FEASIBILITY OF INSTALLING BATTERIES AT CONSUMER END FOR PEAK SHAVING

An Interactive Qualifying Project Report

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By

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Chapter 1 – Abstract and Introduction

1.1 Abstract

The purpose of this project is to assess the economic viability of installing batteries by a large consumer to assist in peak shaving. Its main goals include using system dynamics modeling to determine the pricing and incentive structures that best combine with feasible alternative energy sources to produce savings on the demand side for the local companies. The case of WPI is used to represent a typical large consumer. Furthermore, various scenarios were explored to utilize the current data and to meet the expectations of our sponsor.

1.2 Introduction

In today's society, electricity is used in all aspects of life. We depend on it for so many activities, from starting cars to reading to even talking with one another. However, using electricity ultimately amounts to one thing: paying for it. Everyone who uses electricity has to pay for it and consumers have to pay quite a lot for its usage. So much so that many consumers are looking for means to reduce expenses; this can vary from simply reducing the amount of electricity used to installing devices to generate their own. In the field of installing devices for peak shaving, there are two main categories of devices: distributed generators and batteries. Distributed generators, also know as distributed energy resources or dispersed energy[i], are devices that generate electricity from many small energy sources. Generators, fuel cells, and wind turbines are a few of the many different options for distributed generation. The other option, batteries, is large storage devices that can store energy for an extended period of time, discharge it then charge it back up again.

Chapter 2 – Background

2.1 Previous Work[1]

This project is a continuation of two previous projects undertaken at WPI and is also sponsored by National Grid. The results of the first project, *Retrofitting a Power Distribution Feeder*[ii], showed that storage devices are a feasible solution for peak shaving, but they are not economical. On the other hand, distributed generators provide savings for the distribution company, and are the best option for the extension of transformer life. However, the model created did not include well-developed environmental or cost sectors, thus rendering a financial decision impossible. The students also suggested that structures to measure pollutants and legal pollution restrictions be added to the model. In addition, the students proposed the exploration of installing environmentally friendly and fuel efficient generation technologies.

In the second project, *Impact of Distributed Generation on the Local Electric Grid*[iii], sponsored by National Grid, the students came to the conclusion that distributed generators are an economic solution to postpone the need for transformer upgrade. Their model and subsequent analysis revealed that the effectiveness of the installation depended on several variables, including the size of the transformer, timing of installation relative to the transformer life left, and the different demand profiles specific to the primary feeder (power cable) concerned. They concluded that the installations of the generators should be made only when there are no larger transformers available and only option is to build another grid substation.

While these projects assumed that the generation devices would be financed by National Grid, this project assumes that the consumer, WPI, will be paying for the entire project. Having consumer finance the project is a more economically realistic scenario; if several consumers

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[1] This section was written with the help of Martin Ivanov

were to decide to install batteries with National Grid financing each installation, National Grid would lose money extremely quickly. Also, the consumer would completely own the batteries and not have to pay any tariffs or taxes National Grid might impose for usage of the batteries.

2.2 – Current Technology

As worldwide consumption of energy increases every year, consumers are continually researching options to help offset the rising cost of energy. In the United States, energy consumption is projected to average 10.7 billion kWh per day in 2007, 2.1 percent greater than in 2006[iv]. In residential districts, prices were predicted to rise 2.6 percent in 2007 and another 2.9 percent in 2008[v]. Worldwide, consumers are taking advantage of the abilities of batteries to help manage energy and to increase the quality of power. These batteries not only assist in peak shaving, to save customers money, but also help to decrease the strain on generators, extending their useful lifespan. The extra life saves distribution companies, like National Grid, money by delaying the time until it becomes necessary to install newer or larger generators.

Currently, there are several battery types that consumers can choose from: Lead-Acid (Flooded or Valve-Regulated), Nickel-Cadmium, Sodium-Sulfur, and Regenesys Flow. The Sandia National Laboratories' report to the Department of Energy in 2003[vi] best details each of these batteries which are summarized below.

2.2.1 Lead Acid Batteries: Flooded[vii]

Flooded Lead Acid Batteries are the oldest energy storage devices[viii] are used today for a number of large scale operations. These batteries are the least cost consuming of all the battery types at $150/kWh, the actual installation and upkeep cost of the battery rival the battery cost, making them somewhat expensive. The lifespan of the batteries is around 5 or 6 years, based on the manufacturer's performance data. The efficiency of the batteries can range from 70 percent up to 80 percent. The operation and maintenance (O&M) cost for the batteries is about $15/kW-yr[2]. A common application of Flooded Lead Acid Batteries is automobile batteries.[ix]

2.2.2 *Lead Acid Batteries: Valve-Regulated*[x]

Valve-Regulated Lead Acid Batteries are very similar to its flooded counterparts. It is a bit more expensive, $200/kWh, but its efficiency is about the same, 75 percent. The biggest benefit of the Valve-Regulated Batteries is that they require less maintenance than flooded lead acid batteries. The batteries do require some maintenance, with O&M costing $5/kW-yr. These batteries are ideal for smaller systems, rendering them less suited to the current project.

2.2.3 *Nickel-Cadmium*[xi]

The costs of the Nickel-Cadmium batteries estimated by the Sandia Laboratories' report are based off a site in Alaska[3], which was under construction in 2003. The batteries cost around $900/kWh, with manufacturer's predicting cost to fall to $600/kWh. The life-span can reach up to 10 years, provided only one deep cycle occurs per day. The O&M cost is around $5/kW-yr.

2.2.4 *Regenesys Flow*[xii]

The Regenesys Flow batteries, also called the regenerative fuel cell, are constructed by stacking small cells and utilizing the electrolytic flow to create large voltages. Sodium Bromide is used as in the active electrolyte and sodium polysulfide as the negative electrode. From the

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[2] The operation and maintenance cost is under the assumption of a single person performing maintenance for eight hours a day, 365 days per year.

[3] "A 13 MWh plant in Fairbanks, Alaska, which is rated at 6.5 MWh and 26 MW (15 minutes) for initial operation. The installed converter has a capacity of 40 MW continuous." After taking out the cost of the converter, non-storage related facilities and balance of plant costs 12 million dollars is left for the initial battery set, resulting in a cost of $900/kWh.

two plants[4] that use Regenesys Flow batteries, the batteries cost $300/kWh, with an efficiency between 65 percent and 70 percent, and an O&M cost of $10/kW-yr.

2.2.5 Sodium Sulfur[xiii]

The Japanese company NGK Insulators produces the NaS batteries that are "the most advanced of several energy-storage technologies that utilities are testing,"[xiv] according to *USA Today*. They perform at around 70 percent efficiency, although the Electricity Storage Association (ESA) cites that number higher at 89 percent.[xv] The cost is around $250/kWh plus $150/kW for the power conversion equipment, making these batteries slightly more expensive than others. The lifespan of the battery, according to tests by NGK, is about 10 years with 250 cycles per year. The O&M costs $20/kW-yr.

2.2.6 Comparison

Table 1 below contains data taken from the Sandia National Laboratories 2003 report detailing the major costs of each of the battery types.

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[4] Little Barford, England and Tennessee Valley Authority system, Mississippi

Table 1: Battery Comparison

Battery/Costs	Flooded Lead Acid	Valve-Regulated Lead Acid	NiCd	Flow	NaS
Energy Related Cost ($/kWh)	150	200	600	100	250
Power Related Cost ($/kW)	175	175	175	175	150
O&M costs ($/kW-yr)	15	5	25	20	20
Efficiency	0.75	0.75	0.65	0.7	0.7
Life-span (years)	6	5	10	10	15

When deciding which battery to use, Flow batteries were originally chosen because they are the cheapest and had a long life-span. However, when talking with Dr. John Bzura, the sponsor from National Grid, he recommended investigating NiCd batteries. After contacting Jim McDowell, who works at the Alaskan NiCd site, and requesting information concerning the utilization of NiCd batteries in the project, he stated that NiCd batteries would not be a good choice for a project of this type. The project involves daily charging/discharging cycles and the NiCd batteries are more suitable for once or twice a month cycles. He recommended using the NaS batteries, which would be more suited for the deep, daily discharging cycles. The findings in the Sandia Laboratories report supported Jim McDowell's suggestion. Coupled with the batteries' long life-span and high efficiency, the NaS batteries became the best option for the project.

Chapter 3 – Model Development

In the previous projects students came to the conclusion that batteries are not currently a viable option for peak shaving. However, they did not investigate the extent of influence a possible installation of batteries would have on a consumer, in our case WPI's financial state. They further assumed that batteries would be purchased by National Grid. In the current project WPI is assumed to be solely responsible for funding the entire project. The current model is objectively represented in the links and interrelationships between the variables in our dynamic hypothesis, because the most recent results coincide with the results of the previous reports. A dynamic hypothesis is a visual representation of the feedback loops or links in a complex system over a period of time. It shows the major variables, how increasing or decreasing a particular variable affects the other variables in its direct loop or link and how that change will propagate along subsequent loops or links. The dynamic hypothesis, the outline for the model, is discussed in this section, along with the presentation of the model.

3.1 Dynamic Hypothesis[5]

Figure 1 outlines the key feedback loops in our dynamic hypothesis. Development of the model began with the capital costs associated with installing the batteries. As they significantly dwarf the costs related to operating and servicing the batteries, they were made the basis of our model. The following two sections will explain the details of the hypothesis.

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[5] This section was written with the help of Martin Ivanov.

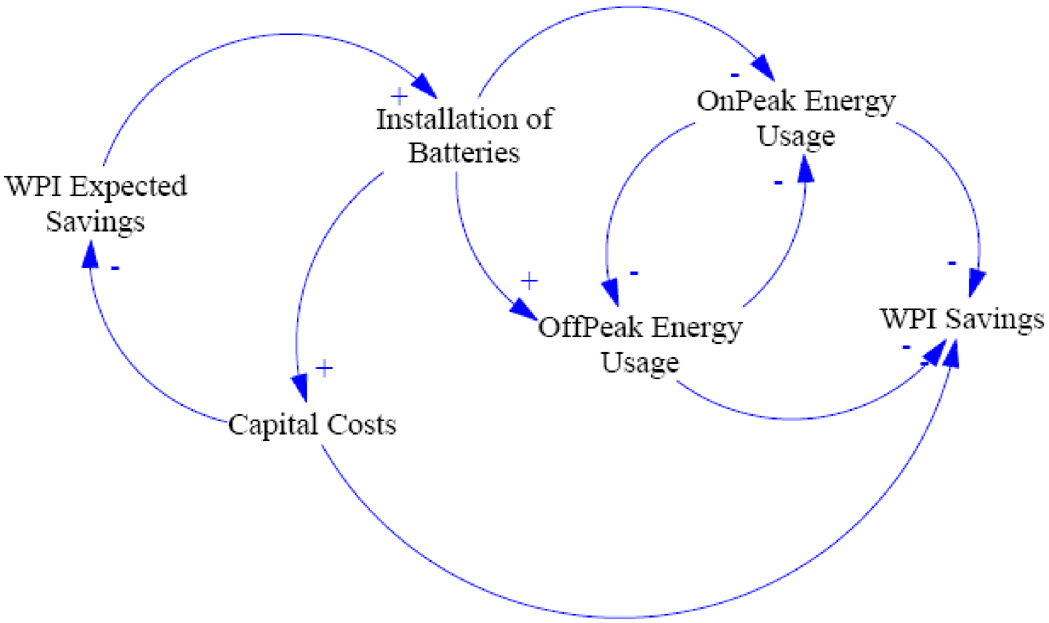

Figure 1: Dynamic Hypothesis

3.1.1 – Links in the Dynamic Hypothesis

The first link is from *Capital Costs* to *WPI Expected Savings*. It depicts that by having increased capital costs, either by installing a greater number or more expensive batteries, the expected savings after finishing the project will decrease. Therefore, to maximize expected savings, the aim is to find the ratio with the lowest price to the highest capacity (kWh).

The next link is from *WPI Expected Savings* to *Installation of Batteries*. The logic behind this link is that if you anticipate significant reduction in your electricity bill (higher expected savings), WPI would install as much battery capacity as possible to take advantage of the savings. The model continues by linking *Installation of Batteries* to *Capital Costs*, under the assumption that a higher battery capacity would lead to greater capital costs.

The next important interactions are those originating from *Installation to Batteries* and going to the energy sector, which consists of *OnPeak Energy Usage* and *OffPeak Energy Usage*.

Once WPI is able to bring a sufficient battery capacity online and is able to keep these batteries operational, WPI will reduce its usage of the more costly, during-the-day energy (*OnPeak Energy Usage)* by shaving the peak load by using the current battery capacity. This would lead to lower usage of energy during the peak periods of the day and to a greater usage of energy during the night, when the batteries have to be recharged. Basically, if the *Installation of Batteries* results in an increased battery capacity, the *OnPeak Energy Usage* would decrease and the *OffPeak Energy Usage* would increase. Here, an assumption is made: the total WPI usage of energy per day stays constant and occurs either during the day or during the night. In other words every decrease in *OnPeak Energy Usage* will lead to a proportional increase in *OffPeak Energy Usage* and visa versa. Both periods of energy usage affect the *WPI Savings: WPI Savings* will increase if the *OnPeak Energy Usage* decreases and the resulting increase in *OffPeak Energy Usage* will still lead to accumulating savings to WPI due to the much lower costs associated with OffPeak energy[6].[xvi] Thus, the success of this project will be determined by the strength of the link between both *OnPeak* and *OffPeak Energy Usage* and *WPI Savings.*

3.1.2 – Loops in the Dynamic Hypothesis

The first loop goes through *Capital Costs, WPI Expected Savings* and *Installation of Batteries.* This balancing loop (negative reinforcement) presents a major obstacle to this project. If current technology does not prove viable or requires large amounts of initial cash outflows, any expected savings will be severely diminished. If the project is deemed unprofitable, no undertaking to install batteries will be initiated. Thus, the current costs and parameters[7] of the batteries are of utmost importance.

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[6] During the OnPeak hours energy costs 1.249 ¢/kWh, while OffPeak hours energy costs 0.017 ¢/kWh.

[7] The parameters include battery capacity, efficiency, and initial cost.

The next loop is the balancing loop between *OnPeak Energy Usage* and *OffPeak Energy Usage*. This takes into account the assumption that WPI's energy consumption is stable during the 24-hour period. Thus, any energy used during the day will have to be recharged by the batteries during the night. The discrepancy between the costs for daily and nightly energy will lead to accumulated savings.

3.3 Model Overview

From the dynamic hypothesis, the model created was split into six main sectors: accounting cost of the project, supply chain, WPI expected savings, WPI actual savings, expected energy sector, and energy sector. Each of these sections will be explained in detail in the following sections.

3.3.1 Accounting Cost and Opportunity Cost of the Project[8]

Financial sectors include the calculation of the accounting and opportunity cost of the project. This cost is a cornerstone factor in the decision to install batteries. Figures 2 and 3 below show overviews of the sectors taken directly from “iThink.”

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[8] This section was written with the help of Martin Ivanov

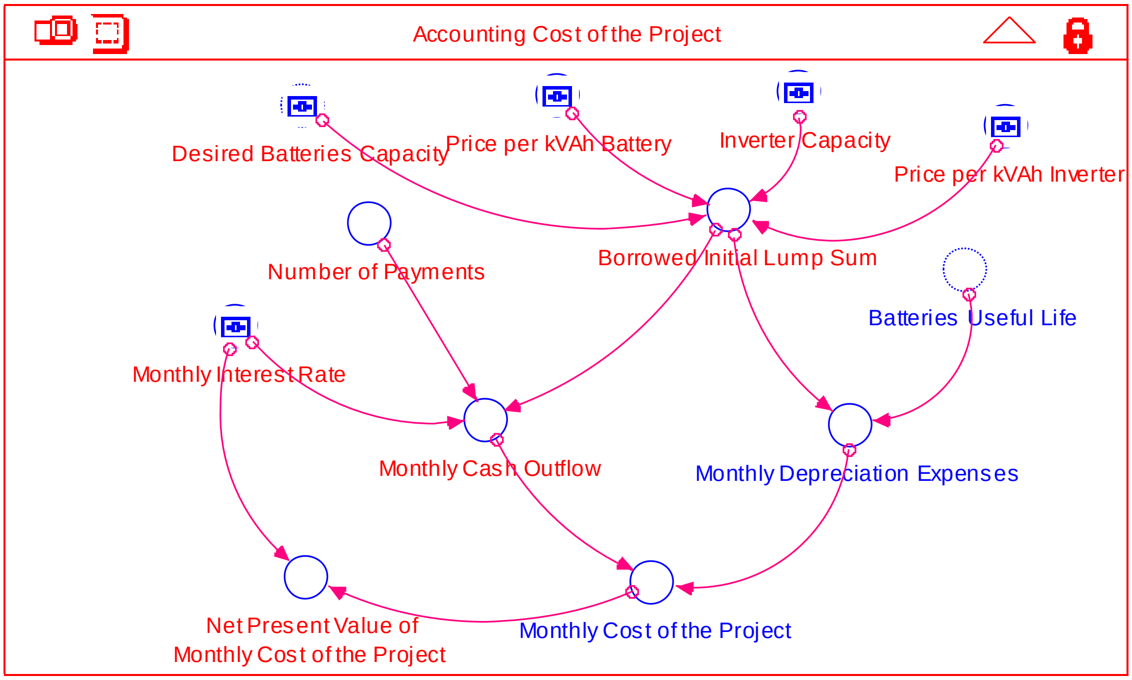

Figure 2: Accounting Cost of the Project

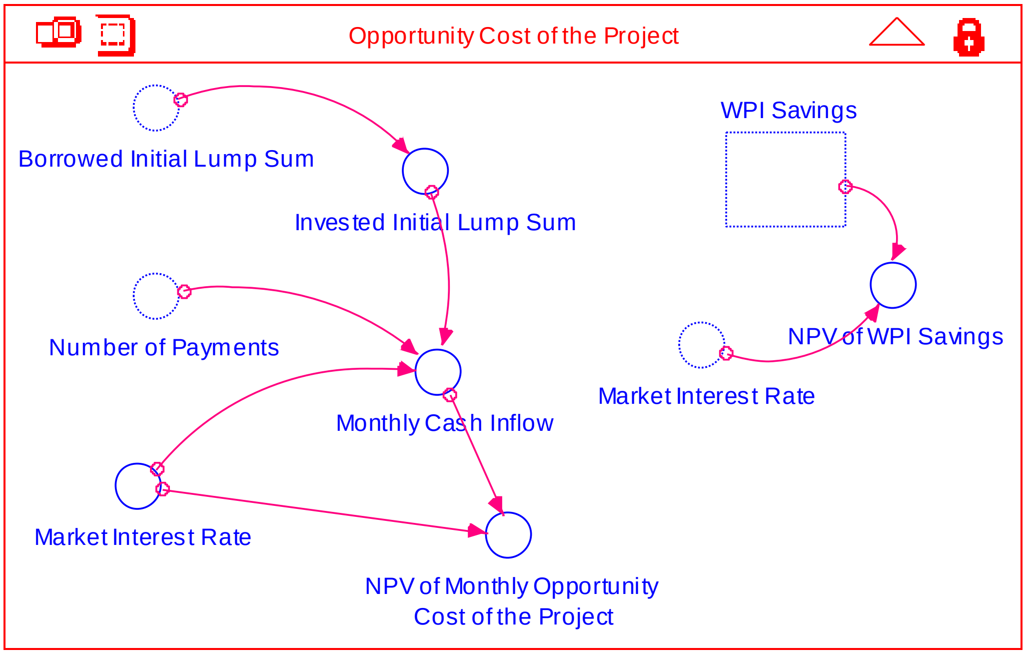

Figure 3: Opportunity Cost of the Project

The calculations are based on the initial assumption that in order to undertake such a long-term project which would require a steady number of cash outflows over the years, WPI would have to borrow the funding. In that sense the node *Borrowed Initial Lump Sum* represents all the investment money needed by WPI to purchase the batteries that would provide enough capacity for peak shaving. The following equations taken from Appendix I show this relationship:

```
Borrowed_Initial_Lump_Sum = Inverter_Capacity * Price_per_kVAh_Inverter + Price_per_kVAh_Battery
* Desired_Batteries_Capacity

Inverter_Capacity = 200
Price_per_kVAh_Battery = 250
Price_per_kVAh_Inverter = 150
Desired_Batteries_Capacity = 500
```

This sum would consist of two major components: batteries cost and inverter cost. These two represent the greatest cash outflows in the project and since they significantly dwarf the operations and management (O&M) cost, they fairly represent the overall cost of the project. The battery cost is calculated by taking into account the *Desired Batteries Capacity* that will enable WPI to generate savings and *$ per kVAh* of batteries that current technology allows for. The latter is the pivotal point in this model as it changes significantly when different capacities of batteries are considered. It will also diminish greatly in the future, due to technological change and current spending undertaken to subsidize environmentally friendly, alternative energy sources. In calculating the *Borrowed Initial Lump Sum*, the cost of the inverter is considered, which consists of the *Inverter Capacity* and the *$ per KW Inverter.* The two previous projects proved insightful in deriving these costs and significantly improved this sector by reflecting realistic values.

Once a value for the *Borrowed Initial Lump Sum* was obtained, the depreciation expenses these batteries was explored. The following equations taken from Appendix I show this relationship:

Monthly_Depreciation_Expenses = Borrowed_Initial_Lump_Sum/Batteries_Useful_Life
Batteries_Useful_Life = 10

The *Borrowed Initial Lump Sum* plus *Batteries Useful Life* were used as variables to determine how much WPI would have to pay for *Monthly Depreciation Expenses* and then theses expenses were added into the *Monthly Cost of the Project*, whose equations are shown below:

Monthly_Cost_of_the_Project = Monthly_Cash_Outflow + Monthly_Depreciation_Expenses

Monthly_Depreciation_Expenses = Borrowed_Initial_Lump_Sum / Batteries_Useful_Life

Monthly_Cash_Outflow = PMT(Monthly_Interest_Rate, Number_of_Payments,
Borrowed_Initial_Lump_Sum, 0)

Another variable that was factored into the *Monthly Cost of the Project* is the *Monthly Cash Outflow*. In deriving this outflow, a financial function built into “iThink” with the *Number of Payments* equal to the number of months that the project would last over (120 months), the *Borrowed Initial Lump Sum*, and the *Monthly Interest Rate* are included in the *Monthly Cash Outflow*. The *Monthly Interest Rate* is highly dependent on market conditions and on WPI's financial state. It was used as a parameter in a sensitivity study to find out to what extent and at what rate WPI could borrow to achieve any savings from this project.

