Alternative Power Source to Draw Underground Water

By:
Grant Masters, Emerson Jones, Beau Drumright, Nathan Heckathorne, and Patrick Schimmelbauer
Team 01

Mid-Point Report

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design – Spring 2013

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Contents

1. Spring 2013 Babbitt Ranches Project

1.1 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.

1.2 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.

1.3 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 1 are approximations. Specific values will be acquired during a site visit planned to occur in the following weeks when weather conditions will be favorable. There is also a house located on the Cedar Ridge.

As can be seen in Table 1, 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. 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 1: 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	

1.4 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. Thus the team will propose the following tentative solutions:

1. Solar Array coupled with a Wind Turbine
2. Exclusively Wind
3. Exclusively Solar

Relative to the CEMEX project, energy demands are much lower. Thus, diesel back-up has not yet been deemed an absolute necessity. A potential back up for water storage would be the 243,000 gallon tank that is currently unused.

2. Simulink® Simulation

2.1 Simulink® Models

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 1 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.

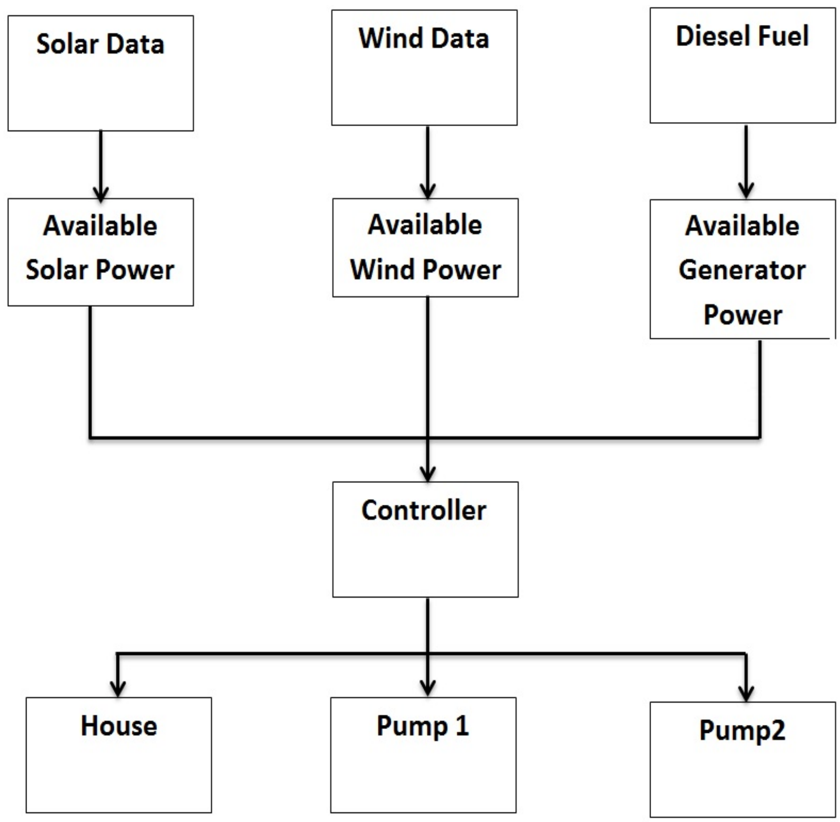

FIGURE 1: SIMULINK® FLOWCHART

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

2.2 Solar Array Model

The simulated solar array it comprised of three major subsystems: input, computation, and output. The data input is solar irradiance. The computations are done by an array of solar cell models. The output is voltage, current, and their product—power. The simulation will be adjustable so that when the team makes design decisions, the model will be easily updated.

2.2.1 Inputs

The team will be using a day's worth of solar irradiance data. Currently, the team is using solar irradiance data from David Willy. The data is titled, "Sunny Day Irradiation" and gives a day's worth of data. Each data point was taken at a ten second interval starting at sunrise and ending at sunset. Around mid-day there is a significant drop in the irradiance data and is presumably due to cloud cover (Figure 8).

The minimum data value is 11.2 W/m^2 and the maximum value is 678.2 W/m^2 (Table 2). The standard deviation of the data set is 237.5 W/m^2. This data is consistent with the value given by the solar resource map below (Figure 2).

TABLE 2: SUNNY DAY IRRADIATION DATA, STATISTICS

	Result	Units
Mean	410.3	[W/m^2]
Standard Deviation	237.5	[W/m^2]
Range	666.9	[W/m^2]
Minimum	11.2	[W/m^2]
Maximum	678.2	[W/m^2]

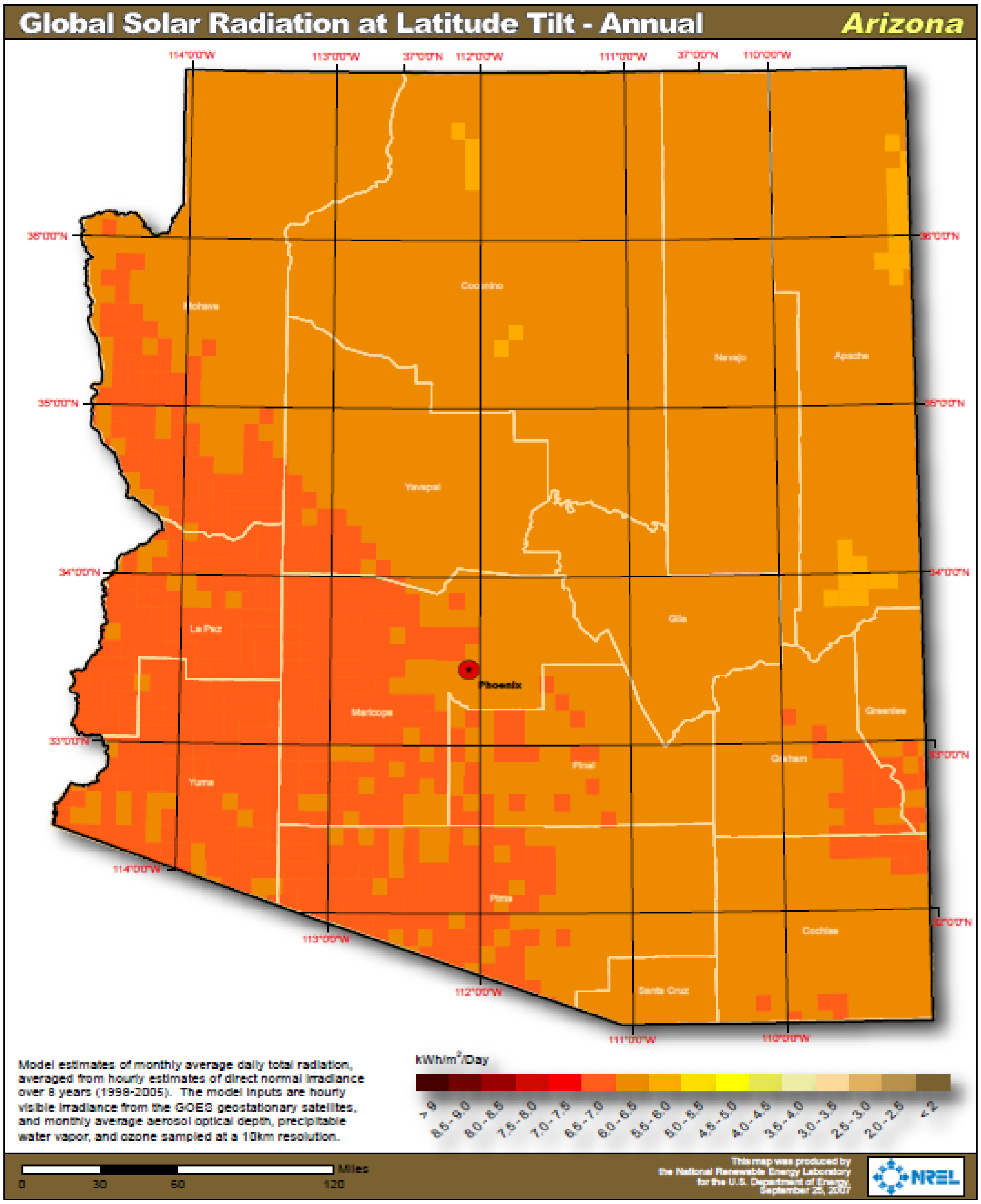

FIGURE 2: SOLAR RESOURCE FOR ARIZONA

2.2.2 The Computational Components

Simulink® contains a pre-made solar cell object. When the team picks a final model of solar panels, the specifications can be directly input into the Simulink® solar cell (Figure 3). The solar cells can be arranged in series and parallel to match the specifications of the solar panel. For preliminary purposes, the team used 72 solar cells grouped in six cells in series (Figure 4).

