CALIFORNIA POLYTECHNIC STATE UNIVERSITY
ELECTRICAL ENGINEERING DEPARTMENT
Advisor: Professor Braun

Energy Harvesting From Exercise Machines

Cal Poly Recreation Center Implementation

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Justin Arakaki

Praveen Lawrence

Audrey Nakamura

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Chapter 1 Introduction

Abstract

As Cal Poly moves towards an environmentally friendly campus, the Energy Harvesting from Exercise Machines (EHFEM) project looks to generate a new source of renewable energy to help power the Cal Poly Recreation Center. The project focuses on retrofitting exercise machines to generate electricity. As of December 2009, Audrey Nakamura, Justin Arakaki, and Praveen Lawrence developed a design which allows the contribution of electricity generated from multiple exercise machines into the power grid.

The project will require an investigation of retrofitted machine designs by Cal Poly students and commercially available products and systems. The information obtained from the product research determines the most feasible approach for the Cal Poly Recreation Center. The proposed design for interconnecting multiple machines must conform to the following requirements:

1. Safety is the number one priority for the Rec Center implementation.
2. The expected life of the system should be at least 8 years with minimum maintenance.
3. The design must not hinder or change the workout experience for the end user.
4. The final design should be considered the most economic and energy efficient.
5. The design should allow several dozen of exercise machines to produce power simultaneously without negatively impacting the Rec Center electrical infrastructure.

Additionally, the proposed design must conform to the following specifications:

1. The design should comply with safety standards of the National Electric Code (NEC), Underwriters Laboratories Inc (UL), Pacific Gas & Electric (PG&E), and Cal Poly regulations.
2. The Rec Center power should be continuous and uninterrupted by operational malfunctions or maintenance of individual exercise units.
3. The operational condition of a single unit should not affect the operation of other exercise equipment.
4. The design should utilize existing Cal Poly equipment by retrofitting the equipment to generate electricity.
5. The final system implementation should be aesthetically appealing.

Expected Problems

Any project should anticipate problems. By predicting potentially negative outcomes and the corresponding mitigations, delayed completion of project tasks can be avoided. The following are some problems that may be encountered throughout the project.

Gaps in communication, miscommunication, or even no communication can lead to costly time delays that can lengthen completion time for tasks and eventually delay the project conclusion. Effective communication throughout the group is essential for operations to run smoothly without any holdups. A clearly defined project plan, clear-cut division of responsibilities, definitive task deadlines, and explicit understanding of each objective, would provide an excellent and very effective strategy for preventing any communication problems within the group. However, communication does not only pertain to group members. Another expected problem that may be encountered concerns communication with persons related to the project, not including immediate senior project group members.

Throughout this project, contacts will be made with consultants, chiefs of certain departments and committees, academic institutions, and companies in order to gain necessary information pertaining to each contact's role. However, the most obvious problem is in regards to timely replies from the contacts. It can be assumed that our future contacts have their own duties and responsibilities to attend to, such that immediate replies should not be expected of. For these cases, it is important to contact these people sooner than later to prevent any time delays that may occur while waiting for their reply. Also by contacting them as soon as possible, related subsequent task deadlines can be managed better. Along with early communication, a clear and succinct first message allows the recipient to know what is being asked of them and ensures a speedy and valuable response.

Even though previous EHFEM teams have completed retrofit projects on an elliptical and an exercise bike, research continues on them to improve certain aspects of these projects where it is deemed wanted or necessary. Since our project encompasses the use of these Cal Poly created exercise machines, our project must envision and hypothesize the operation of the final product in time for us to implement the data gathered from them. Since the completion of these projects are out of our control, utilization of theoretical and ideal results or possibly omitting their use as an option in our project proposal may be necessary for us to move forward with our project.

Another problem that may be encountered relates to project requirements. As the project progresses, requirements that were defined in the beginning can often change and evolve. While researching, new information can cause problems with the original plan, further delaying progress after making necessary corrections. Also, external factors such as unexpected layout changes may cause our original project plan to change. These problems are unavoidable and could potentially end up prolonging the completion of our project into next year. Since the plans for the Cal Poly Rec Center has already been established, the design must be integrated with the existing design without any modifications to the layout. This may pose some obstacles in implementing a multiple exercise machine system.

In order to make the EHFEM concept a reality, Cal Poly will need to generate funds to support the design and implementation of the project. Given the current state of the economy and university budget, Cal Poly will need to find external sources to aid the funding of the EHFEM Project. California has many renewable energy incentive programs geared towards implementing more sustainable sources of energy generation throughout the state. Nakamura, Arakaki, and Lawrence have researched the requirements of several programs offered by the Department of Energy (DOE), the CEC, and other public organizations and have determined EHFEM's eligibility accordingly. Unfortunately, most of the programs offered throughout California are geared towards the production of wind and solar generation farms. Cal Poly is eligible for all programs listed in the *Potential Funding* section of this report and may be able to work with various public organizations to find ways of qualifying for other incentive programs outside of wind and solar. Other alternatives include seeking donations from private philanthropists and student fee increases.