The final node in this sector represents the method chosen to determine the financial viability of the project. Given the *Monthly Interest Rate* and the *Monthly Cost of the Project*, the *Net Present Value of Monthly Cost of the Project* determines what the present value of the future payments WPI would commit itself to pay when reflecting the time value of money. The following equations taken from Appendix I show this relationship:

Net_Present_Value_of_Monthly_Cost_of_the_Project = ABS(NPV(Monthly_Cost_of_the_Project,
Monthly_Interest_Rate))

Figure 3 below shows a graph of the *Net Present Value of Monthly Cost of the Project.*

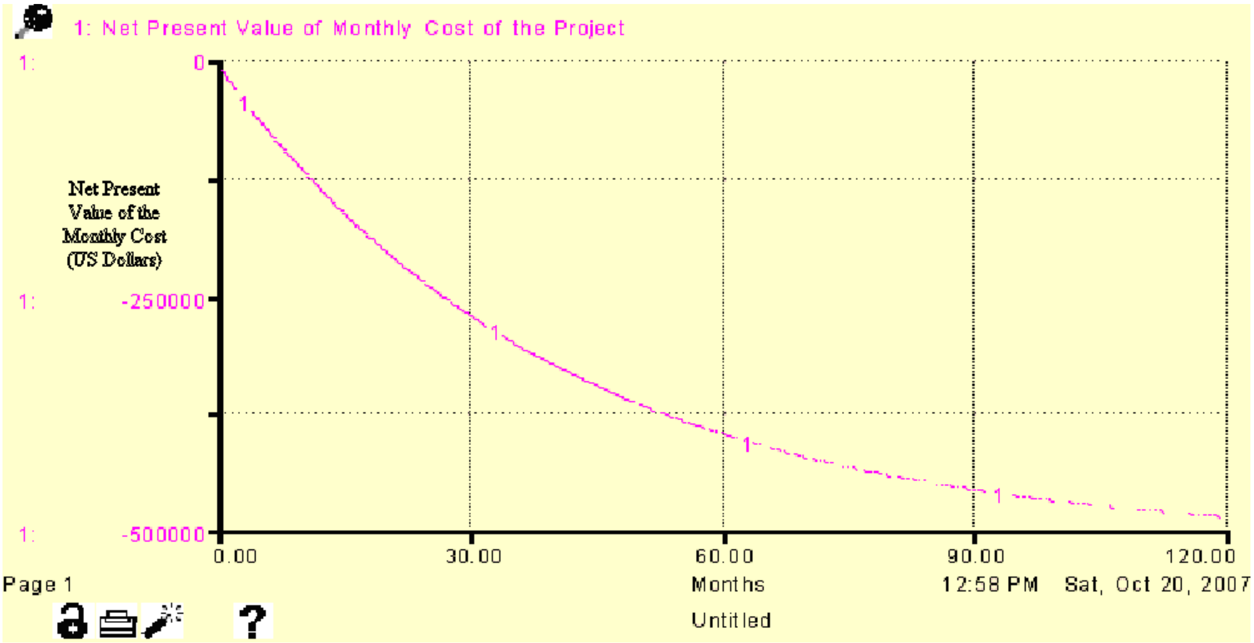

Figure 4: Net Present Value of Monthly Cost of the Project

Figure 4 shows that the present value of the monthly cost to be incurred in the future decreases as the payment date is extended further into the future. The figure depicts a negative value for the net present value, because it is a cost for WPI, or a loss of money. The present value also falls faster the higher the interest rate. This is because at high rates, costs to be incurred in the future are worth very little today.

3.3.2 Supply Chain[9]

The second main component of the model is the supply chain. It represents different stages at which battery capacity comes online. This is a fair model of reality because it includes time delays which prohibit the instantaneous installation of batteries. The supply chain begins with the decision to install batteries which in our case is a cost-benefit analysis. We compare the *Net Present Value of Monthly Cost of the Project* to *Net Present Value of WPI Projected Monthly Savings* to determine whether or not the project is feasible. If *Net Present Value of WPI*

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[9] This section was written with the help of Martin Ivanov.

Projected Monthly Savings is greater, then the decision rule implemented at *Cost-Benefit Analysis* allows the project to start. Once the *Cost-Benefit Analysis* calculates that installation of batteries is feasible, the user can determine the economic size of the battery. An economic size of 250 kVAh was set as the initial value. The *Decision to Install Capacity* is further affected by the *Desired Batteries Capacity* which is a variable manipulated in the sensitivity studies. The equations for the two decisions are as follows:

```
Cost_Benefit_Analysis = IF (Net_Present_Value_of_WPI_Projected_Monthly_Savings >
        Net_Present_Value_of_Monthly_Cost_of_the_Project)
        THEN 1
        ELSE 0

Decision_to_Install_Capacity = IF (Cost_Benefit_Analysis=1)
        THEN ( IF (Desired_Batteries_Capacity-Batteries_Capacity_Approved-Batteries_Delivery
        -Batteries_Capacity_OnLine) > (Economic_Size_of_a_Battery)
        THEN PULSE(Economic_Size_of_a_Battery, TIME,10000)
        ELSE 0)
        ELSE 0
```

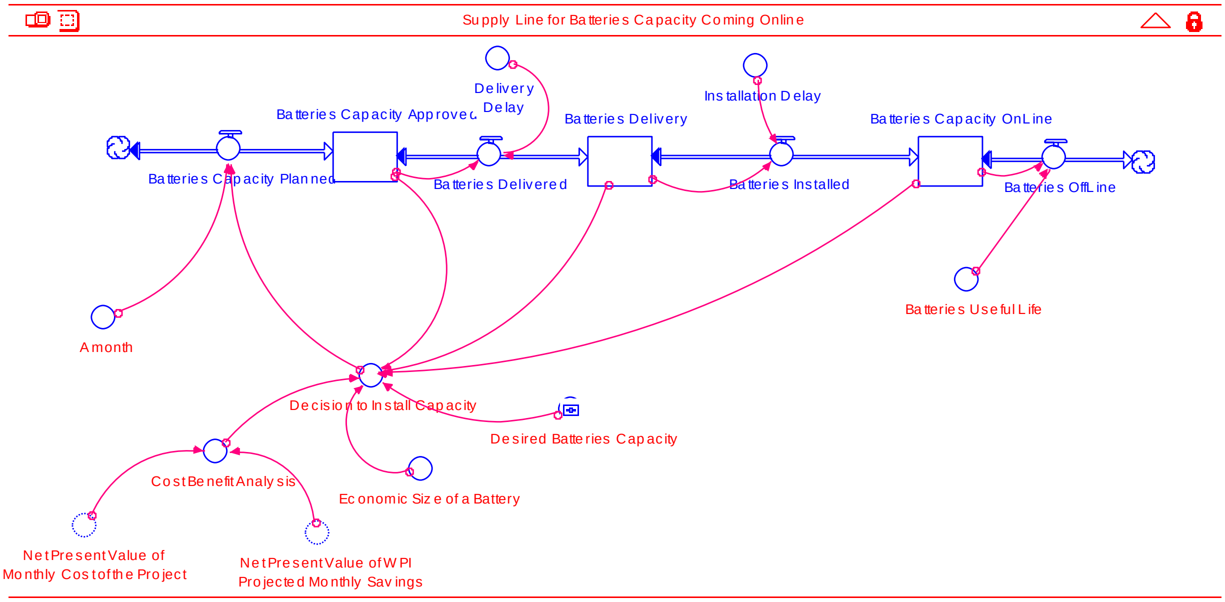

Figure 5: Supply Line for Batteries Capacity Coming Online

The supply chain in Figure 5 itself starts with the *Batteries Capacities Planned* which accumulates into the stock *Batteries Capacity Approved.* The logic behind this first stage is that

WPI would need some time to approve the desired capacity planned at the first stage of the project. The equations are as follows:

Batteries_Capacity_Approved(t) = Batteries_Capacity_Approved(t - dt) + (Batteries_Capacity_Planned – Batteries_Delivered) * dt

Batteries_Capacity_Planned = Decision_to_Install_Capacity/A_month

The next stage of the supply chain depends on the delivery rate by the manufacturer. The *Delivery Delay* could be changed by the user when deemed appropriate to account for the speed and reliability of battery delivery. The equations for the delivery delay are as follows:

Batteries_Delivered = Batteries_Capacity_Approved / Delivery__Delay

Delivery__Delay = 3

After that, the installation time of the batteries could be adjusted at the *Installation Delay* node. This is an important node in the supply chain because the installation of the batteries depends on their technological complexity. The equations for the installation delay are as follows:

Batteries_Installed = Batteries_Delivery/Installation_Delay

Installation_Delay = 3

At the end of the supply chain, the outflow *Batteries Offline* decreases the stock *Batteries Capacity Online*. This outflow is linked to the *Batteries Useful Life*, which depends on the type[10] of battery under consideration. The equations are as follows:

Batteries_OffLine = Batteries_Capacity_OnLine/Batteries_Useful_Life

Batteries_Useful_Life = 1200[11]

---

[10] The *Batteries Useful Life* is a constant because only one type of battery is being studied.

[11] The lifespan of the batteries is in months.

In Figure 5 below can see how the batteries capacity increases until it reaches the *Desired Batteries Capacity* and then slowly diminishes because of the outflow.

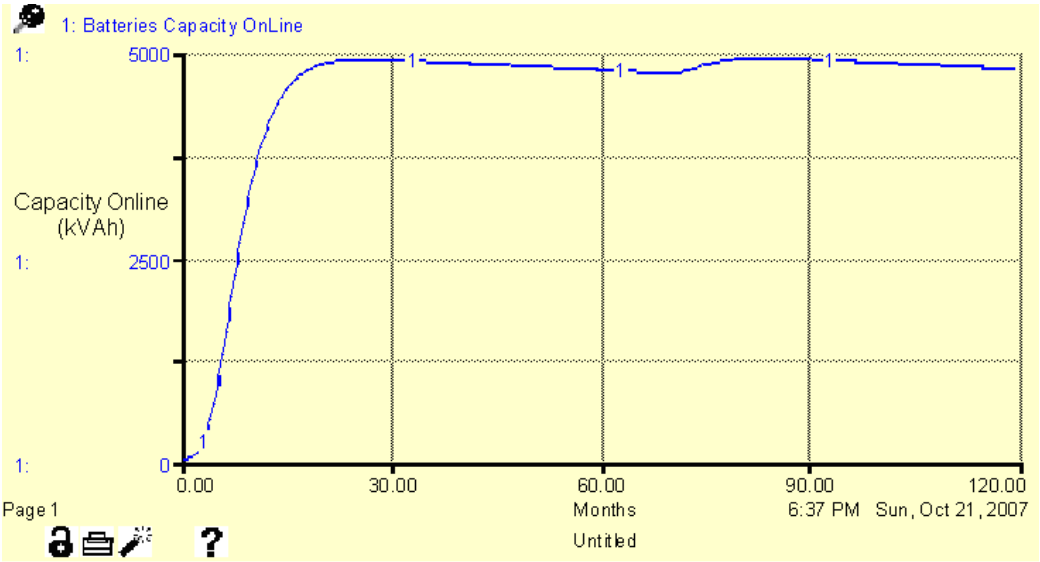

Figure 6: Battery Capacity OnLine with a 5000 kVAh *Desired Batteries Capacity*

Figure 6 shows how the model depicts the battery capacity coming online. However, in reality, the batteries will be installed in chunks, like a step graph rather than the smooth curve created by “iThink.” Also, the capacity online will stay at the installed value, without decreasing until the battery’s useful life has run out. Because the outflow *Batteries OffLine* is connected to the supply chain, “iThink” creates the fluctuation seen in Figure 6 from month 30 to month 120, which should be constant. After the batteries useful life has expired (after month 120) the graph will decrease as a step function, in chunks, until that capacity is reinstalled.

3.3.3 WPI Expected Savings

In this sector, the projected monthly savings for WPI was modeled assuming a certain installed battery capacity and is depicted in Figure 7 below.

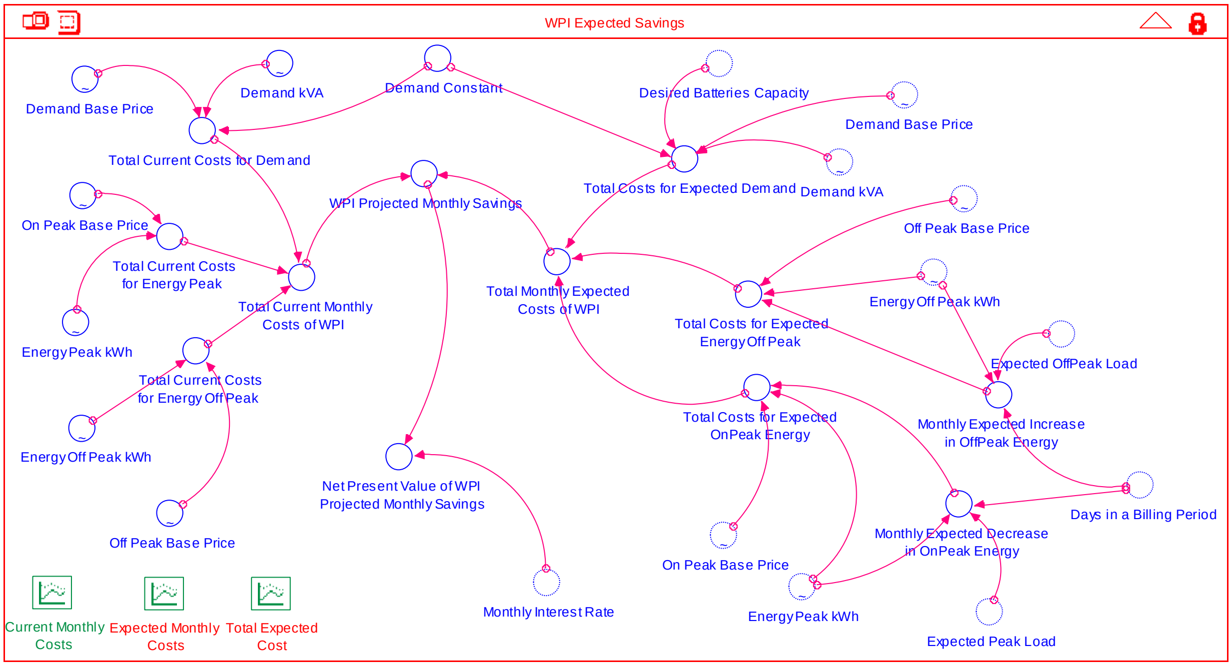

Figure 7: WPI Expected Savings

The nodes to the left of *WPI Projected Monthly Savings* detail the pre-installation cost values, taken directly from the bills received from Plant Services. The nodes to the right detail the expected post-installation costs. In order to determine the monthly savings, we subtracted the expected costs from the pre-installation costs, as shown below:

WPI_Projected_Monthly_Savings =
Total_Current_Monthly_Costs_of_WPI - Total_Monthly_Expected_Costs_of_WPI

3.3.3.1 Pre-installation Section

All of the node values for the pre-installation section of WPI Expected Savings Sector were taken directly from the WPI electrical bills. The bills were split into three basic cost sectors: Off-Peak cost, On-Peak cost, and Demand (in kVA or kilo Volt-Amperes, a measure of power).

The node *Off Peak Base Price* is the price factor National Grid applies to the energy used during the off-peak hours. This factor varies from month to month. The model was analyzed for a 10 year period, and the same price factor graph was assumed for each of the years (price factor year one is the same as the price factor in the tenth year). The node *Energy Off Peak kWh* is the graph of the energy WPI uses over the 10 year period. Due to the fact that we only had access to one years worth of data, we simply assumed a 3 percent yearly (or increase of 0.25 percent monthly increase) in energy consumption (year two energy consumption is 1.03 times the consumption of year one). The basic curve from year to year is the same shape, but shifted up slightly. From these two graphs we created the node *Total Current Costs for Energy Off Peak*. This node multiplies the *Energy Off Peak kWh* node by the *Off Peak Base Price* node to determine the monthly cost of off-peak energy over the next 10 years. The following equation from Appendix I depicts the *Total Current Cost for Energy Off Peak*:

```
Total_Current_Costs_for_Energy_Off_Peak =
Energy_Off_Peak_kWh * Off_Peak_Base_Price/1000
```

The *Total Current Costs for Energy Peak* and *Total Current Costs for Demand* nodes use the same general equation as the aforementioned *Total Current Costs for Energy Off Peak* node. As with the *Off Peak Base Price* node, the *On Peak Base Price* node and the *Demand Base Price* node graph the price factors for On-Peak energy and the Demand. These price factors also stay the same from year to year. The Demand sector has one additional node, *Demand Constant*. In WPI's electrical bills the demand that WPI is charged for is 90 percent of the actual demand listed. This factor is the same for each month, so it is incorporated into the model. Assuming a 3 percent annual increase in *Energy Peak kWh* and *Demand kVA*, when multiplied by their respective price factors, the *Total Current Costs for Energy On Peak* node and *Total Current Cost for Demand* node are calculated. To get the *Total Current Monthly Costs of WPI* node, each of the individual total cost nodes were added. The equations for the *Total Current Costs for Energy On Peak* node and *Total Current Cost for Demand* node are shown below:

Total_Current_Costs_for_Demand = Demand_kVA * Demand_Base_Price * Demand_Constant

Total_Current_Costs_for_Energy_Peak = Energy_Peak_kWh * On_Peak_Base_Price

Figure 8 shows the trend of all three costs and the resulting total current monthly cost.

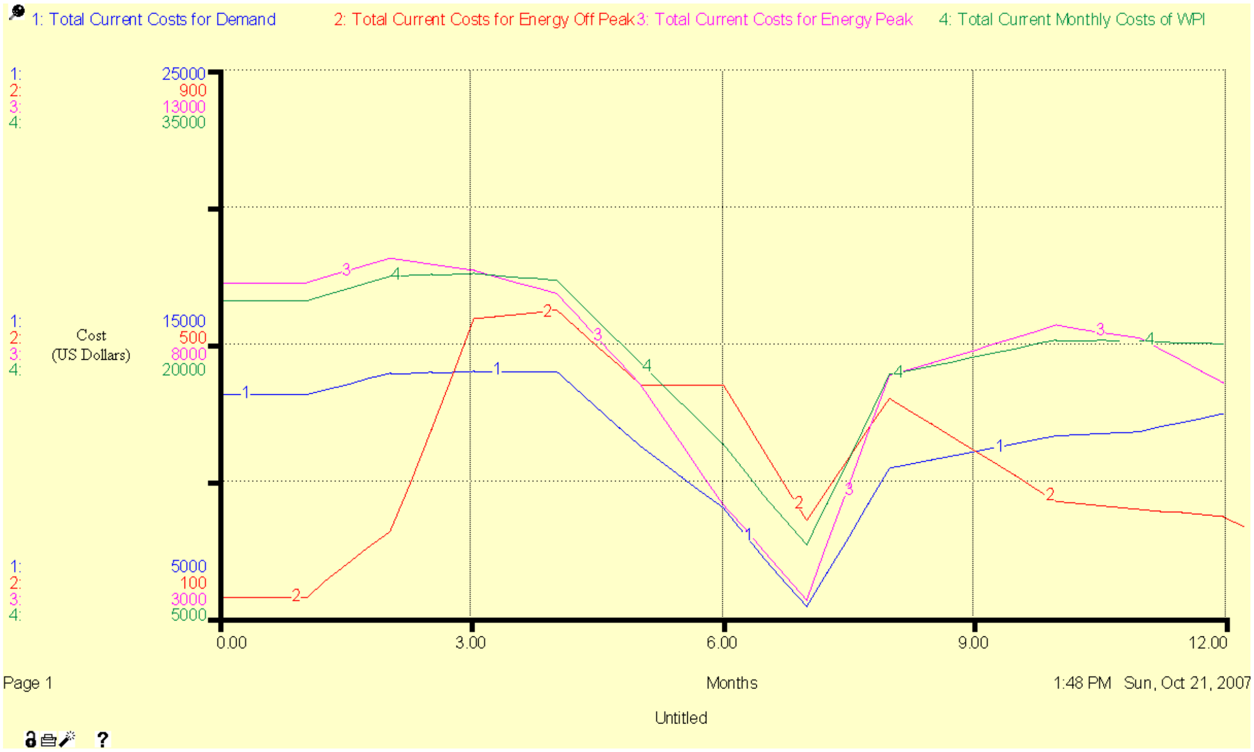

Figure 8: Current Monthly Costs, On-Peak, Off-Peak, Demand and Total[12]

Figure 8 shows the different current monthly costs for Demand (line 1), Off-Peak energy (line 2), On-Peak energy (line 3), and the Total (line 4) costs. The figure shows the trend over a period of twelve months rather that 120 to better illustrate each of the costs[13]. The trough around month seven reflects the summer months, when classes are not in session so students are no

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[12] Note that each of the costs are on different scales.

[13] The twelve month period was chosen because the graphs repeat yearly with minimal variance.

longer on campus. WPI's energy usage decreases dramatically during this time period, and increases dramatically with the start of the fall term.

3.3.3.2 Post-installation Section

In the Post-installation Sector, the expected costs were modeled, assuming a certain capacity of the batteries has been installed at WPI.