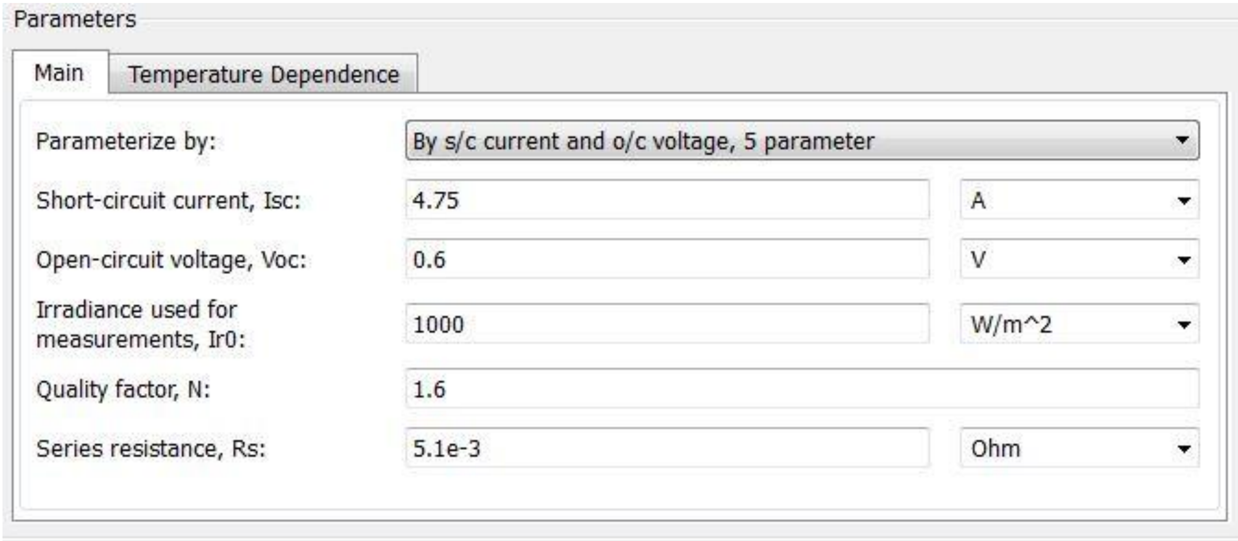

FIGURE 3: SOLAR CELL PARAMETERS

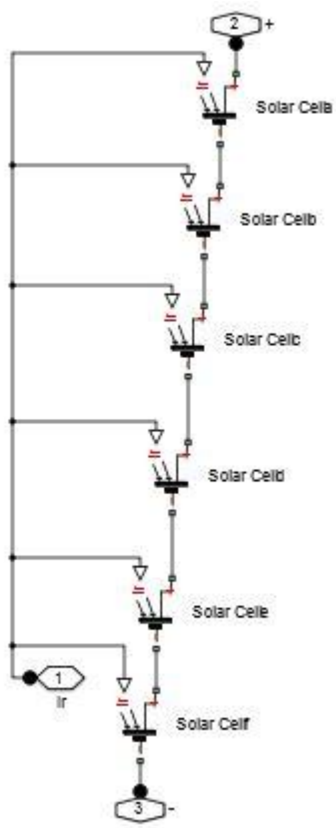

FIGURE 4: SIX SOLAR CELLS IN SERIES

With the solar cells modeled, the team then designed a simulated system which monitors the voltage and current produced by the solar panel (Figure 5). The voltage and current sensors are blocks within the Simulink® library.

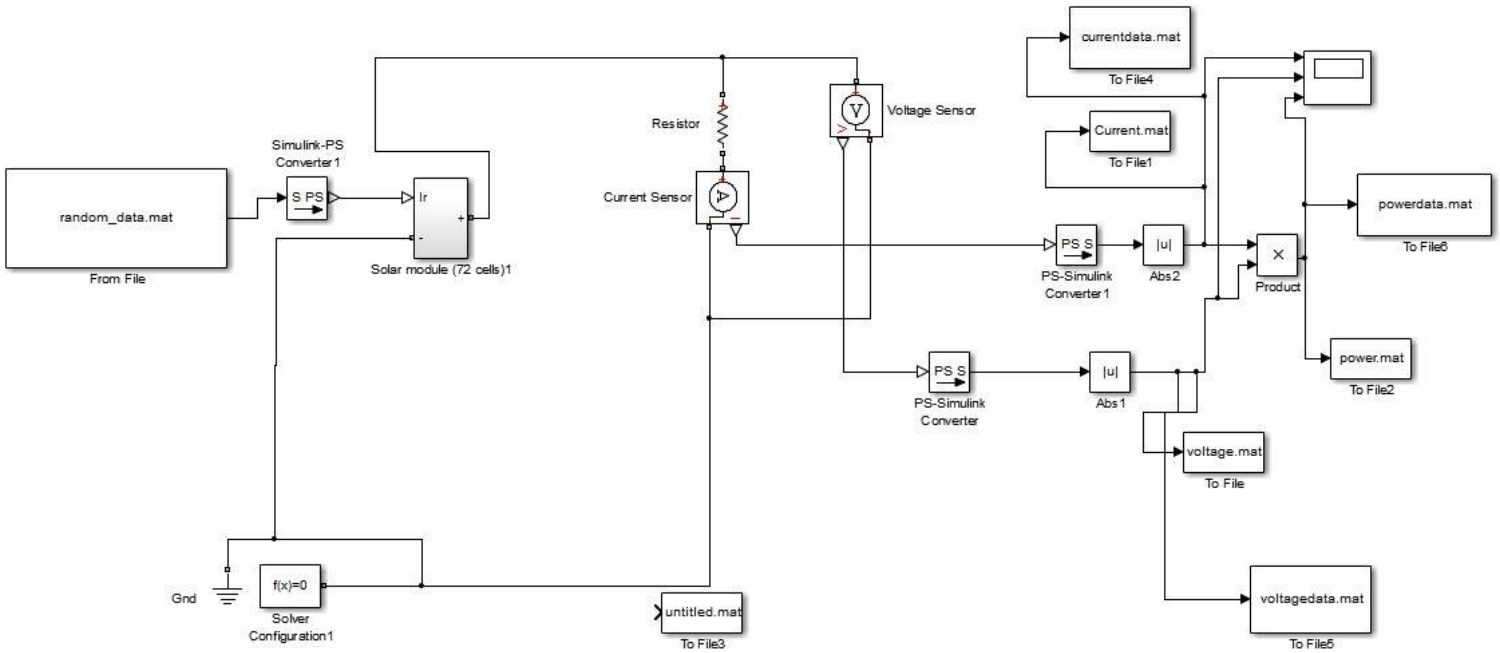

FIGURE 5: SOLAR ARRAY MODEL

2.2.3 The Outputs

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 cells in series, the current is a function of the number of cells in parallel and the power is simply the multiplication of the voltage and current.

The preliminary output of the current can be seen in Figure 6, the voltage in Figure 7, and the power in Figure 8. The irradiance data used for the aforementioned results is from “Sunny Day Irradiation” from David Willy. Currently the x-axis of the time series plots is in seconds. This will be updated in the future to the corresponding hour of the day.

