fuel.

The upcoming Tier 4 Emissions Standards were initiated by the EPA in 2006 for all non-road diesel generator sets. The program introduces a significantly more stringent set of limitations placed on diesel generators to reduce carbon emissions. The program started taking place in 2011 and finalizes in 2015. The time period for conforming to the new Tier 4 standards is indicative of generator size, with larger generator sets required to conform earlier followed by smaller generators to conform by 2015. The following chart illustrates the year in which specific generator sets must comply with the new EPA standards.



EPA Stationary Diesel **Non-Emergency** Genset Emissions Standards

bkW	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<8gggg	10.5 8.0, 1.0	7.5 8.0, 0.80	7.5 8.0, 0.40		7.5 8.0, 0.60					
8<19	9.5 6.6, 0.80	7.5 6.6, 0.80	7.5 6.6, 0.40							
19<37	9.2	7.5 5.5, 0.60	7.5 5.5, 0.30					4.7 5.5, 0.03		
37< 56 Option 1	9.2	7.5 5.0, 0.40	4.7 5.0, 0.30					4.7 5.0, 0.03		
37< 56 Option 2	9.2	7.5 5.0, 0.40	4.7 5.0, 0.40				4.7 0.5, 0.03			
56<75	9.2	7.5 5.0, 0.40	4.7 5.0, 0.40				3.4, 0.19 5.0, 0.02			0.40, 0.19 5.0, 0.02
75<130	9.2	4.0 5.0, 0.30					3.4, 0.19 5.0, 0.02			0.40, 0.19 5.0, 0.02
130<225	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
225<450	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
450<560	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
560<900	9.2, 1.3 11.4, 0.54	6.4 3.5, 0.20				3.5, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03
900<2237	9.2, 1.3 11.4, 0.54	6.4 3.5, 0.20				0.67, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03
>2237	9.2, 1.3 11.4, 0.54					0.67, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03

FIGURE 9: TIER 4 EMISSIONS STANDARDS-COURTESY WWWW.GENERAC.COM

As can be seen from Figure 9, the 60 kW diesel generator used at the CEMEX site does not need to be replaced until 2015. This being said, it has been difficult to price an exact generator to fulfill the needs of the client because generator manufacturers have released only larger generator sets to conform to the standards that take place in the initial stages of the Tier 4 program.

After contacting generator manufactures, it is assumed, by information given by sales agents, that although no official MSRPs have been released, they cost of a new generator that conforms to the new EPA standards should be comparable to the cost of current generators of equal power, in the range of $35,000-$40,000. Cummings Diesel stated that they offered a Tier 4 maintenance program which guaranteed that if a new generator was purchased that did not currently conform to Tier 4 standards they would overhaul or replace the generator before the standards were set to take effect. The price quoted for this guarantee was $5,000, but it was stated that was only an approximation and not an exact quote.

1.10 Recommendation

Two natural resources were initially considered for a renewable energy system to pump water: wind and solar. The wind resource was found to be insufficient to meet the project requirements. This left solar as the only option. A solar system with battery storage was initially considered so the system could be completely autonomous with no back-up system required. The cost of a battery bank, sized to the project requirements, was found to be cost prohibitive. This left a final option for solar: using an over-sized solar array to power an inverter which would feed electricity directly to the pump during the hours of the day when the solar energy would be high enough to generate the required electricity.

In terms of engineering analysis, this option was found to be the most viable because solar is an abundant resource at the site and it also eliminated the extremely large battery bank. The major shortcoming of this system is that back-up diesel generation would be required.

In the calculations, it was assumed that the solar system would be able to pump 80% of the annual water requirements, thus, only 20% of the water would need to be pumped with a diesel generator.

The solar/diesel system was then financially compared to a diesel-only system. The major costs associated with a solar system are the initial investment and annual maintenance, which consists of cleaning, replacing parts, system monitoring and more. The major costs associated with a diesel only system are the initial purchase, regular maintenance, and fuel.

In comparing the two, it was found that diesel would have increase 4.5% year over year for a solar/diesel system to be cost effective (Figure 8). This means that in twenty years the price of diesel per gallon would be close to $8.44. Under these conditions it would take 20 years to recover the cost of the initial investment.

The analysis is highly subject to a variety of assumptions and beliefs about future costs. With the high energy requirement of the project, solar energy is worth considering as an alternative or supplement to diesel under any of the following conditions:

1) Technological innovation decreases solar system cost
2) Bigger alternative energy incentives are offered
3) Cost of diesel increases by 4.5% or more every year

Although a solar/diesel system currently is not a cost effective option, it is worth noting its potential for future energy generation.

1.11 Proposal

After the team presented the proposal to the client, the client chose not to act upon the option of a solar panel system in conjunction with the diesel generator. The main reason for not using this for the client’s problem was the payback period. As stated before the payback period for the whole system would be 19 years. The client mentioned that the overall lifetime of a PV array is not that much longer than those 19 years, therefore only a minimal amount of money would have been saved. As a solution to the problem the client will purchase a new generator that compiles with the newest tier 4 standards. Also the client is only using the area on Babbitt Ranches for another 25 years. The team is not able to guarantee that the whole system will last for that long without replacing panels, which would have caused an increase in the overall cost for the whole project.

2. Spring 2013 Babbitt Ranches Project

2.1 Introduction

The client, Babbitt Ranches, has proposed a direction for the Spring 2013 Capstone project. Babbitt Ranches currently pumps water at the Cedar Ridge Well as its primary head water for many of its stock tanks. It is located northwest of Flagstaff off of Fort Valley road and has a 243,000 gallon storage tank in proximity. Currently, the storage tank is not in use because the well has not been pumping at the capacity it was when initially installed. The Slate Mountain Well is a supplemental supply of water to Cedar Ridge Well. Slate Mountain Well is on US Forest Service land and is a contracted supply of water for Babbitt Ranches. Both wells currently operate using diesel generators, which the client would like to substitute for cost saving alternative energy sources.

2.2 Goals

Goal Statement: The team will design an alternative energy system that can be utilized to draw water from wells at 120 to 600 feet that can reduce the client's current operating expenses and simulate the system under a variety of conditions.

Scope of the Goal Statement: The team plans to analyze the problems that Babbitt Ranches are experiencing, and through the analysis, create a design that meets the objectives set forth for this project. A simulation will be created that will test such a system under a variety of conditions.

2.3 Constraints

The team's sponsor requested that the Ranch Manager for the Cedar Ridge/Slate Mountain site be contacted for information regarding the redefined project. The data acquired and presented in Table 9 are approximations.

As can be seen in Table 9, the project will include three wells at two locations. These two sites are close in proximity and work in conjunction as the head water for most of the gravity fed pipe system operating on Babbitt Ranches. Comparing the new data with the original project data, it can be seen that the new sites have much shallower wells and substantially slower flow rates.

These two factors will be an advantage when attempting to design an alternative energy system to draw the necessary water. The most notable disadvantage is that the current diesel generator system is pumping water continuously. This factor is always a problem for alternative energy systems. The majority of systems engineered to surpass this issue result in higher initial costs, which results in prolonged payoff periods.

TABLE 9: CONSTRAINTS

	Cedar Upper	Cedar Lower	Slate Mtn.	units
Depth	120	300-400	400-600	ft
Flow Rate	18	5	32	gpm
Pump	Submersible 460 3 Phase			
Generator Distance from Well	.5 mile	400 yds.	on site	
Generator Type	Perkins 20kW, 4 cylinder	Perkins 12kW, 3 cylinder	Perkins 12kW, 3 cylinder	
Fuel Usage	0.75 - 1.0			gph
Avg Daily Run Time	24 hours per day			
Time of Year Opp.	All Year		April - November	
Pipe Outlet Dia.	1.25		2	in
Fuel Tank	1800		500	gal
Refueling Time	2 - 3 months		Refueled from Cedar Tank	

2.4 Possible Solutions

The team has discussed several solutions which have been deemed feasible. The new project has lower flow rates, shallower well depths, and the renewable energy resources are greater at the new site, mainly through higher wind speed averages. The team chose to combine the power requirements of the two pumps located at the Cedar Ridge site and model a system that could meet the needs of the Cedar Ridge location. If the solution was deemed feasible, the principles could be applied to the Slate Mountain location. Accordingly, the team will propose the following solution:

1. The power needs will be met by a solar panel array in conjunction with a wind turbine. If the needs are not met by the two alternative energy sources, a backup diesel generator will be brought on line to supply the demands.

3. Simulink Simulation

3.1 Simulink Model

In order to show the effectiveness that the team's designed solution will have, a simulation is extremely beneficial to prepare. The team will be using Simulink, which is a subprogram of MATLAB, and can model dynamic systems. Figure 10 below depicts the overall flowchart for which the entire simulation should model. Solar and wind data will be used to calculate available power from the solar and wind resources, while the available power from the diesel generator will be held as a constant. A controller will then decide which energy resource is of best use and will distribute the appropriate amount of power to two pumps and a house that is on site.

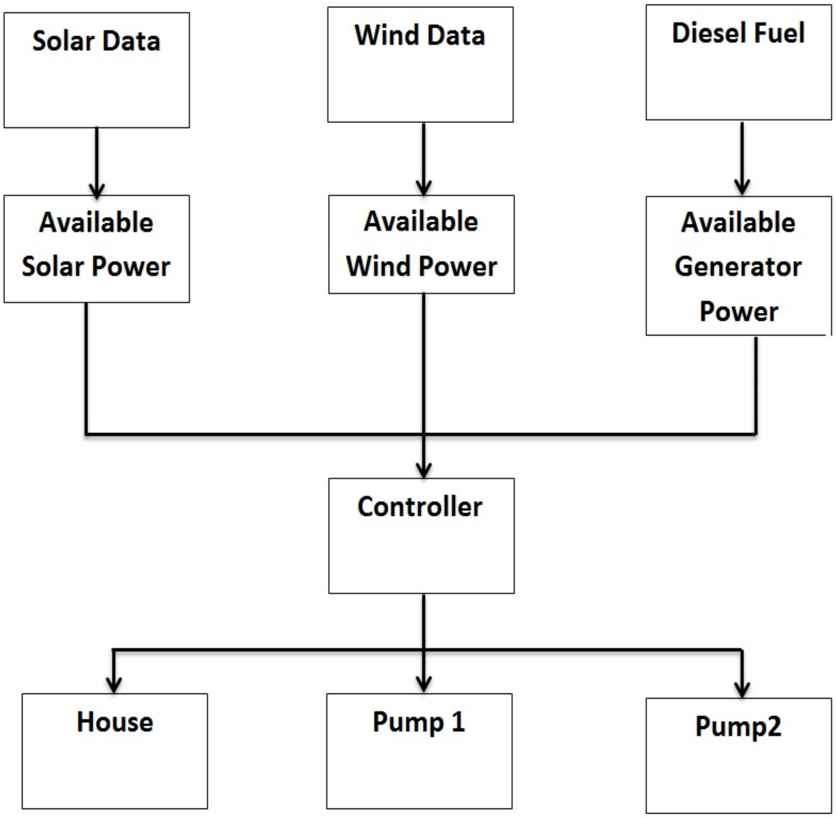


FIGURE 10: SIMULINK FLOWCHART

In order to maximize the team efficiency, the large simulation has been broken down into several models for separate subgroups to handle. There are currently four models: solar array/battery bank model, wind turbine/gearbox/generator, backup diesel generator model, and a controller model.

3.2 Solar Array Model

The simulated solar array it comprised of three major subsystems: input, computation, and output. The data input is solar insolation. The computations are done by an array of solar cell models. The output is voltage, current, and their product—power.

For example, Figure 11 shows the insolation curve and resulting power generated by the solar array for the first day of April, 2006 at the Mesa Butte. The solar array generates enough power to run the pump when the insolation on the solar array is at 450 W/m^2 or higher.

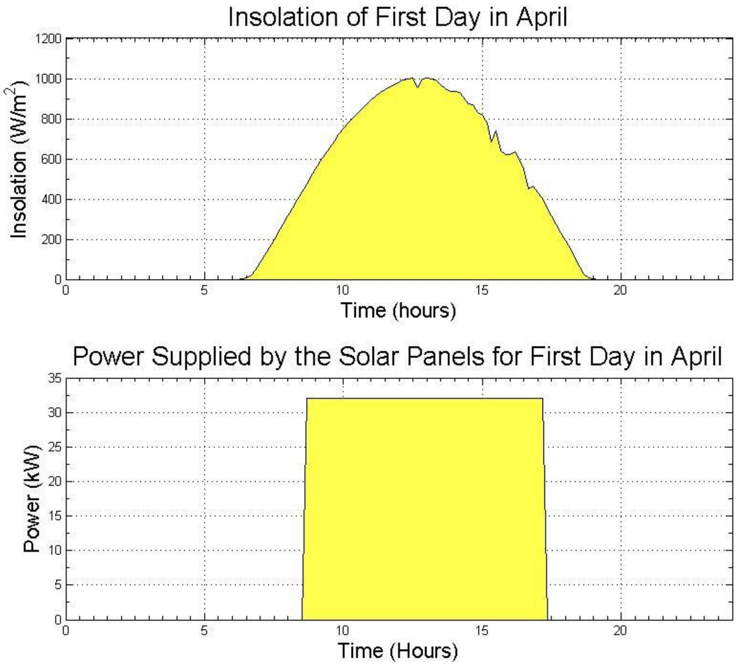


FIGURE 11: EXAMPLE OF APRIL 1ST INSOLATION AND RESULTING POWER FROM SOLAR ARRAY

3.2.1 Inputs

The team will be using a data collected at the Mesa Butte site. Each data point was taken at a ten second interval over the course of a year. The simulation is capable of running each month, each season or the entire year of data.