For the On-Peak section, the *On Peak Base Price* node and the *Energy Peak kWh* node were cloned. As explained above, these nodes gave the current monthly cost, which was needed in order to calculate the expected cost. In the node *Total Costs for Expected On Peak Energy*, the *On Peak Base Price* is multiplied by the difference between *Energy Peak kWh* and the *Monthly Expected Decrease in On Peak Energy*. This *Monthly Expected Decrease in OnPeak Energy* node calculates the amount that the On-Peak energy consumption would be decreased by, given a certain battery capacity, discharging efficiency and billing period[14]. The equations below detail the relationships explained:

Total_Costs_for_Expected_OnPeak_Energy =
On_Peak_Base_Price * (Energy_Peak_kWh - Monthly_Expected_Decrease_in_OnPeak_Energy)

Monthly_Expected_Decrease_in_OnPeak_Energy =
Energy_Peak_kWh - (Expected_Peak_Load * Days_in_a_Billing_Period)

The Off-Peak section is very similar to the On-Peak. The base price and consumption nodes were cloned to give the current costs. The node *Monthly Expected Increase in Off Peak Energy* calculates the increase in Off-Peak energy consumption, given a charging efficiency, battery capacity and billing period[15]. This value is added to the *Energy Off Peak kWh* and

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[14] This calculation is explained in the Expected Energy Sector of the report.

[15] This calculation is explained in the Expected Energy Sector of the report.

multiplied by *Off Peak Base Price* to get the node *Total Costs for Expected Energy Off Peak*. The equations for this node are shown below:

Total_Costs_for_Expected_Energy_Off_Peak =
(Off_Peak_Base_Price/1000[16]) * (Energy_Off_Peak_kWh +
Monthly_Expected_Increase_in_OffPeak_Energy)

Monthly_Expected_Increase_in_OffPeak_Energy =
(Expected_OffPeak_Load * Days_in_a_Billing_Period)-Energy_Off_Peak_kWh

For the Demand sector, the *Desired Battery Capacity*, divided by the number of hours in the On-Peak period (13 hours), is subtracted from the *Demand kVA* to get the adjusted demand. The adjusted demand was then multiplied by the *Demand Constant* and the *Demand Base Price* to achieve the *Total Costs for Expected Demand*. Each of the total expected cost nodes are added together to create the node *Total Monthly Expected Cost of WPI*. The equations for the Demand cost node are detailed below:

Total_Costs_for_Expected_Demand =
(Demand_kVA - Desired_Batteries_Capacity) *Demand_Base_Price *Demand_Constant

Figure 9 details the trend of these values.

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[16] The Off Peak Base Price must be divided by 1000 because "iThink" could not graph values smaller than 0.001

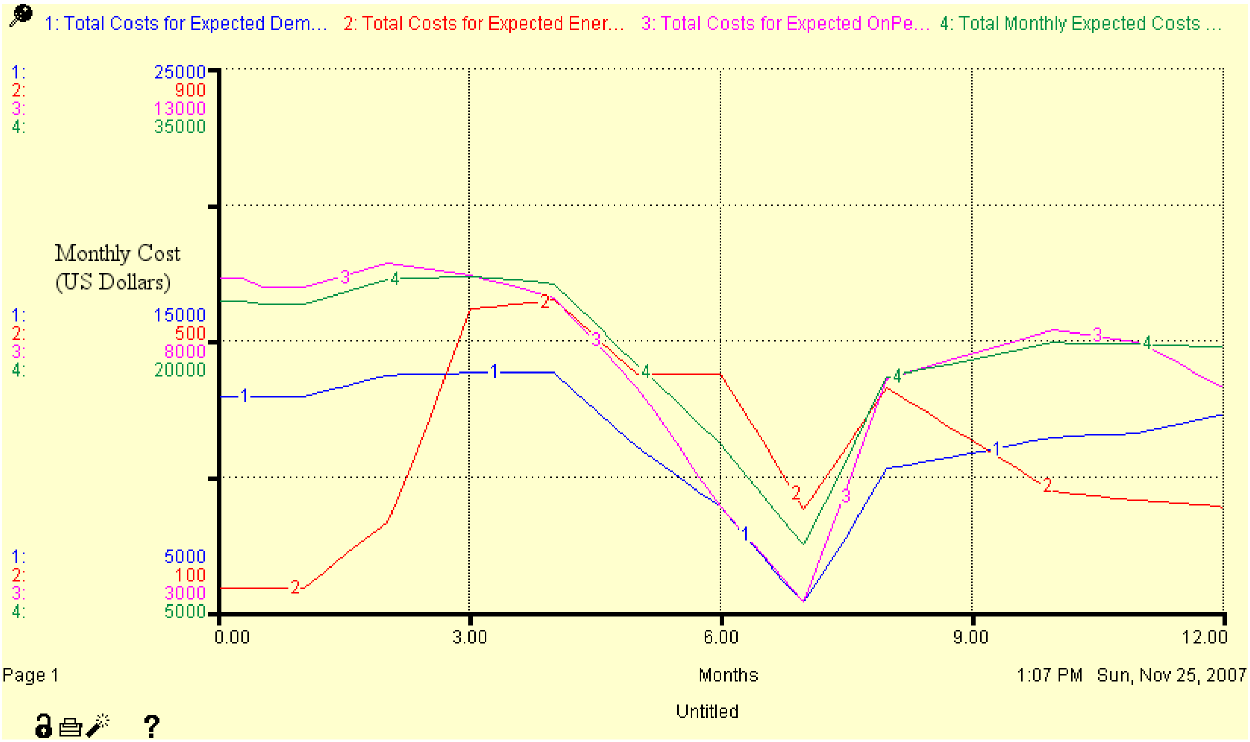

Figure 9: Expected Monthly Costs, On-Peak, Off-Peak, Demand and Total, with a 1000 kVAh battery

Figure 9 shows a 12 month period with a 1000 kVAh battery installed. The Demand cost is line 1, the Off-Peak cost is line 2, the On-Peak cost is line 3 and the Total cost is line 4. Comparing Figure 9 to Figure 8 (the current costs) the Demand, On-Peak and Total monthly costs decrease after installation while the Off-Peak increases slightly, with all four costs following the same general yearly curve as they did in Figure 8. This is exactly what is expected to happen from the dynamic hypothesis.

Finally, the *Total Monthly Expected Cost of WPI* is subtracted from the *Total Current Monthly Costs of WPI* in order to achieve the *WPI Projected Monthly Savings*. This is detailed below in Figure 10.

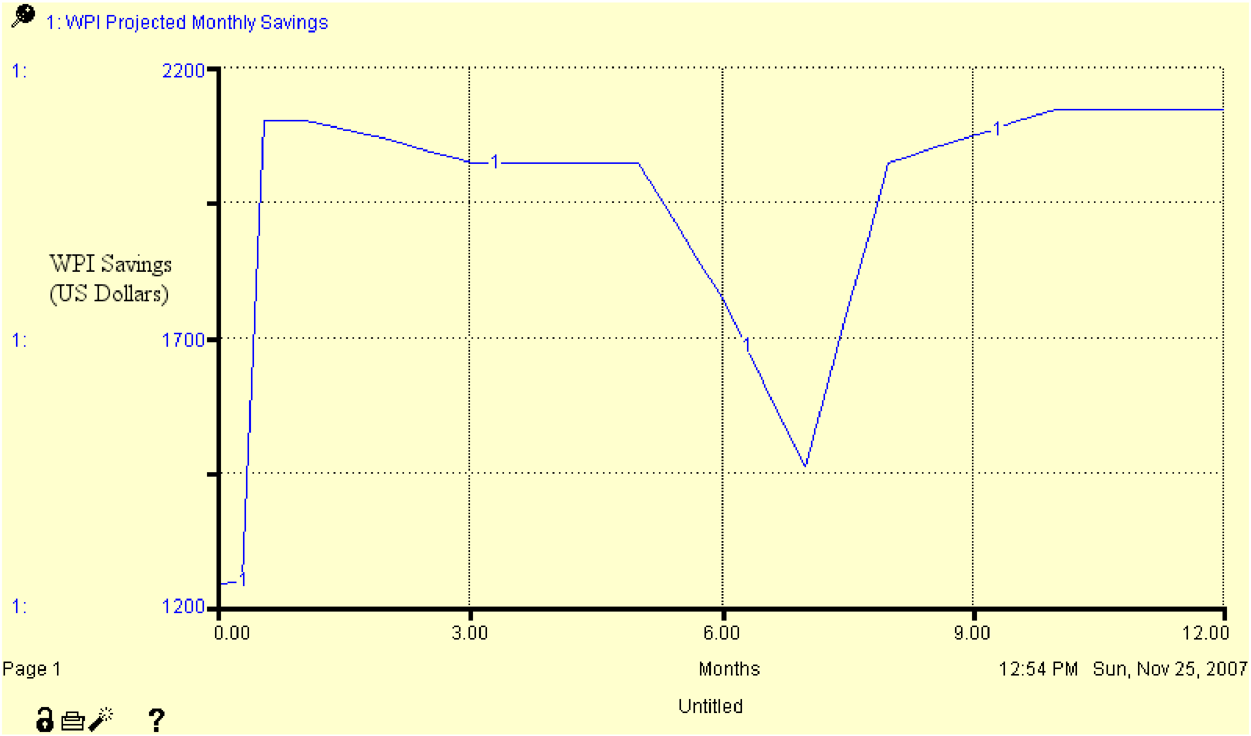

Figure 10: Projected Monthly Savings, with a 1000 kVAh battery

Figure 10 shows the projected monthly savings for each month for the first twelve months once WPI installs the batteries. WPI would save more money during the fall, winter and spring months due to higher energy consumption and less in the summer, from months 5 to 8, due to lower energy consumption.

The decision to install the batteries involved a cost-benefit analysis, which is a comparison between the *Net Present Value of Monthly Opportunity Cost of the Project* and *Net Present Value of WPI Projected Monthly Savings.* The equation for the decision is shown below:

Net_Present_Value_of_WPI_Projected_Monthly_Savings =
NPV(WPI_Projected_Monthly_Savings, Monthly_Interest_Rate)

The latter node is the present value of future monthly savings for WPI from this project, discounted at the current monthly interest rate. It is based on the *WPI Projected Monthly Savings* which were derived by comparing current energy costs with those expected when the project is completed and savings begin to accumulate. The present value method provides for the best financial appraisal of such a long-term project. The *Monthly Interest Rate* will be explored further in the sensitivity studies to account for the risk of volatile economic conditions and changing interest rates. It is an exogenous factor to this project and can greatly affect the outcome of such an undertaking. Furthermore, the present value method presents a value showing how much this project adds to WPI's worth.

3.3.4 Expected Energy Sector

In the Expected Energy Sector, how the installing a specified battery capacity would effect the On-Peak and Off-Peak loads was modeled. The data from this sector was used to help determine what the expected savings of WPI would be. Figure 11 shows an overview of this sector.

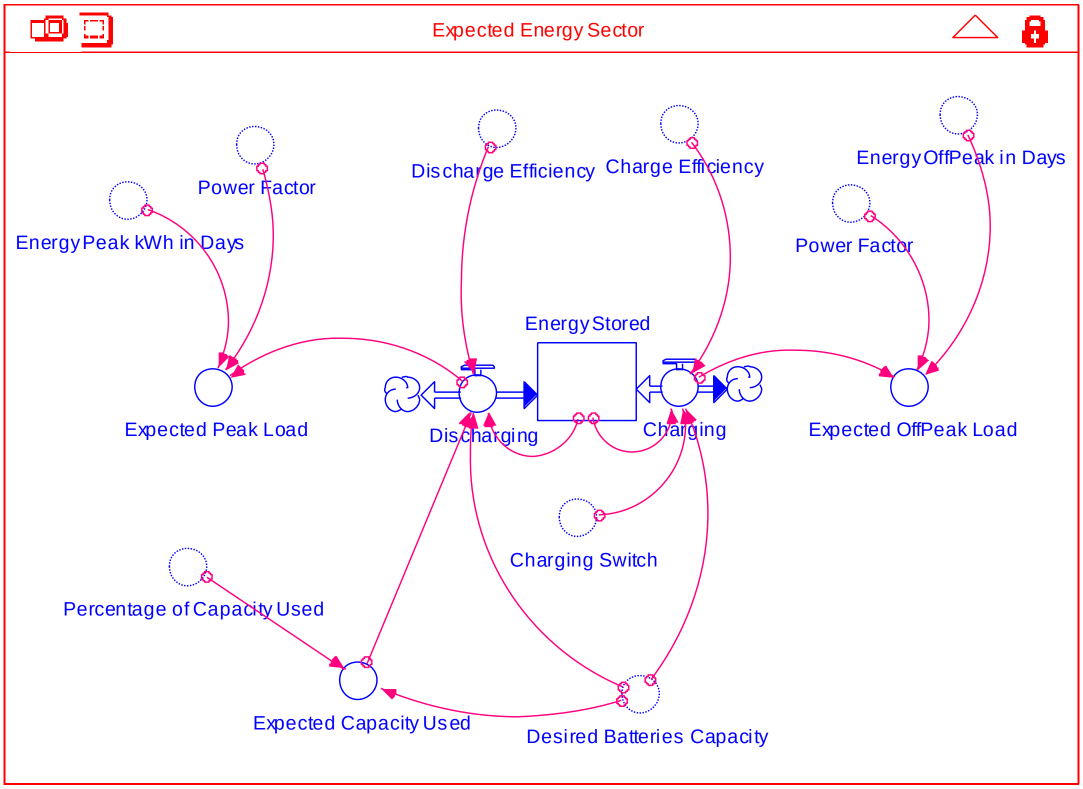

Figure 11: Expected Energy Sector

The core of this part of the model is the stock and flow of the *Energy Stored,* whose equations is shown below:

```
Energy_Stored(t) = Energy_Stored(t - dt) + (Charging - Discharging) * dt

INIT Energy_Stored = 0
```

The two nodes influencing the stock are the *Discharging* and *Charging* nodes. The *Discharging* node contains the decision of when to recharge. The following decision from Appendix I details the *Discharging* node.

```
Discharging = IF(Energy_Stored>0.3 * Desired_Batteries_Capacity)
        THEN(Expected_Capacity_Used * Discharge_Efficiency)
        ELSE(0)
```

This decision states that if the amount of energy stored is more than 30 percent of the desired capacity, the battery can discharge a certain percent of the stored energy. The reason behind this decision is that if the total energy stored discharges below 30 percent of its maximum value, it will degrade the battery's useful life. If the model decides that it is fine to discharge, the amount discharged is equal to the *Expected Capacity Used* multiplied by the *Discharge Efficiency*. The *Expected Capacity Used* is set to a certain percentage of the battery's full capacity that is desired to be discharged, up to 70 percent of full capacity. Also, because the battery is not 100 percent efficient, the amount of energy discharged is less than the amount desired, hence the multiplication by the *Discharge Efficiency*, which is less than 1. In other words, if the battery needs to discharge 10 kVAh, it will effectively have to discharge 14 kVAh at 70 percent efficiency.

The *Charging* node also contains a decision on when to charge; this decision states that if the battery is currently discharging the battery cannot charge. If the battery is able to charge, the amount is equal to the *Desired Battery Capacity* minus the *Energy Stored*, all divided by the

Charge Efficiency. As with the *Discharging* node, the battery is not 100 percent efficient at charging energy either, so the amount must be divided by the efficiency to increase the amount needed to charge. The following decision from Appendix I details the *Charging* node.

```
Charging = IF Charging_Switch=1
        THEN ((Desired_Batteries_Capacity-Energy_Stored)/Charge_Efficiency)
        ELSE (0)
```

The nodes *Expected Peak Load* and *Expected OffPeak Load* are the most important nodes in this sector. These nodes are utilized in the WPI Expected Savings Sector, which influences WPI's decision of whether to install batteries or not. For the *Expected Peak Load* node, the *Discharging* is multiplied by the *Power Factor* and then subtracted from the *Energy Peak kWh in Days*. In order to determine the *Energy Peak kWh in Days*, the *Energy Peak kWh* (from the WPI Expected Savings Sector) is divided by the *Days in a Billing Period*. Also, the battery capacity is measured in kVAh, which is the apparent energy being used, so to change into real energy, kWh, the energy discharged must be multiplied by the power factor[17]. The following equation from Appendix I details the *Expected Peak Load*:

Expected_Peak_Load = Energy_Peak_kWh_in_Days – Discharging * Power_Factor

The *Expected OffPeak Load* is found the same way, except *Charging* multiplied by the *Power Factor* is added to the *Energy OffPeak in Days*. These values help WPI to make an informed decision concerning the installation of the batteries. The following equation from Appendix I details the *Expected OffPeak Load*:

Expected_OffPeak_Load = Charging * Power_Factor + Energy_OffPeak_in_Days

---

[17] Power Factor is fully explained in the Sensitivity Analysis later in the report.

3.3.5 Energy Sector

In the Energy Sector, how the installing a specified battery capacity would effect the On-Peak and Off-Peak loads was modeled. The data from this sector was used to help determine what the actual savings of WPI would be. Figure 12 shows an overview of this sector.

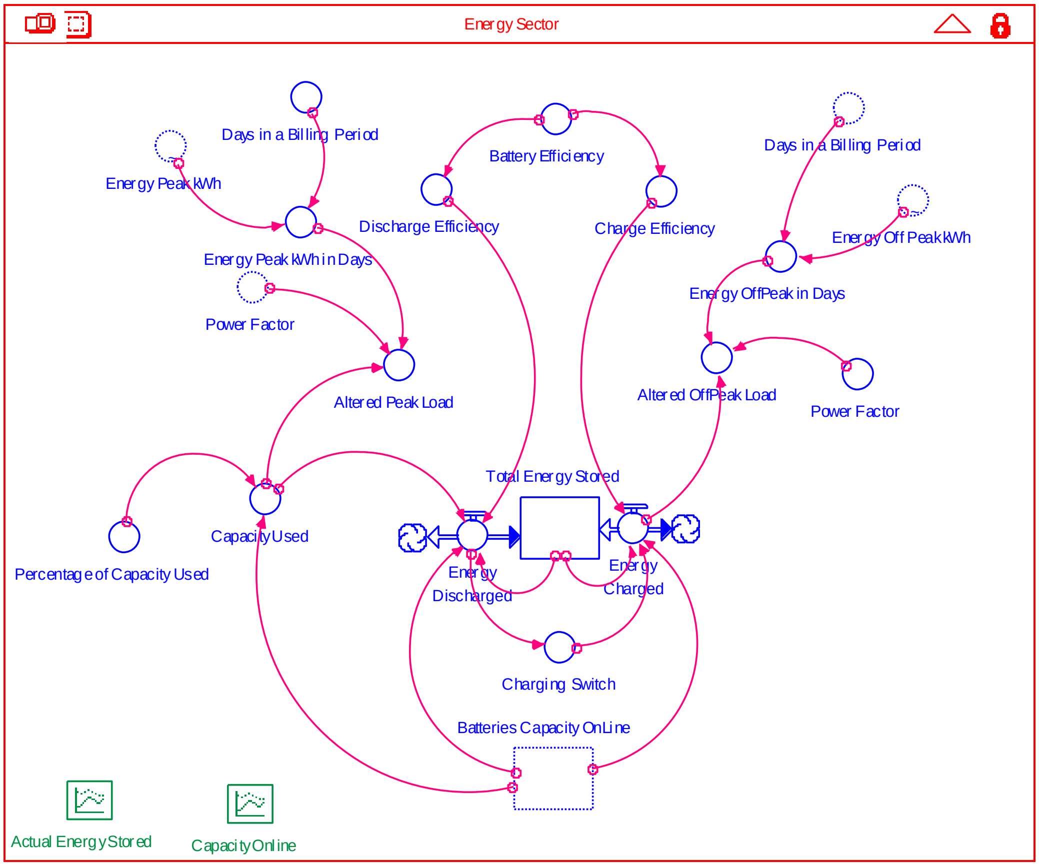

Figure 12: Energy Sector

As with the Expected Energy Sector, the main part of the Energy Sector is the stocks and flows modeling how the energy is charged and discharged; the equation is shown below:

Total_Energy_Stored(t) = Total_Energy_Stored(t - dt) + (Energy_Charged - Energy_Discharged) * dt

INIT Total_Energy_Stored = 0

However, the decisions for discharging and charging are more complicated than in the Expected Energy Sector. The *Energy Discharged* node decides if there is enough energy stored to allow for discharging. The node first looks at the *Total Energy Stored* and subtracts from it the *Capacity Used* multiplied by the *Discharge Efficiency*. If the amount left over is greater than 30 percent of the *Batteries Capacity Online*, the battery is allowed to discharge. As explained earlier, the lifespan of the battery will be adversely affected if the total energy stored falls below the 30 percent level. The following decision from Appendix I details the *Energy Discharged*:

```
Energy_Discharged = IF(Total_Energy_Stored-Capacity_Used * Discharge_Efficiency  > 0.3 *
        Batteries_Capacity_OnLine)
        THEN(Capacity_Used * Discharge_Efficiency)
        ELSE(0)
```

In the *Energy Charged* node, the first aspect looked at is if the battery is currently discharging, which is determined via the *Charging Switch*. If the battery is discharging, then it is not allowed to charge; however, if the battery is not discharging, it attempts to charge by an amount equal to the *Batteries Capacity OnLine* minus the *Total Energy Stored* multiplied by the *Charge Efficiency*. The following decision from Appendix I details the *Energy Discharged*:

```
Energy_Charged = IF Charging_Switch=1
        THEN (Batteries_Capacity_OnLine - (Total_Energy_Stored * Charge_Efficiency))
        ELSE (0)
```

In an attempt to show that the battery is not charging at the same time it is discharging, both nodes are shown in Figure 13 below. The graph does not display the whole 120 month time span in order to show the details of the curves.