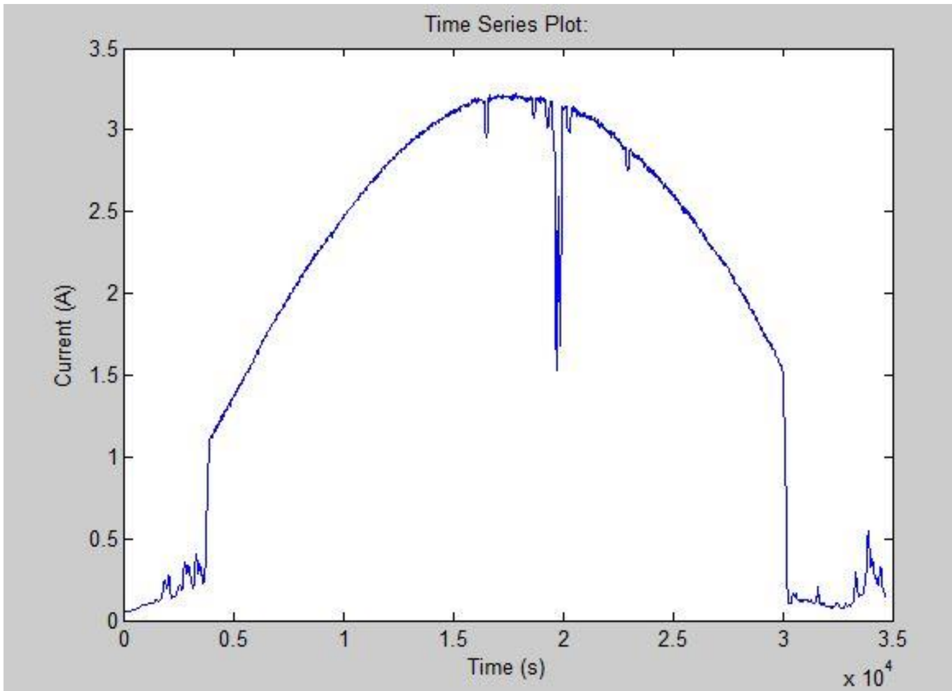

FIGURE 6: SIMULATION RESULTS - CURRENT

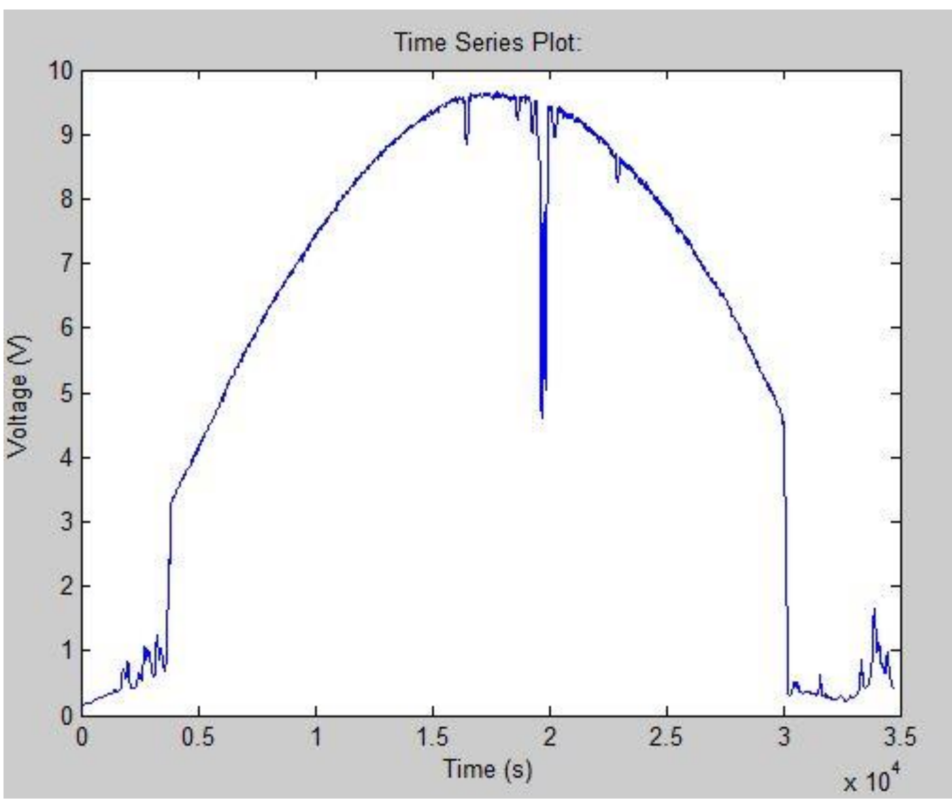

FIGURE 7: SIMULATION RESULTS - VOLTAGE

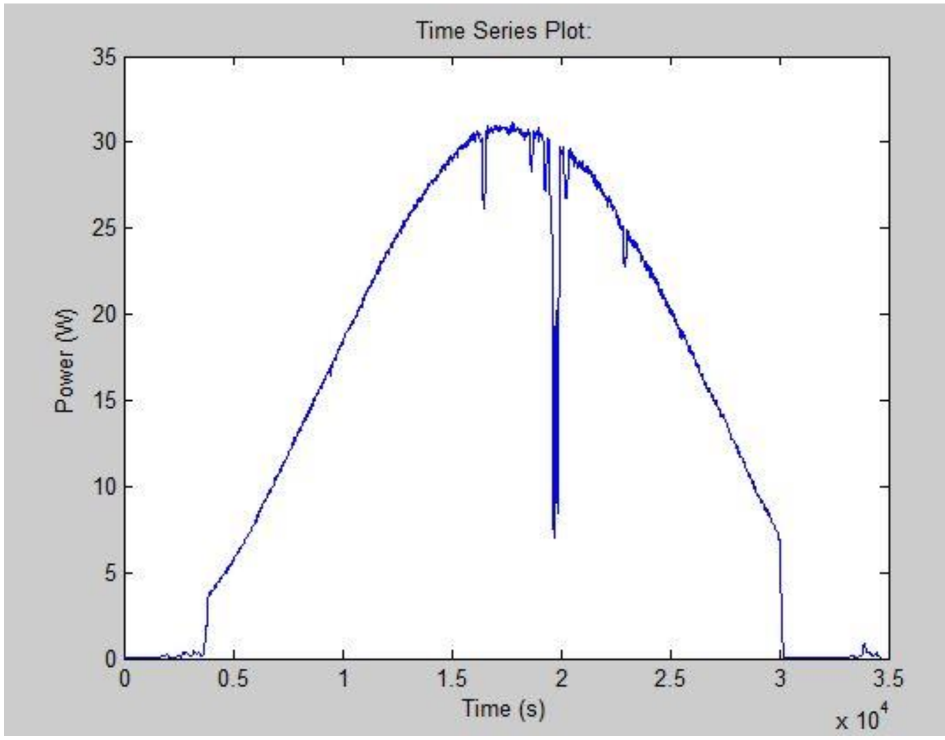

FIGURE 8: SIMULATION RESULTS - POWER

2.3 Wind Turbine Model

2.3.1 Wind Turbine Rotor Sizing

The new 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 9).

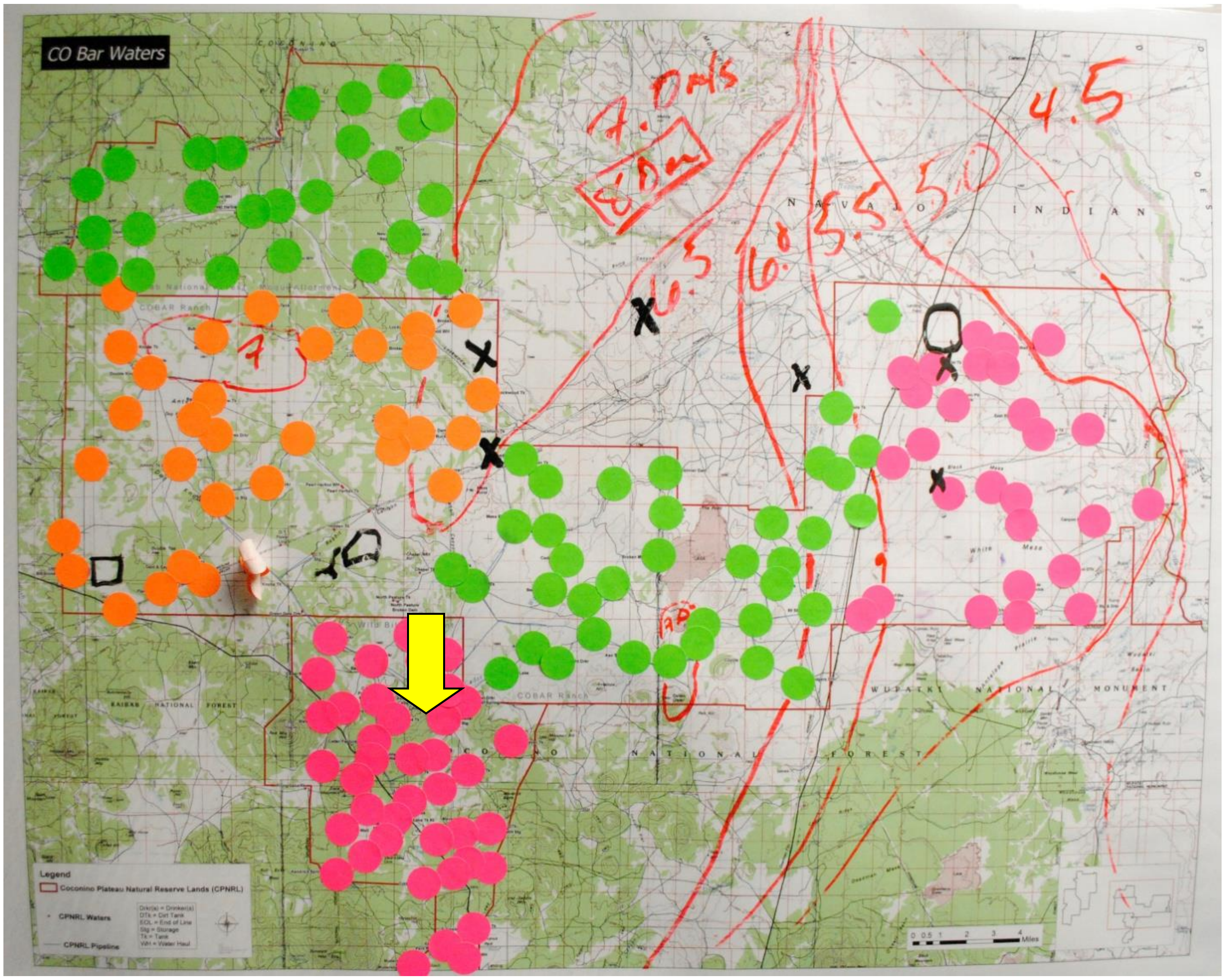

FIGURE 9: TOPOGRAPHICAL MAP OF CO BAR RANCHLANDS [COURTESY: DAVID WILLY]

A MATLAB code was written to plot a Raleigh distribution based on an average wind speed of 6.5 m/s. Figure 10 is one result of that code. Figure 10 displays how the frequency of wind speeds may vary throughout a typical day with an average of 6.5 m/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. Figure 10 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.