ABET Senior Project Analysis

Economic

The REC center expansion has provided the Cal Poly community with another opportunity to show its ongoing support towards more green and sustainable efforts. Cal Poly Associated Students

Incorporated (ASI) has vowed to support the effort by implementing building strategies that meet or exceed the State of California's requirements for energy efficiency. The strategies used throughout the renovation largely determine the economic and environmental feasibility of each strategy's implementation. This section focuses on the various expenses and incentives the EHFEM project requires and provides during the REC Center Expansion.

Economic Incentives

The retrofitted elliptical designed by Michelle Lum and Jonathon Yuen cost approximately $440 USD per elliptical machine. The Lum and Yuen design generates about 0.100kWh. (1) Lum and Yuen calculated the breakeven point for the retrofit investment at approximately 8 years considering 10 hours of operation for 7 days a week per machine.

Renewable Energy Revolution (ReRev) provides similar retrofitting services for elliptical machines. ReRev states that each machine is capable of generating up to 0.100kWh as well. If the ReRev retrofit is of a comparable price, it too will also take 8 years to achieve the breakeven point. However, we anticipate a higher cost per retrofit done by ReRev due to the increased cost of out-of-house labor.

Each stock elliptical contains two resistive coils used to dissipate user-generated energy as heat. Each retrofitted elliptical will lack the two stock resistive coils. When considering large-scale use of these machines, the reduction of dissipated heat significantly reduces the temperature fluctuation occurring within the Recreation Center.

The reduction of temperature fluctuations will results in a lower operation cost of the Rec Center HVAC system. One may consider the opportunity cost of investing $440 USD per elliptical machine since the payback period is relatively long (8 years). However, increasing energy costs may allow for a faster investment recovery over the next few years. See Chapter 4 for a more extensive economic analysis.

Environmental

The new craze in the twenty-first century is all about "going green", which alludes to the awareness of the environment. The public's attention focuses on current lifestyles which utilize resources inefficiently and deteriorate the environment. According to the Energy Information Administration (EIA) in 2007, the average household consumes 936 kilowatt-hours per month the United States (2). The agency also reports that close to 1.3 billion metric tons of carbon dioxide was released to fuel the residential sector, which accounts for about 22% of the total carbon emission in 2007 (2). Introducing the exercise machine as an alternate means of generating electricity can decrease household and some commercial energy consumption and simultaneously decrease carbon dioxide emissions; thereby, reducing our impact towards global warming.

A typical one-hour workout can create between 50 and 100Whr. The generated power can power a fluorescent light bulb for 2 hours and 30 minutes or power a laptop for up to 1 hour (3). Imagine connecting several machines together to produce power. The combine generation could add up to an incredible amount of energy. A system with 15 retrofitted ellipticals can generate between 2 and 7 kilowatts per day. The 7 kW of energy produced by the system can replace the power produced by oil and gas generation systems effectively reducing the carbon dioxide emitted by these facilities.

The International Health, Racquet & Sportsclub Association (IHRSA) announced the existence of 26,830 facilities in the United States as of January 2005 (4). If each of these facilities contained 15 energy harvesting exercise machines, the total energy would amount up to 187 MW per day. Although each individual machine does not appear to have a great impact on society, the accumulation of thousands of systems would significantly reduce the load demand of the world.

Sustainability

Reliance on limited resources, such as fossil fuels, pose problems that present generations need to address in order to ensure that future generations are able sustain their energy needs. The subject of sustainability is the main force driving our society toward a more environmentally conscious one, thus bringing awareness to the delicate balance between the consumption and maintenance of our world's resources. More specifically, [it] describes a condition in which natural systems and social systems survive and thrive together indefinitely (5). To help achieve this equilibrium, advances in technology can bring us closer to finding more sustainable solutions. Analysis of sustainable issues considered relates to the "Four E's of sustainability", *Energy*, *Environment*, *Economics*, and *Equity*.

The primary purpose of the project revolves around the production of energy connected to the utility. Ordinarily, exercise machines use frictional forces to disperse the kinetic energy created by the user. By retrofitting certain exercise equipment, we can use the kinetic energy from the user to generate electricity. Thereby utilizing the user's output energy to produce an electrical output that can power a multitude of electronics. Further increasing the number of retrofitted equipment will increase the potential to power additional items.

Generation of electricity is powered mostly by burning fossil fuels, a very limited resource that pollutes and harms the environment. By implementing a sustainable system of exercise machines with the ability to contribute user-generated power back into the grid, less power is needed from the utility companies. Decreasing power consumption at each facility will burn less fossil fuels and the negative impact of pollution on the environment decreases.