3.2.2 Physical Model

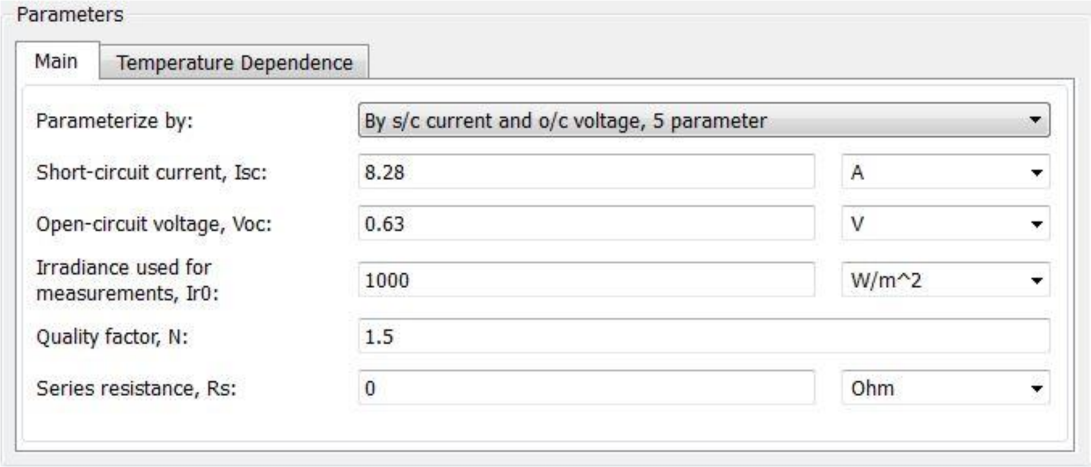
The solar array model currently consists of 30 panels in series and 30 panels in parallel for a total of 900 panels. The number of panels in series affects the voltage and the number of panels in parallel affects the current. The solar panel used in the model to make up the array is the SunModule® 250W. It consists of 60 mono-crystalline cells. The solar panel operates at 14.91% efficiency, which is near the current industry standard. The panel specifications can be seen in Table 10.

TABLE 10: SUNMODULE® 250W SOLAR PANEL SPECIFICATIONS [21]

	Value	Units
Maximum Power	250	W
Open Circuit Voltage	37.8	V
Short Circuit Current	8.28	A
Maximum Power Point Voltage	31.1	V
Maximum Power Point Current	8.05	A
Efficiency	14.91	%

3.2.3 Solar Panel

In this initial stage of the model, the insolation data is converted to a physical signal for the model and run through a single solar panel. Each cell within the solar panel was modeled using a predefined Simulink® solar cell. To match the specifications of the selected solar panel, 60 cells make up one panel and the open circuit voltage of each cell in the panel is 0.63 V and the short circuit current is 8.28 A (Figure 12). Each panel contains six parallel strings of ten cells in series (Figure 13 & Figure 14).



Parameterize by: By s/c current and o/c voltage, 5 parameter

Short-circuit current, Isc: 8.28 A

Open-circuit voltage, Voc: 0.63 V

Irradiance used for measurements, Ir0: 1000 W/m^2

Quality factor, N: 1.5

Series resistance, Rs: 0 Ohm

FIGURE 12: PARAMETERS OF A SINGLE SOLAR CELL WITHIN SOLAR PANEL

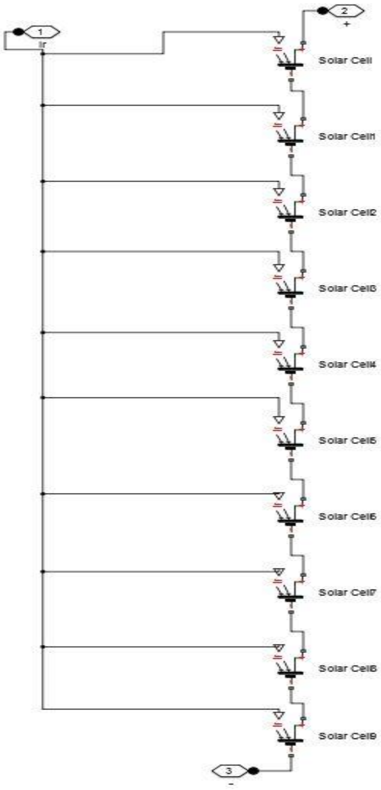


FIGURE 13: TEN SOLAR CELLS IN SERIES

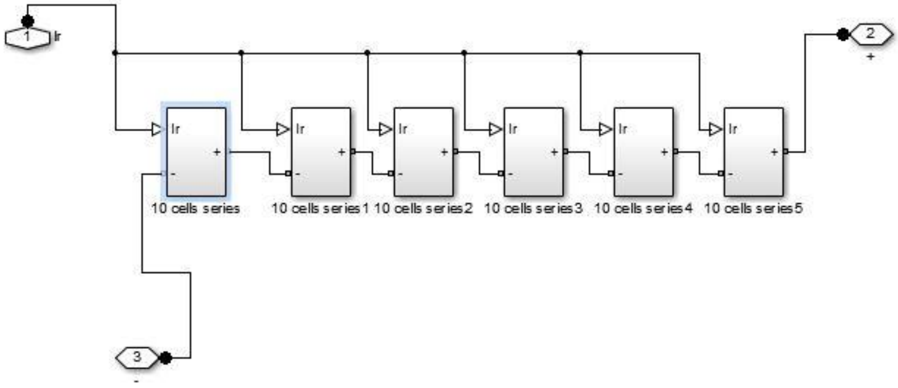


FIGURE 14: SIX PARALLEL STRINGS OF SOLAR CELLS

3.2.4 Voltage and Current Computation: Solar Array

Once the insolation data has been run through the solar panels, the resulting voltages and currents are read by sensors. The voltage is multiplied by the number of solar panels in series and the current is multiplied by the number of panels in parallel (Figure 15). Thus, the single solar panel is turned into an array of panels. The total power of the array is calculated by multiplying the resulting voltage and the current.

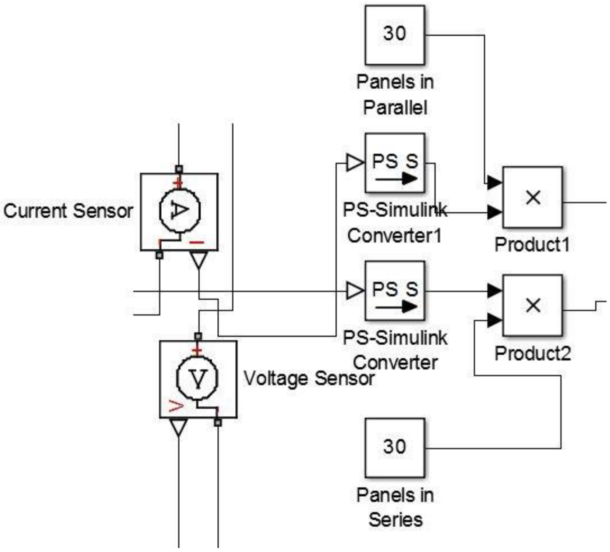


FIGURE 14: PANELS IN PARALLEL AND SERIES

3.2.5 Voltage Regulation

Insolation readings vary throughout the day. It is at a minimum when the direct beam of the sun is near parallel to the solar panel. This occurs near dawn and dusk. The insolation readings are at a maximum when incident to the surface of the solar array or panel. This causes the voltage and current of the array to vary drastically throughout the day, thus, it creates wide variation in the resulting power of the array.

To prevent wide variations in power, a voltage bucker is used before the controller. A voltage bucker is a type of transformer which variably steps down the voltage to result in an appropriate power. The power of the solar array is stepped down to 32 kW when the power from the array is great than 32 kW. The voltage bucker was modeled with an “if” statement: “If the power from the solar array is less than 32 kW, then the power from the bucker is zero, and conversely, If the power from the solar array is equal or above 32 kW, the power from the bucker is exactly 32 kW” (Figure 16).

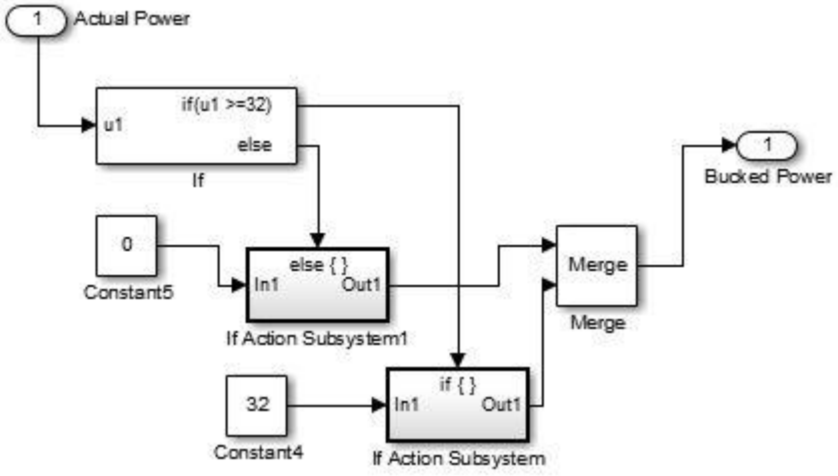


FIGURE 15: VOLTAGE REGULATION “IF” STATEMENT

3.2.6 Results

The solar simulation takes solar irradiance data, currently in ten second intervals, and computes the voltage, current, and power of the interval. The voltage is function of the number of panels in series, the current is a function of the number of panels in parallel and the power is simply the multiplication of the voltage and current.

The simulation was run for each month of the year, each season, and for the whole year. Both the monthly and seasonal histograms show what percent of the month the solar array could have run the pump (Figures 17 & 18). The annual data shows how much power came from each component of the system. The solar array would have produced 18% of the year's power at the Mesa Butte site (Figure 37).

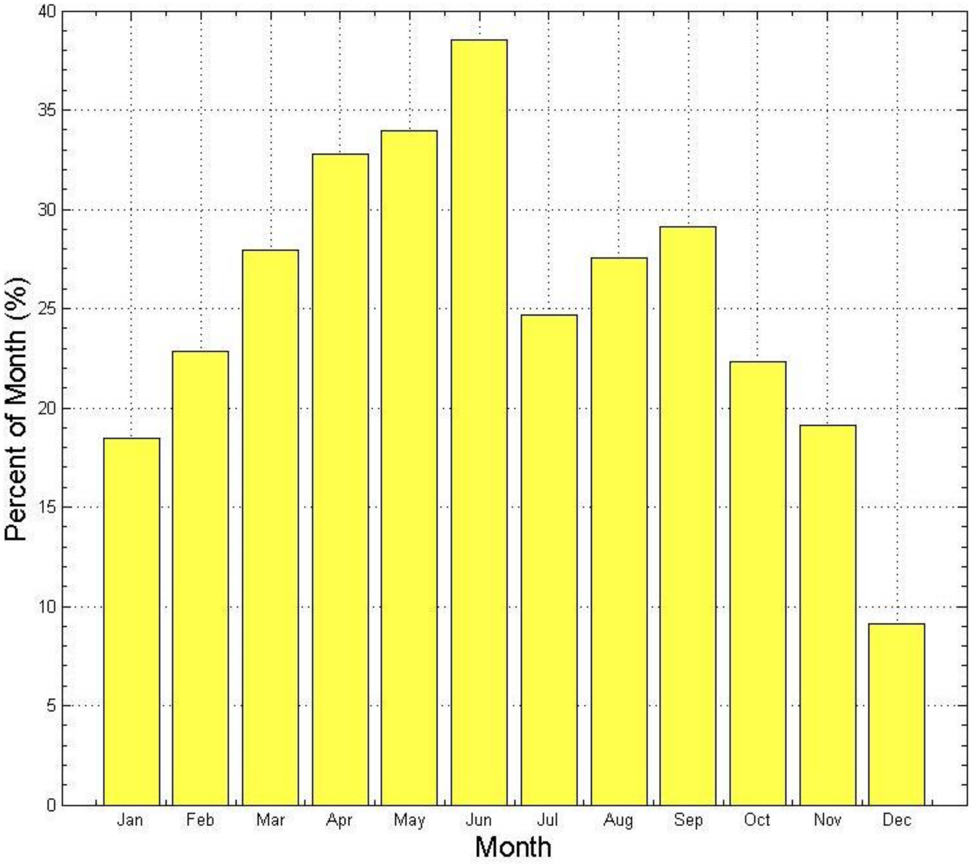


FIGURE 16: MONTHLY PERCENT SOLAR SYSTEM MEETS NEEDS OF PUMP (32 KW)

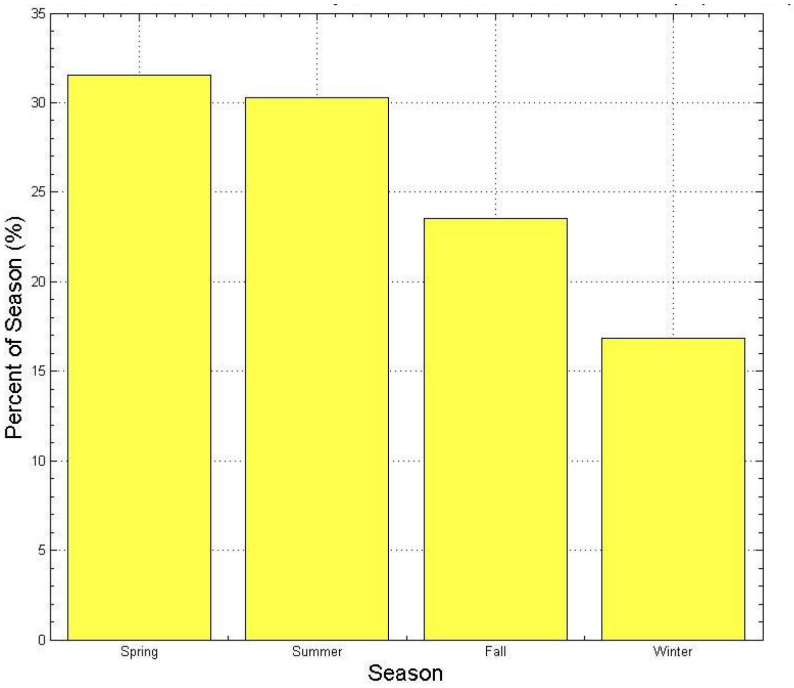


FIGURE 17: SEASONAL PERCENT SOLAR SYSTEM MEETS NEEDS OF PUMP (32 KW)

3.3 Wind Turbine Model

3.3.1 Pump Power Specification

The pump employed by Babbitt Ranches is a submersible pump that requires 460 Volts, 3 Phase, 60 Hz power supply. Considering this criteria, the team chose a 6 pole AC generator that would be connected with the wind turbine shaft via a gear box and operate at 1200 RPM to supply the pump.