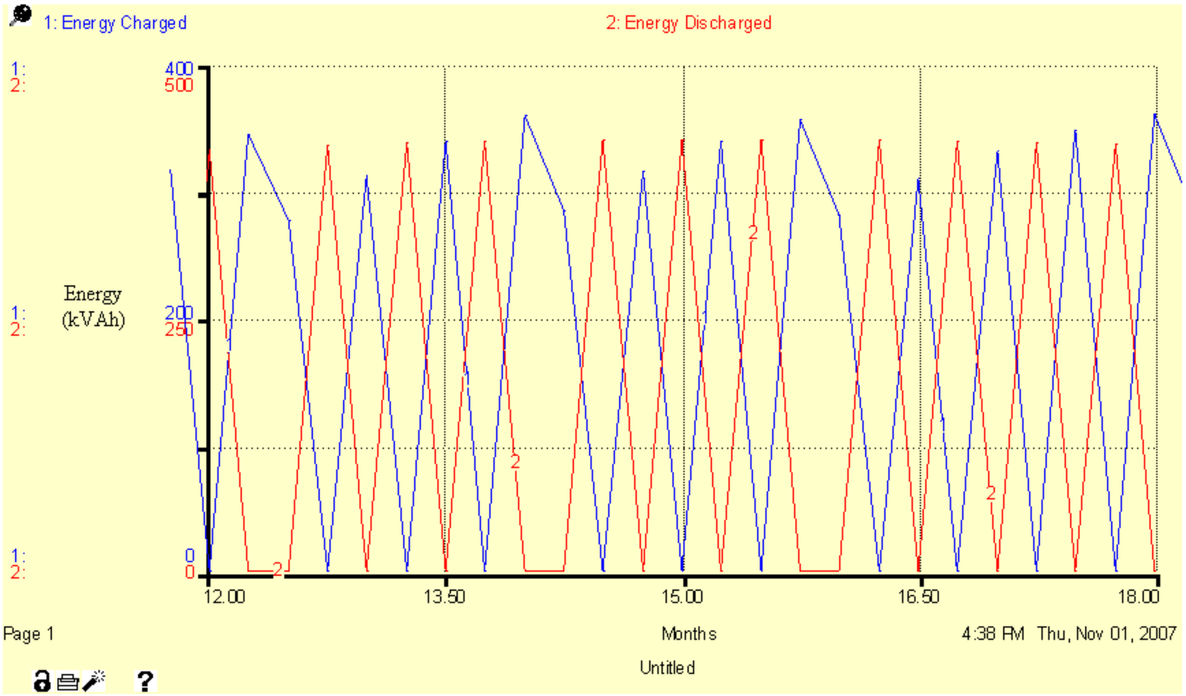

Figure 13: Energy Discharged and Energy Charged, using a 1000 kVAh battery

Figure 13 shows the energy charged (line 1) and energy discharged (line 2). Unfortunately, because the decisions of when to charge and discharge are not based on set times in the model, they overlap. However, in reality, the batteries would only be allowed to discharge during On-Peak hours and charge during Off-Peak. The decision in the model is a basic *if-then-else* statement, stating that if the energy discharged is greater than zero, then the energy charged is zero, as shown below:

```
Charging_Switch = IF (Energy_Discharged>0)
        THEN 0
        ELSE (1)
```

If modeled correctly, the graph of the *Total Energy Charged* looks similar to a sinusoidal wave, with its trough never falling below 30 percent of full capacity. Figure 14 below depicts this curve:

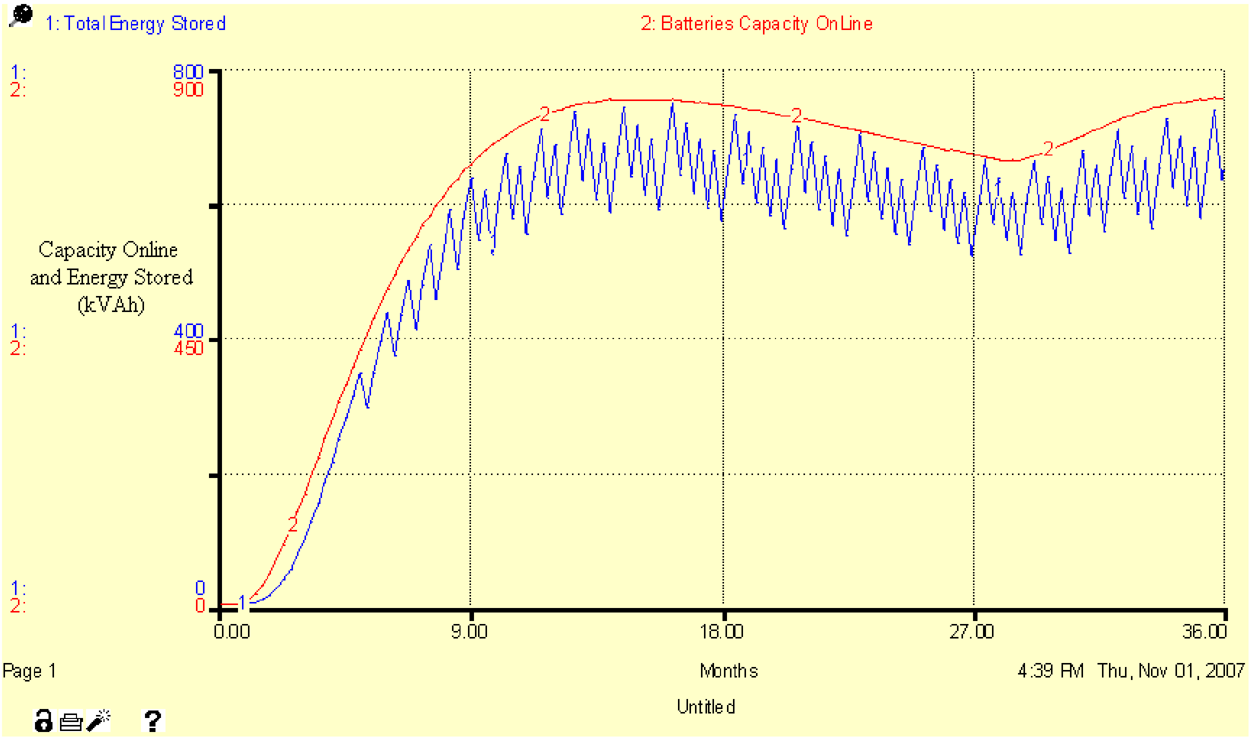

Figure 14: Total Energy Stored and Batteries Capacity OnLine, using a 1000kVAh battery

Figure 14 shows the total energy stored in the battery (line 1) along with the actual battery capacity online (line 2). As the batteries start coming online, they charge at almost the same time. Once the entire capacity has been installed, the batteries begin their charging/discharging cycles.

From the stock and flow of the *Total Energy Stored*, the *Altered Peak Load* and *Altered OffPeak Load* can be determined. To achieve the *Altered Peak Load*, the *Energy Peak kWh* must be divided by the *Days in a Billing Period* to get *Energy Peak kWh in Days*. In the model, the assumption is made that the energy consumption over one day follows a similar curve to the consumption of the corresponding month the day is in. For example, the energy consumption curve for September 4 would look similar to the consumption curve for the entire month. This is done because there was no access to the day-to-day energy consumption data. The *Altered Peak Load* is found by subtracting the *Capacity Used* multiplied by the *Power Factor* and *Discharge*

Efficiency from the *Energy Peak kWh in Days*. The following decision from Appendix I details the *Altered Peak Load*:

```
Altered_Peak_Load =
          Energy_Peak_kWh_in_Days - (Capacity_Used * Discharge_Efficiency * Power_Factor)

Energy_Peak_kWh_in_Days = Energy_Peak_kWh/Days_in_a_Billing_Period

Capacity_Used = Percentage_of_Capacity_Used * Batteries_Capacity_OnLine

Percentage_of_Capacity_Used = .6

Power_Factor = .85
```

The *Altered OffPeak Load* is calculated by adding the *Energy Charged* multiplied by the *Power Factor* to the *Energy OffPeak in Days*. The following decision from Appendix I details the *Altered OffPeak Load*:

```
Altered_OffPeak_Load = Energy_Charged * Power_Factor  +Energy_OffPeak_in_Days

Energy_OffPeak_in_Days = Energy_Off_Peak_kWh/Days_in_a_Billing_Period
```

Figures 15 and 16 below show examples of the altered loads compared to the current ones, with the On-Peak load decreased and the Off-Peak load increased.

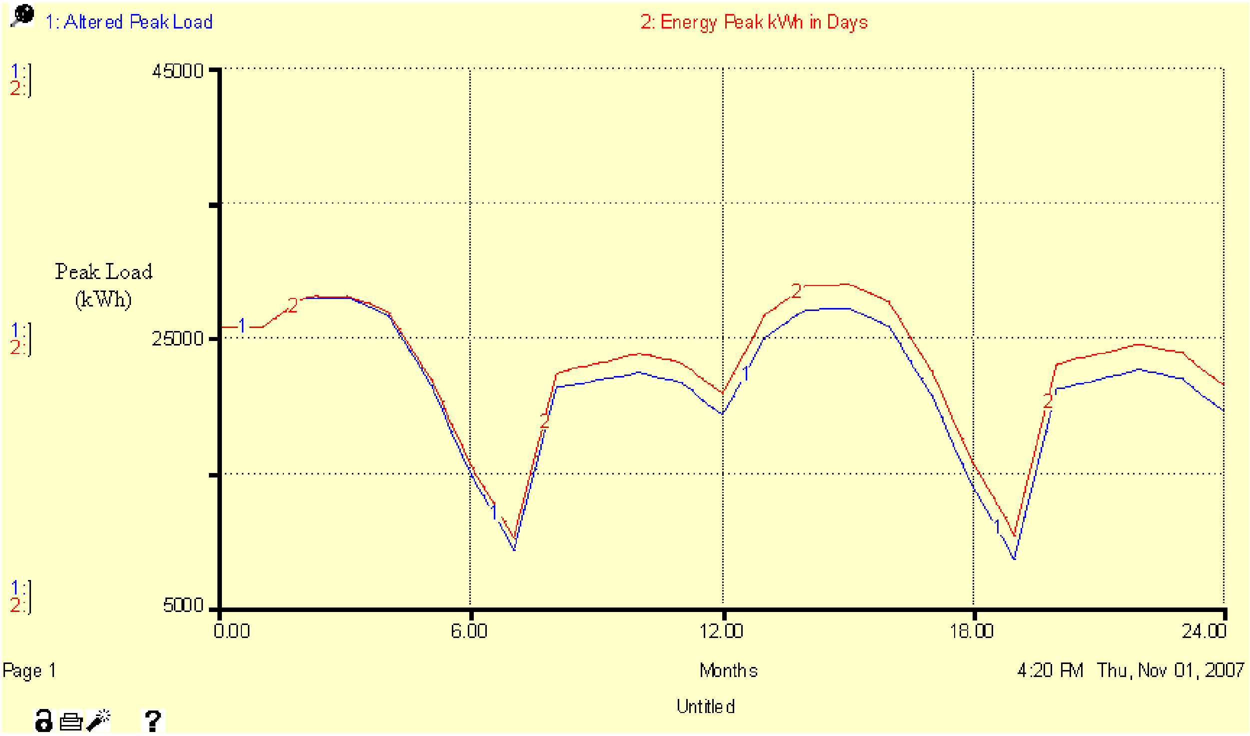

Figure 15: Peak Load and Current Peak Load, with a 5000 kVAh battery

Figure 15 shows the comparison between the peak loads; the altered peak load, line 1 and the current peak load, line 2. For the model, the batteries are still coming online during the first eight to twelve months. However, after month 12 the peak load is altered by the correct amount of the full battery capacity. The two deep troughs correspond to the summer months of the two years shown, while the shallower troughs at months 12 and 24 represent the reduced consumption during Winter Break. As Figure 15 shows, installing batteries and discharging them during the day reduces the peak load, in turn saving WPI money.

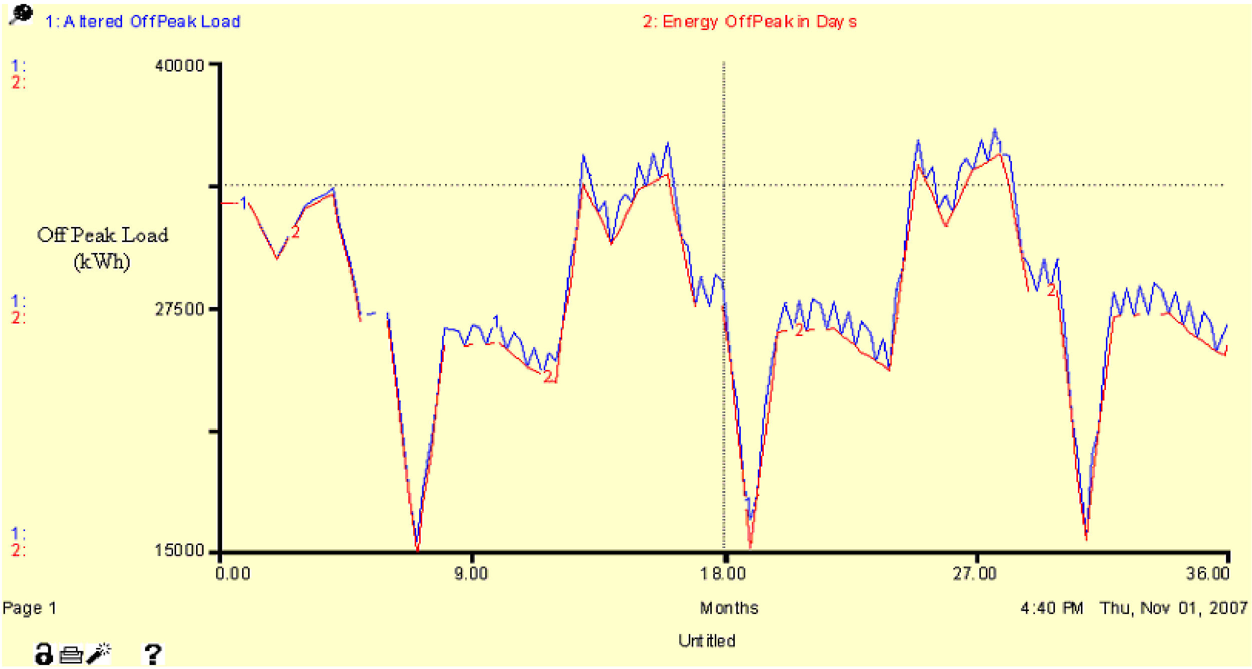

Figure 16: Altered Off Peak Load and Current Off Peak Load, with a 5000 kVAh battery

Figure 16 shows the altered Off-Peak load, line 1, compared to the current Off-Peak load, line 2. For the model, the batteries are still coming online during the first eight to twelve months. As explained for Figure 15, after month twelve, the batteries have been fully installed so the off-peak load is altered by the correct amount of the full battery capacity. The reason why the altered off-peak load fluctuates after month 7 is because the batteries do not have to recharge every night; there is sometimes enough energy stored to discharge two nights in a row without having to recharge. During the off-peak hours, the batteries charge which increased the amount of Off-Peak energy used, which in turn, costs WPI more money.

Chapter 4 – Sensitivity Analysis

In this section, sensitivity analyses were conducted on different aspects of the battery, including capacity, capacity used, power factor and cost. When varying each individual parameter, all other parameters were kept constant. From the data accumulated, an optimal solution was found.

4.1 Battery Capacity

For the analysis of battery capacity, the effect of varying the desired battery capacity on the following was studied: *Altered On* and *Off Peak Loads*, *Initial Borrowed Lump Sum*, *WPI Savings*, and the *Monthly Cost of the Project*. The following figures (17, 18, 19, 20 and 21) show how 1000, 2000, 3000, 4000 and 5000 kVAh batteries would affect each of the desired parameters. For this analysis the constants are the following: *Price per kVAh Battery* is $250/kVAh, *Price per kVAh Inverter* is $150/kVAh, *Percentage of Capacity Used* is 60 percent, *Power Factor* is 0.85, *Battery Efficiency* is 0.70, and *Inverter Capacity* is 500 kVAh.

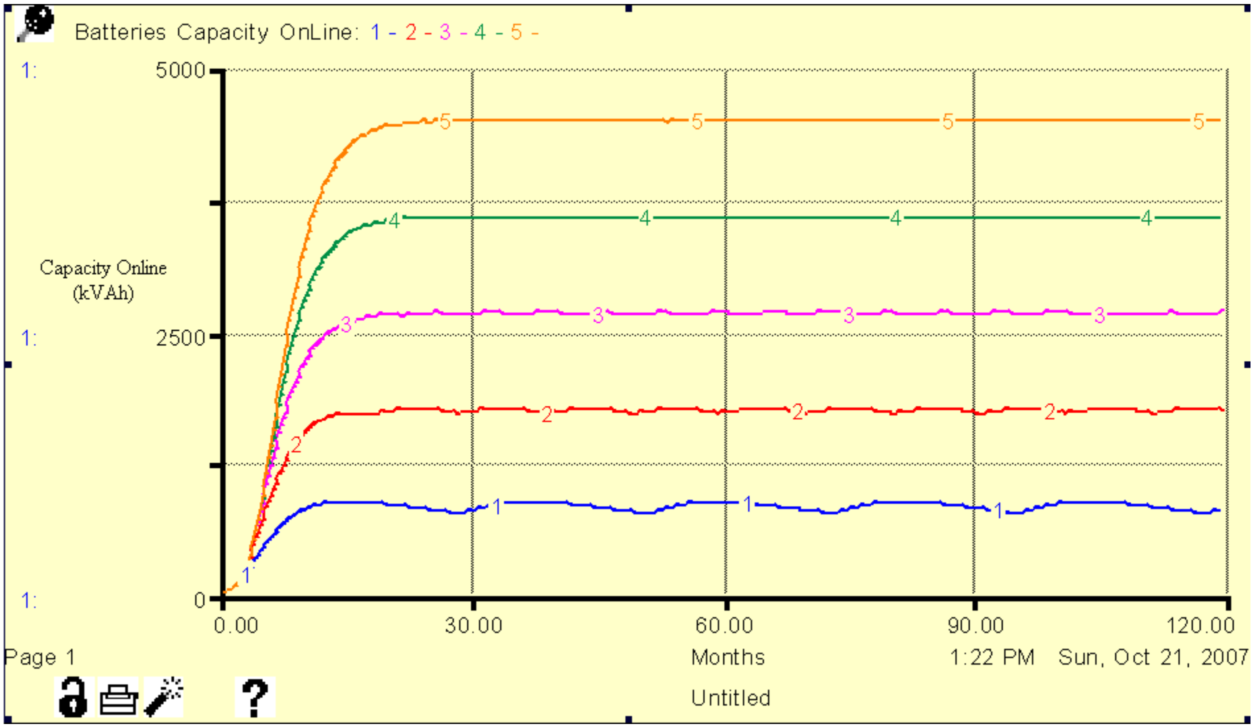

Figure 17: Battery Capacity Coming Online, with Capacities of 1000, 2000, 3000, 4000 and 5000 kVAh

Figure 17 shows how the model displays the total battery capacity coming online. Line 1 shows 1000 kVAh, line 2 shows 2000 kVAh, line 3 shows 3000 kVAh, line 4 shows 4000 kVAh, and line 5 shows 5000 kVAh. Each battery installed is set at a certain capacity, the economic battery size (chosen to be 250 kVAh); a capacity of 1000 kVAh would need four batteries installed, and a capacity of 5000 kVAh would need twenty batteries installed. As explained in Figure 6, in reality, the batteries would be installed in chunks and better represented by a step function, not the smooth curve created by “iThink.”

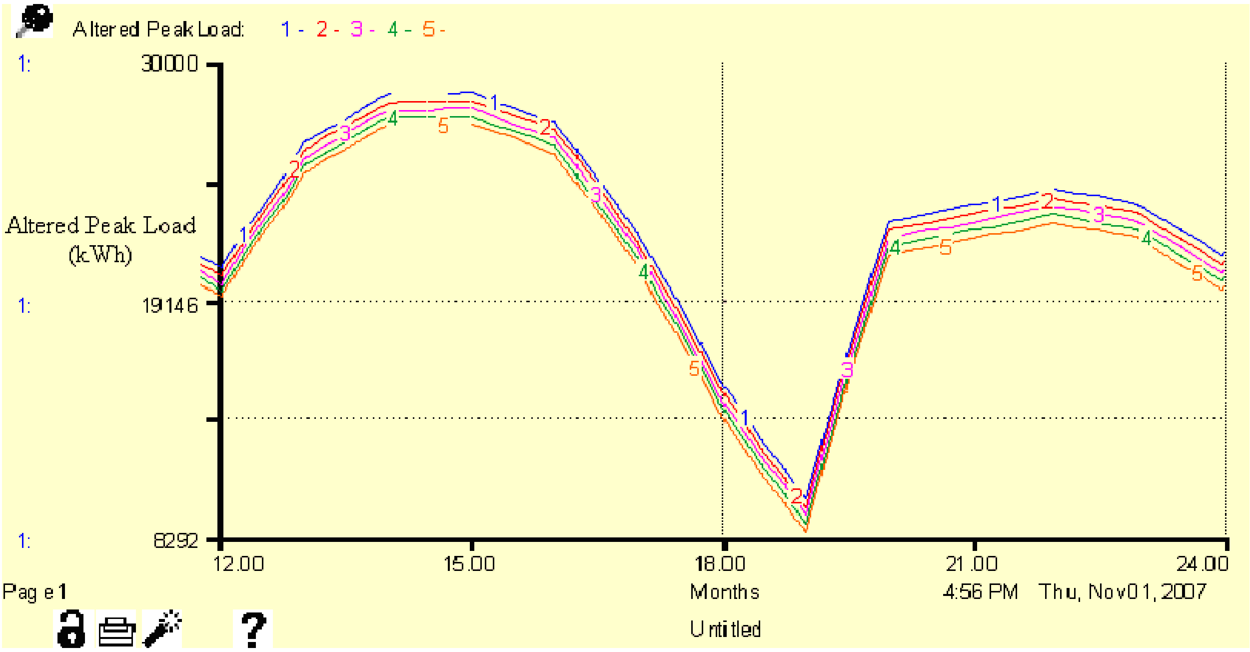

Figure 18: Altered Peak Load, with Capacities of 1000, 2000, 3000, 4000 and 5000 kVAh

Figure 18 shows the altered peak load with varying capacities installed. Line 1 shows 1000 kVAh, line 2 shows 2000 kVAh, line 3 shows 3000 kVAh, line 4 shows 4000 kVAh, and line 5 shows 5000 kVAh. As logic dictates, the larger the capacity, the more capacity can be used to shave the peak load, resulting in a smaller and smaller altered peak load. For example, the energy consumption of line 2 is less than the energy consumption of line 1.