With the decrease of power consumption and the decrease of power generation from the utility companies, costs for supplying power ultimately decreases as well and so do expenses paid by the University to the Utilities for the supplied power. Potentially, if surplus energy were created, it could be put back into the power grid, effectively making the electric meter "run backward". When this happens, some utilities often credit customers thus effectively reducing the electricity bills.

If a system like this is implemented, much of the benefits will be shared among the population of Cal Poly and the City of San Luis Obispo. The City of San Luis Obispo will share the benefit of having a cleaner more "green" environment when this system is utilized.

Manufacturability

The harvesting of energy from exercise equipment requires that both the REC center and its exercise machinery be retrofitted. The retrofitted machines may use DC-DC converters to convert the human kinetic energy to a constant DC current. The DC-DC converters will be mounted inside the exercise machines in a fashion that does not hinder functionality or safety of the user.

In order to utilize the energy generated by the exercise equipment, each machine will also utilize an inverter to convert the DC current to AC current. If micro-inverters are implemented in the final design, mounting of the inverter must be in a location that minimizes tampering by the user. As an alternative, several machines may simultaneously supply DC current to a single central inverter.

All safety requirements of PG&E, NEC, UL, and PIER must be complied with during the manufacturing process. Since the equipment will be generating large amounts of current, it is important to minimize the exposure of components to the end users. One may consider running wiring underneath the floors to minimize exposure.

OEM Precor Elliptical's are capable of powering itself. The elliptical's ability to power itself further simplifies the retro-fit process, especially on a large scale level. The Precor Elliptical has a lot of free space within its chassis, thereby making it unnecessary to modify the housing of the machine. Micro-inverters and DC-DC converters can be mounted inside the existing chassis of the elliptical or physically mounted externally in an enclosure. Central inverter implementations will only require three wires to run from the existing electronics of the elliptical and can either run underground via conduit or above ground in approved enclosures to the central inverter.

If Cal Poly elects to develop its own DC-DC converter design, the DC-DC converter's can be produced at either a mass production or batch production facility. All other retrofits can be performed in house with appropriate training and guidelines for the facilities technicians.

ReRev was able to retrofit a twenty elliptical system at CSUSB within a single business day. If Cal Poly elects to move forward with a central inverter design, they should be able to install the system within one to two business days as well. The Cal Poly design may take longer to install since it aims to provide greater efficiency, reliability, safety, and flexibility during times of maintenance.

Ethical

The manufacturing process of the exercise machines still requires the use of resources which create pollution and waste that are detrimental to the environment. Therefore, it is necessary to determine whether the negative aspects outweigh the potential benefits of having a system of power-generating exercise machines.

There is a debate to whether or not it is ethical to allow facilities to generate power from user work. The issue of semi-powering the Recreation Center using humans may spark conflicts with some human rights activists. On the other hand, it is not required for people to use these machines. Because users volunteer to use these specific machines, this may not be too big of an issue.

Another ethical implication that should be discussed pertains to reimbursements of users work done on the exercise machines. Not every student or faculty may use these machines, thus some users may feel that they should receive a more direct return for their contributions.

This project also provides us with positive ethical incentives. With the generation of power being less than power consumption, this project cannot be seen only for its economic value. Rather, people should take this as an ethical stepping stone. By generating "green" energy, Cal Poly will be reducing its carbon footprint. This may provide the users with a feeling of doing the right thing. Use may also increase users "green" approach in other areas as well. From this ethical implication, we hope to achieve our main goal, creating awareness in clean energy.

Health & Safety

The Center for Disease Control and Prevention has monitored obesity as it has steadily increased over the past 20 years. The National Health and Nutrition Examination Survey reveals that 32.7 percent of US adults 20 years and older are overweight while 34.3 percent are obese (6). The introduction of energy harvesting exercise machines may motivate people to exercise and maintain a healthy lifestyle. The Surgeon General suggests that adults take part in at least 2 hours and 30 minutes of aerobic activity each week (6). This recommended amount of exercise could amount up to 250Wh of energy a week. The retrofitted exercise machines will undoubtedly provide a positive health benefit for many individuals. For some, being able to relate calories burned to electricity produced will provide continual motivation and incentives to work out.

A main concern for the new machines is their safety. The retrofitted exercise machines should be functionally equivalent to its OEM counterpart. The public should be able to easily operate the energy harvesting machines without injuring themselves or damaging the machines. The exercise machines should also be properly installed into the building's infrastructure to avoid electrical interruptions. This includes concealing all electrical equipment from public access to avoid misuse and injury. The machines and associated equipment should be manufactured and fitted to anticipate conditions of use in the Rec Center.

Social and Political

With energy prices and concerns of global warming on the rise, nations worldwide are searching for more sustainable means of producing energy to meet the growing demands of energy consumers while preserving the exhaustible resources of the planet.