3.3.2 Wind Turbine Rotor Sizing

The site for generating electricity to pump water is located in an area that has an average wind velocity of 6.5 m/s (see Figure 19).

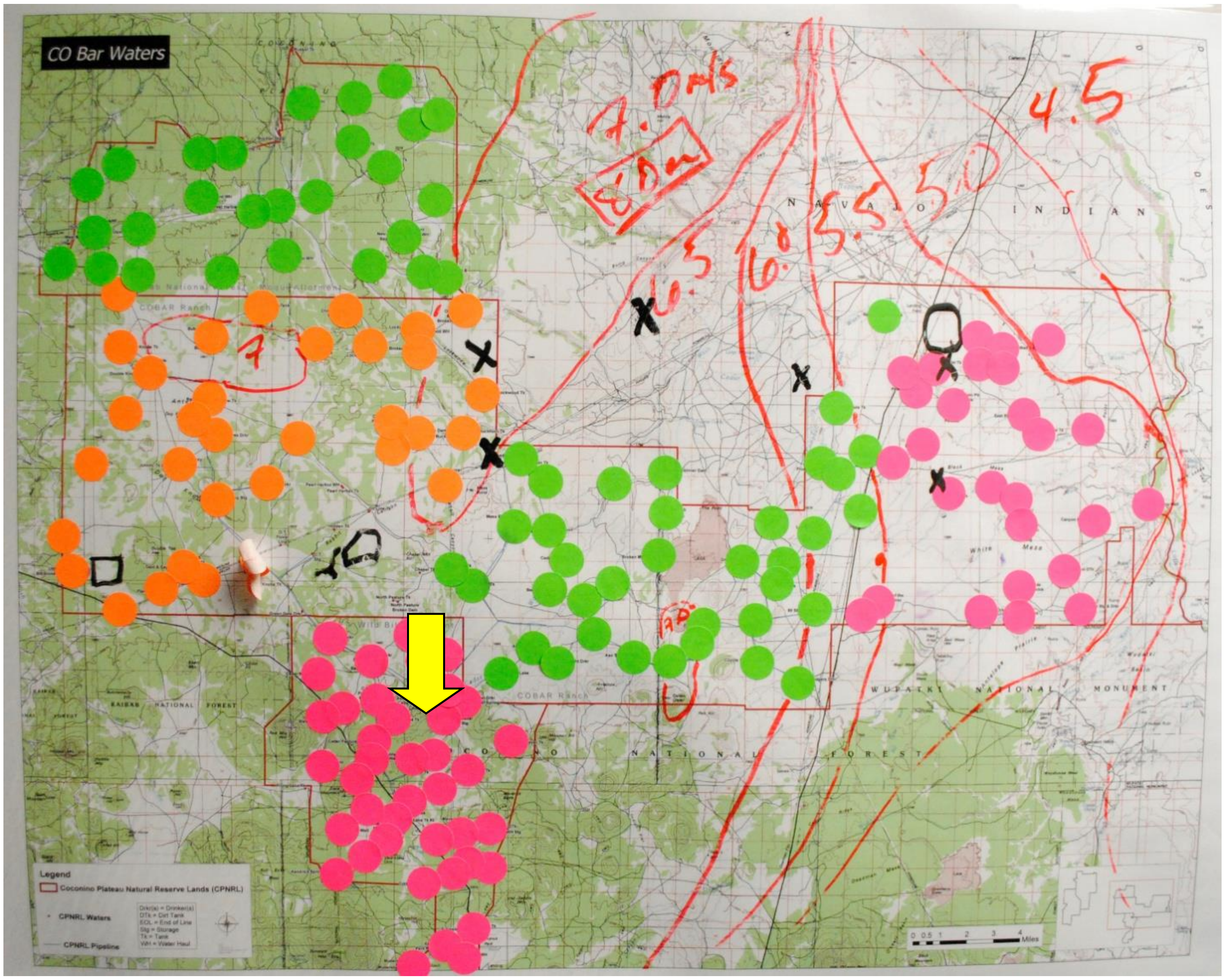


FIGURE 18: TOPOGRAPHICAL MAP OF CO BAR RANCHLANDS [COURTESY: DAVID WILLY]

A MATLAB code was written to plot a Raleigh distribution based on an average wind speed of 6.5 m/s. Figure 20 is one result of that code. Figure 20 displays how the frequency of wind speeds may vary throughout a typical day with an average of 6.5 m/s. Figure 20 shows that the site would receive usable wind speed (above 4.5 m/s) 73% of the time with an average usable wind velocity of 7.9 m/s.

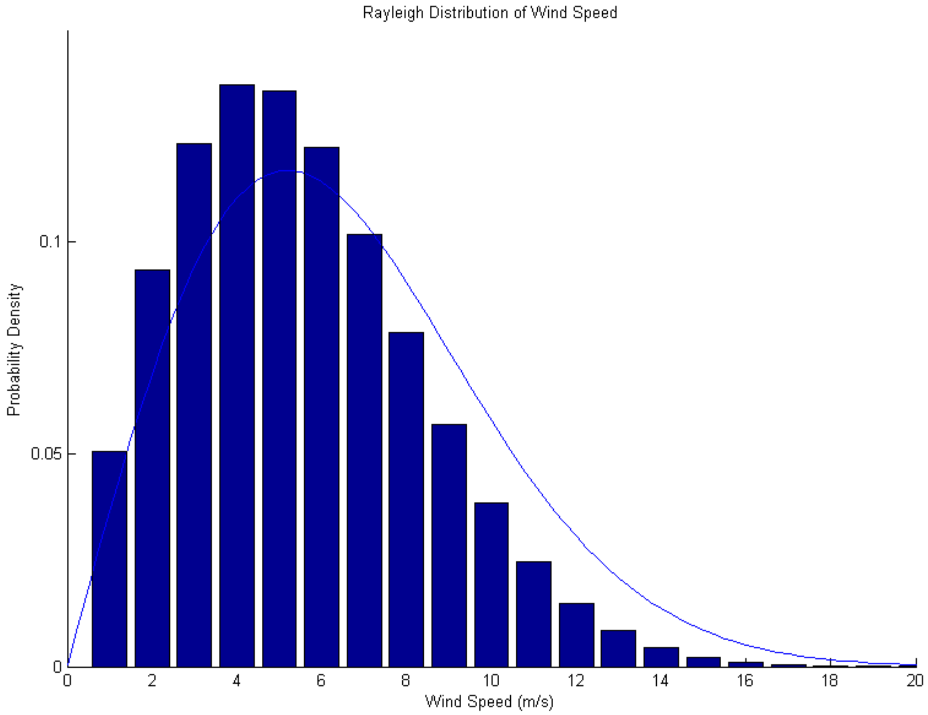


FIGURE 19: RAYLEIGH DISTRIBUTION

The wind turbine model is based upon the power that may be extracted from a laminar air stream in steady conditions. Thus the power of the variable pitch wind turbine is characterized by Equation 1:

$$P = \frac{1}{2}\rho\pi R^2 v^3 C_p(\lambda,\beta)\eta_{gb}\eta_{gen} \qquad (1)$$

Where:

P = Power output of the turbine (W)	λ = Tip speed ratio
C_p = Coefficient of performance [1]	β = Blade pitch angle (deg)
ρ = Air density (kg/m3)	η_{gen} = Generator efficiency
R =Turbine rotor radius (m)	η_{gb} = Gear box efficiency
v = Wind speed (m/s)	

Equation 1 was solved for rotor radius of 15 m, taking the coefficient of performance to be an idealized value of 0.4.

3.3.3 Wind Turbine Simulation Parameters

An idealized value of 0.4 for the coefficient of performance, Cp , is not appropriate for all wind velocities because the coefficient of performance is a function of blade angle, β, and tip speed ratio, λ. The coefficient of performance is based upon the variable pitch wind turbine characteristic, and can be expressed as:

$$C_p(\lambda,\beta) = c_1({}^{c_2}/_{\lambda_i} - c_3\beta - c_4)e^{-c_5/\lambda_i} + c_6\lambda \tag{2}$$

Where :

$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$

$\lambda = \frac{\omega R}{v}$

β- Blade angle

ω- Angular frequency

R – Rotor radius

v – Wind Velocity

c_1- 0.5176

c_2 - 116

c_3 - 0.4

c_4 -5

c_5 – 21

c_6 – 0.0068

Assuming all other variables in Equation 1 remain fixed for the chosen configuration, Equation 2 was optimized for the useful range of wind velocities, v, (4.5 m/s to 25 m/s) with respect to the blade angle, β, and a lookup table was generated for the coefficient of performance. Manipulating the blade angle with respect to the instantaneous wind velocity allows the system to maintain an output of 32 kW as often as possible. Hence the system is optimized with lookup tables for values of the coefficient of performance, C_p. The output of the wind turbine system is rotor shaft torque and angular frequency which are the usable inputs of the gearbox and generator that are connected with the wind turbine rotor shaft. The ultimate goal of the optimization is to select the combination of the governing parameters such that the wind turbine produces $34 \pm 1\ kW$ by altering the blade angle, β, with respect to wind velocity, $v,$ while holding shaft speed at $1230 \pm 30\ RPM$.

3.3.4 Wind Turbine Simulation Results

Four individual months shown in Figures 21-24 were chosen to illustrate the characteristics of the wind turbine simulation given various wind velocity profiles.