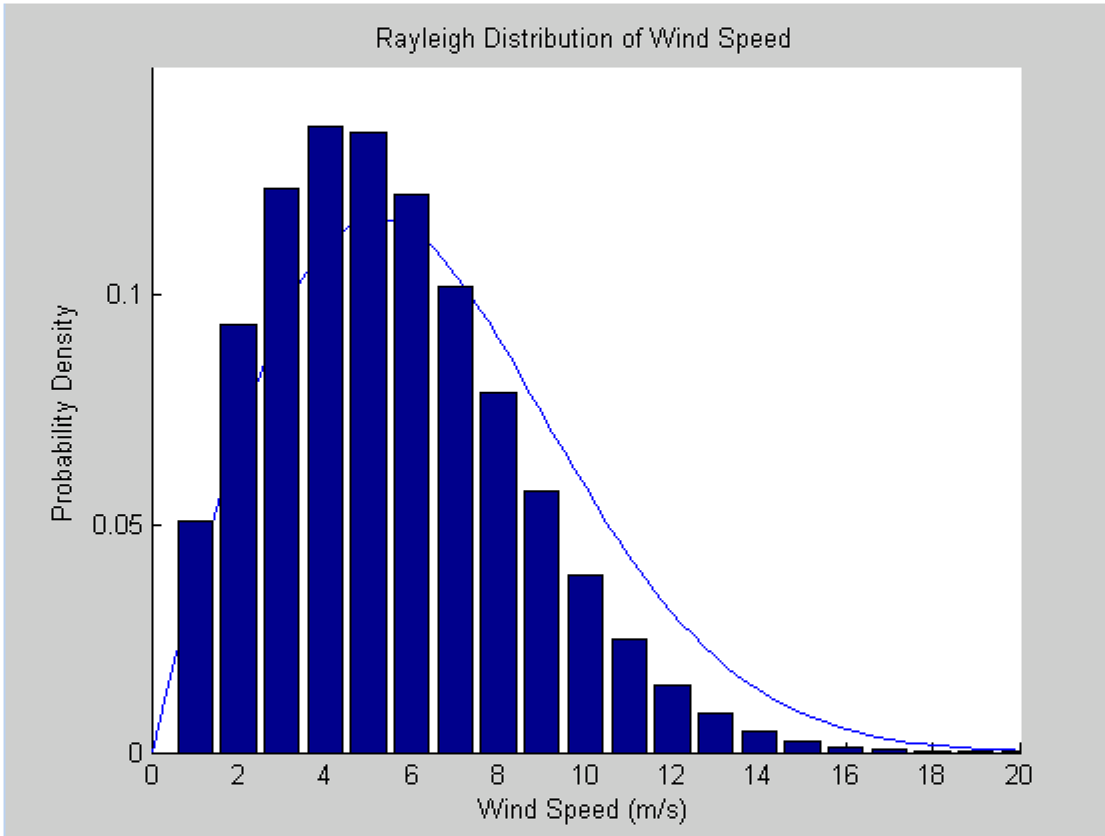

FIGURE 10: RAYLEIGH DISTRIBUTION

The formula for available power that can be extracted from an area of fluid can be expressed as:

$$P = \frac{\rho}{8}\pi D^2 C_p v^3 \quad (1)$$

Where: ρ – Fluid density

D – Diameter of turbine rotor

C_p – Coefficient of performance

v – Velocity of fluid

Using the known power requirements of 32kW, an ideal Cp value of 0.4, average air density 0.924 kg/m3, and an average usable wind velocity of 7.9 m/s, Equation 1 can be rearranged and solved for an optimal rotor diameter. The results of this calculation were then rounded up to a typically available rotor diameter size of 25 meters.

2.3.2 Wind Turbine Simulation Parameters

Using Equation 1 as the basis for defining input parameters, a Simulink® model was constructed to illustrate the output of the wind turbine rotor shaft (see Figure 11). Two of the main blocks were compressed into subsystems to avoid clutter in the model. The subsystem labeled "Cut In If Statements" dictates that the rotor shaft will not turn with wind velocities under 4.5 m/s. The subsystem labeled "Wind Turbine Subsystem" models Equation 1 without the Cp term.

An idealized value of 0.4 for the coefficient of performance, Cp , is not appropriate for all wind velocities because it 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 of [19], and can be expressed as:

$$c_p(\lambda,\beta) = c_1\left(c_2 / \lambda_i - c_3\beta - c_4\right)e^{-c_5/\lambda_i} + c_6\lambda, \quad (2)$$

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

Equation 2 was optimized for given wind velocities, v, 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 Cp and angular frequency, ω, for which RPM is directly proportional. The output of the wind turbine system is rotor shaft torque and RPM which are the usable inputs of the gearbox and generator that are connected with the wind turbine rotor shaft.

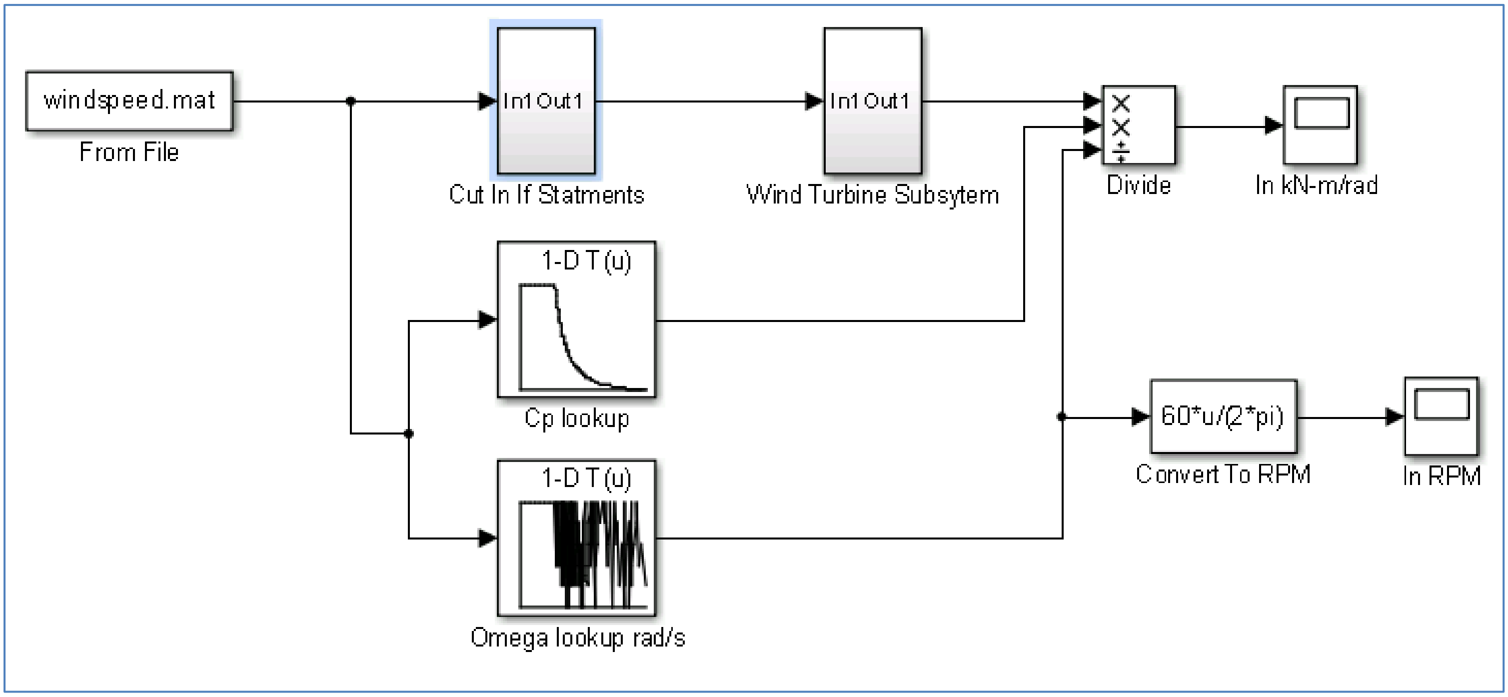

FIGURE 11: SIMULINK® MODEL OF WIND TURBINE

2.3.3 Wind Turbine Simulation Results

A wind velocity was generated in MATLAB for the period of one hour (Figure 12). The data set is read into the wind turbine simulation as “windspeed.mat” (Figure 11). The Simulink® simulation is built in such a way that any wind velocity profile can be read in as the data set if the data is taken in an area where the average wind speed is 6.5 m/s.