The United States Senate passed the Green Jobs Act of 2007 in an effort to promote the development of renewable energy generation and sustainable practices. "The Green Jobs Act (GJA) of 2007 authorized $125 million per year to create an Energy Efficiency and Renewable Energy Worker Training Program as an amendment to the Workforce Investment Act(WIA) (7)." The GJA is a trial program that aims to promote careers and programs that enable a growth in sustainability. Examples areas of industry the GJA hopes to promote include "energy efficiency building by retro-fit or initial construction, renewable electric power, energy efficient vehicles, bio-fuels, and manufacturing that produces sustainable products and uses sustainable processes and materials (7)."

Currently government incentives promote the growth of renewable practices; however, it is the responsibility of companies, organizations, and individuals worldwide to take the first step towards enforcing sustainable practices. The EHFEM project is an example of Cal Poly's ongoing effort to set an example for the community. Many of the students who attend Cal Poly will move to various areas of the country upon graduation. Cal Poly students and faculty have learned the importance of sustainable practices since the beginning of their academic careers. Cal Poly alumni and faculty will take these values with them wherever they go and hopefully influence other towards making more sustainable choices and practices.

The EHFEM project promotes health and sustainable efforts while allowing each Cal Poly student or faculty member to participate in the sustainable revolution. This initial contribution towards sustainable efforts will hopefully motivate students to practice further sustainable efforts throughout their academic and professional careers as well as their lifestyles. The EHFEM project does not generate nearly as much energy as other renewable generation sources (i.e. solar, wind, and fuel cells). However, the EHFEM project establishes a connection between the athlete and energy production. The EHFEM project aims to increase energy usage awareness by creating a relationship between the user and energy production. If the user understands the amount of work it takes to generate enough electricity to power a light bulb for an hour or run the hot water for an additional five minutes in the morning, they will most likely reconsider leaving the lights on when they leave the house or taking an extra long shower in the morning.

Even though the energy generated from the EHFEM project may not drastically reduce our dependencies on brown energy, the message portrayed has the potential to save drastic amounts of energy in the future. It is important that governments and public institutions do all they can to further increase energy awareness amongst the general population. Increased awareness combined with cleaner energy generation practices will lead to significantly reduced carbon emissions in the future.

Chapter 2 Project Planning

Project Planning

Project planning is very vital to completing a senior project in a timely manner. To start the project planning, a list of all tasks must be brainstormed and put in chronological order. For our project, we categorized our tasks into phases. Our phases included: Project Planning Report, Research, Design, Documentation, Contacting Consultants, and Presentations.

Each task, once defined, is designated to a group member. Some tasks involve all three group members to collaborate to complete the task. For these tasks, it is expected for every team member to put time into researching and documenting the given task.

For each task, a specific time should be given to each task. The time should be determined based on the difficulty of the task. Once the entire project is laid out, a complete timeline is produced and an expected end time is predicted. For our project, the timeline spans from January 4, 2010 to May 7, 2010, which is 147 days. Figure 1 Gantt Chart from Initial Project Timeline shows the initial project timeline determined by our team prior to starting the project.

During the project, the Gantt Chart is updated based on actual performance during the project. See Figure 2: Final Project Timeline for the final project timeline.