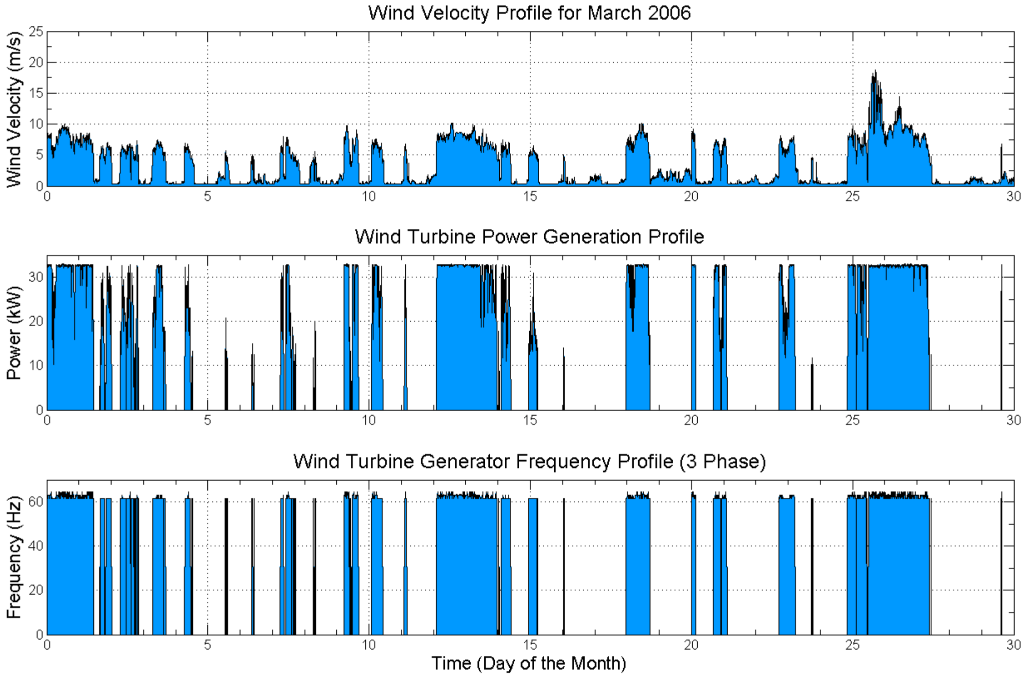


FIGURE 20: WIND TURBINE CHARACTERISTICS – MARCH

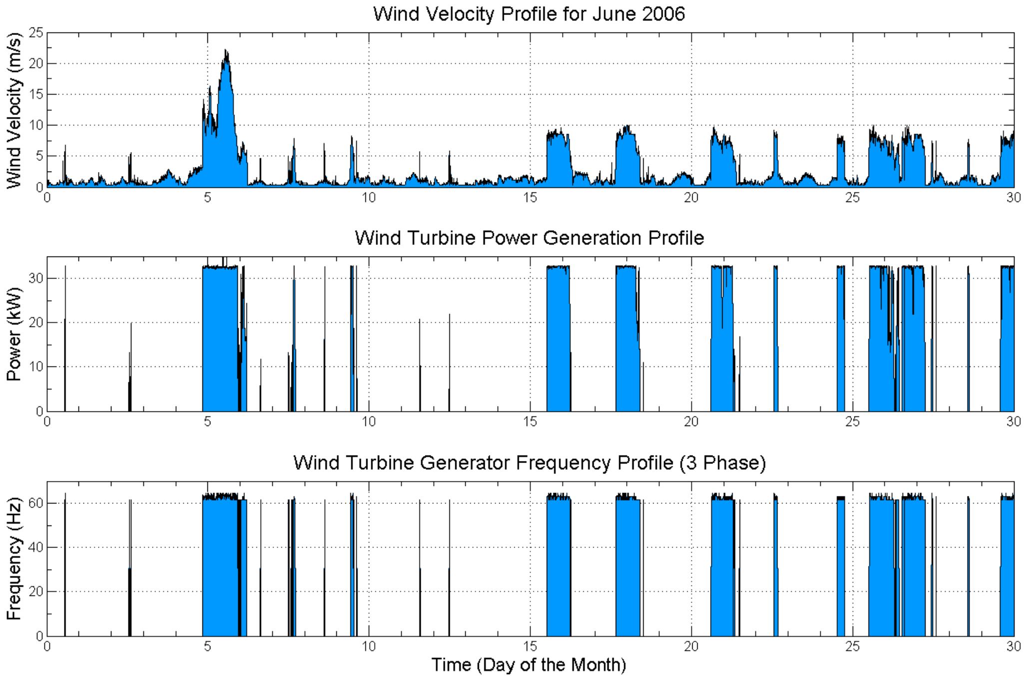


FIGURE 21: WIND TURBINE CHARACTERISTICS- JUNE

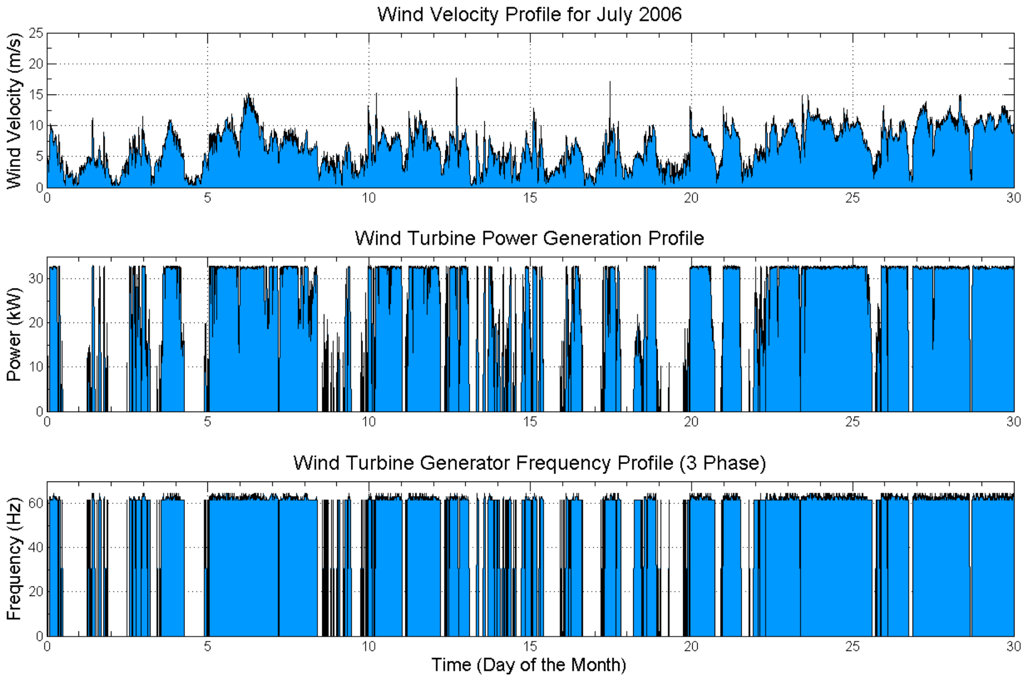


FIGURE 22: WIND TURBINE CHARACTERISTICS - JULY

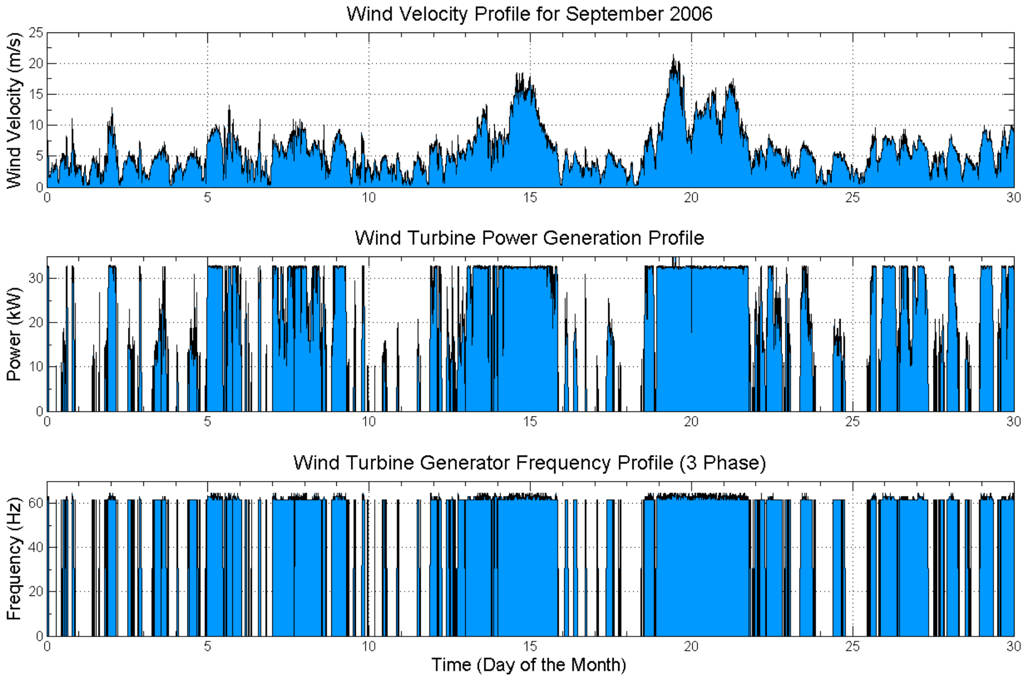


FIGURE 23: WIND TURBINE CHARACTERISTICS – SEPTEMBER

Figure 25 illustrates a monthly breakdown of the percentage of the pump power that the wind turbine was able to supply.

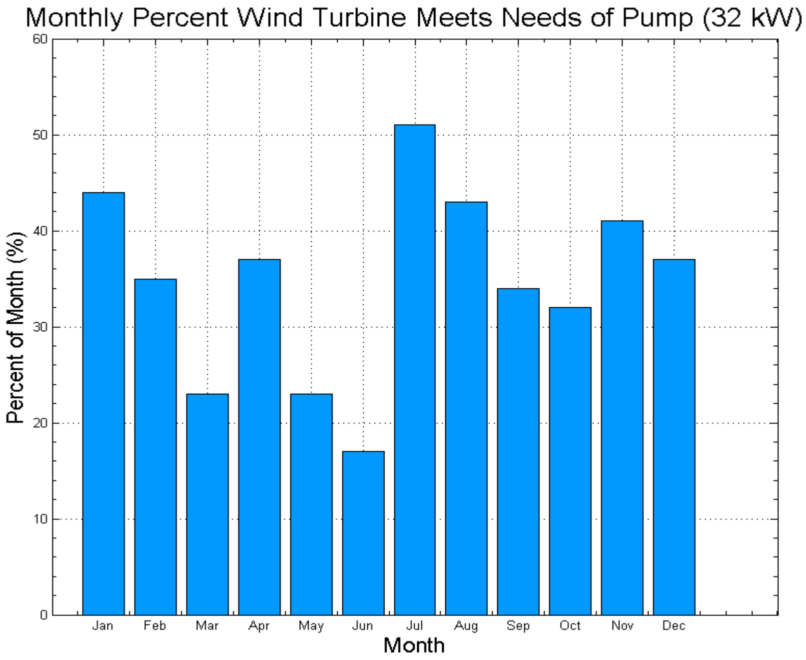


FIGURE 24: WIND TURBINE MONTHLY PERCENTAGES

3.4 Gearbox/Generator Model

Utilizing the outputs generated by the wind turbine simulation a model will be used to illustrate the total available power produced by the wind that can be used at the site. The following Figure 26 is a current state of the Simulink® model for the gearbox and generator.

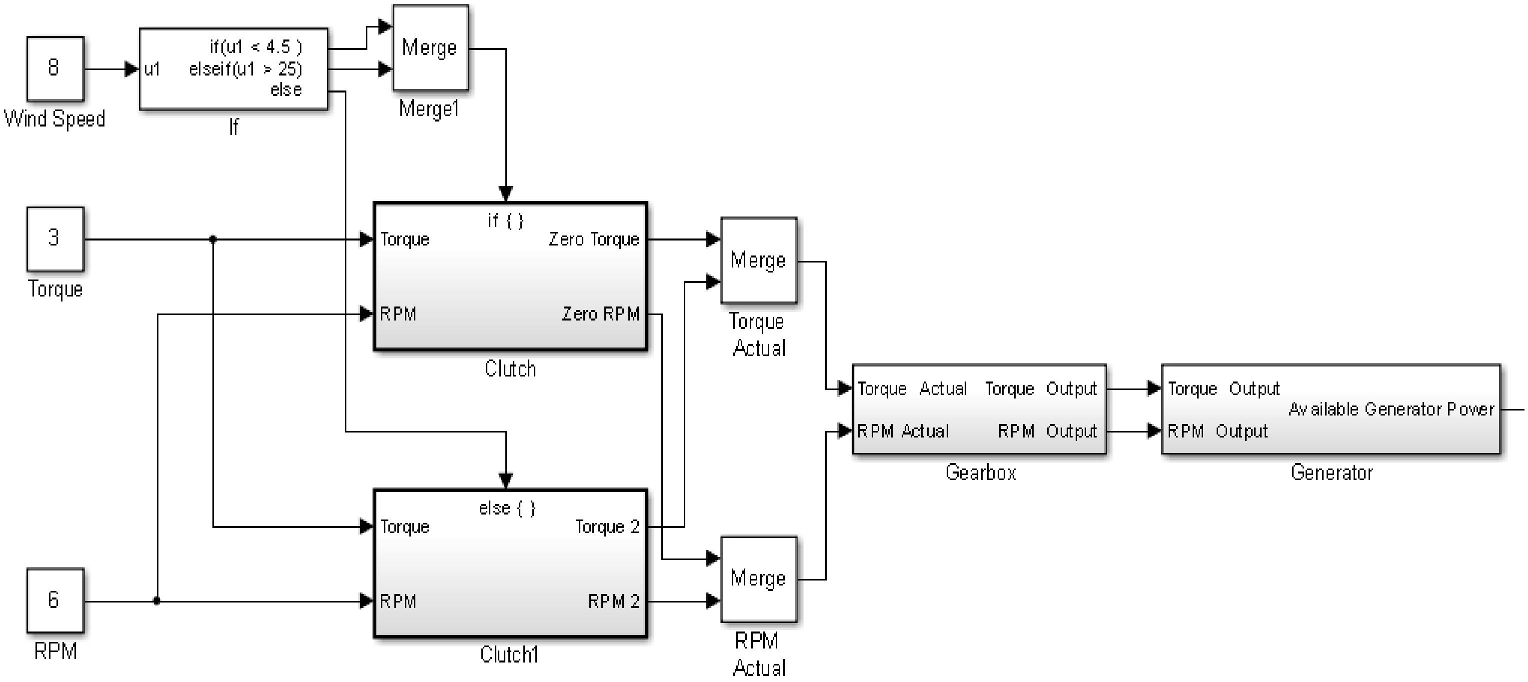


FIGURE 25: SIMULINK® MODEL OF GEARBOX/GENERATOR

As can be seen on the left side of Figure 26, inputs for wind speed, torque and rpm will be received from the wind turbine model. The system is governed by the wind speed data which is ran through an if statement which will determine f the wind speed is above or below the cut-in or cut-off speed specified for a particular turbine. If the wind speed falls outside of these parameters then the model will pass zero values for both rpm and torque. If the value for wind speed falls within these parameters the inputs for both torque and rpm will be passed into the gearbox. The gearbox is designed to step down the torque and increase the rpm values which will then pass to the generator. These variables will be manipulated in accordance to the specifications for torque and rpm requirements dictated by the generator manufacturer. The generator box will then interpret these values and an associated efficiency to predict a final power output.