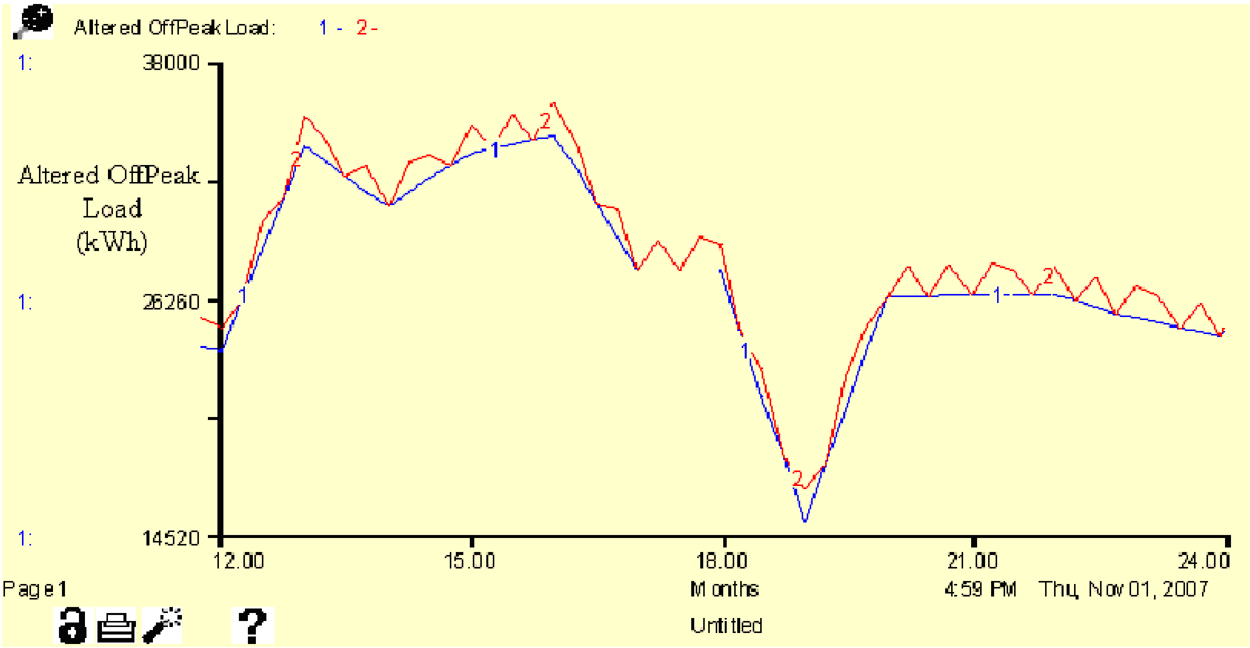

Figure 19: Altered Off Peak Load, with Capacities of 0 and 5000 kVAh

Figure 19 shows the altered Off-Peak load with a capacity of 0 kVAh, line 1 (which is if no batteries are installed), and 5000 kVAh capacity, line 2. As shown in Figure 18, the larger the battery capacity, the more energy can be discharged; this results in a greater amount to be charged and an increased altered Off-Peak load.

Table 2: Borrowed Initial Lump Sum, with Capacities of 1000, 2000, 3000, 4000 and 5000 kVAh

Battery Capacity (kVAh)	$/kVAh battery	$/kVAh inverter	Inverter Capacity (kVAh)	Initial Borrowed Lump Sum ($)
1000	250	150	500	325,000.00
2000	250	150	500	575,000.00
3000	250	150	500	825,000.00
4000	250	150	500	1,075,000.00
5000	250	150	500	1,325,000.00

Table 2 shows how much WPI would have to spend simply on installation costs and battery purchase. The larger the capacity, the more batteries WPI would have to pay for.

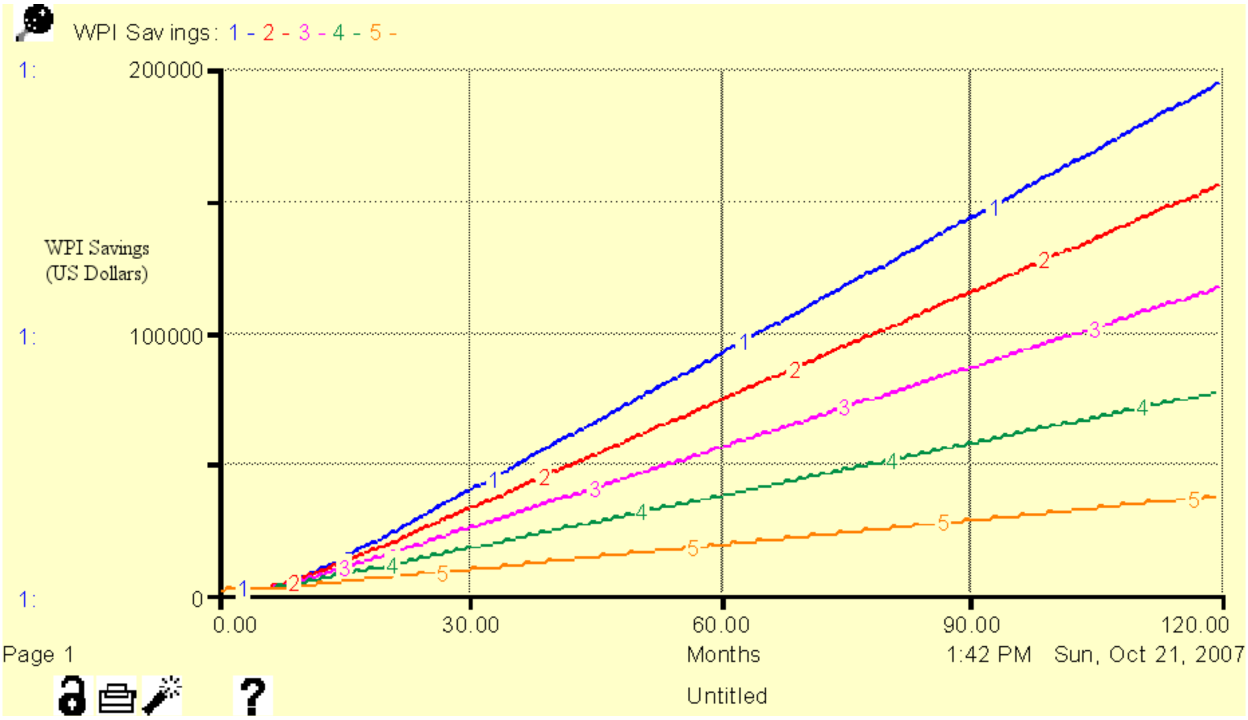

Figure 20: WPI Savings, with Capacities of 1000, 2000, 3000, 4000 and 5000 kVAh

Figure 20 shows how much WPI would save over the entire 120 months with varying capacities. The figure shows the cumulative savings of WPI, with the end value representing the total amount of money WPI will save over the period of the project. After the 12 month mark (once the battery capacity is fully online) is where WPI begins to save money. WPI will save more money faster with a larger battery capacity online. Line 5 shows 1000 kVAh, line 4 shows 2000 kVAh, line 3 shows 3000 kVAh, line 2 shows 4000 kVAh, and line 1 shows 5000 kVAh.

From the graphs above, the battery capacity that would result in the greatest WPI Savings is 5000 kVAh. However, with this large capacity, the total cost of the project, Table 2, is $1.325 Million. As shown in Figure 20, the maximum amount of money WPI would save over the ten year period does not exceed $200,000. If the lifespan of the battery lasts the full 10 years, WPI would have to spend an additional $1.25 million to replace the batteries after the ten year mark.

The amount of money WPI would save is nowhere near enough to compensate for the cost of the project.

4.2 Percentage of Capacity Used

For the *Percentage of Capacity Used*, all the other parameters are kept the as they were in the capacity analysis, except now the battery capacity is set to 5000 kVAh. The *Percentage of Capacity Used* is set to be 0 percent initial, and then increase by intervals of 10, up to 70 percent of the total capacity used. The following figures (21, 23, and 23) show the effect on the altered peak loads and *WPI Savings*.

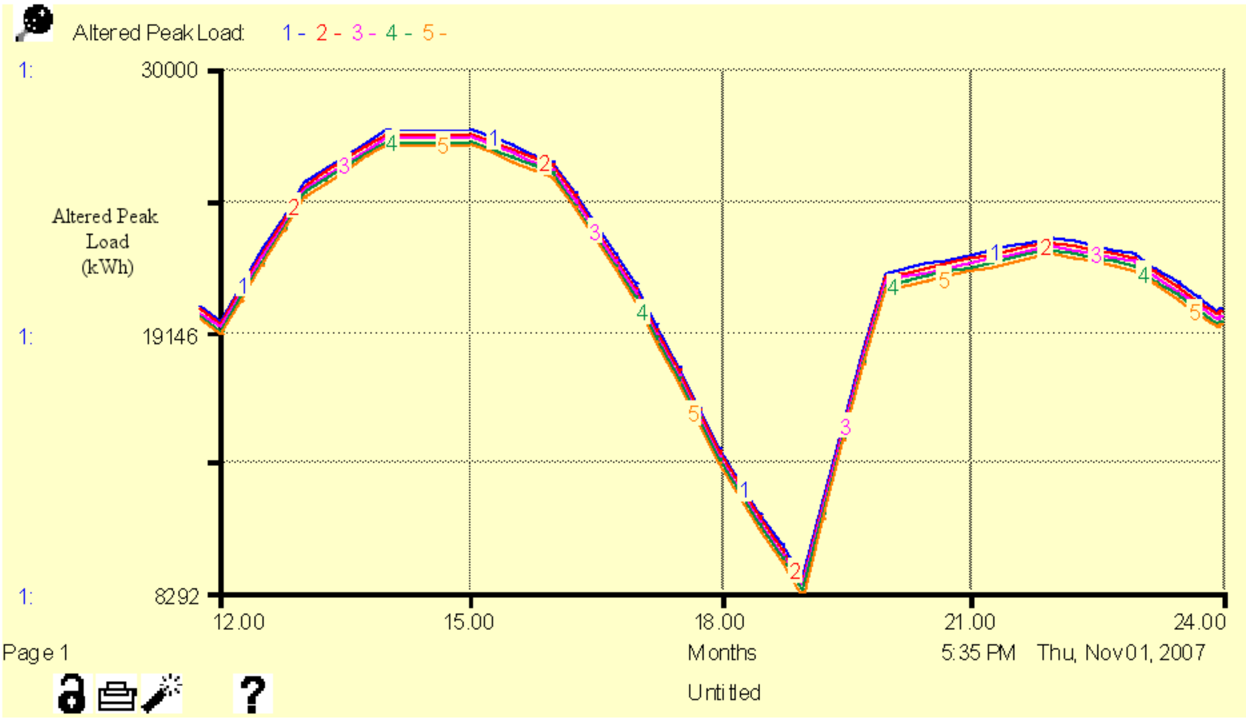

Figure 21: Altered Peak Load, with 50, 55, 60, 65 and 70 percent Capacity Used

Figure 21 shows how varying the total amount of the battery capacity used would affect the peak load. Line 1 shows 50 percent, line 2 shows 55 percent, line 3 shows 60 percent, line 4 shows 65 percent, and line 5 shows 70 percent. If the percent used is set to a higher value, WPI would save more money. The difference is somewhat small, however, the savings do add up.

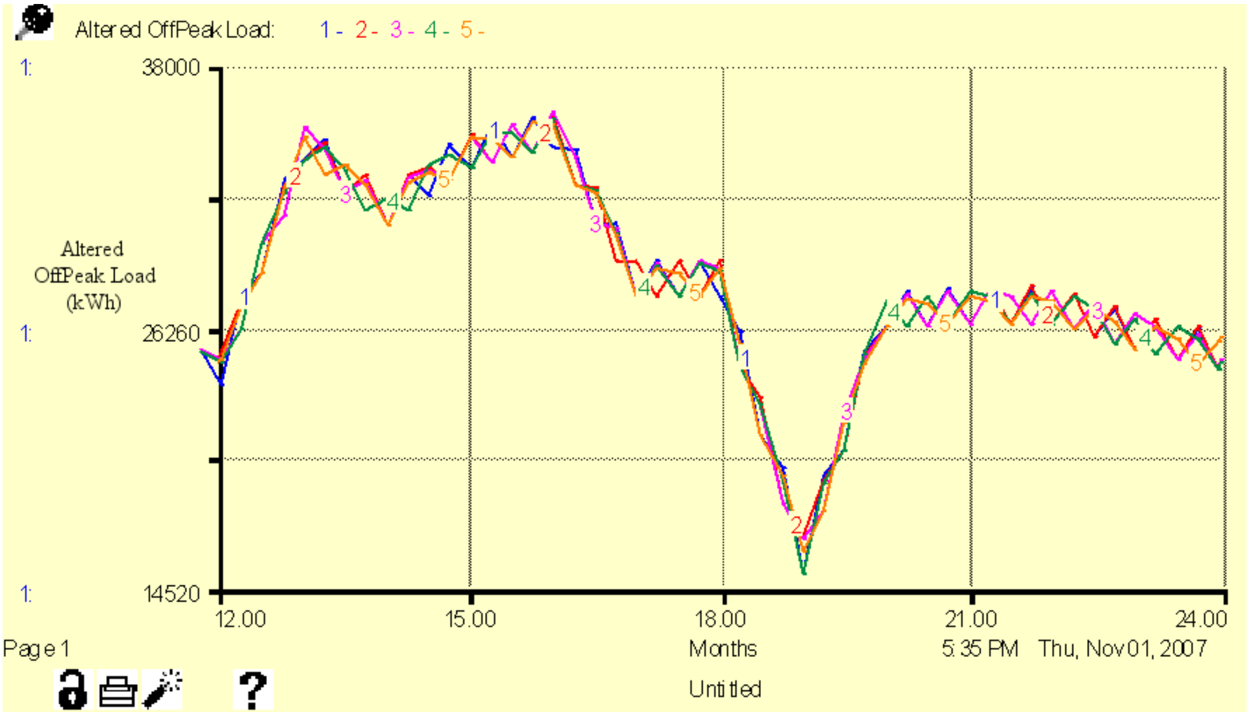

Figure 22: Altered Off-Peak Load, with 50, 55, 60, 65 and 70 percent Capacity Used

Figure 22 shows how altering the capacity used will affect the Off-Peak Load. Line 1 shows 50 percent, line 2 shows 55 percent, line 3 shows 60 percent, line 4 shows 65 percent, and line 5 shows 70 percent. In this figure, it is hard to tell what is happening exactly, but as the capacity used increases, the altered off-peak load increases as well.

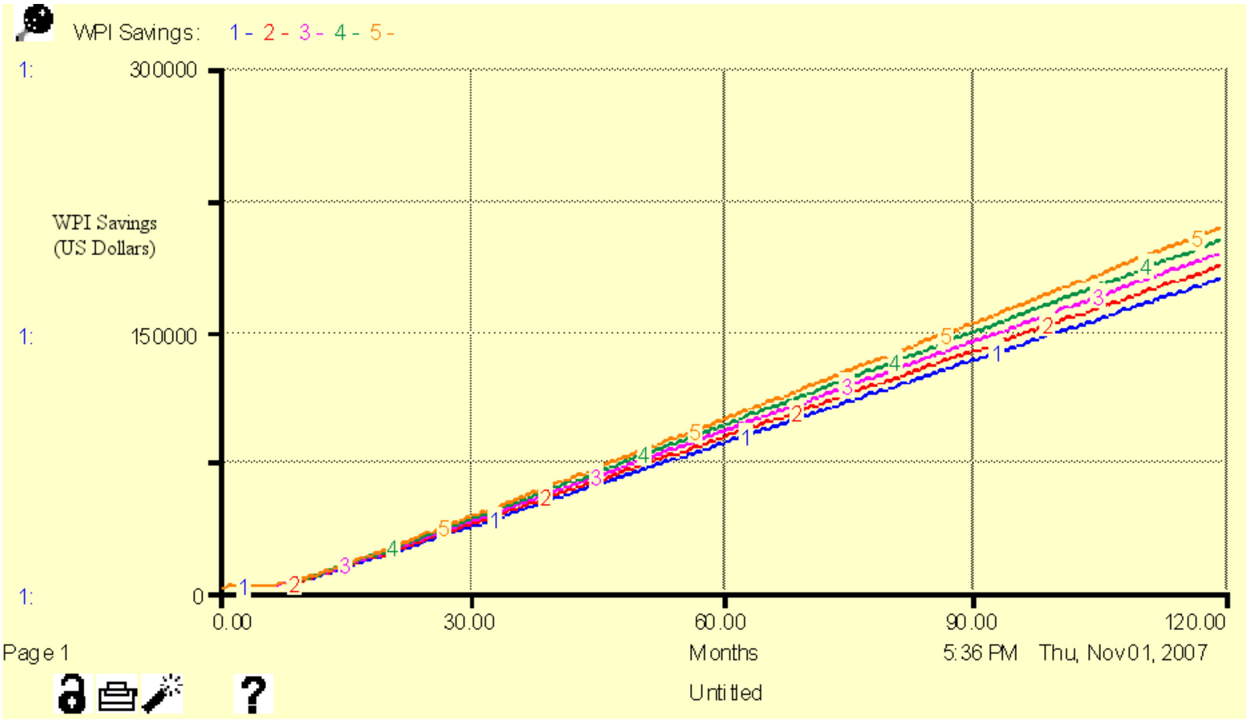

Figure 23: WPI Savings, with 50, 55, 60, 65 and 70 percent Capacity Used

Figure 23 shows how varying the capacity used will affect the total WPI savings. The figure shows the cumulative savings of WPI, with the end value representing the total amount of money WPI will save over the period of the project. Line 1 shows 50 percent, line 2 shows 55 percent, line 3 shows 60 percent, line 4 shows 65 percent, and line 5 shows 70 percent. As the capacity used increases, WPI savings also increase. This is a direct result of the inverted relationship the capacity used has with the *Altered Peak Load*; as the capacity used increases, the *Altered Peak Load* decreases, saving money for WPI.

As expected, the more capacity used, the more money WPI would save. Because the lifespan of NaS batteries depends on the total number of charge-discharge cycles per year, the best option for WPI would be to utilize the maximum amount of capacity, going no higher than 70 percent of the total capacity used except in emergency scenarios.

4.2 – Power Factor

Due to the fact that the battery capacity is measured in kVAh and the energy consumption is measured in kWh, there has to be a conversion factor to see the effect the battery will have on the energy consumption loads. This conversion factor is known as the power factor. The power factor is the ratio between the amount of power supplied (kVA) and the actual amount of usable power (kW).[xvii] The basic relationship is shown below in Figure 24:

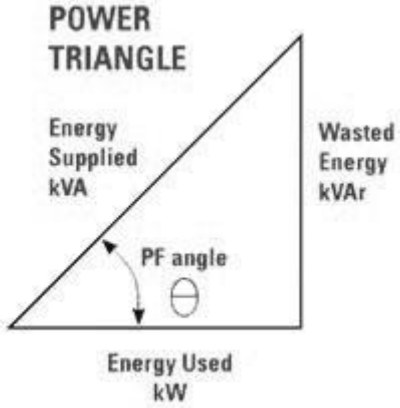

Figure 24: Power Triangle

Figure 24 shows the relationship between the power supplied (kVA) and power used (kW). The power factor ratio is also equal to the cosine of the phase angle[xviii] so the largest the power factor can be is one. In our model, the battery capacity is in kVAh, but kWh is needed. However, because we would be converting kVAh to kVA then to kW and kWh, the redundant division then multiplication by time is not necessary.

The goal is to achieve a power factor of one or "unity power factor" since if the power factor is less than one, more current must be supplied for a given amount of power use.[xix] The following figures (25, 26 and 27) show the affect of the power factor.

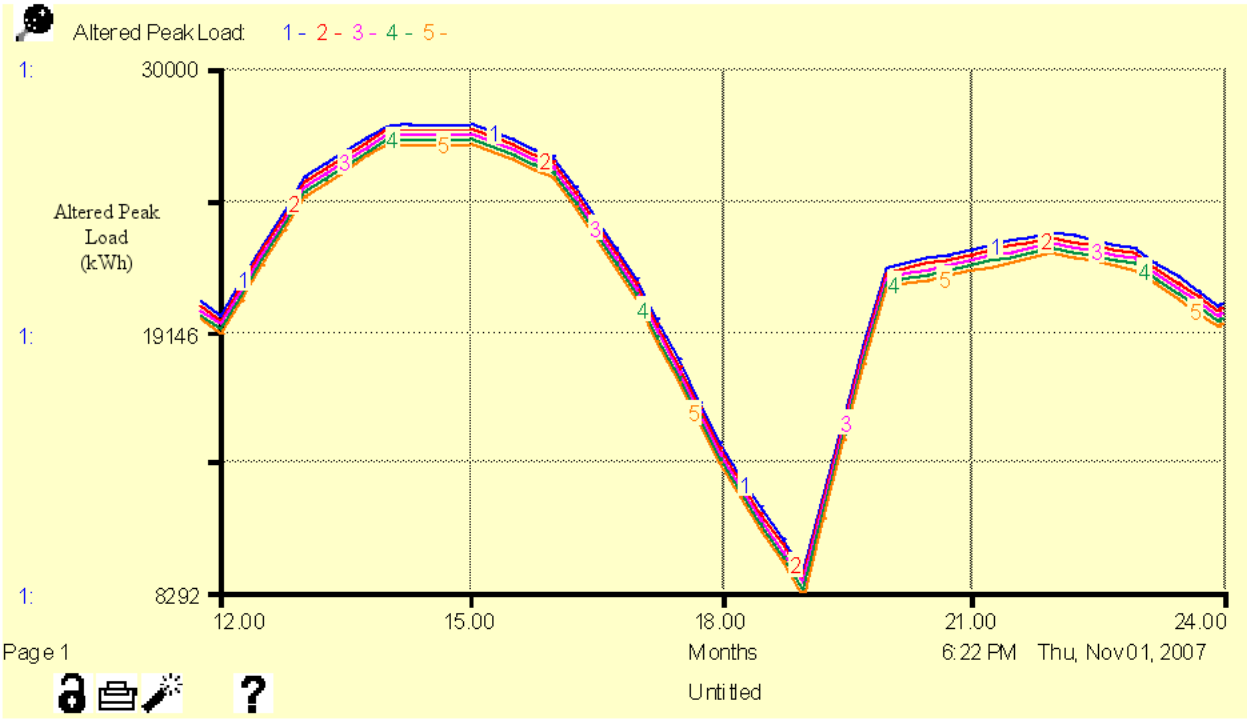

Figure 25: Altered Peak Load, with a Power factor of 0.60, 0.70, 0.80, 0.90, and 1.00

Figure 25 shows how varying the power factor will affect the peak load. Line 1 shows 0.60, line 2 shows 0.70, line 3 shows .080, line 4 shows 0.90, and line 5 shows 1.00. The higher the power factor, the more usable energy can be discharged from the battery, resulting in a lower peak load.