Gantt Charts

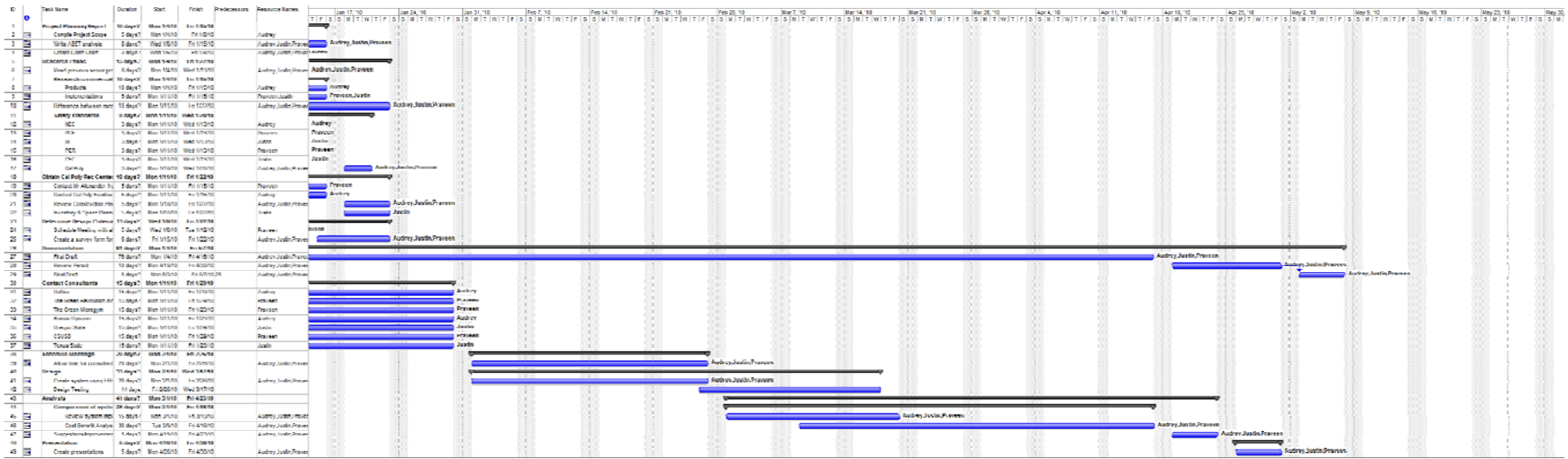

Figure 1 Gantt Chart from Initial Project Timeline

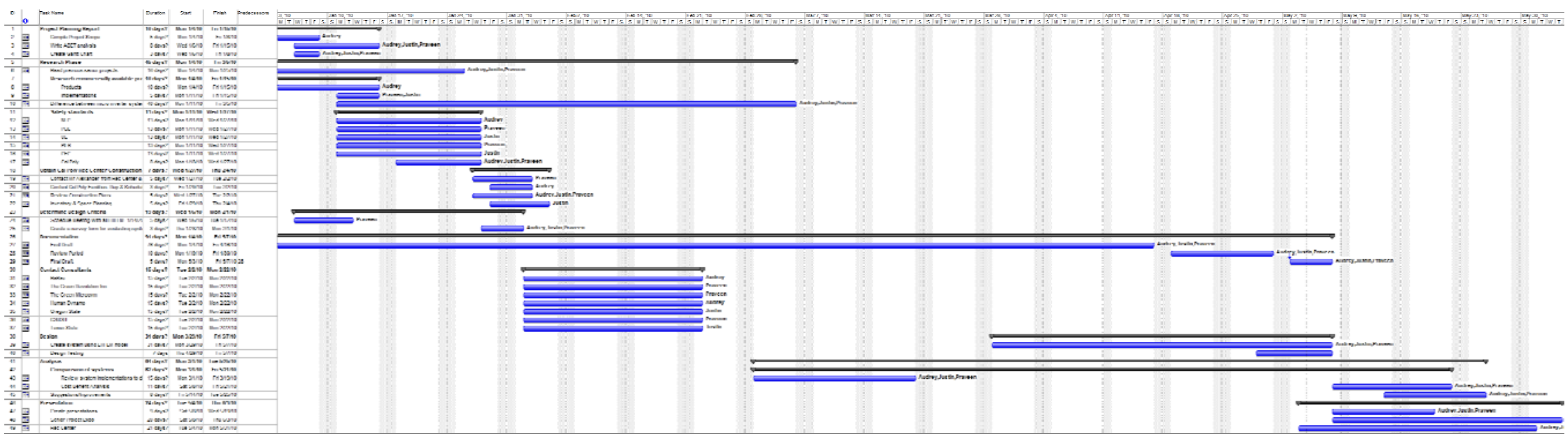

Figure 2: Final Project Timeline

Figure 2: Final Project Timeline shows the final project timeline that has been continually updated throughout the projects progression. As expected, some problems were encountered during the project. Communication delays between companies, organizations, as well as certain persons were encountered which caused certain tasks to be extended or moved to different dates. Another reason for changes with the Gantt chart were other obligations that came up, which caused tasks to be extended or moved as well.

Chapter 3 Research

Safety Standards

National Electric Code (NEC)

This section of the report will give an overview of the National Electric Code (NEC) pertaining to the energy harvesting exercise machines. This section lists excerpts from the code taken into account during the design process.

Note: All references to photovoltaic installations shall be applied to energy harvesting exercise machines.

Equipment

The exercise equipment in the Recreation Center is exposed to liquids, varying temperatures and sweat, which could negatively impact the machines. To avoid maintenance issues associated with exposure to deteriorating agents, all equipment shall be listed to protect against the foreseen deteriorating conditions in the Rec Center environment.

110.11 Deteriorating Agents – Unless identified for use in the operating environment, no conductors or equipment shall be located in damp or wet locations; where exposed to gases, fumes, vapors, liquids, or other agents that have a deteriorating effect on the conductors or equipment; or where exposed to excessive temperatures.

System Protection

To design the protection system for the energy harvesting machines, the NEC will be used as guidelines to determine location and sizing of protection equipment. The proposed design will make sure that the system is sufficiently protected from both the energy harvesting machines and utility. The protection architecture will include circuit breakers or fuses and a main utility lockable disconnect. Along with circuit protection equipment, anti-islanding inverters will be used, which shut off if utility reference is lost. The location of the protection equipment should be away from public access to avoid misuse.

690.5 Ground-Fault Protection – Grounded dc photovoltaic arrays shall be provided with dc ground-fault protection

(A) Ground-Fault Detection and Interruption – The ground-fault protection device or system shall be capable of detecting a ground-fault current, interrupting the flow of fault current, and providing an indication of the fault.