3.5 Controller Model

The purpose of the controller model is to read in the data produced from both the solar and wind simulations and to determine if the power produced is adequate to meet the demands required at the site. The controller model can be seen below in Figure 28.

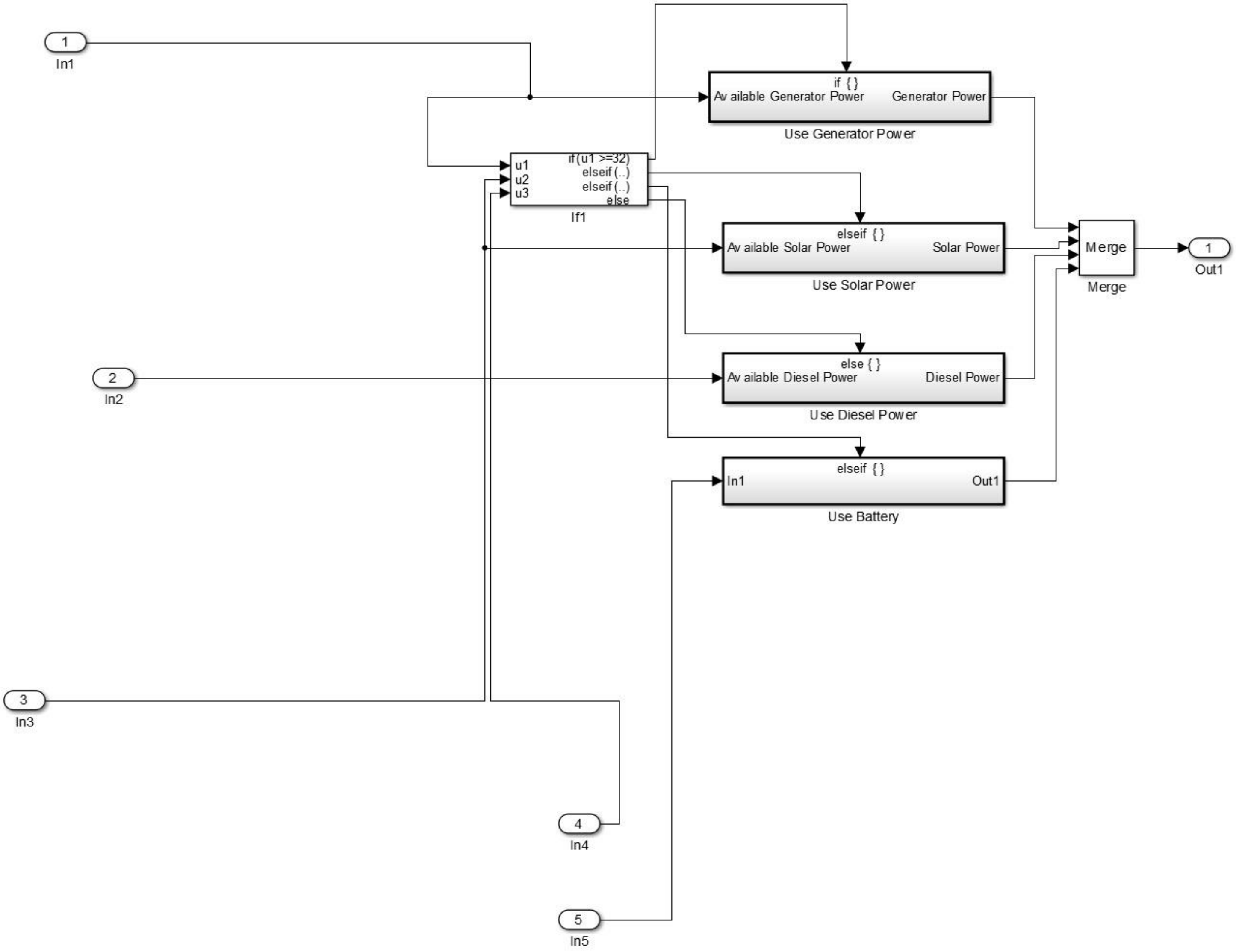


FIGURE 26: SIMULINK® MODEL OF CONTROLLER

The current state of the controller passes the wind and solar data through an if statement to determine if the available power is sufficient for the needs of the system. If 32kW or greater is produced by either the wind or solar models, that source will be allocated to the output scope which will read out the available power. If neither of the two systems are generating adequate power, the if statement will default to the diesel generator which meets the demands of the current system.

3.6 Battery Model

The installed battery bank for the overall system consists of forty batteries total. Two batteries are set in parallel and twenty batteries are in series. In order to calculate the number of batteries needed, one day of autonomous function has been considered. This means that the batteries would be able to supply the system with ample power for a full day without solar energy available.

The battery voltage is 24 volts per battery and the overall DC system voltage is 480 volts. One battery that will meet these specifications will cost $6800. Forty batteries will amount to a total of $272,000 cost for the whole battery bank. This price does not include costs of instillation that a contractor charges, as well as the maintenance cost of the batteries.

In order to charge the batteries, excess solar power is used. Every time the controller does not choose solar power to directly supply the load, the power produced from the solar array is used to charge the batteries in the battery bank. Whenever the solar array is also producing more than 32kW, the extra power charges the batteries as well.

Figure 29 shows the subsystem of the battery bank. The truncated solar power gets to the system through the ‘in 1’ block. Then the power is converted into positive and negative currents. The two different currents run through the battery bank and charge the batteries. When discharging the batteries, the positive current and negative current are converted back into usable power. That power then is the actual available power of the battery bank. It gets send to the controller, which is indicated by the block “out 1”, where it could be of further use to the system.

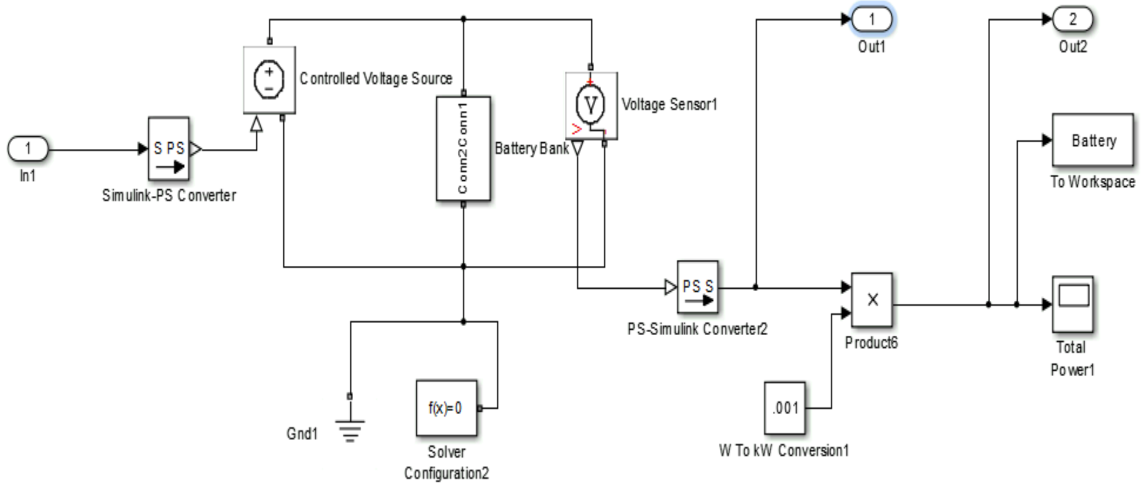


FIGURE 27: BATTERY SUBSYSTEM

Figure 30 shows the average available power from the battery bank a whole year. It shows that the available power is significantly below the 32kW needed. During the summer months more power is available than compared to the winter months. Figure 30 also shows that there is one month during summer, August, which is noticeably lower than the other summer months. This is because most of the solar power acquired by the system in August is of direct use to the system and will bypass the battery. Most of the time during that month the controller chooses solar power as the power source to get the 32kW needed. Therefore only the extra solar power is used to charge the batteries.

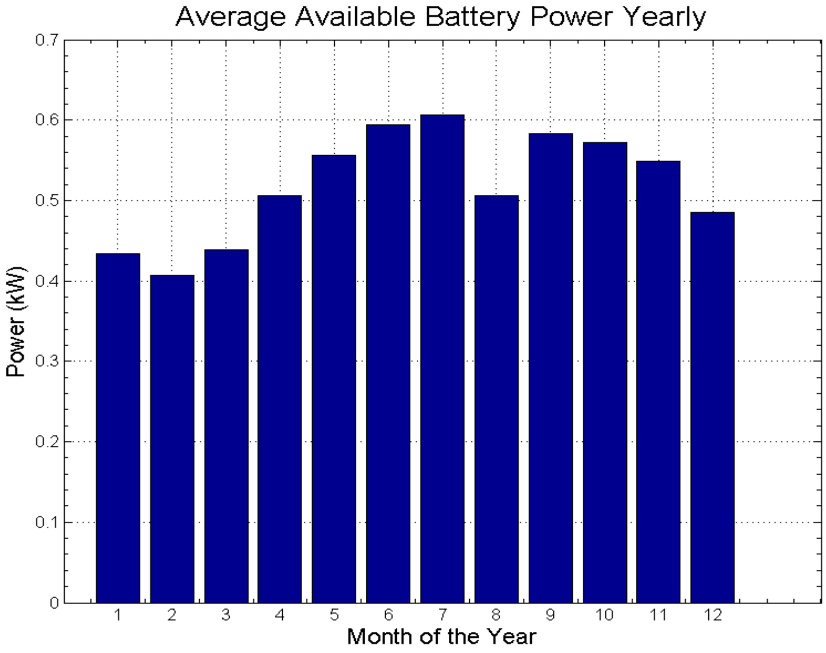


FIGURE 28: AVERAGE AVAILABLE BATTERY POWER THROUGH A YEAR

In conclusion, the battery bank is not a feasible option. In order to have a battery bank that is capable of producing enough power to run the applications the solar array needs to be increased significantly. The current solar array does not produce enough power to charge the batteries to 32kW. A much higher price needs to be invested if the clients wish to have a battery bank with the solar system. As mentioned before, the battery bank itself costs $272,000 that does not include the installing and maintenance cost. Batteries for such a big application have a very low efficiency. To make up for the losses, a bigger battery bank is needed, which would increase the price.

The team's recommendation to the client is not to install a battery bank. If the client decides to install a solar system, the system should directly be connected to the pump.

3.7 Results

The different simulations were combined into one large Simulink assembly as shown in Figure 31. It shows that the wind turbine, diesel generator, and solar array subsystems process information which is then sent to the controller. These images contain the various subsystems but provide an overall view of the hierarchy of the system. The battery was previously shown to be very far from cost effectiveness and was thusly not included in any further simulations.

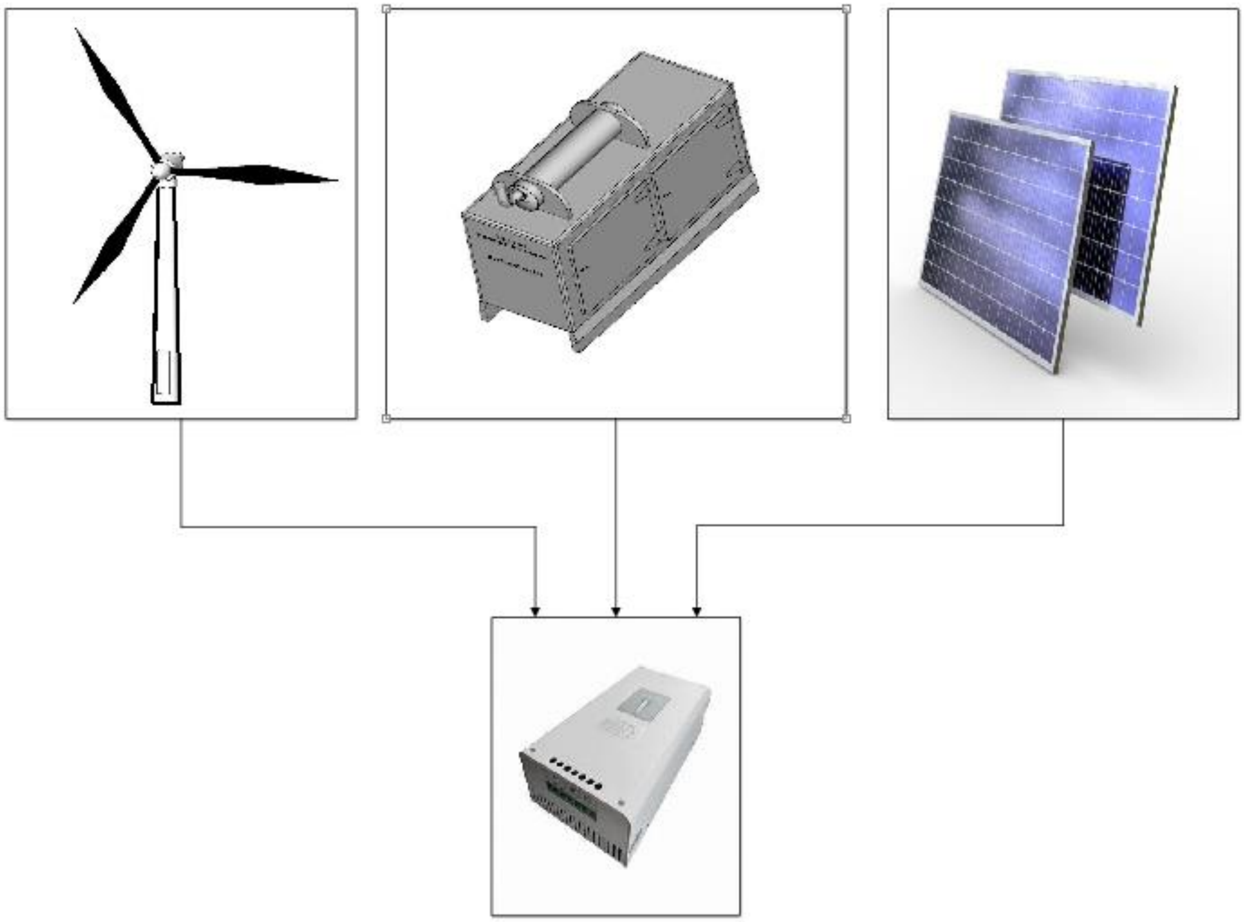


FIGURE 29: SIMULINK ASSEMBLY: WIND TURBINE, DIESEL GENERATOR, SOLAR ARRAY, CONTROLLER

In order to obtain real results that would be comparable to what the client would actually experience it was necessary to use actual data. Wind and solar data, including wind velocities and insolation, was provided by Dr. Tom Acker of the Institute for Sustainable Energy Solutions. The data came from a MET tower located at Mesa Butte, which is a location north of Flagstaff comparable to the site being investigated. The data spans one year's time, using ten minute averages, and was predominantly recorded in 2006. The Simulink simulation is able to process this data to produce results for every month and season as well as the entire year.