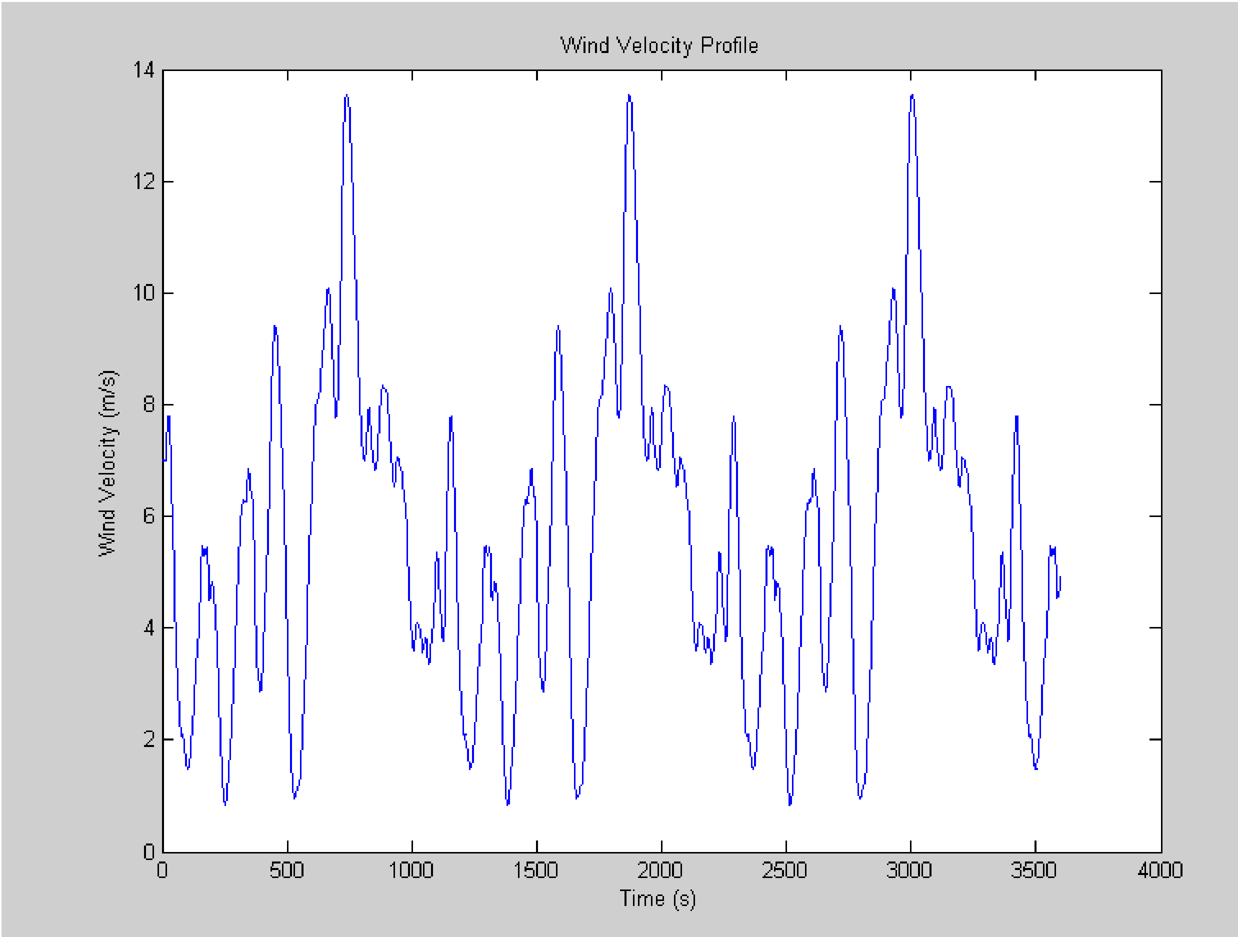

FIGURE 12: WIND VELOCITY PROFILE

The torque output of the simulation is illustrated in Figure 13 and the RPM output can be seen in Figure 14.

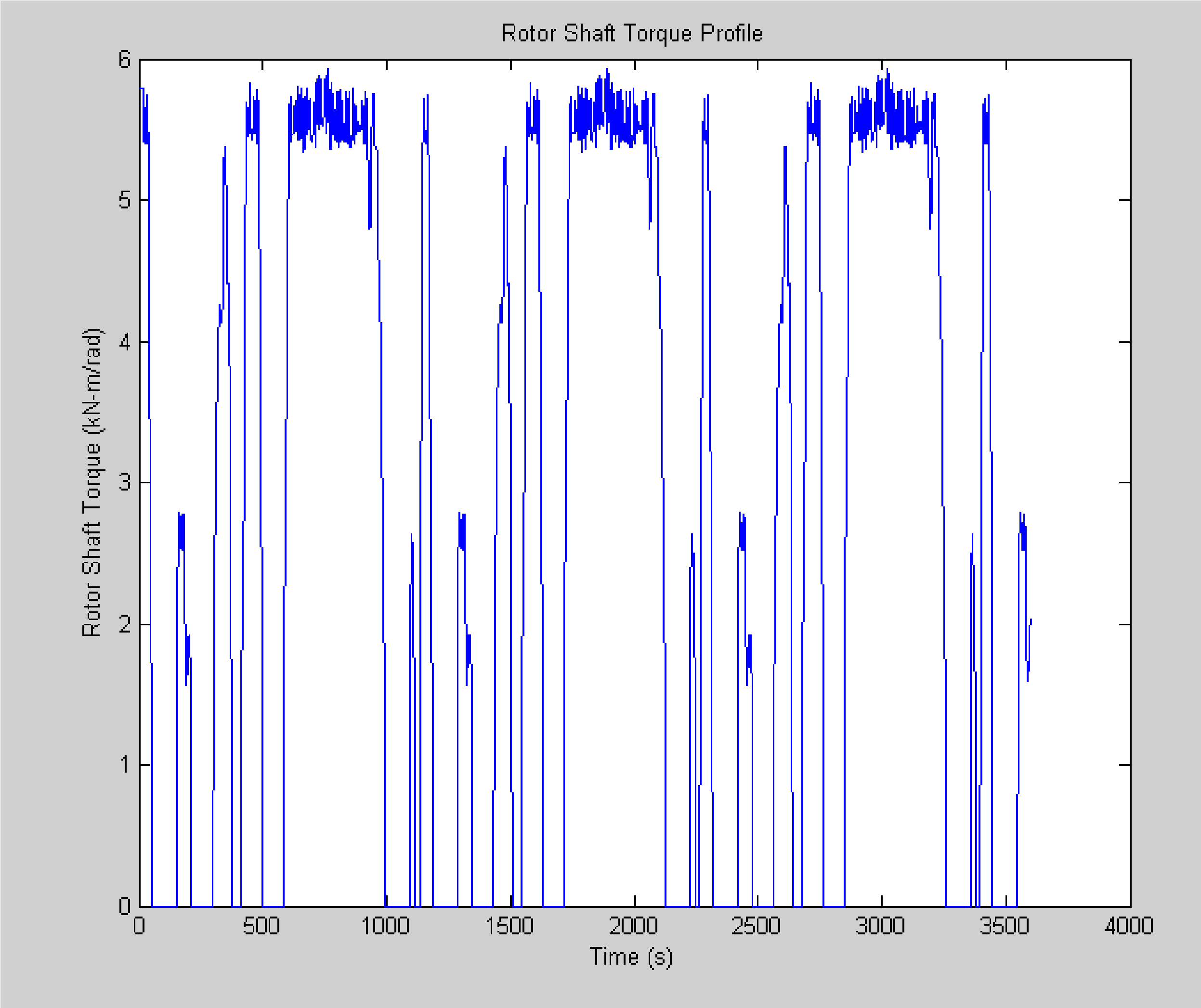

FIGURE 13: TORQUE OF WIND TURBINE ROTOR SHAFT

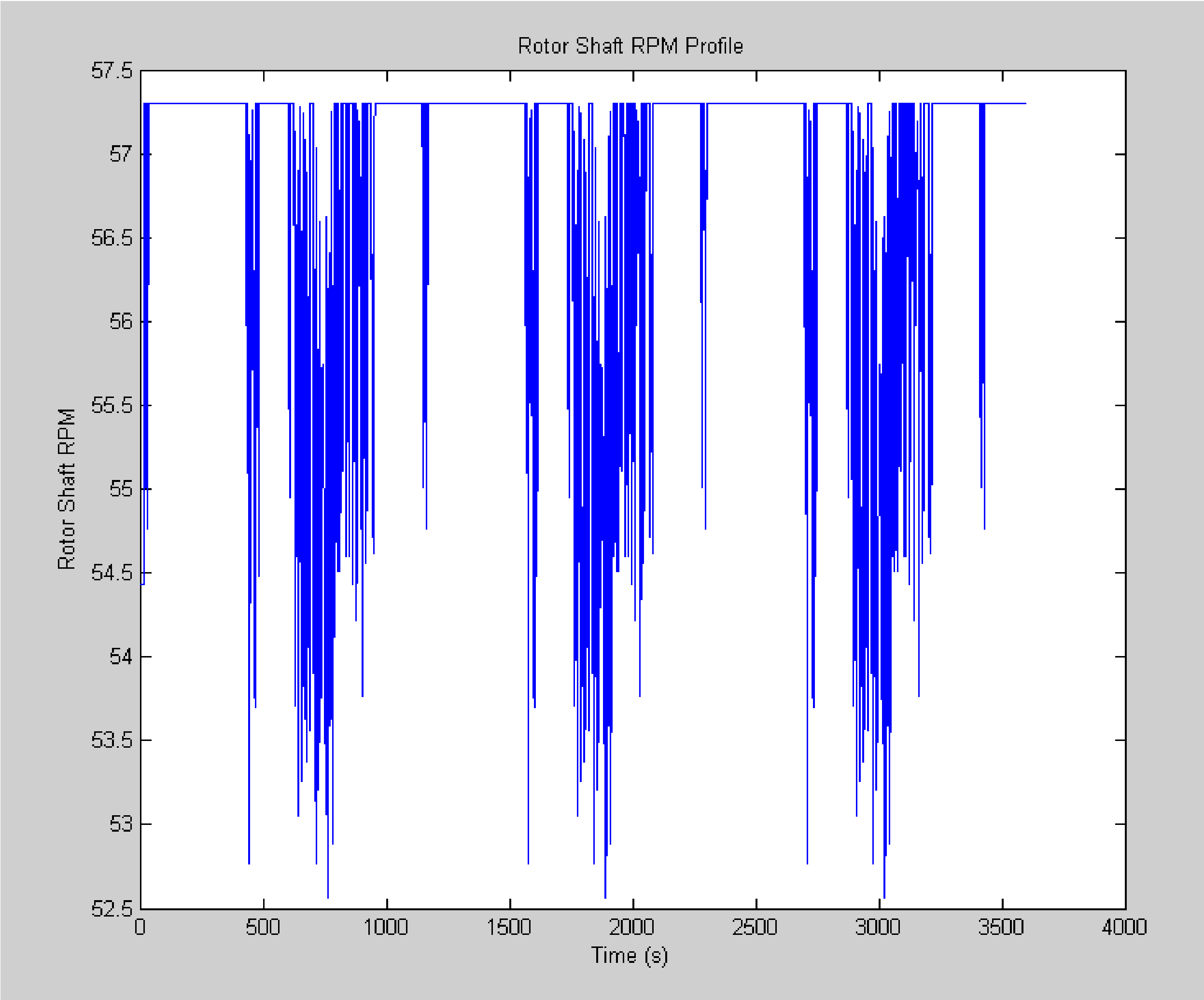

FIGURE 14: WIND TURBINE ROTOR RPM

Power is the product of torque and angular frequency and can be expressed as:

$$P = \tau\omega \tag{3}$$

Where: P- Power

τ- Torque

ω- Angular frequency

The power output of the simulation can be seen in Figure 15. Figure 15 also illustrates that the wind turbine rotor produces at least 32 kW of shaft power 36% of the time for this particular wind velocity profile.