(B) Isolating Faulted Circuits – Faulted circuit shall be isolated by:

The ungrounded conductors of the faulted circuit shall be automatically disconnected

The inverter fed by the faulted circuit shall automatically cease to supply power to output circuits.

240.4 Protection of Conductors (B) Devices Rated 800 Amperes or Less – The next higher standard overcurrent device rating (above ampacity of the conductors being protected) shall be permitted to be used.

240.4(D) Small Conductors – The overcurrent protection shall not exceed that required by (D)(1) through (D)(7) after any correction factors for ambient temperature and number of conductors have been applied.

240.6 Standard Ampere Ratings (A) Fuses and Fixed-Trip Circuit Breakers

690.9(D) Direct-Current Rating – Overcurrent devices, either fuses or circuit breakers, used in any dc portion of photovoltaic power system shall be listed for use in dc circuits and shall have the appropriate voltage, current, and interrupt ratings.

240.21 Location in Circuit – Overcurrent protection shall be provided in each ungrounded circuit conductor and shall be located at the point where the conductors receive their supply.

240.24 Location in or on Premises – Overcurrent device shall be readily accessible and shall be installed so that the center of the grip of the operating handle of the switch or circuit breaker, when in its highest position, is not more than 2.0m(6 ft 7 in) above the floor or working platform.
Cannot be installed in bathrooms or above stairways.

240.30 (A) Protection from Physical Damage – Overcurrent devices shall be protected from physical damage by one of the following:
(1) Installation in enclosures, cabinets, cutout boxes, or equipment assemblies
(2) Mounting on open-type switchboards, panelboards, or control boards that are in rooms or enclosures free from dampness and easily ignitable material and are accessible only to qualified personnel

690.13 Disconnection Means All conductors – Means shall be provided to disconnect all current-carrying conductors of a photovoltaic power source from all other conductors in a building or other structure.

690.14(C)(4) Maximum Number of Disconnects – The photovoltaic system disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard.

690.15 Disconnection of Photovoltaic Equipment – Means shall be provided to disconnect equipment, such as inverters, batteries, charge controllers, and the like from all ungrounded conductors of all sources. A single disconnecting means in accordance with 690.17 shall be permitted for the combined ac output of one or more inverters or ac modules in an interactive system.

690.61 Loss of Interactive System Power - An inverter or an ac module in an interactive solar photovoltaic system shall automatically de-energize its output to the connected electrical production and distribution network upon loss of voltage in that system and shall remain in that state until the electrical production and distribution network voltage has been restored.

Wiring
The articles listed in this section gives reference material for determining the conductor sizes.
240.23 Change in Size of Grounded Conductor – Where a change occurs in the size of the ungrounded conductor, a similar change shall be permitted to be made in the size of the grounded conductor.

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Table 310.16 Allowable Ampacities Insulated Conductors Rated 0 Through 2000 Volts

Installation
This section gives guidelines on how the system should be installed. The main concern that will be taken into account is isolating the exercise energy harvesting system from other power circuits within the Rec Center. Isolation of energy generated by exercise machines ensures the continuity of power during outages of the exercise equipment.

690.4 (B) Conductors of Different Systems – Photovoltaic source circuits and photovoltaic output circuits shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as feeders or branch circuits of other systems, unless the conductors of the different systems are separated by a partition or are connection together.

690.4(C) Module Connection Arrangement – The connections to a module or panel shall be arranged so that removal of a module or panel from a photovoltaic source circuit does not interrupt a grounded conductor to another photovoltaic source circuit.

Grounding
Electrical circuits should maintain a common ground so that they are all referenced to the same potential. The following articles of the code outline grounding techniques for properly sizing grounding conductors and making proper connections for a continuous ground reference.
240.22 Grounded Conductors – No overcurrent device shall be connected in series with any conductor that is intentionally grounded.

250.4 General Requirements for Grounding & Bonding

250.66 Size of Alternating-Current Grounding Electrode Conductor – use table 250.66

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

250.166 Size of Direct-Current Grounding Electrode Conductor (B) Not Smaller Than the Largest Conductor – the grounding electrode conductor shall not be smaller than the largest conductor supplied by the system, and not smaller than 8 AWG copper or 6 AWG aluminum.

690.43 Equipment Grounding – An equipment grounding conductor between a PV array and other equipment shall be required in accordance with 250.110

690.47 (C) Systems with AC and DC Grounding Requirements-
(1)The DC grounding system shall be bonded to the ac grounding system
(2) A bonding conductor between these systems shall be sized as the larger of the dc requirement, the ac requirements, and the system bonding requirements.
(3) A conductor that serves as both an equipment grounding conductor and as part of the bond between ac and dc systems for an inverter incorporating dc ground-fault protection shall meet the requirements for equipment bonding jumpers in accordance with 250.28.
(4) A bonding conductor equipment grounding conductor that serves multiple inverters shall be sized based on the sum of applicable maximum currents used.
(5) A common ground bus shall be permitted to be used for both systems.
(6) A common grounding electrode shall be permitted to be used for both systems, in which case the grounding electrode conductor shall be connected to the ac ground system bonding point.