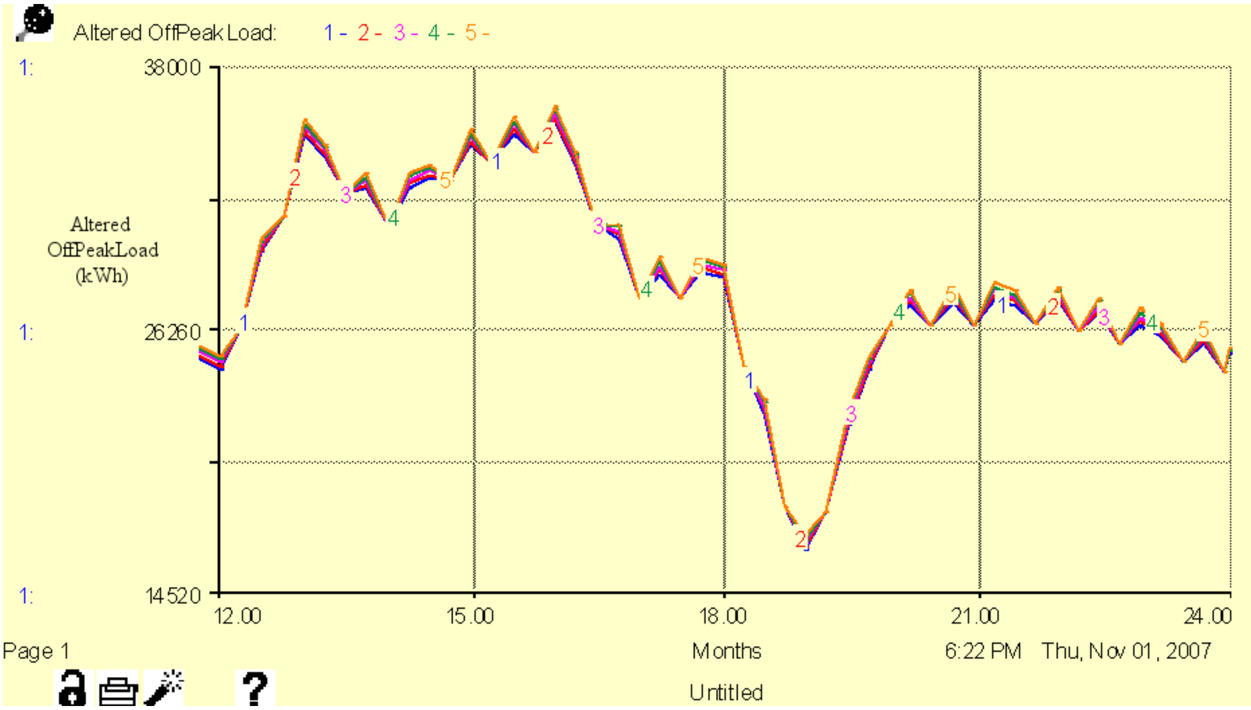

Figure 26: Altered Off-Peak Load, with a Power factor of 0.60, 0.70, 0.80, 0.90, and 1.00

Figure 26 shows how varying the power factor will affect the off-peak load. Line 1 shows 0.60, line 2 shows 0.70, line 3 shows .080, line 4 shows 0.90, and line 5 shows 1.00. As shown in Figure 25, the higher the power factor, the more usable energy can be discharged from the battery; this results in a larger off-peak load.

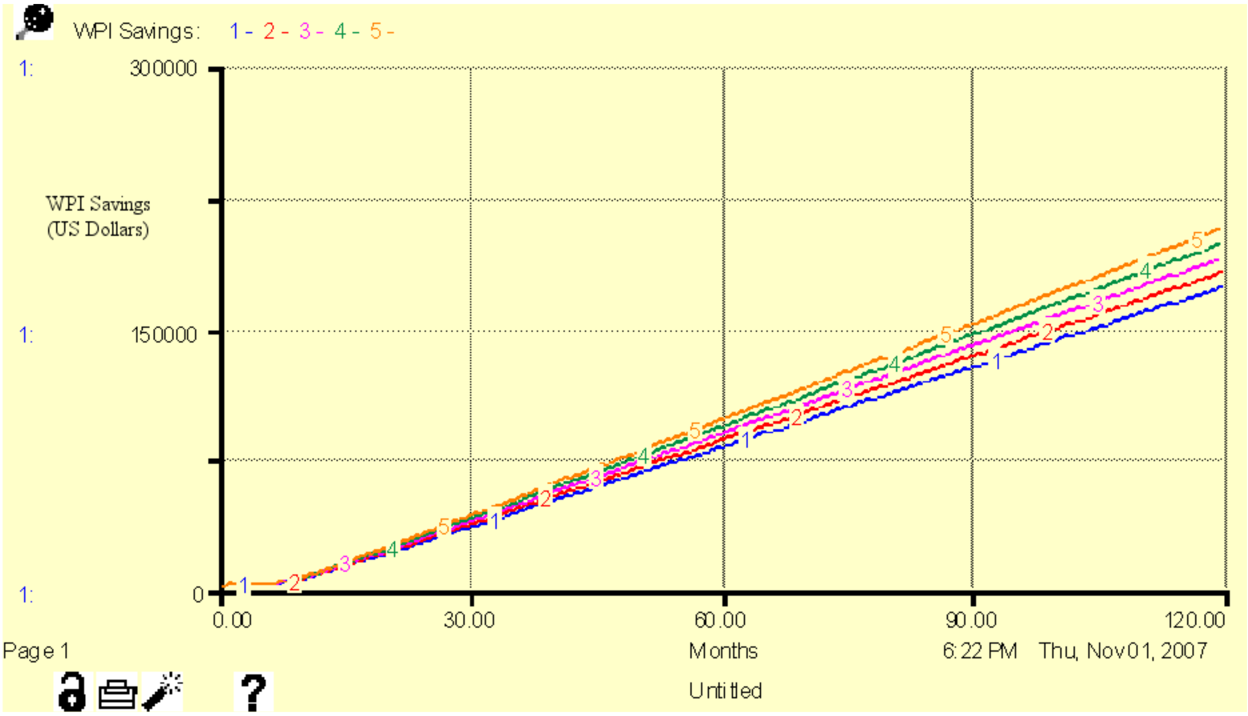

Figure 27: WPI Savings, with a Power factor of 0.60, 0.70, 0.80, 0.90, and 1.00

Figure 27 shows how varying the power factor will affect the WPI Savings. The figure shows the cumulative savings of WPI, with the end value representing the total amount of money WPI will save over the period of the project. Line 1 shows 0.60, line 2 shows 0.70, line 3 shows .080, line 4 shows 0.90, and line 5 shows 1.00. If the power factor is equal to 1, then all available energy is being used, so the closer the power factor is to one, the more WPI would save money.

The figures above prove that if the power factor can be brought closer to one, then WPI would save the most amount of money. There are a few methods to increase the power factor, one being a capacitor bank, which helps balance out the reactive (or wasted) power.[xx]

4 .3 – Battery Efficiency

The efficiency of NaS batteries is a debatable number, depending on the source. In the Sandia National Laboratories 2003 report to the DOE, they listed the efficiency at 70 percent, but other sources have listed it as upwards of 90 percent.[xxi] For the purposes of the sensitivity analysis, values of 70 percent, 75 percent, 80 percent, 85 percent and 90 percent were used to see how the efficiency would affect the altered loads and the *WPI Savings*.

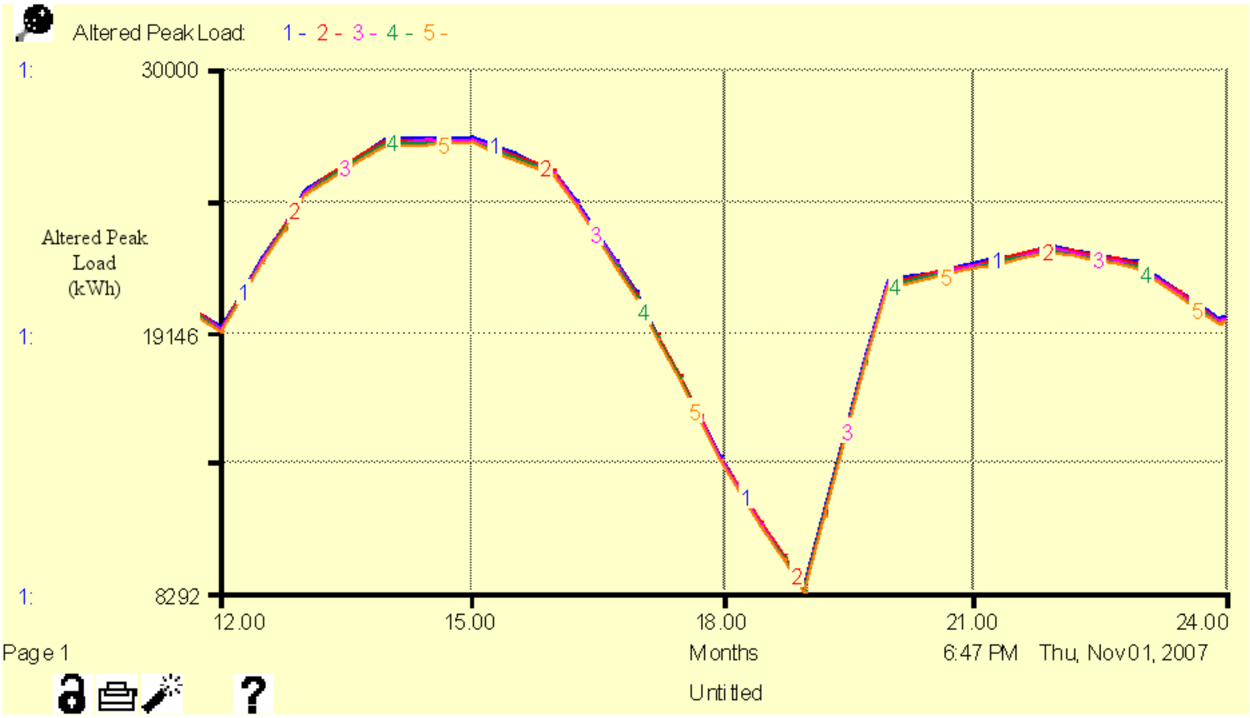

Figure 28: Altered Peak Load, with efficiencies of 70 percent, 75 percent, 80 percent, 85 percent and 90 percent

Figure 28 shows how varying the efficiency of the battery affects the peak load. The figure suggests that having a greater efficiency will lead to a lowered peak load. There is a difference, but it is not significant enough that the efficiency would have a large impact on *WPI Savings*.

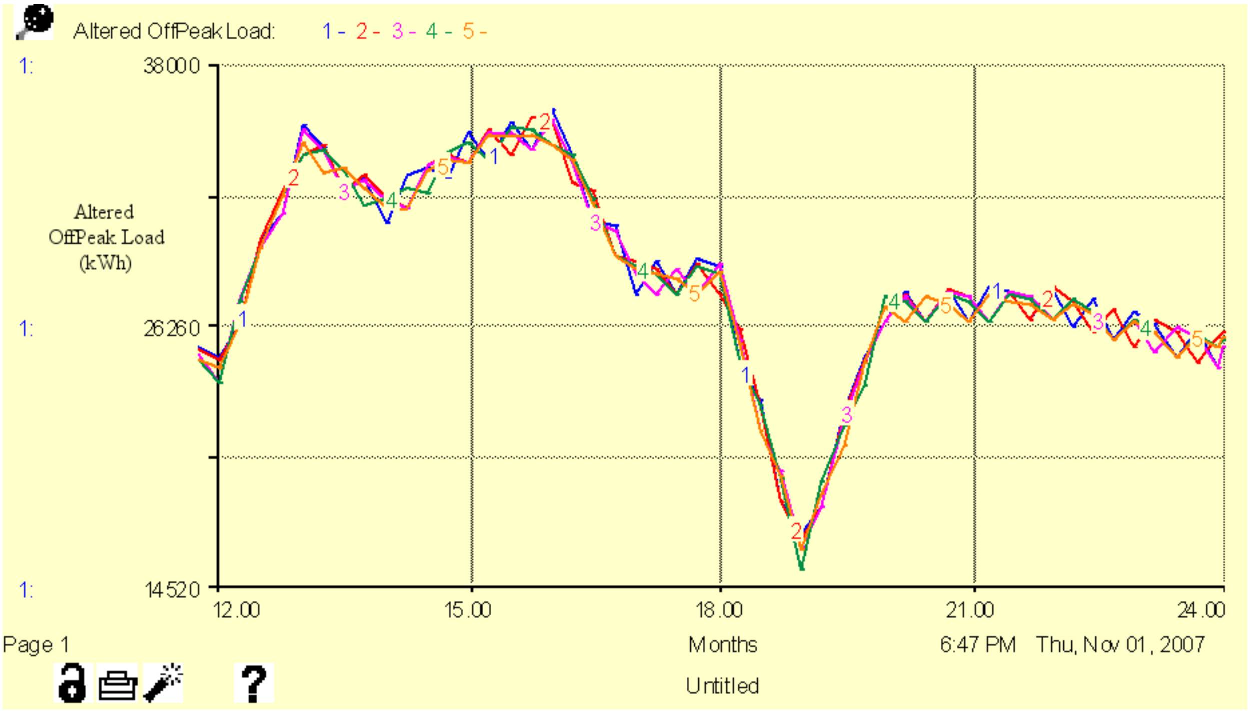

Figure 29: Altered Off-Peak Load, with efficiencies of 70 percent, 75 percent, 80 percent, 85 percent and 90 percent

Figure 29 shows how varying the efficiency will affect the off-peak load. It is slightly difficult to tell, but because the peak load is lowered even further with an increased efficiency[18], more energy is needed to charge in order to reach full capacity, so the off-peak load would be increased.

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[18] See Figure 28

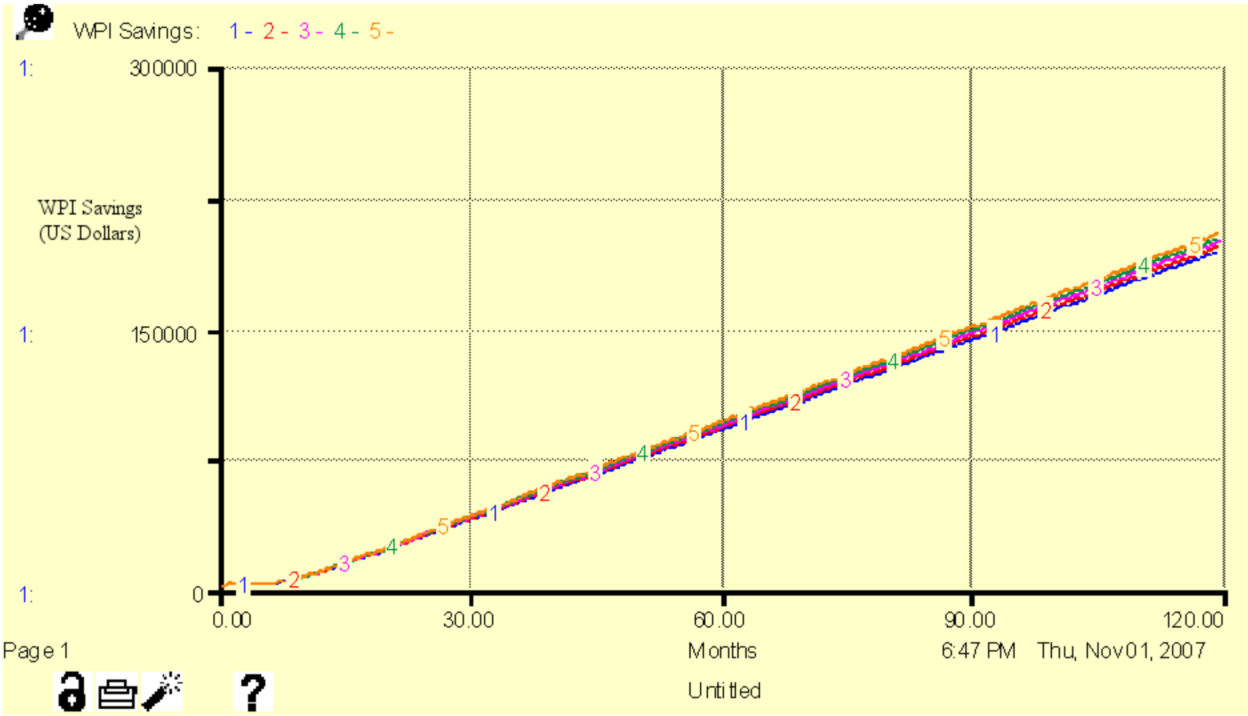

Figure 30: WPI Savings, with efficiencies of 70 percent, 75 percent, 80 percent, 85 percent and 90 percent

Figure 30 shows the affect of efficiency on WPI Savings. The figure shows the cumulative savings of WPI, with the end value representing the total amount of money WPI will save over the period of the project. The figure proves the more efficient the batteries are, the more money WPI would save. The figure also supports that varying the efficiencies would not have a great impact on WPI savings.

4.4 – Costs

In the sensitivity analysis for the costs, varying the cost of the battery, the cost of the inverter and the monthly interest rate were investigated. In research, several different prices for the cost of the battery were found, ranging from \$170/kWh[xxii] to \$250/kWh[xxiii] and some even more costly. The battery cost was included, because as with the inverter cost, as the technology becomes more common and improved, the cost will decrease.

4.4.1 – Battery Cost

As you can see in Figure 31 below, the model shows that if the battery cost drops to about $150/kVAh, WPI would need to borrow about $800,000 in order to implement this project. However, as battery costs are still very high, it is more likely that in the near future WPI would have to pay between $250/kVAh and $350/kVAh, thus significantly increasing its initial borrowed sum to a maximum value of just under $1,825,000.

Table 3: Borrowed Initial Lump Sum, with Battery cost of 150, 200, 250, 300 and 350 $/kVAh

Battery Capacity (kVAh)	$/kVAh battery	$/kVAh inverter	Inverter Capacity (kVAh)	Initial Borrowed Lump Sum ($)
1000	150	150	500	225,000.00
2000	200	150	500	475,000.00
3000	250	150	500	825,000.00
4000	300	150	500	1,275,000.00
5000	350	150	500	1,825,000.00

As Table 3 shows, with the current battery technology WPI would incur huge costs which it would not be able to pay back. Again, this project determined that WPI would have to wait until prices drop or new alternative energy sources are established in order to profit from this undertaking.

4.4.2 – Inverter Cost

Installing the desired batteries capacity would require installing an inverter, which also adds to the overall costs of the project. By ranging the inverter capacity from $50 to $250/kVAh in the model, the borrowed initial lump sum increases by about $100,000. Again, it follows that prices are still not feasible and would not allow for the profitable implementation of batteries on the part of WPI.

Table 4: Borrowed Initial Lump Sum, with Inverter cost of 150, 200, 250, 300 and 350 $/kVAh

Battery Capacity (kVAh)	$/kVAh battery	$/kVAh inverter	Inverter Capacity (kVAh)	Initial Borrowed Lump Sum ($)
1000	250	150	500	325,000.00
2000	250	200	500	600,000.00
3000	250	250	500	875,000.00
4000	250	300	500	1,150,000.00
5000	250	350	500	1,425,000.00

For battery and inverter costs, the less expensive they are, the less money WPI would have to spend. At the current time, the unreasonable overall cost is the biggest drawback of the project.

4.5 – Interest Rate

In this section how the monthly interest rate would affect the *WPI Savings* along with the *Monthly Cost of the Project* is shown.