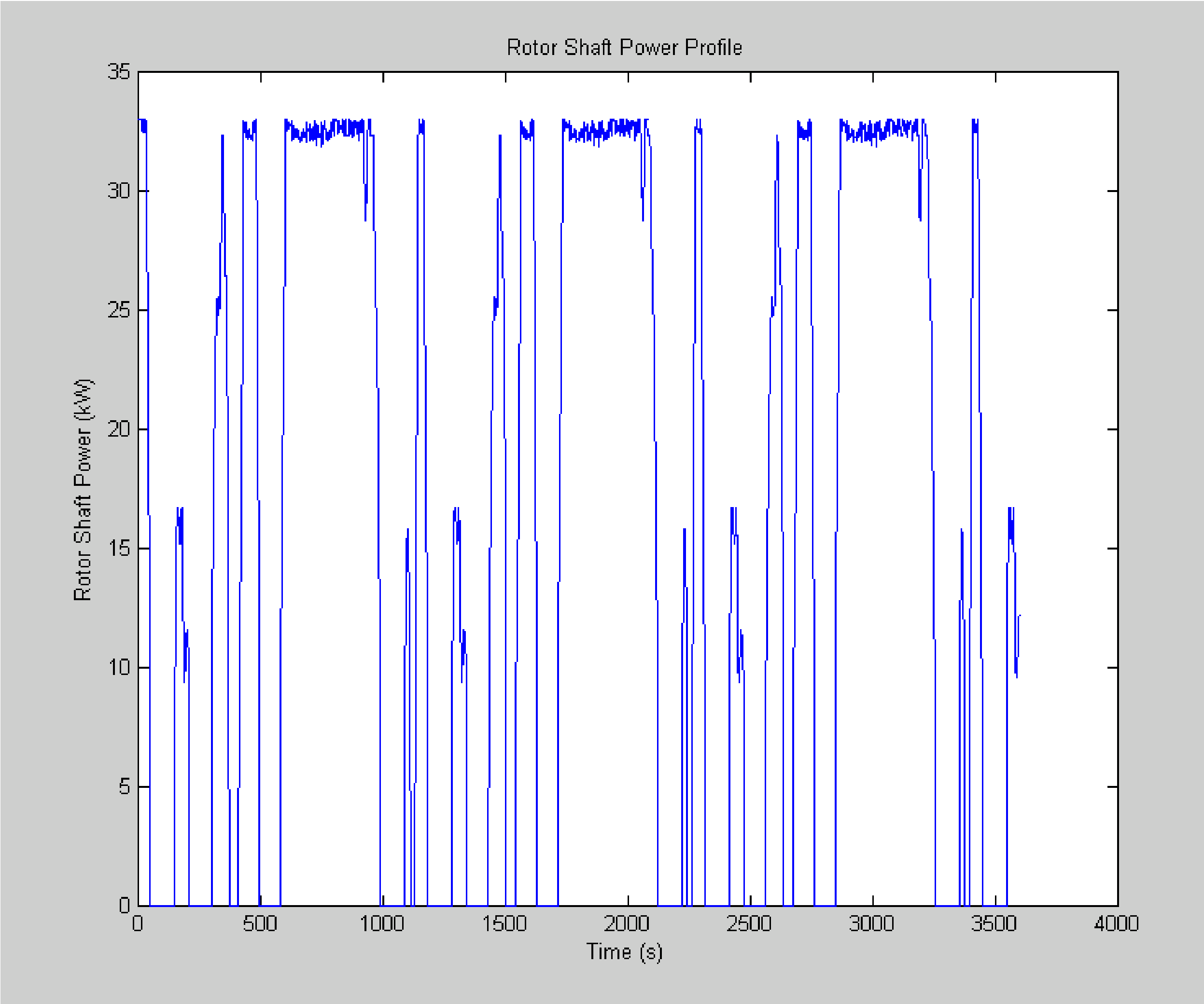

FIGURE 15: ROTOR SHAFT POWER PROFILE

2.4 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. Figure 16 is a current state of the Simulink® model for the gearbox and generator. Adaptations will be made as the formation of the overall simulation is finalized.

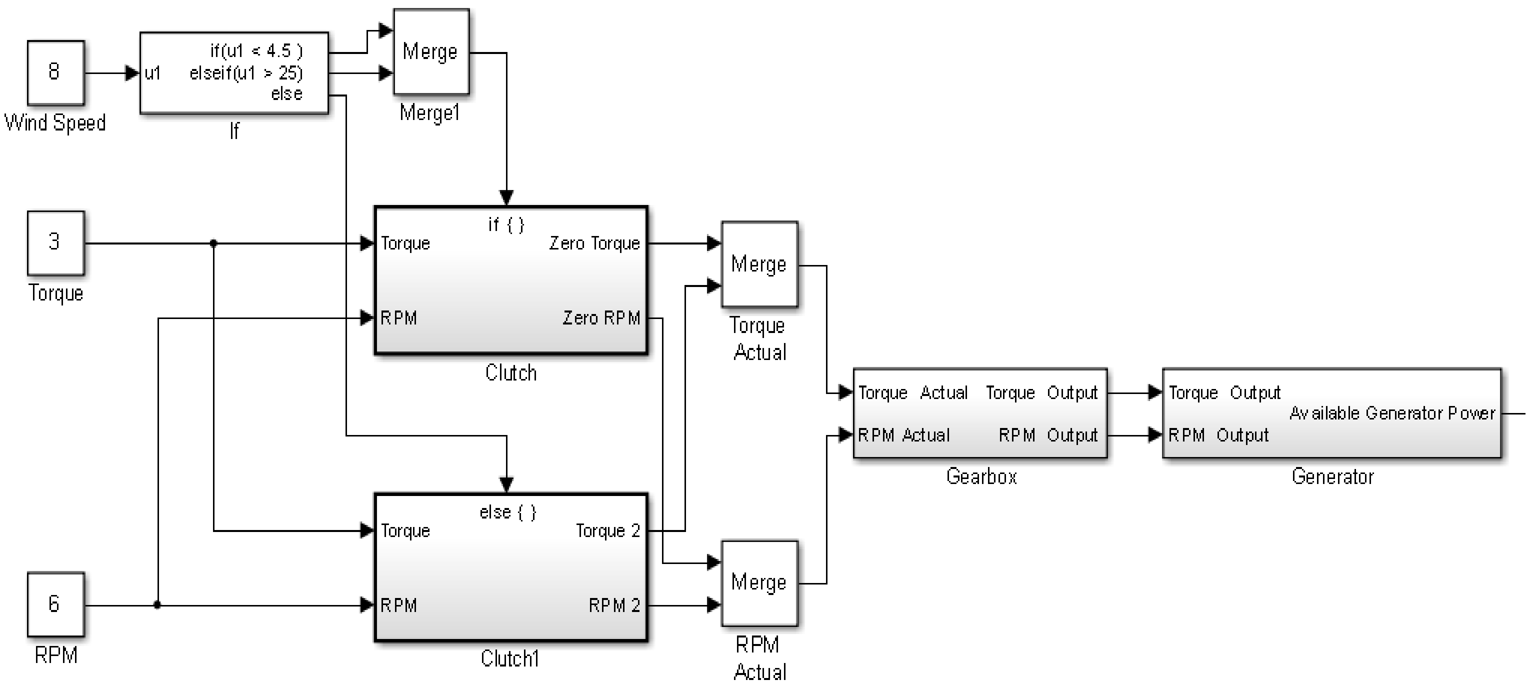

FIGURE 16: SIMULINK® MODEL OF GEARBOX/GENERATOR

As can be seen on the left side of Figure 16, 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 if 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.

The Wind Model, as mentioned in the previous section, is then connected to the Gearbox/Generator Model, including wind speed, torque, and RPM. With these inputs the gearbox and generator will simulate the process from taking the mechanical motion of the wind turbine and turning it into actual power. For this preliminary trial a set of wind speeds were generated. Figure 17 below shows the output of the actual power that is generated from the wind turbine in this simulation.