(7) Grounding electrode conductor shall be sized to meet the requirements of both 250.66 and 250.166.
(8) For systems with utility-interactive inverters, the premises grounding system serves as the ac grounding system.

Interconnection

The Energy Harvesting from Exercise Machines will be interconnected as a load side connection. It is considered a load side connection because it will be connected after the utility main circuit breaker. Although it is not expected for the exercise machine to produce enough power to feed the utility, the equipment above the exercise machines should be sized to account for backfed current from the exercise equipment in addition to power supplied to other loads.

- **690.64 (B) Load Side**- The output of a utility-interactive inverter shall be permitted to be connected to the load side of the service disconnecting means of the other source(s) at any distribution equipment on the premises. Where distribution equipment, including switchboards and panelboards, is fed simultaneously by a primary source(s) of electricity and one or more utility-interactive inverters, and where this distribution equipment is capable of supplying multiple branch circuits or feeders, or both, the interconnection provisions for the utility-interactive inverter(s) shall comply:
    - (1) Dedicated Overcurrent and Disconnect – Each source interconnection shall be made at a dedicated circuit breaker or fusible disconnecting means.
    - (2) Bus or Conductor Rating – The sum of the ampere ratings of overcurrent devices in circuits supply power to a busbar or conductor shall not exceed 120% of the rating of the busbar or conductor. In systems with panelboards connected in series, the ratings of the first overcurrent device directly connected to the output of a utility-interactive inverter(s) shall be used in the calculates for all busbar and conductors.
    - (3) Ground-Fault Protection – The interconnection point shall be on the line side of all ground-fault protection equipment.
    - (5) Suitable for Backfed- Circuit breakers, if backfed, shall be suitable for such operation.
    - (7) Inverter Output Connection – Unless the panelboard is rated not less than the sum of the ampere ratings of all overcurrent devices supplying it, a connection in a panelboard shall be positioned at the opposite(load) end from the input feeder location or main circuit location. The bus or conductor rating shall be sized for the loads connected in accordance with Article 220.

Pacific Gas & Electric (PG&E)

Any facility that generates power must adhere to the set standards and regulations of the local electric utility. The distribution infrastructure within San Luis Obispo is owned and operated by The Pacific Gas and Electric Company (PG&E). PG&E requires that customers who generate 30 kilowatts or less sign a Standard Net Energy Metering (NEMS) agreement with PG&E prior to operating any generation facility. Facilities that generate greater than 30 kilowatts of energy but less than 1 Megawatt must apply for an Expanded Net Energy Metering Agreement (Expanded NEM) (8). It is expected that the Cal Poly REC Center will generate up to 8 kilowatts on average per day if all bicycles and elliptical are retrofitted. Therefore, Cal Poly will need to file for a Standard NEM. If Cal Poly decides to run other generation sources in parallel with the EHFEM generation in the future (i.e. wind or solar generation) they may need to apply for an Expanded NEM. Applying for an Expanded NEM is necessary if the upgraded system exceeds 30 kilowatts in size.

By mandate of PG&E Electric Rule 21, Cal Poly may not operate any generation facilities until they have received written authorization from PG&E to do so. Both application processes for Standard NEM and Expanded NEM are included below. As Expanded NEM may be needed in the future should Cal Poly decide to increase the size of the EHFEM system or incorporate other sources of generation.

Standard NEM Application Process (9)

In order to be considered for a Standard NEM, Cal Poly must submit the following documents to PG&E:

1. **Agreement Form 79-1101** – Provides important customer, contractor, and system information about the project.
2. **Single Line Diagram for Technical Review** – Please see Figure __ for an example of the single line diagram.

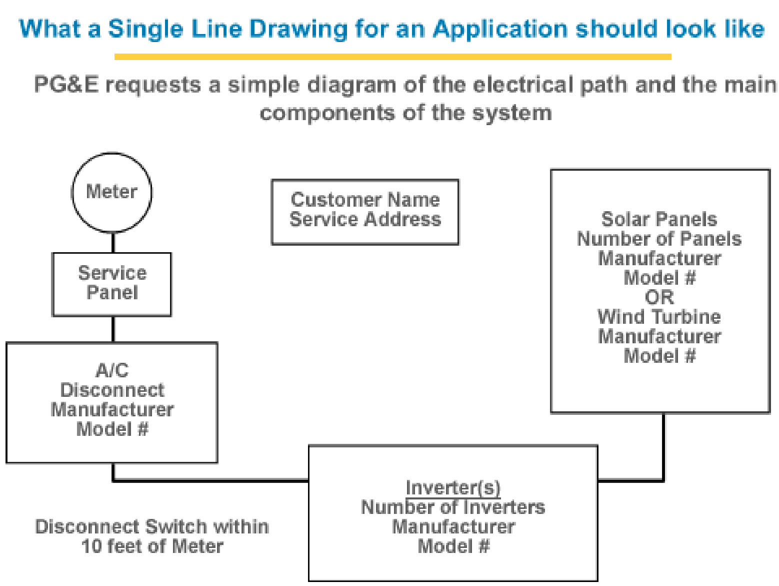

Figure 3: Example of Single Line Submission to PG&E

3. **Singed off building permit** – Provides PG&E with proof of project approval by local building authority. PG&E only requires the final signed off permit showing that the construction is

complete, approved by local authorities, and ready for installation of the NEM 'bi-directional' meter.