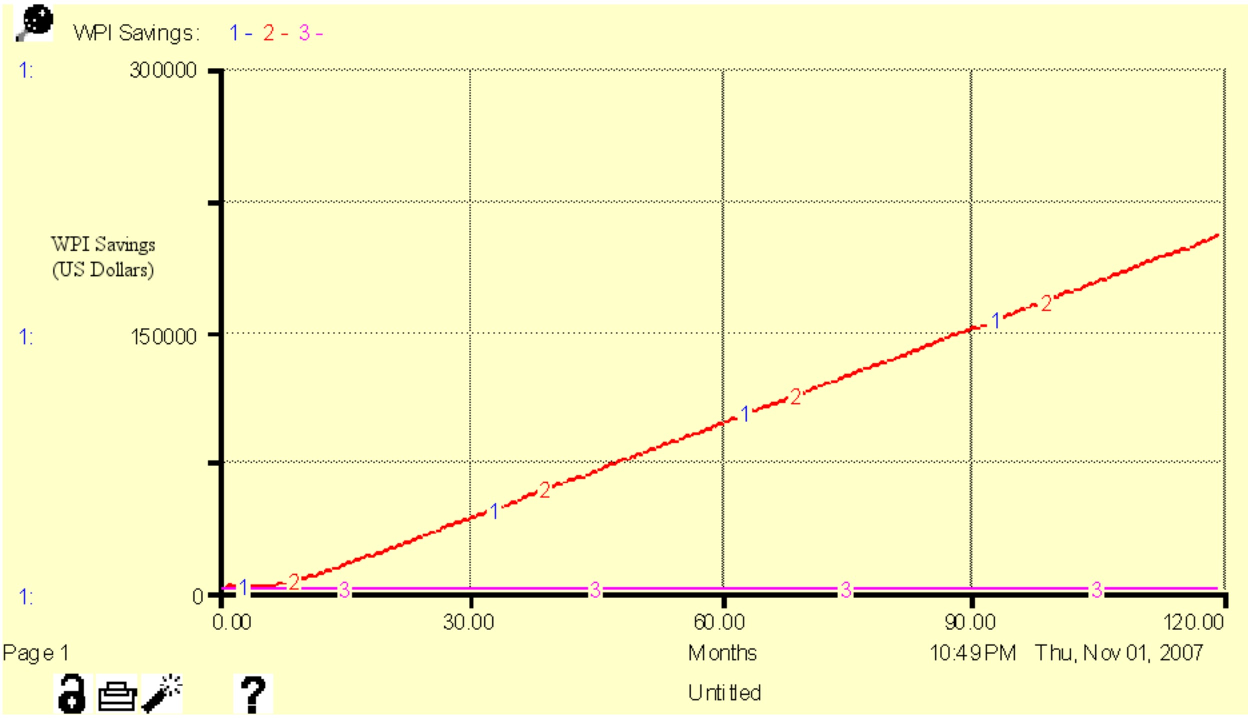

Figure 31: WPI Savings with Interest Rate of 0.5 percent, 1.5 percent and 2.5 percent

Figure 31 shows how by varying the interest rate WPI Savings would decrease. As the monthly interest rate determines the monthly interest payment paid by WPI on the initial lump sum borrowed from investors, the interest rate has a crucial influence on the savings. Line 1 is with interest rate set at 0.5 percent, Line 2 with 1.5 percent and Line 3 with 2.5 percent. The lines clearly show that increasing the monthly interest rate leads to diminishing savings for WPI, and if the interest rate is too high, the decision to install the batteries is never allowed.

Table 5: Monthly Cost of the Project with Interest Rate of 0.5 percent, 1.5 percent and 2.5 percent

Interest Rate (percent)	Monthly Cost of the Project ($/month)
0.5	15184
1	20114
1.5	24979

Table 5 further extends the argument for the effect of the monthly interest rate on the monthly cost of the project. As the interest rate increases, the monthly cost of the project increases significantly. If the monthly cost of the project becomes too large, the decision to install the batteries does not allow the batteries to be installed.

As WPI would need to borrow the money in order to successfully implement this project, a sensitivity study on the interest rate at which WPI could borrow was examined to see how it would affect WPI savings. The model starts at a monthly interest rate of 0.5 percent, which is credible given the status of WPI as a financially stable university. At that rate the model shows that WPI savings accumulate up to about $200,000. At the same time, the monthly cost of the project, which includes interest payments on the initial lump sum investment and depreciation expenses, is about $15,000. In the model the monthly cost is given a negative sign in order to account for the fact that this is an actual outflow of cash for WPI.

As the interest rate is increased, the model shows that beyond the threshold of 0.64 percent monthly interest rate, WPI starts losing money. The savings generated from peak shaving are severely reduced by the monthly interest payments required by the project.

Chapter 5 – Conclusion

In this project the feasibility of installing batteries at WPI for peak shaving was analyzed. How the batteries would be installed and how they would affect the current energy consumption of WPI was modeled using “iThink,” based on electrical bills received from Plant Services. Overall, the idea to use batteries to peak shave is a sound idea, currently used in many installations around the world. However, for WPI, the current cost of the NaS batteries makes the project financially impossible. Even with the manipulation of battery parameters, enough savings were not accrued over the 10 years to create profit for WPI. While altering the total capacity online lead to the greatest increase in savings, it also resulted in an even greater increase in cost, which could not be compensated. When analyzing the efficiency, percent used, and power factor, even increasing these parameters to their maximum values was not enough to generate significant savings. Only if the price of the batteries decreases dramatically in the following years, would the project become a sound investment for WPI.

For future projects, we recommend the analysis of how installing batteries would affect the profit off National Grid, still assuming the customers are fully financing the purchase and installation of the batteries. While the batteries installed would cause National Grid to lose money, the batteries would help to reduce the strain on the generators at National Grid. We recommend that subsequent projects investigate how the resulting extension of the lifespan of said generators would affect National Grid. If subsequent projects are found to adversely affect

National Grid as well as WPI, we recommend investigating the utilization of Distributed Generation, purchased and installed by WPI.

Also, we did not investigate how installing the NaS batteries would affect the environment, so it may be an important factor to take into consideration in future projects, considering the environmentally conscious society of today.

Appendices

Appendix I – Model Equations

Accounting Cost of the Project

Borrowed_Initial_Lump_Sum = Inverter_Capacity*Price_per_kVAh_Inverter+Price_per_kVAh_Battery*Desired_Batteries_Capacity

Inverter_Capacity = 200

Monthly_Cash_Outflow = PMT(Monthly_Interest_Rate,Number_of_Payments,Borrowed_Initial_Lump_Sum,0)

Monthly_Cost_of_the_Project = Monthly_Cash_Outflow+Monthly_Depreciation_Expenses

Monthly_Depreciation_Expenses = -Borrowed_Initial_Lump_Sum/Batteries_Useful_Life

Monthly_Interest_Rate = 0.005

Net_Present_Value_of_Monthly_Cost_of_the_Project = ABS(NPV(Monthly_Cost_of_the_Project,Monthly_Interest_Rate))

Number_of_Payments = 120

Price_per_kVAh_Battery = 250

Price_per_kVAh_Inverter = 150

Energy Sector

Total_Energy_Stored(t) = Total_Energy_Stored(t - dt) + (Energy_Charged - Energy_Discharged) * dt

INIT Total_Energy_Stored = 0

INFLOWS:

Energy_Charged = IF Charging_Switch=1 THEN (Batteries_Capacity_OnLine-(Total_Energy_Stored/Charge_Efficiency))

ELSE (0)

OUTFLOWS:

Energy_Discharged = IF(Total_Energy_Stored-Capacity_Used*Discharge_Efficiency>0.3*Batteries_Capacity_OnLine)

THEN(Capacity_Used*Discharge_Efficiency)

ELSE(0)

Altered_OffPeak_Load = Energy_Charged*Power_Factor+Energy_OffPeak_in_Days

Altered_Peak_Load = Energy_Peak_kWh_in_Days-(Capacity_Used*Discharge_Efficiency)*Power_Factor

Battery_Efficiency = .89

Capacity_Used = Percentage_of_Capacity_Used*Batteries_Capacity_OnLine

Charge_Efficiency = Battery_Efficiency^(0.5)

Charging_Switch = IF (Energy_Discharged>0) THEN 0

ELSE (1)

Days_in_a_Billing_Period = 30

Discharge_Efficiency = (Battery_Efficiency)^(0.5)

Energy_OffPeak_in_Days = Energy_Off_Peak_kWh/Days_in_a_Billing_Period

Energy_Peak_kWh_in_Days = Energy_Peak_kWh/Days_in_a_Billing_Period

Percentage_of_Capacity_Used = .6

Power_Factor = .85

Expected Energy Sector

Energy_Stored(t) = Energy_Stored(t - dt) + (Charging - Discharging) * dt

INIT Energy_Stored = 0

INFLOWS:

Charging = IF Charging_Switch=1 THEN ((Desired_Batteries_Capacity-Energy_Stored)/Charge_Efficiency)

ELSE (0)

OUTFLOWS:

Discharging = IF(Energy_Stored>0.3*Desired_Batteries_Capacity)

THEN(Expected_Capacity_Used*Discharge_Efficiency)

ELSE(0)

Expected_Capacity_Used = Desired_Batteries_Capacity*Percentage_of_Capacity_Used

Expected_OffPeak_Load = Charging*Power_Factor+Energy_OffPeak_in_Days

Expected_Peak_Load = Energy_Peak_kWh_in_Days-Discharging*Power_Factor

Opportunity Cost of the Project

Invested_Initial_Lump_Sum = -Borrowed_Initial_Lump_Sum

Market_Interest_Rate = 0.008

Monthly_Cash_Inflow = PMT(Market_Interest_Rate,Number_of_Payments,Invested_Initial_Lump_Sum,0)

NPV_of_Monthly_Opportunity_Cost_of_the_Project = NPV(Monthly_Cash_Inflow,Market_Interest_Rate)

NPV_of_WPI_Savings = ABS(NPV(WPI_Savings,Market_Interest_Rate))

Supply Line for Batteries Capacity Coming Online

Batteries_Capacity_Approved(t) = Batteries_Capacity_Approved(t - dt) + (Batteries_Capacity_Planned - Batteries_Delivered) * dt

INIT Batteries_Capacity_Approved = 0

INFLOWS:

Batteries_Capacity_Planned = Decision_to_Install_Capacity/A_month

OUTFLOWS:

Batteries_Delivered = Batteries_Capacity_Approved/Delivery__Delay

Batteries_Capacity_OnLine(t) = Batteries_Capacity_OnLine(t - dt) + (Batteries_Installed - Batteries_OffLine) * dt

INIT Batteries_Capacity_OnLine = 0

INFLOWS:

Batteries_Installed = Batteries_Delivery/Installation_Delay

OUTFLOWS:

Batteries_OffLine = Batteries_Capacity_OnLine/Batteries_Useful_Life

Batteries_Delivery(t) = Batteries_Delivery(t - dt) + (Batteries_Delivered - Batteries_Installed) * dt

INIT Batteries_Delivery = 0

INFLOWS:

Batteries_Delivered = Batteries_Capacity_Approved/Delivery__Delay

OUTFLOWS:

Batteries_Installed = Batteries_Delivery/Installation_Delay

A_month = 1

Batteries_Useful_Life = 1200

Cost_Benefit_Analysis = IF (Net_Present_Value_of_WPI_Projected_Monthly_Savings>Net_Present_Value_of_Monthly_Cost_of_the_Project) THEN 1

ELSE 0

Decision_to_Install_Capacity = IF (Cost_Benefit_Analysis=1)

THEN (IF (Desired_Batteries_Capacity-Batteries_Capacity_Approved-Batteries_Delivery-Batteries_Capacity_OnLine) > (Economic_Size_of_a_Battery)

THEN PULSE(Economic_Size_of_a_Battery, TIME,10000)

ELSE 0)

ELSE 0

Delivery__Delay = 3

Desired_Batteries_Capacity = 500

Economic_Size_of_a_Battery = 250

Installation_Delay = 3

WPI Actual Savings

WPI_Savings(t) = WPI_Savings(t - dt) + (WPI_Actual_Monthly_Savings) * dt

INIT WPI_Savings = 0

INFLOWS:

WPI_Actual_Monthly_Savings = Total_Current_Monthly_Costs_of_WPI-Total_Actual_Monthly_Costs_of_WPI

Monthly_Actual_Decrease_in_OnPeak_Energy = Energy_Peak_kWh-(Altered_Peak_Load*Days_in_a_Billing_Period)

Monthly_Increase_in_OffPeak_Energy = (Altered_OffPeak_Load*Days_in_a_Billing_Period)-Energy_Off_Peak_kWh

OnPeak_Hours = 13

Total_Actual_Monthly_Costs_of_WPI = Total_Costs_for_Actual_Demand+Total_Costs_for_Actual_OnPeak_Energy+Total_Costs_for_Actual_OffPeak_Energy

Total_Costs_for_Actual_Demand = (Demand_kVA-(Batteries_Capacity_OnLine/OnPeak_Hours)/A_month)*Demand_Constant*Demand_Base_Price

Total_Costs_for_Actual_OffPeak_Energy = (Off_Peak_Base_Price/1000)*(Energy_Off_Peak_kWh+Monthly_Increase_in_OffPeak_Energy)

Total_Costs_for_Actual_OnPeak_Energy = On_Peak_Base_Price*(Energy_Peak_kWh-Monthly_Actual_Decrease_in_OnPeak_Energy)

WPI Expected Savings

Demand_Constant = 0.9

Monthly_Expected_Decrease_in_OnPeak_Energy = Energy_Peak_kWh-(Expected_Peak_Load*Days_in_a_Billing_Period)

Monthly_Expected_Increase_in_OffPeak_Energy = (Expected_OffPeak_Load*Days_in_a_Billing_Period)-Energy_Off_Peak_kWh

Net_Present_Value_of_WPI_Projected_Monthly_Savings = NPV(WPI_Projected_Monthly_Savings,Monthly_Interest_Rate)

Total_Costs_for_Expected_Demand = (Demand_kVA-Desired_Batteries_Capacity)*Demand_Base_Price*Demand_Constant

Total_Costs_for_Expected_Energy_Off_Peak = (Off_Peak_Base_Price/1000)*(Energy_Off_Peak_kWh+Monthly_Expected_Increase_in_OffPeak_Energy)

Total_Costs_for_Expected_OnPeak_Energy = On_Peak_Base_Price*(Energy_Peak_kWh-Monthly_Expected_Decrease_in_OnPeak_Energy)

Total_Current_Costs_for_Demand = Demand_kVA*Demand_Base_Price*Demand_Constant

Total_Current_Costs_for_Energy_Off_Peak = Energy_Off_Peak_kWh*Off_Peak_Base_Price/1000

Total_Current_Costs_for_Energy_Peak = Energy_Peak_kWh*On_Peak_Base_Price

Total_Current_Monthly_Costs_of_WPI = (Total_Current_Costs_for_Demand+Total_Current_Costs_for_Energy_Peak+Total_Current_Costs_for_Energy_Off_Peak)

Total_Monthly_Expected_Costs_of_WPI = (Total_Costs_for_Expected_Demand+Total_Costs_for_Expected_OnPeak_Energy+Total_Costs_for_Expected_Energy_Off_Peak)

WPI_Projected_Monthly_Savings = Total_Current_Monthly_Costs_of_WPI-Total_Monthly_Expected_Costs_of_WPI

Demand_Base_Price = GRAPH(TIME)

(1.00, 3.63), (2.00, 3.63), (3.00, 3.63), (4.00, 3.63), (5.00, 3.63), (6.00, 2.90), (7.00, 2.00), (8.00, 3.63), (9.00, 3.69), (10.0, 3.75), (11.0, 3.75), (12.0, 3.75), (13.0, 3.63), (14.0, 3.63), (15.0, 3.63), (16.0, 3.63), (17.0, 3.63), (18.0, 2.90), (19.0, 2.00), (20.0, 3.63), (21.0, 3.69), (22.0, 3.75), (23.0, 3.75), (24.0, 3.75), (25.0, 3.63), (26.0, 3.63), (27.0, 3.63), (28.0, 3.63), (29.0, 3.63), (30.0, 2.90), (31.0, 2.00), (32.0, 3.63), (33.0, 3.69), (34.0, 3.75), (35.0, 3.75), (36.0, 3.75), (37.0, 3.63), (38.0, 3.63), (39.0, 3.63), (40.0, 3.63), (41.0, 3.63), (42.0, 2.90), (43.0, 2.00), (44.0, 3.63), (45.0, 3.69), (46.0, 3.75), (47.0, 3.75), (48.0, 3.75), (49.0, 3.63), (50.0, 3.63), (51.0, 3.63), (52.0, 3.63), (53.0, 3.63), (54.0, 2.90), (55.0, 2.00), (56.0, 3.63), (57.0, 3.69), (58.0, 3.75), (59.0, 3.75), (60.0, 3.75), (61.0, 3.63), (62.0, 3.63), (63.0, 3.63), (64.0, 3.63), (65.0, 3.63), (66.0, 2.90), (67.0, 2.00), (68.0, 3.63), (69.0, 3.69), (70.0, 3.75), (71.0, 3.75), (72.0, 3.75), (73.0, 3.63), (74.0, 3.63), (75.0, 3.63), (76.0, 3.63), (77.0, 3.63), (78.0, 2.90), (79.0, 2.00), (80.0, 3.63), (81.0, 3.69), (82.0, 3.75), (83.0, 3.75), (84.0, 3.75), (85.0, 3.63), (86.0, 3.63), (87.0, 3.63), (88.0, 3.63), (89.0, 3.63), (90.0, 2.90), (91.0, 2.00), (92.0, 3.63), (93.0, 3.69), (94.0, 3.75), (95.0, 3.75), (96.0, 3.75), (97.0, 3.63), (98.0, 3.63), (99.0, 3.63), (100, 3.63), (101, 3.63), (102, 2.90), (103, 2.00), (104, 3.63), (105, 3.69), (106, 3.75), (107, 3.75), (108, 3.75), (109, 3.63), (110, 3.63), (111, 3.63), (112, 3.63), (113, 3.63), (114, 2.90), (115, 2.00), (116, 3.63), (117, 3.69), (118, 3.75), (119, 3.75), (120, 3.75)

Demand_kVA = GRAPH(TIME)

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Energy_Off_Peak_kWh = GRAPH(TIME)

(1.00, 981600), (2.00, 892800), (3.00, 972000), (4.00, 996000), (5.00, 799200), (6.00, 799200), (7.00, 435600), (8.00, 760800), (9.00, 763200), (10.0, 765600), (11.0, 729600), (12.0, 703200), (13.0, 1e+006), (14.0, 919584), (15.0, 1e+006), (16.0, 1e+006), (17.0, 823176), (18.0, 823176), (19.0, 448668), (20.0, 783624), (21.0, 786096), (22.0, 788568), (23.0, 751488), (24.0, 724296), (25.0, 1e+006), (26.0, 947172), (27.0, 1e+006), (28.0, 1.1e+006), (29.0, 847871), (30.0, 847871), (31.0, 462128), (32.0, 807133), (33.0, 809679), (34.0, 812225), (35.0, 774033), (36.0, 746025), (37.0, 1.1e+006), (38.0, 975587), (39.0, 1.1e+006), (40.0, 1.1e+006), (41.0, 873307), (42.0, 873307), (43.0, 475992), (44.0, 831347), (45.0, 833969), (46.0, 836592), (47.0, 797254), (48.0, 768406), (49.0, 1.1e+006), (50.0, 1e+006), (51.0, 1.1e+006), (52.0, 1.1e+006), (53.0, 899507), (54.0, 899507), (55.0, 490272), (56.0, 856287), (57.0, 858988), (58.0, 861690), (59.0, 821171), (60.0, 791458), (61.0, 1.1e+006), (62.0, 1e+006), (63.0, 1.1e+006), (64.0, 1.2e+006), (65.0, 926492), (66.0, 926492), (67.0, 504980), (68.0, 881976), (69.0, 884758), (70.0, 887540), (71.0, 845806), (72.0, 815202), (73.0, 1.2e+006), (74.0, 1.1e+006), (75.0, 1.2e+006), (76.0, 1.2e+006), (77.0, 954287), (78.0, 954287), (79.0, 520129), (80.0, 908435), (81.0, 911301), (82.0, 914166), (83.0, 871181), (84.0, 839658), (85.0, 1.2e+006), (86.0, 1.1e+006), (87.0, 1.2e+006), (88.0, 1.2e+006), (89.0, 982915), (90.0, 982915), (91.0, 535733), (92.0, 935688), (93.0, 938640), (94.0, 941591), (95.0, 897316), (96.0, 864847), (97.0, 1.2e+006), (98.0, 1.1e+006), (99.0, 1.2e+006), (100, 1.3e+006), (101, 1e+006), (102, 1e+006), (103, 551805), (104, 963759), (105, 966799), (106, 969839), (107, 924235), (108, 890793), (109, 1.3e+006), (110, 1.2e+006), (111, 1.3e+006), (112, 1.6e+006), (113, 1e+006), (114, 1e+006), (115, 568359), (116, 992671), (117, 995803), (118, 998934), (119, 951963), (120, 917517)

Energy_Peak_kWh = GRAPH(TIME)

(1.00, 772800), (2.00, 837600), (3.00, 840000), (4.00, 801600), (5.00, 652800), (6.00, 454800), (7.00, 296400), (8.00, 667200), (9.00, 688800), (10.0, 710400), (11.0, 691200), (12.0, 621600), (13.0, 795984), (14.0, 862728), (15.0, 865200), (16.0, 825648), (17.0, 672384), (18.0, 468444), (19.0, 305292), (20.0, 687216), (21.0, 709464), (22.0, 731712), (23.0, 711936), (24.0, 640248), (25.0, 819864), (26.0, 888610), (27.0, 891156), (28.0, 850417), (29.0, 692556), (30.0, 482497), (31.0, 314451), (32.0, 707832), (33.0, 730748), (34.0, 753663), (35.0, 733294), (36.0, 659455), (37.0, 844459), (38.0, 915268), (39.0, 917891), (40.0, 875930), (41.0, 713332), (42.0, 496972), (43.0, 323884), (44.0, 729067), (45.0, 752670), (46.0, 776273), (47.0, 755293), (48.0, 679239), (49.0, 869793), (50.0, 942726), (51.0, 945427), (52.0, 902208), (53.0, 734732), (54.0, 511881), (55.0, 333601), (56.0, 750939), (57.0, 775250), (58.0, 799561), (59.0, 777952), (60.0, 699616), (61.0, 895887), (62.0, 971008), (63.0, 973790), (64.0, 929274), (65.0, 756774), (66.0, 527238), (67.0, 343609), (68.0, 773468), (69.0, 798508), (70.0, 823548), (71.0, 801290), (72.0, 720605), (73.0, 922764), (74.0, 1e+006), (75.0, 1e+006), (76.0, 957152), (77.0, 779477), (78.0, 543055), (79.0, 353917), (80.0, 796672), (81.0, 822463), (82.0, 848255), (83.0, 825329), (84.0, 742223), (85.0, 950447), (86.0, 1e+006), (87.0, 1e+006), (88.0, 985867), (89.0, 802862), (90.0, 559347), (91.0, 364535), (92.0, 820572), (93.0, 847137), (94.0, 873702), (95.0, 850089), (96.0, 764490), (97.0, 978960), (98.0, 1.1e+006), (99.0, 1.1e+006), (100, 1e+006), (101, 826948), (102, 576127), (103, 375471), (104, 845189), (105, 872551), (106, 899913), (107, 875591), (108, 787424), (109, 1e+006), (110, 1.1e+006), (111, 1.1e+006), (112, 1e+006), (113, 1.2e+006), (114, 593411), (115, 386735), (116, 870545), (117, 898728), (118, 926911), (119, 901859), (120, 811047)