Figure 32 displays the result of running the entire simulation for the full year of data. The area colored in blue denotes the amount of power that is being provided by the wind turbine. The following yellow and green areas represent power provided by the solar array and diesel generator respectively. These areas are stacked and will always add up to to 32 kW to satisfy the system's needs.

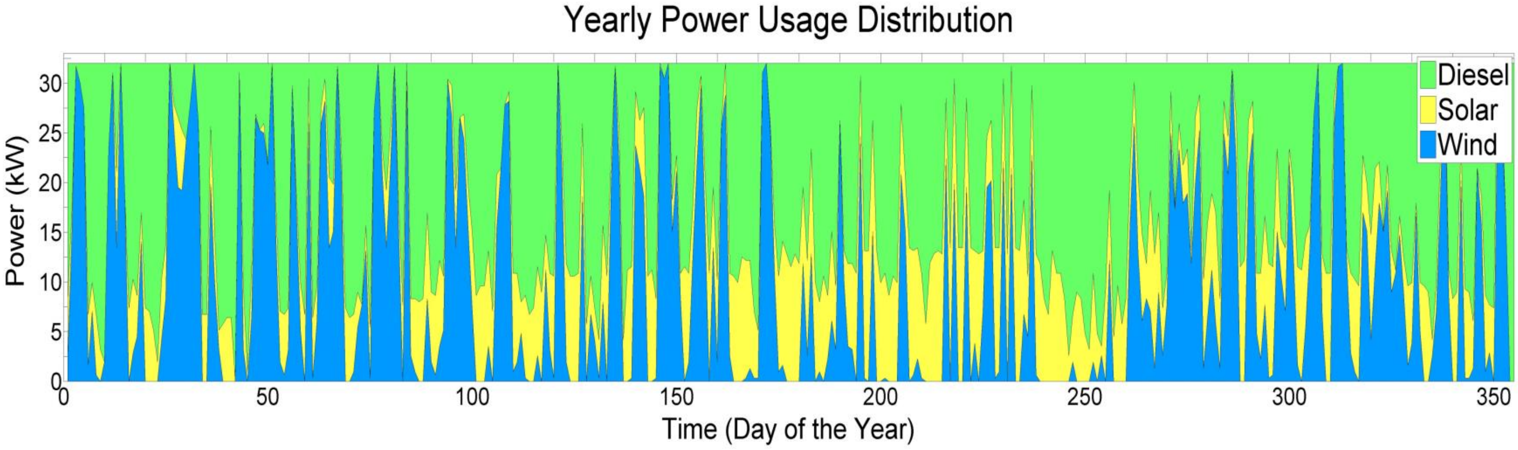


FIGURE 30: POWER DISTRIBUTION ACROSS THREE POWER SOURCES

Figures 33-36 provide a zoomed in view for each season of the year, to provide a better view at how the varying seasons change the sources used. For example, the summer months provide a large amount of solar power because the sun has the longest track in the sky at that time.