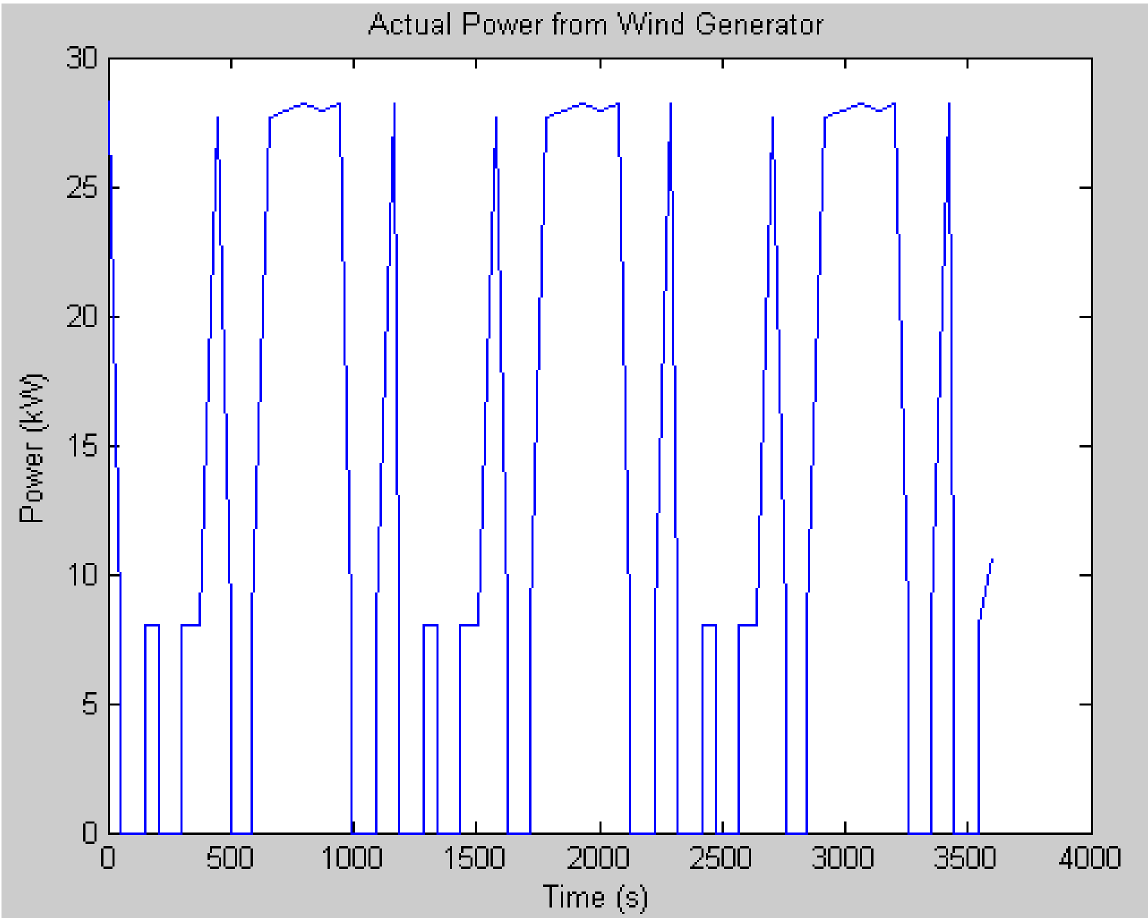

FIGURE 17: SIMULINK® ACTUAL POWER FROM WIND GENERATOR

It is clear that in this trial there were several time periods with negligible power outputs and the overall highest amount of wind generator power never reached the required power of 32kW. Further trials with actual wind data from nearby sites will determine if the required power can be actually reached.

2.5 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 18.

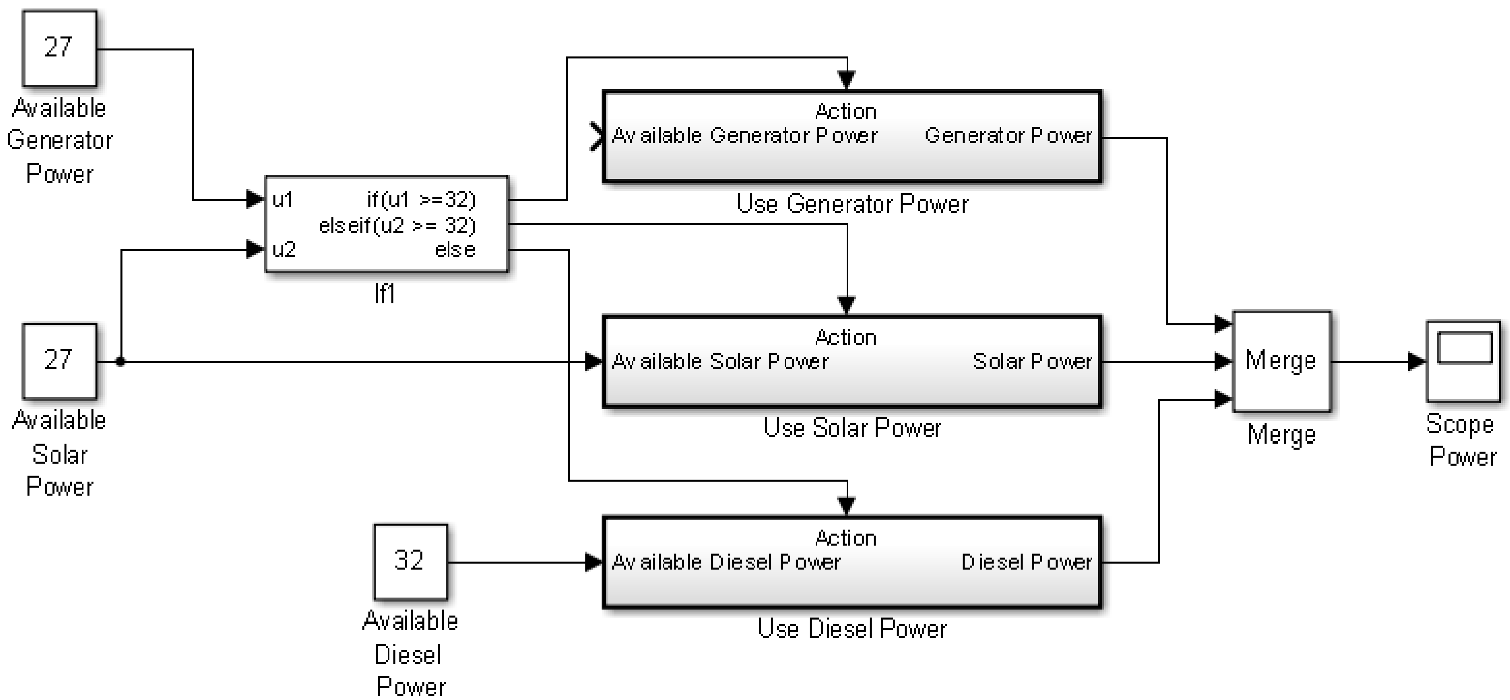

FIGURE 18: SIMULINK® MODEL OF CONTROLLER

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.

Figure 19 shows the assembly of several different models described thus far. The complexity of the system is quite high, but is made up of previous models shown in Figures 11, 16, and 18. The controller model takes all of this data that is generated and processed and decides which form of energy to use. As described in section 2.4, the wind velocities for the current simulation did not generate enough power to meet the 32kW demand. The simulation also assumed that solar power also did not generate the required demand. Figure 18 shows the output of the controller which is the actual power supplied. It can be noted that the power is constant at 32kW, which is all coming from the diesel generator at this time.