Off_Peak_Base_Price = GRAPH(TIME)

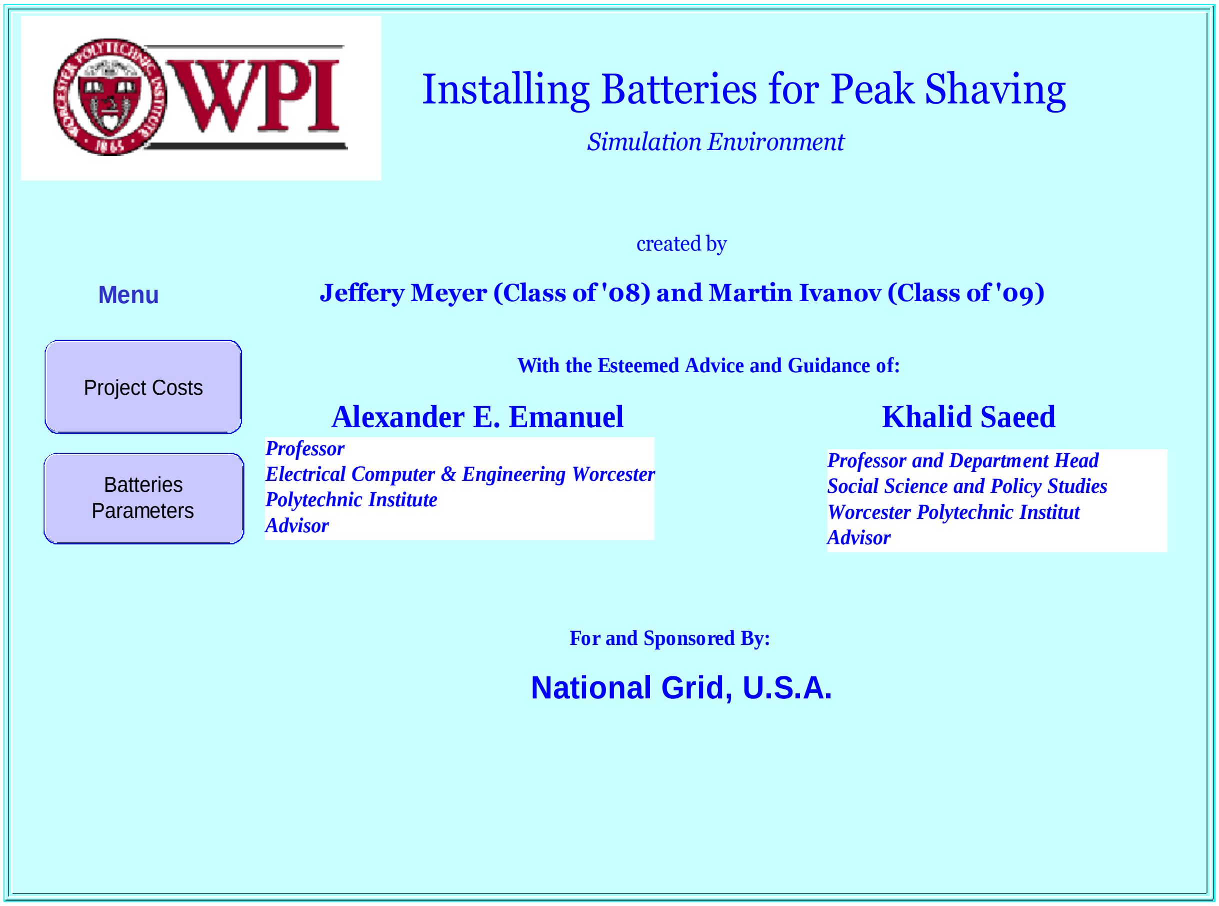
(1.00, 0.13), (2.00, 0.25), (3.00, 0.55), (4.00, 0.55), (5.00, 0.55), (6.00, 0.55), (7.00, 0.55), (8.00, 0.55), (9.00, 0.45), (10.0, 0.35), (11.0, 0.35), (12.0, 0.35), (13.0, 0.13), (14.0, 0.25), (15.0, 0.55), (16.0, 0.55), (17.0, 0.55), (18.0, 0.55), (19.0, 0.55), (20.0, 0.55), (21.0, 0.45), (22.0, 0.35), (23.0, 0.35), (24.0, 0.35), (25.0, 0.13), (26.0, 0.25), (27.0, 0.55), (28.0, 0.55), (29.0, 0.55), (30.0, 0.55), (31.0, 0.55), (32.0, 0.55), (33.0, 0.45), (34.0, 0.35), (35.0, 0.35), (36.0, 0.35), (37.0, 0.13), (38.0, 0.25), (39.0, 0.55), (40.0, 0.55), (41.0, 0.55), (42.0, 0.55), (43.0, 0.55), (44.0, 0.55), (45.0, 0.45), (46.0, 0.35), (47.0, 0.35), (48.0, 0.35), (49.0, 0.13), (50.0, 0.25), (51.0, 0.55), (52.0, 0.55), (53.0, 0.55), (54.0, 0.55), (55.0, 0.55), (56.0, 0.55), (57.0, 0.45), (58.0, 0.35), (59.0, 0.35), (60.0, 0.35), (61.0, 0.13), (62.0, 0.25), (63.0, 0.55), (64.0, 0.55), (65.0, 0.55), (66.0, 0.55), (67.0, 0.55), (68.0, 0.55), (69.0, 0.45), (70.0, 0.35), (71.0, 0.35), (72.0, 0.35), (73.0, 0.13), (74.0, 0.25), (75.0, 0.55), (76.0, 0.55), (77.0, 0.55), (78.0, 0.55), (79.0, 0.55), (80.0, 0.55), (81.0, 0.45), (82.0, 0.35), (83.0, 0.35), (84.0, 0.35), (85.0, 0.13), (86.0, 0.25), (87.0, 0.55), (88.0, 0.55), (89.0, 0.55), (90.0, 0.55), (91.0, 0.55), (92.0, 0.55), (93.0, 0.45), (94.0, 0.35), (95.0, 0.35), (96.0, 0.35), (97.0, 0.13), (98.0, 0.25), (99.0, 0.55), (100, 0.55), (101, 0.55), (102, 0.55), (103, 0.55), (104, 0.55), (105, 0.45), (106, 0.35), (107, 0.35), (108, 0.35), (109, 0.13), (110, 0.25), (111, 0.55), (112, 0.55), (113, 0.55), (114, 0.55), (115, 0.55), (116, 0.55), (117, 0.45), (118, 0.35), (119, 0.35), (120, 0.35)

On_Peak_Base_Price = GRAPH(TIME)

(1.00, 0.0118), (2.00, 0.0114), (3.00, 0.0111), (4.00, 0.0111), (5.00, 0.0111), (6.00, 0.0111), (7.00, 0.0111), (8.00, 0.0111), (9.00, 0.0114), (10.0, 0.0117), (11.0, 0.0117), (12.0, 0.0117), (13.0, 0.0118), (14.0, 0.0114), (15.0, 0.0111), (16.0, 0.0111), (17.0, 0.0111), (18.0, 0.0111), (19.0, 0.0111), (20.0, 0.0111), (21.0, 0.0114), (22.0, 0.0117), (23.0, 0.0117), (24.0, 0.0117), (25.0, 0.0118), (26.0, 0.0114), (27.0, 0.0111), (28.0, 0.0111), (29.0, 0.0111), (30.0, 0.0111), (31.0, 0.0111), (32.0, 0.0111), (33.0, 0.0114), (34.0, 0.0117), (35.0, 0.0117), (36.0, 0.0117), (37.0, 0.0118), (38.0, 0.0114), (39.0, 0.0111), (40.0, 0.0111), (41.0, 0.0111), (42.0, 0.0111), (43.0, 0.0111), (44.0, 0.0111), (45.0, 0.0114), (46.0, 0.0117), (47.0, 0.0117), (48.0, 0.0117), (49.0, 0.0118), (50.0, 0.0114), (51.0, 0.0111), (52.0, 0.0111), (53.0, 0.0111), (54.0, 0.0111), (55.0, 0.0111), (56.0, 0.0111), (57.0, 0.0114), (58.0, 0.0117), (59.0, 0.0117), (60.0, 0.0117), (61.0, 0.0118), (62.0, 0.0114), (63.0, 0.0111), (64.0, 0.0111), (65.0, 0.0111), (66.0, 0.0111), (67.0, 0.0111), (68.0, 0.0111), (69.0, 0.0114), (70.0, 0.0117), (71.0, 0.0117), (72.0, 0.0117), (73.0, 0.0118), (74.0, 0.0114), (75.0, 0.0111), (76.0, 0.0111), (77.0, 0.0111), (78.0, 0.0111), (79.0, 0.0111), (80.0, 0.0111), (81.0, 0.0114), (82.0, 0.0117), (83.0, 0.0117), (84.0, 0.0117), (85.0, 0.0118), (86.0, 0.0114), (87.0, 0.0111), (88.0, 0.0111), (89.0, 0.0111), (90.0, 0.0111), (91.0, 0.0111), (92.0, 0.0111), (93.0, 0.0114), (94.0, 0.0117), (95.0, 0.0117), (96.0, 0.0117), (97.0, 0.0118), (98.0, 0.0114), (99.0, 0.0111), (100, 0.0111), (101, 0.0111), (102, 0.0111), (103, 0.0111), (104, 0.0111), (105, 0.0114), (106, 0.0117), (107, 0.0117), (108, 0.0117), (109, 0.0118), (110, 0.0114), (111, 0.0111), (112, 0.0111), (113, 0.0111), (114, 0.0111), (115, 0.0111), (116, 0.0111), (117, 0.0114), (118, 0.0117), (119, 0.0117), (120, 0.0117)

Appendix II – Model Interface

Below is the interface of the model:



Installing Batteries for Peak Shaving

Simulation Environment

created by

Jeffery Meyer (Class of '08) and Martin Ivanov (Class of '09)

With the Esteemed Advice and Guidance of:

Alexander E. Emanuel

Professor
Electrical Computer & Engineering Worcester Polytechnic Institute
Advisor

Khalid Saeed

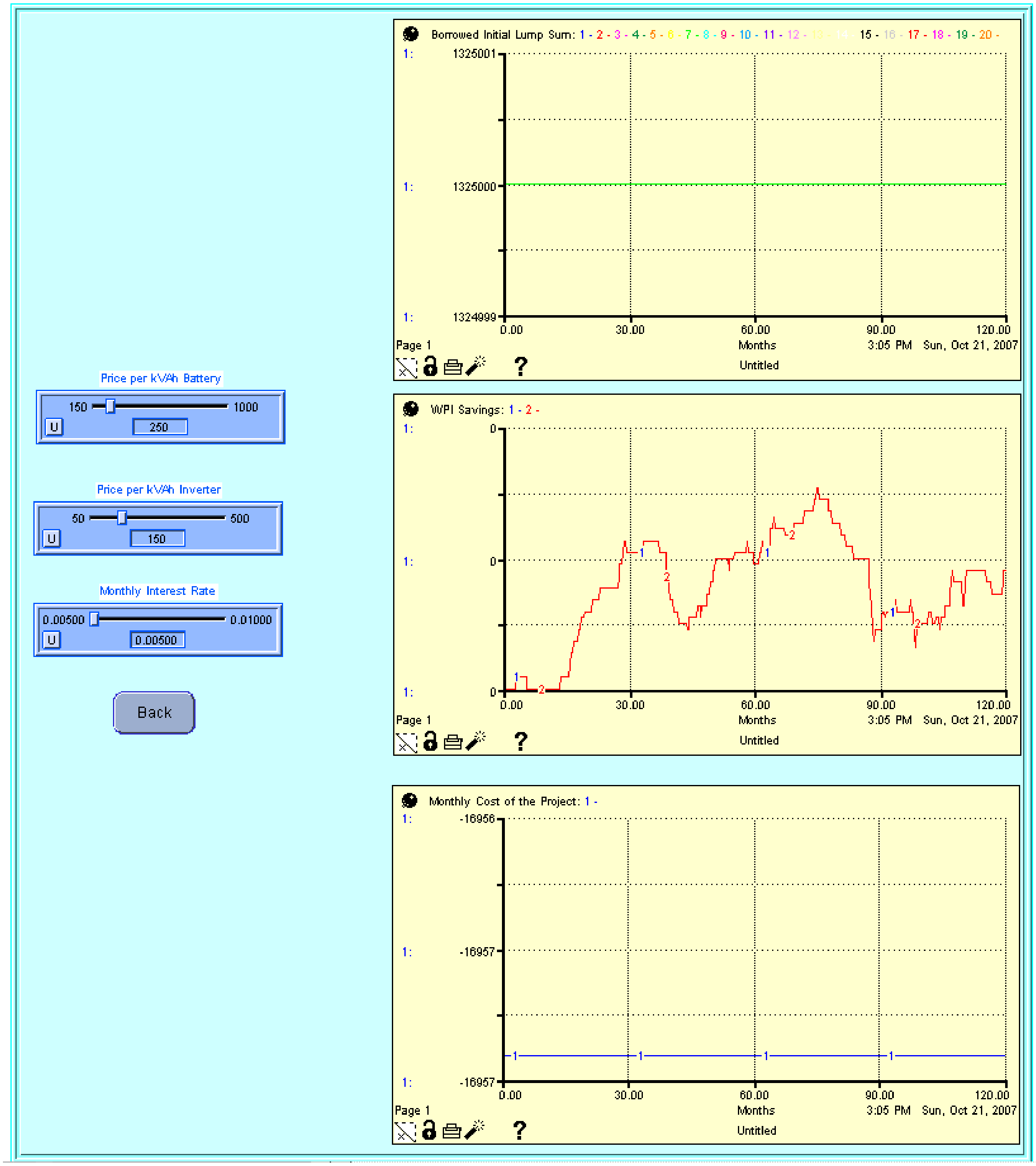
Professor and Department Head
Social Science and Policy Studies
Worcester Polytechnic Institut
Advisor

For and Sponsored By:

National Grid, U.S.A.

Figure 32: Main Window

This is the main window where the user can choose between going to the *Project Costs* Menu or to the *Batteries Parameters* Menu.



Price per kVAh Battery

150 1000

U 250

Price per kVAh Inverter

50 500

U 150

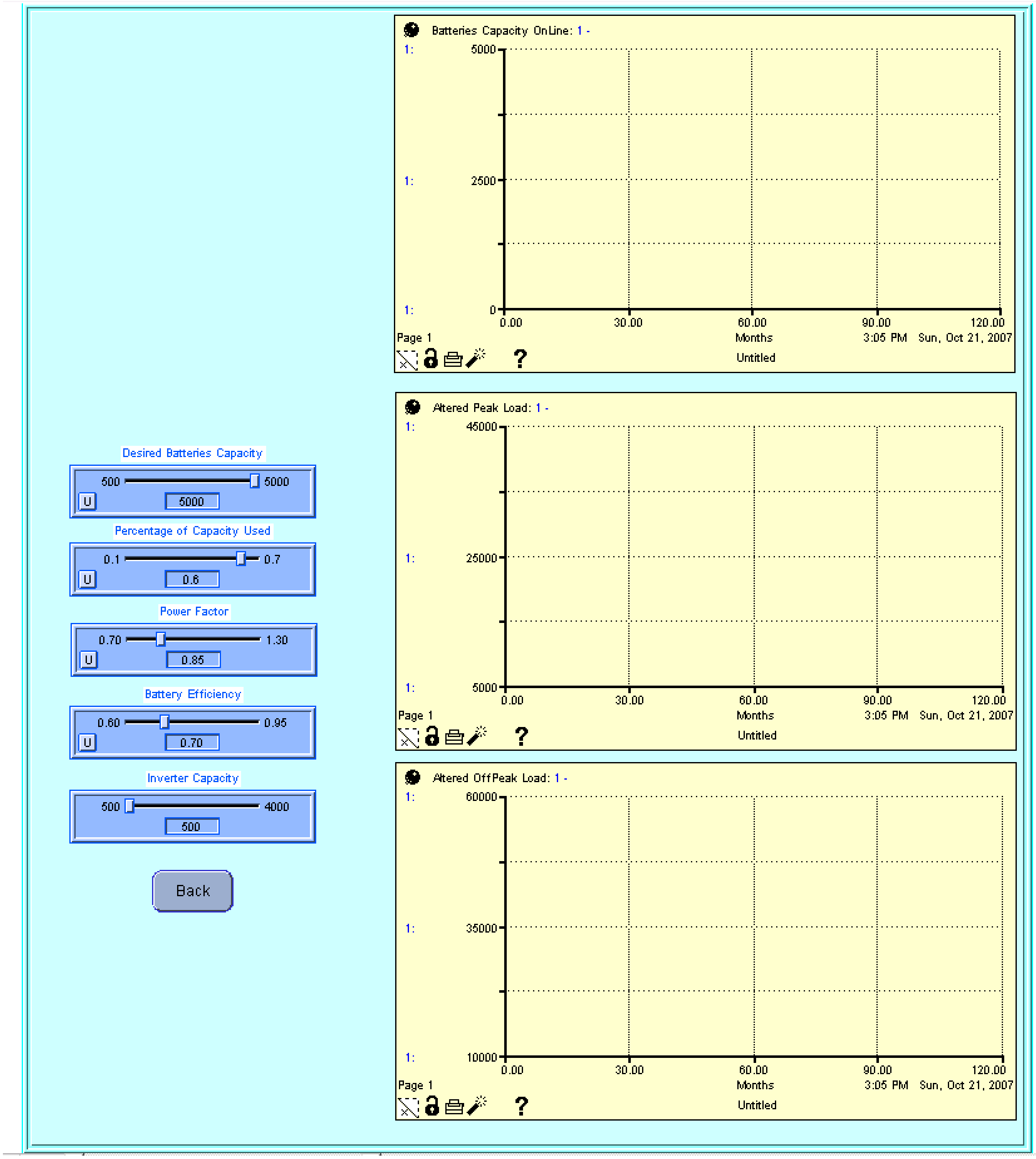
Monthly Interest Rate

0.00500 0.01000

U 0.00500

Figure 33: Project Costs Window

In the *Project Costs* window the user can adjust the *Price per kVAh Battery, the Price per kVAh Inverter* and the *Monthly Interest Rate*. On the right there are three graphs: *Borrowed Initial Lump Sum*, *WPI Savings*, and the *Monthly Cost of the Project.*


Desired Batteries Capacity: 500 – 5000, 5000

Percentage of Capacity Used: 0.1 – 0.7, 0.6

Power Factor: 0.70 – 1.30, 0.85

Battery Efficiency: 0.60 – 0.95, 0.70

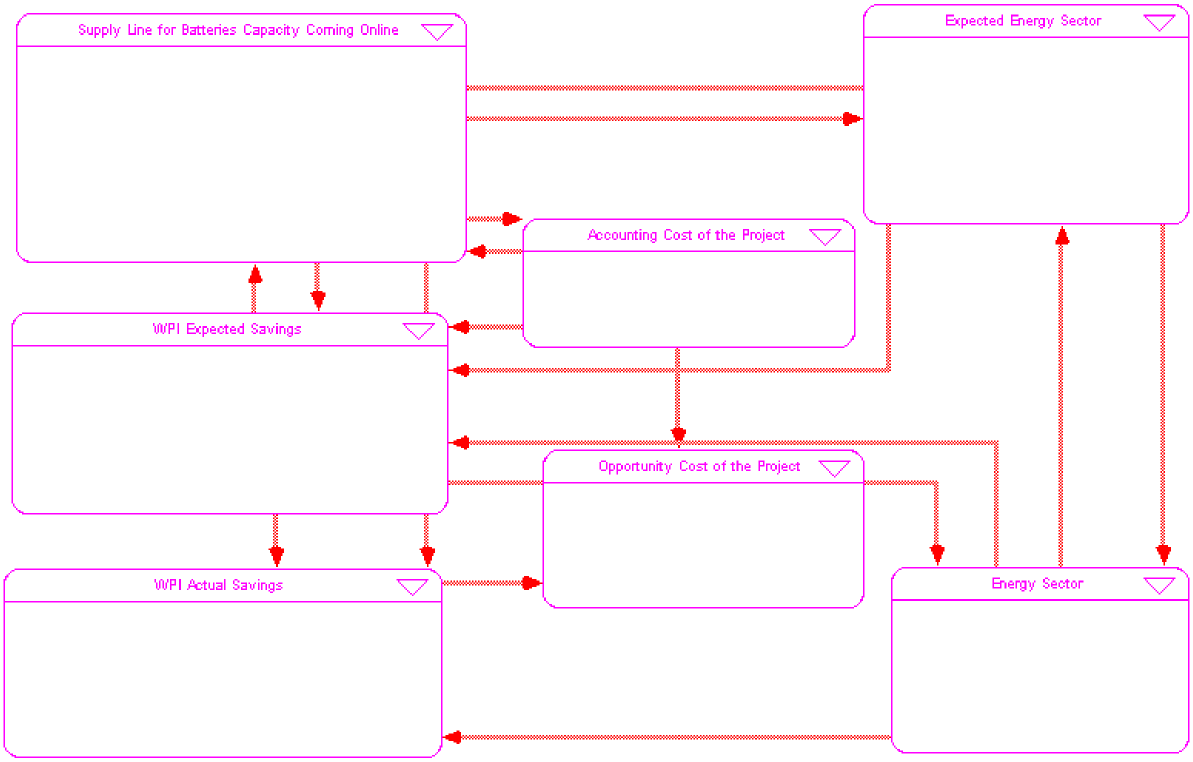
Inverter Capacity: 500 – 4000, 500

Figure 34: Batteries Parameters Window

In the *Batteries Parameters* window the user can adjust the *Desired Batteries Capacity, Percentage of Capacity Used, Power Factor, Battery Efficiency* and *Inverter Capacity*. On the right there are three graphs: *Batteries Capacity Online, Altered Peak Load* and *Altered Offpeak Load*.

Appendix III - Sector Map

Below is a map of the interactions between all the sectors of the model.



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