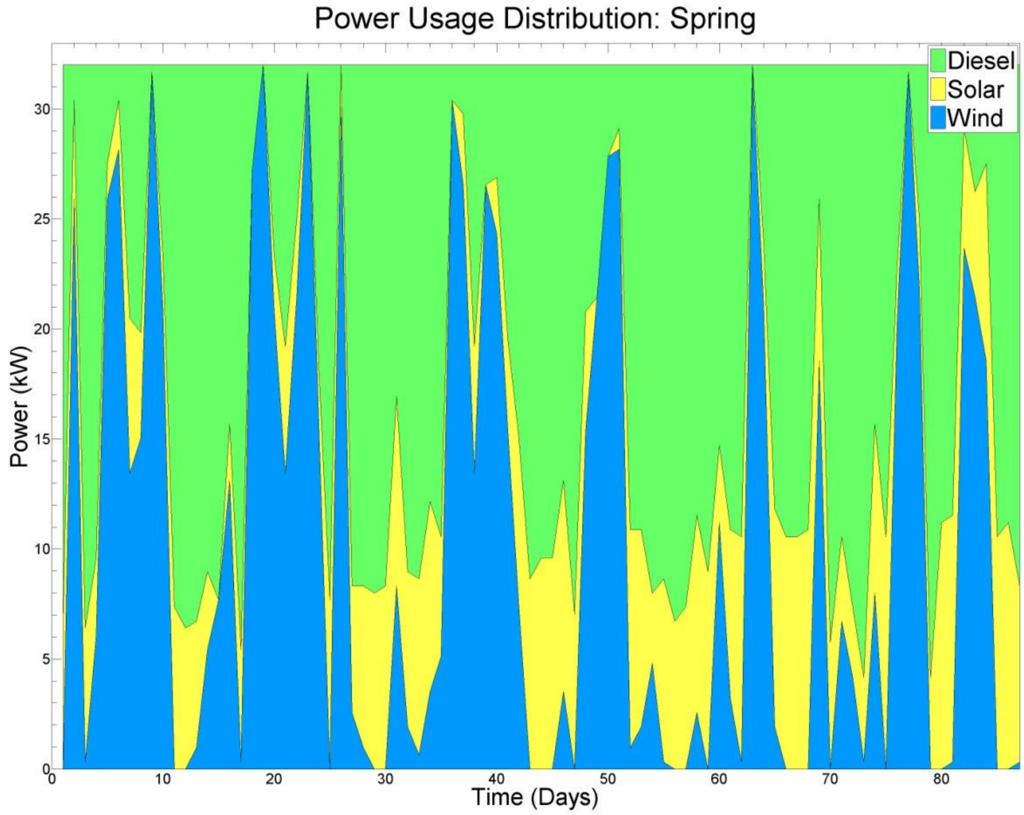


FIGURE 31: POWER DISTRIBUTION: MARCH - MAY

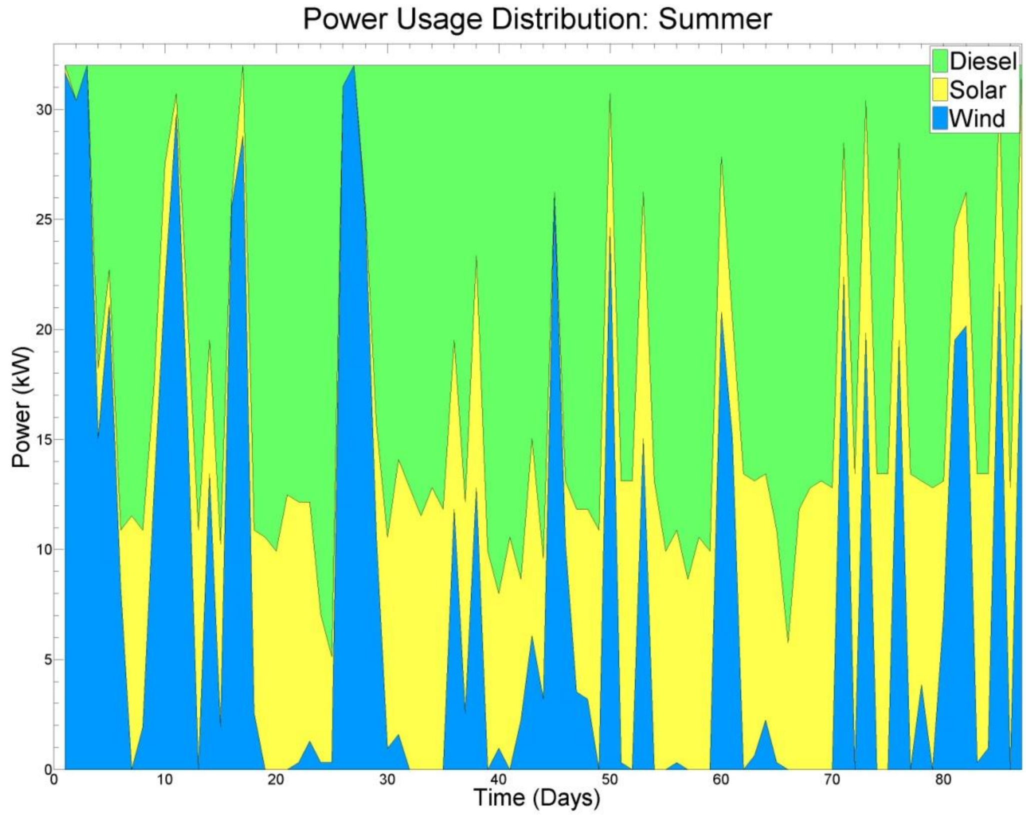


FIGURE 32: POWER DISTRIBUTION: JUNE - AUGUST

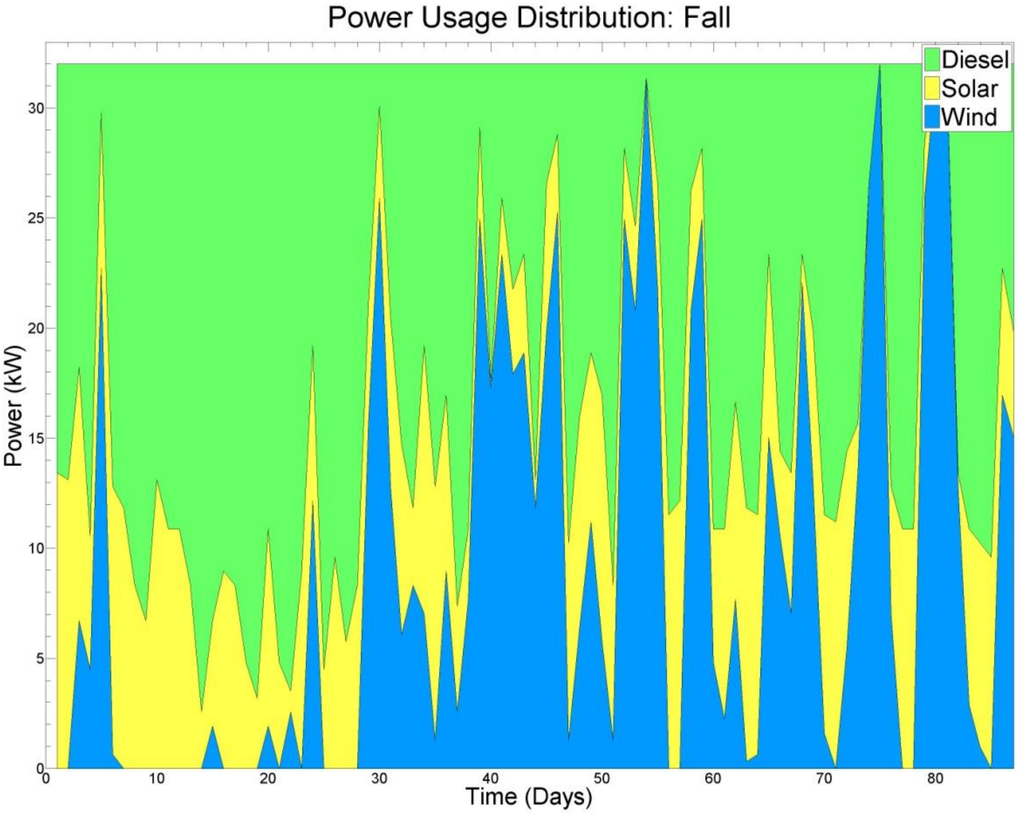


FIGURE 33: POWER DISTRIBUTION: SEPTEMBER - NOVEMBER

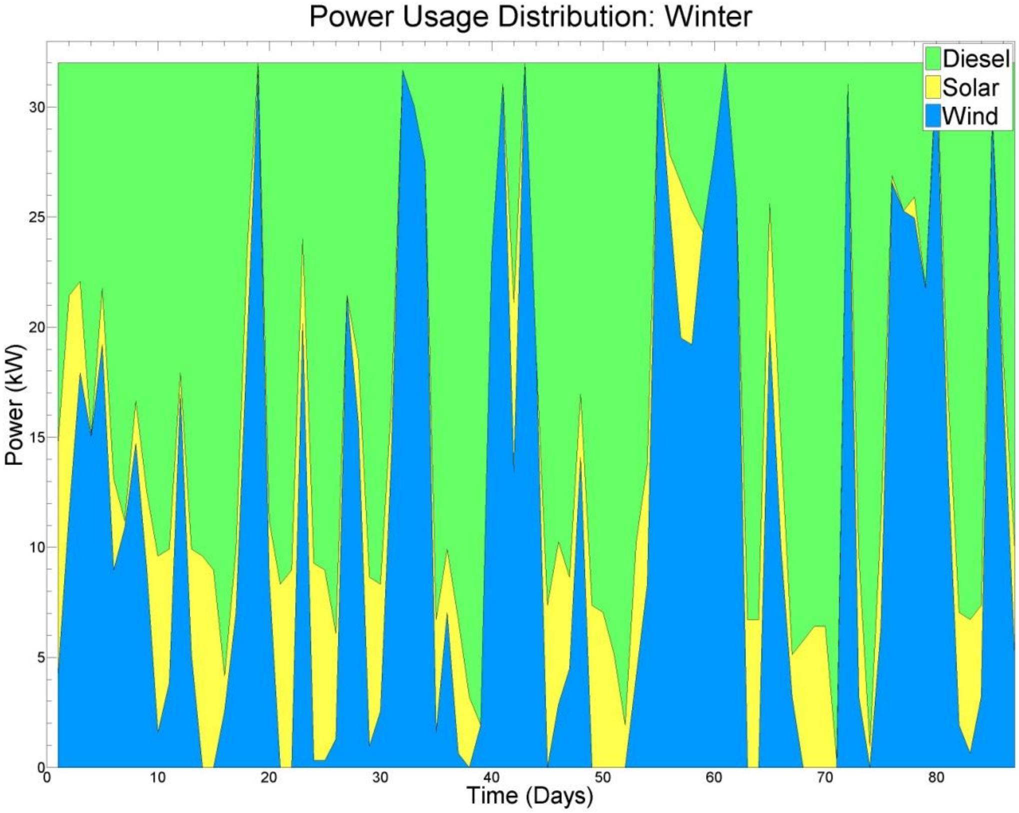


FIGURE 34: POWER DISTRIBUTION: DECEMBER - FEBRUARY

Figure 37 displays the total percentage that each power source contributed to the system for the entire year. Table 11 shows the total percentage that each power source contributed to the system for each month.

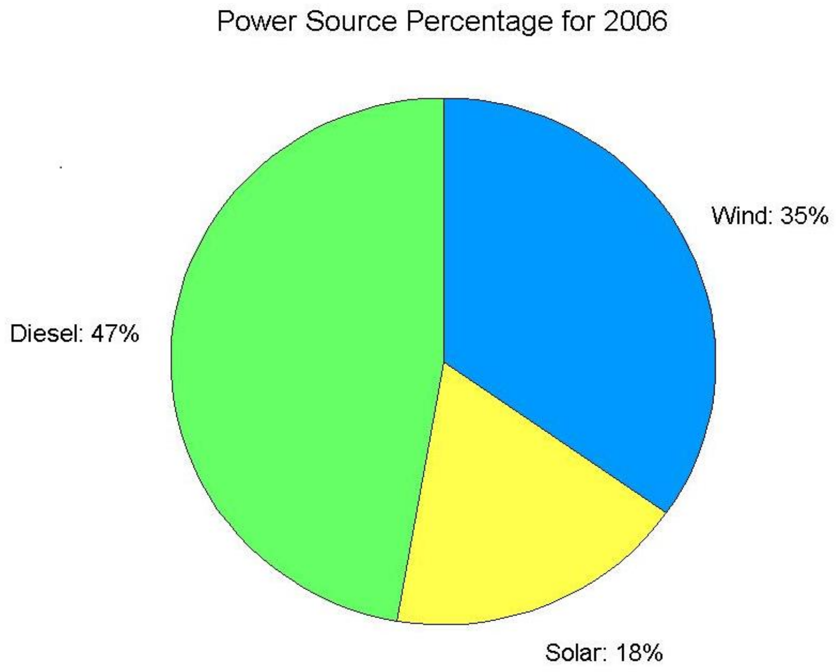
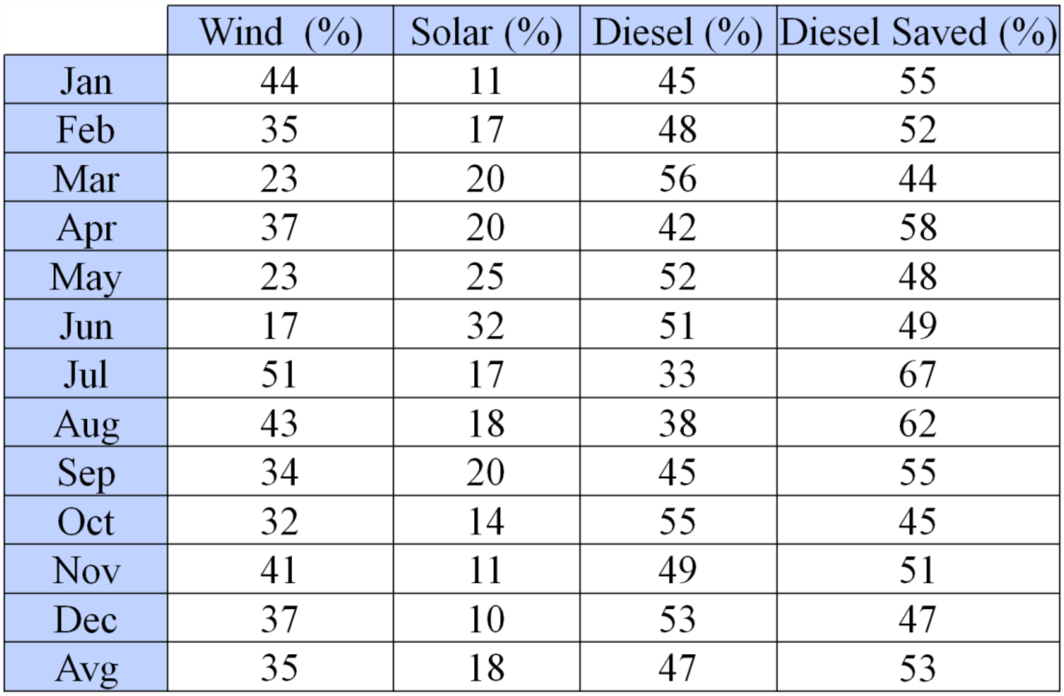


FIGURE 35: POWER DISTRIBUTION FOR 2006

TABLE 11: MONTHLY POWER DISTRIBUTION



	Wind (%)	Solar (%)	Diesel (%)	Diesel Saved (%)
Jan	44	11	45	55
Feb	35	17	48	52
Mar	23	20	56	44
Apr	37	20	42	58
May	23	25	52	48
Jun	17	32	51	49
Jul	51	17	33	67
Aug	43	18	38	62
Sep	34	20	45	55
Oct	32	14	55	45
Nov	41	11	49	51
Dec	37	10	53	47
Avg	35	18	47	53

4. Conclusions

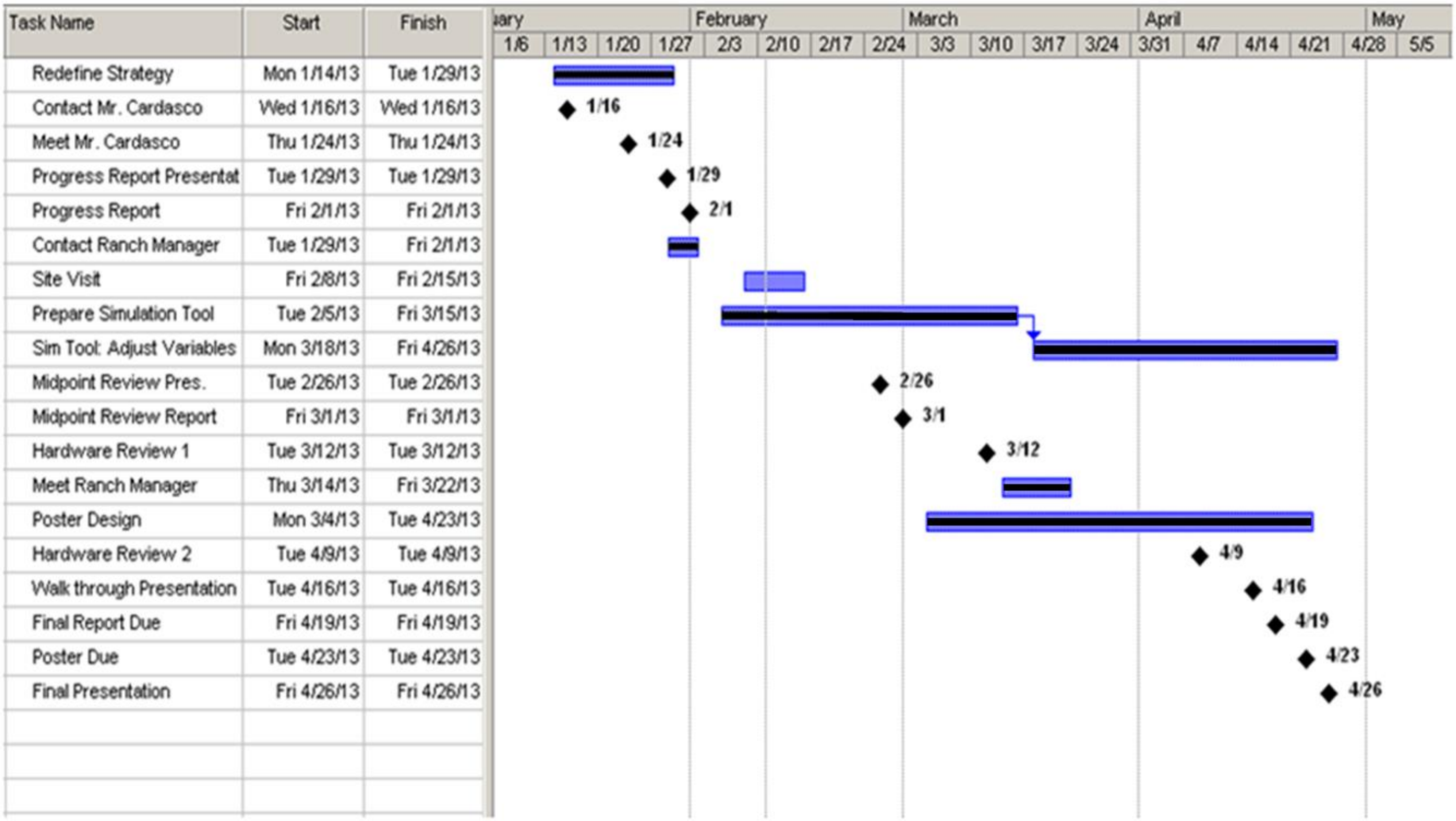
From the large amount of research and calculations from the Fall 2012 CEMEX project, it was very apparent that a large solar array or wind turbine would not be feasible for both Babbitt Ranches or CEMEX. Both clients needed full power continuously, often 24 hours per day, and did not have the option of being grid tied. The two best alternative energy options were solar and wind, both of which were highly variable. This would mean that the diesel generator that the clients were looking to dispose of would have to be retained for a large amount of backup use. The cost analysis for these renewable energy technologies provided far too long of payoffs for the clients to consider going forward with these two systems.

For the spring 2013 semester, Babbitt Ranches requested that the team complete a virtual analysis of the system. This simulation would provide accurate data on how much these renewable energy technologies would replace the diesel generator, which could be helpful in future cost analysis.

In order to demonstrate how the team's power generation system would work, a Simulink® simulation was created. The simulation takes inputs of wind velocity and solar insolation data and converts it into available power from the wind turbine and solar array. The controller distributes the power to the load based on the ability of each system to provide the necessary power, with a preference for wind and solar power. The system provides a yearly distribution of power and ultimately shows that approximately fifty three percent of the total power being used to pump water would be supplied by alternative power in the team's power generation system. It also shows the variability through the year of each power system, based on results for months and seasons.

The simulation is fully capable of processing different sets of data from varying locations and times, as it would be useful in the future. The simulation showed that approximately fifty three percent of the diesel power would be replaced with renewable energy if this system was implemented in the future.