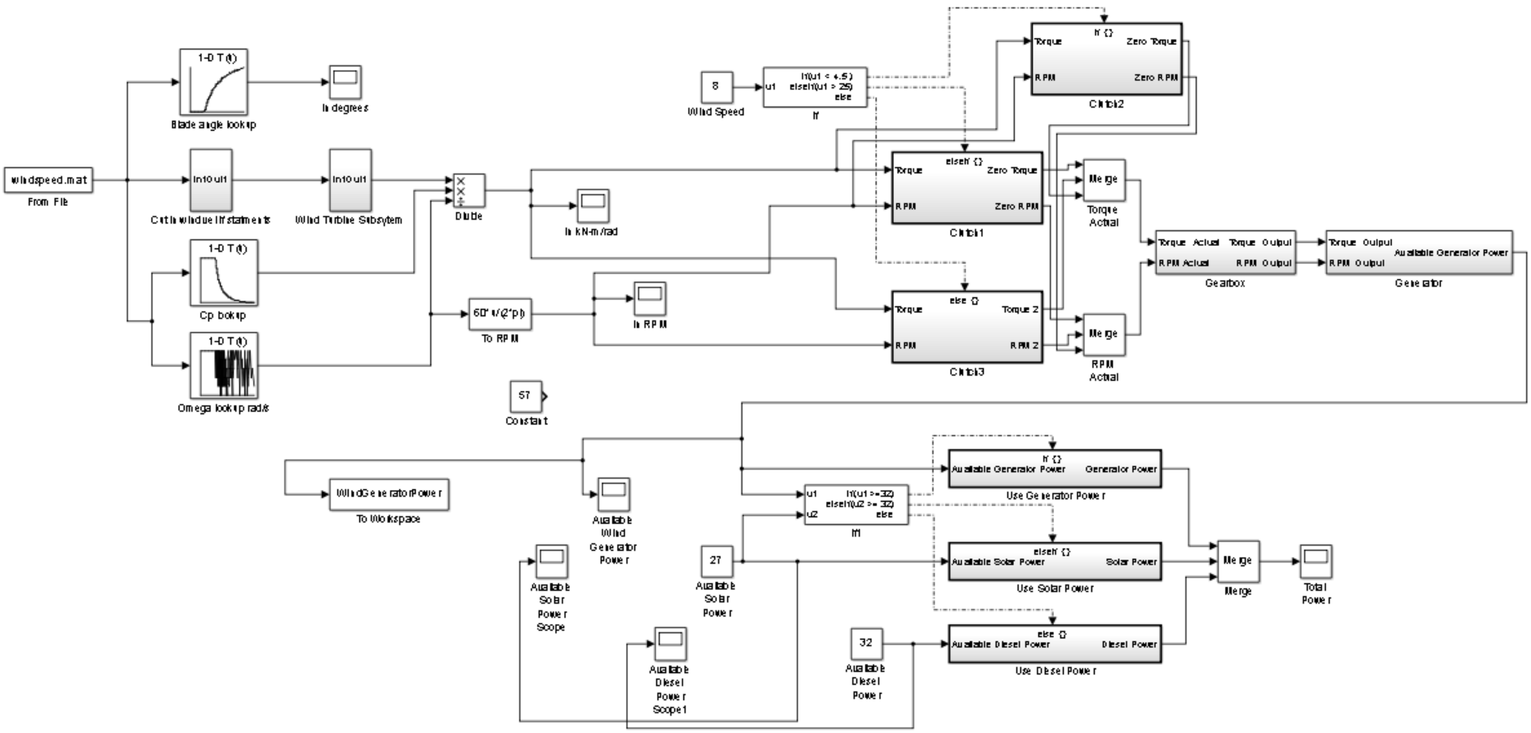

FIGURE 19: SIMULINK® WIND/GEARBOX/GENERATOR/CONTROLLER ASSEMBLY

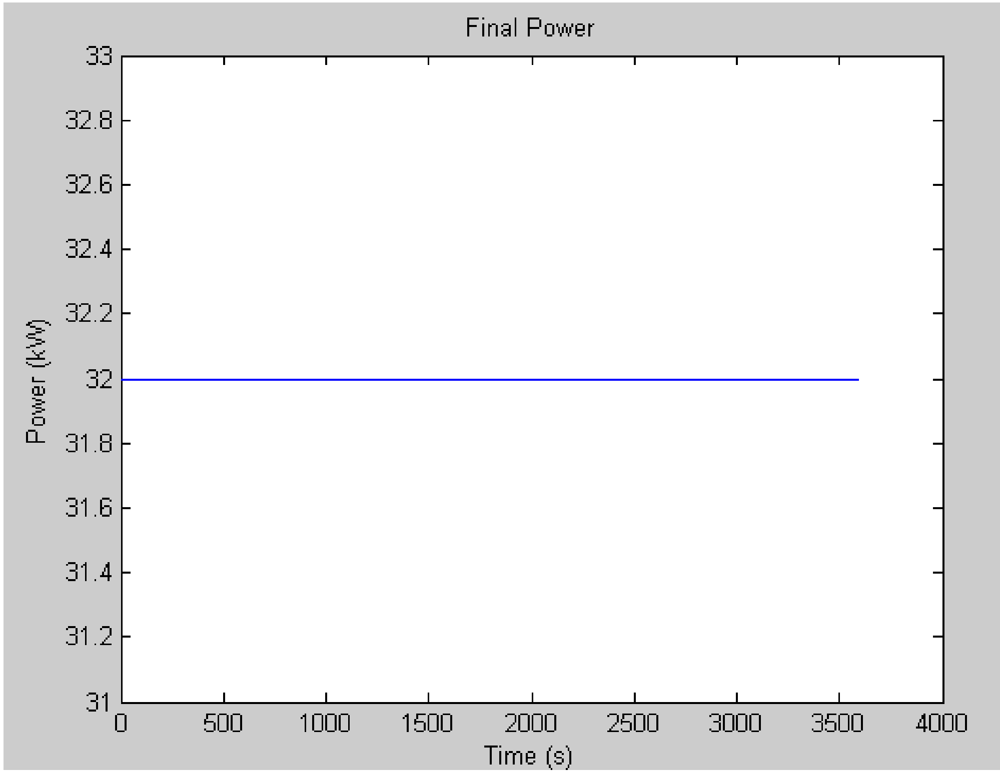

FIGURE 20: SIMULINK® FINAL POWER

3. Next Steps

Due to unforeseeable weather circumstances two previous site visits have had to been cancelled. In the following weeks the team will set up a new appointment for a site visit, or if necessary a phone interview with the pump specialist that is at the site. Information such as flow rates, maximum pumping capacity, resource availability, reliability, water consumption, well depth will be acquired in these meetings. From these specific values the team will design an alternative energy system that meets the needs of the client.

Once such a system has been designed, the team will modify the existing Simulink® simulation to accommodate constants retrieved during the site visit. Final analysis can then be performed using the Simulink® simulation as a tool to analyze different scenarios, such as varying wind and solar resource conditions. The profitability of such a system can then be determined based on the amount that the alternative energy sources supplement the diesel generator.

4. Gantt Chart

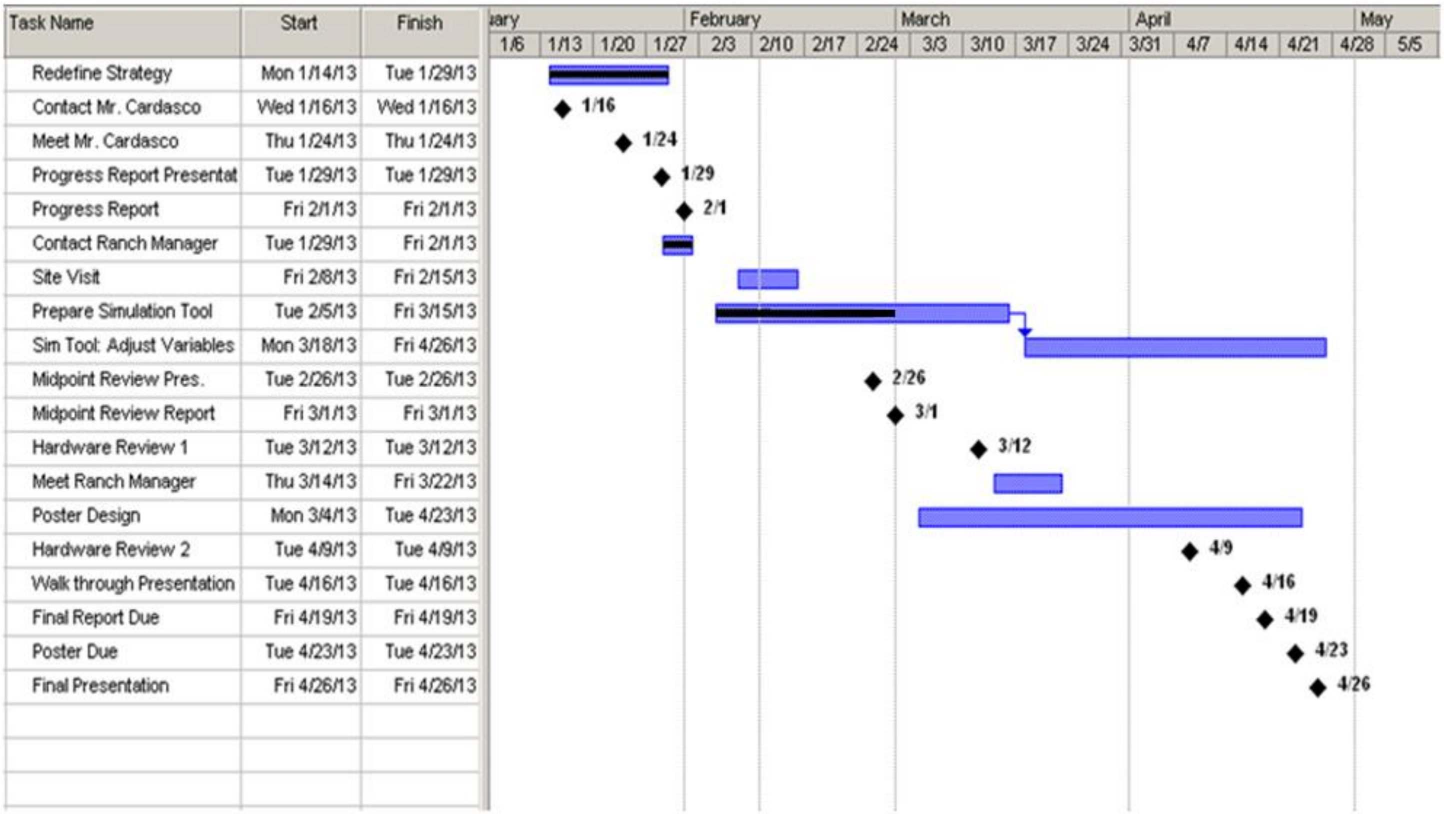

FIGURE 21: GANTT CHART

5. References

1. Doug Stevens – CEMEX
2. Bill Cardasco – Babbitt Ranches
3. www.energy.ca.gov
4. www.lipower.org
5. www.usasolarwind.com
6. http://www.azgs.az.gov/geothermal
7. www.nau.edu
8. http://www.zbbenergy.com/
9. http://www.windustry.org/
10. http://www.wind-estimate.org
11. solarenergy.advanced-energy.com
12. www.wind-sun.com
13. www.solarworld-usa.com
14. APS. WEB. http://www.aps.com/_files/solarRenewable/NONRES-PVGT-UFI.pdf
15. SES1. WEB. http://www.solarelectricsupply.com/systems/commercial/index.html
16. SES2. WEB.http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=AZ20F&re=1&ee=0
17. www.wind-power-program.com/mean_power_calculation.htm
18. The Cadmus Group, 1998. Regional Electricity Emission Factors Final Report.
19. Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems," John Wiley & Sons Ltd, 1998, ISBN 0-471-97143-X
20. http://www.mathworks.com/help/physmod/powersys/ref/windturbine.html