5. Gantt Chart



Task Name	Start	Finish
Redefine Strategy	Mon 1/14/13	Tue 1/29/13
Contact Mr. Cardasco	Wed 1/16/13	Wed 1/16/13
Meet Mr. Cardasco	Thu 1/24/13	Thu 1/24/13
Progress Report Presentat	Tue 1/29/13	Tue 1/29/13
Progress Report	Fri 2/1/13	Fri 2/1/13
Contact Ranch Manager	Tue 1/29/13	Fri 2/1/13
Site Visit	Fri 2/8/13	Fri 2/15/13
Prepare Simulation Tool	Tue 2/5/13	Fri 3/15/13
Sim Tool: Adjust Variables	Mon 3/18/13	Fri 4/26/13
Midpoint Review Pres.	Tue 2/26/13	Tue 2/26/13
Midpoint Review Report	Fri 3/1/13	Fri 3/1/13
Hardware Review 1	Tue 3/12/13	Tue 3/12/13
Meet Ranch Manager	Thu 3/14/13	Fri 3/22/13
Poster Design	Mon 3/4/13	Tue 4/23/13
Hardware Review 2	Tue 4/9/13	Tue 4/9/13
Walk through Presentation	Tue 4/16/13	Tue 4/16/13
Final Report Due	Fri 4/19/13	Fri 4/19/13
Poster Due	Tue 4/23/13	Tue 4/23/13
Final Presentation	Fri 4/26/13	Fri 4/26/13

FIGURE 36: GANTT CHART

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Appendix

The following are images of the Simulink subprograms:

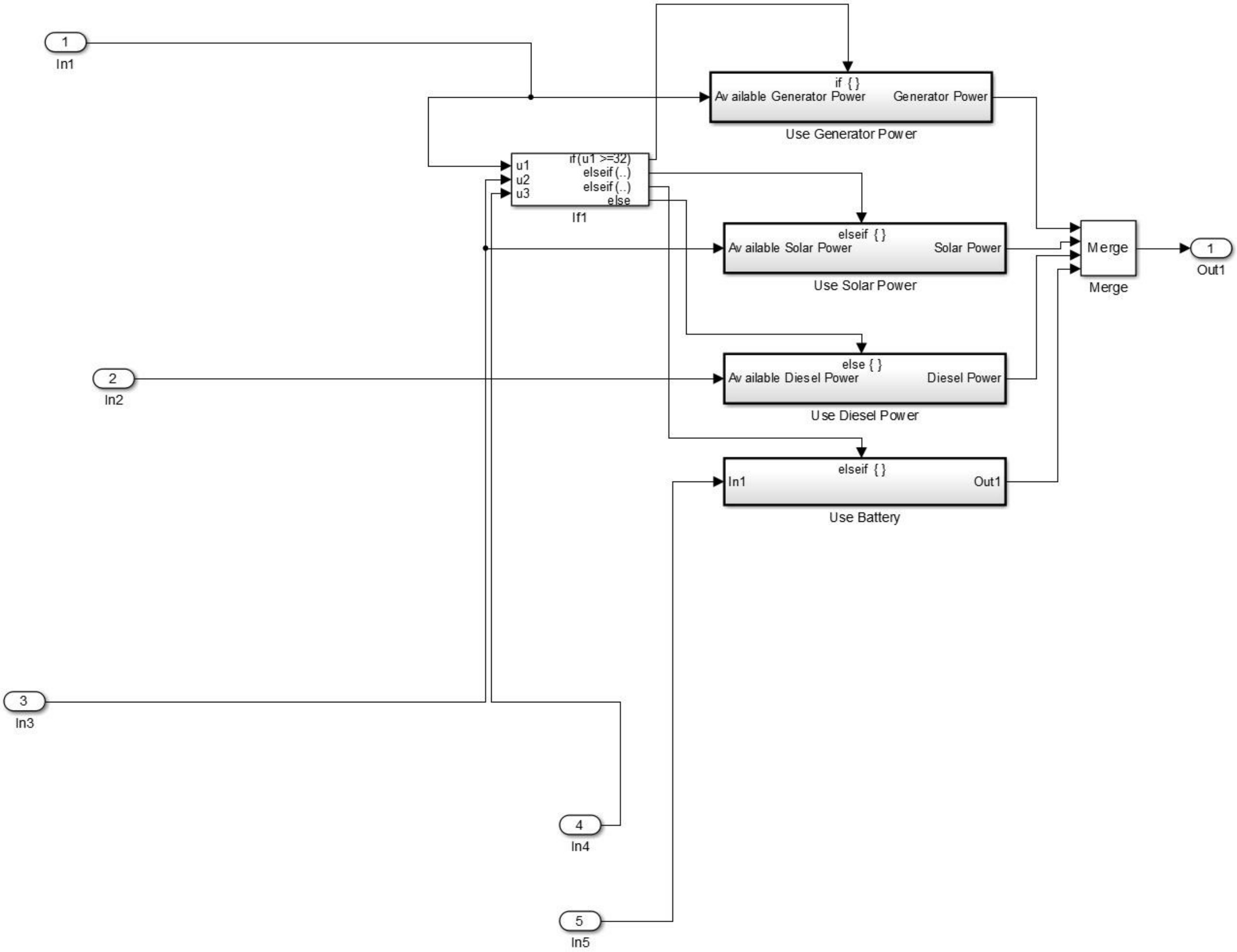

FIGURE 37: CONTROLLER ASSEMBLY

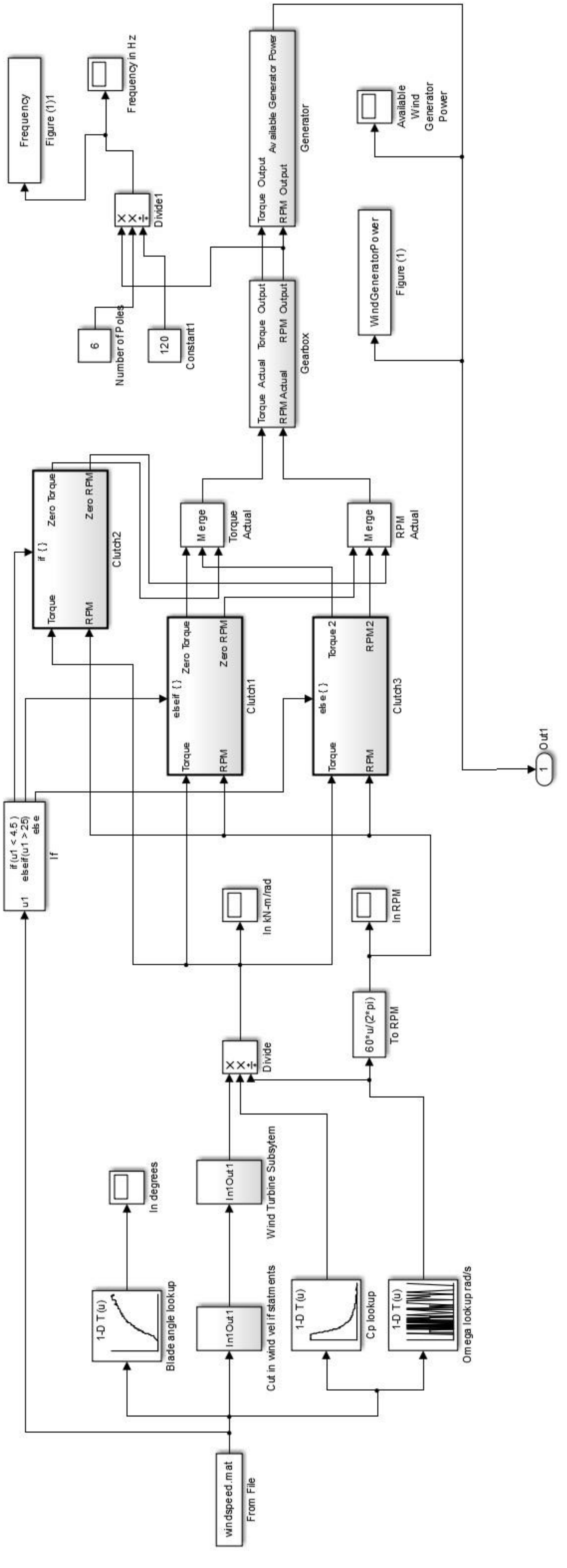

FIGURE 38: WIND TURBINE ASSEMBLY

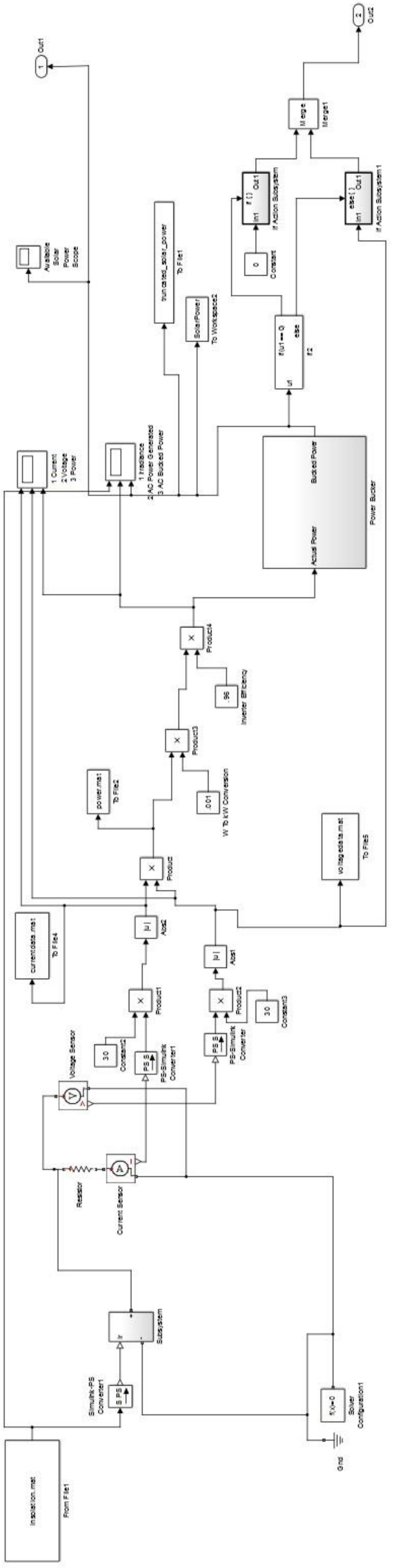

FIGURE 39: SOLAR ARRAY ASSEMBLY

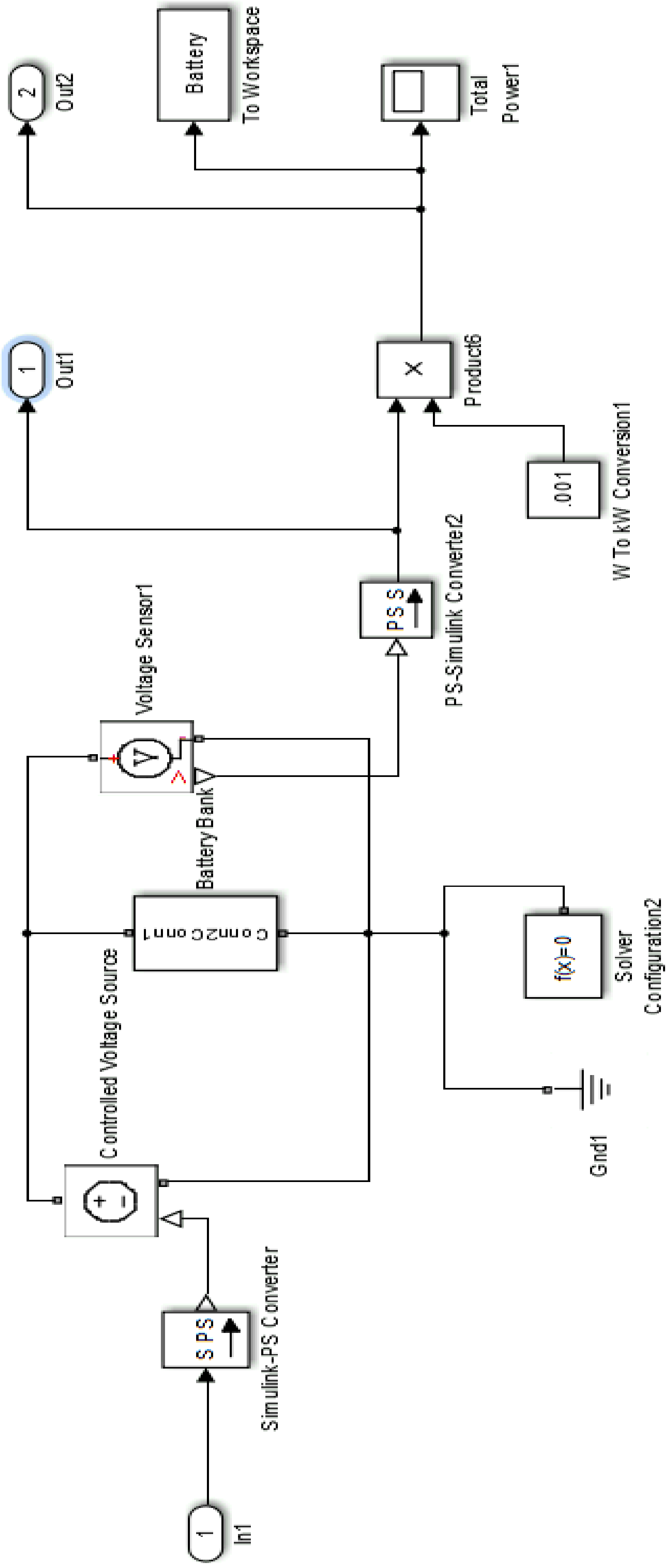

FIGURE 40: BATTERY ASSEMBLY