4. **Copy of recent electric bill for project site** – Used as a method of customer account verification.
5. **Payment of Meter Fee (if applicable)** – Certain models of meters will need to be reprogrammed in order to comply with the NEM. A list of approved meters and their associated fees are enclosed in PG&E's NEM Meter Fee Matrix (Appendix I).

Standard NEM Application Time Line (9)
PG&E is required to perform the interconnection within 30 days of receiving a complete agreement package. To ensure minimal delays, please submit all documents/information listed in *Standard NEM Application Process* Section.

Expanded NEM Application Process (10)
In order to be considered for an Expanded NEM, Cal Poly must submit the following documents to PG&E:

1. **Application form 79-974 (Form I)** - Provides important customer, contractor, and system information about the project.
2. **Supplemental Application Form 79-978 (Form II)** – Provides alternating current disconnect information and notifies PG&E of potential access issues.
3. **Interconnection Agreement Form 79-978 (Form III)** – Legal contract between PG&E and the customer outlining each party's responsibilities.
4. **Single Line Diagram for Technical Review** - Please see Figure 3: Example of Single Line Submission to PG&Efor an example of the single line diagram.
5. **Declaration Page of Facility Insurance (Form IV)** – Provides PG&E with information about the level of insurance coverage for the Recreational Facility (if any)
6. **Signed Off Building Permit (Form V)**. Indicates that the project has been finished and approved by local building authority.
7. **Copy of Recent Electric Bill for Project Site (Form VI)** .Verifies a customer's account info for their project site.
8. **Authorization form to Receive Customer Information or Act on a Customer's Behalf (Form VII)** - Required if a third party is to handle the application process. This gives the third party (usually the contractor) temporary authorization to act on the customers behalf and receive confidential customer information. Required for third party to receive a copy of customer's Permission to Operate.

Expanded NEM Application Timeline (10)

Project Phase	Required documentation	Time Frame
Engineering Review	Completed Application Form 79-974, Completed Supplemental Form 79-998, Single Line Drawing	Typically up to 10 business days from receipt of documents
Pre-inspection (may be required if rate schedule is **not** A1 or A6)	Engineering approval	Typically up to 10 business days from engineering approval
Final Inspection	Engineering approval, Net Energy Metering Agreement Form 79-978, Signed off Building Permit (finished project approved by local inspectors), Copy of Declarations Page of Home Owner Insurance, Metering Fee, if applicable	PG&E is required to perform the final inspection within 30 working days of a complete application. You or your authorized representative will be contacted to set up an appointment for inspection.
Interconnection Approved, Contract & Permission to Operate Letter Sent to Customer by PG&E	Confirmation by PG&E inspectors that project passed inspection	Typically within 3 business days of notification that your project passed inspection

Table 1: Extended NEM Application Timeline

Table 1 portrays the processing time between each phase of the Expanded NEM application process. PG&E suggest that the application for an Extended NEM be submitted early, preferably even before the construction of the generation facility (in this case, the implementation of the exercise machines).

Generation Requirements (8)
The following generation requirements are applicable to both Standard NEMs and Expanded NEMs.

The following requirements are listed in the Supplemental Form 79-998.

1. Customer- Generator's Generating Facility must meet all applicable safety and performance standards established by the National Electrical Code, the Institute of Electrical of Electronics Engineers, and accredited testing laboratories such as safety and reliability including Rule 21.
2. Customer-Generator shall:
    a. Maintain the Generating Faculty and interconnection Facilities in a safe and prudent manner and in conformance with all applicable laws and regulation including, but not limited to those listed above in requirement 1.
    b. Obtain any governmental authorizations and permits required for the construction and operation of the Generating Facility and Interconnection Facilities. Customer-Generator shall reimburse PG&E for any and all losses, damages, claims, penalties, or liability it incurs as a result of Customer-Generator failure to obtain or maintain any governmental authorizations and permits required for construction and operation of Customer-Generator's Generating Facility.
3. Customer-Generator shall not commence parallel operation of the Generating Facility until PG&E has provided express written approval. Such approval shall normally be provided no later than thirty business days following PG&E's receipt of the following:
    a. A completed *Generating Facility Interconnection Application* (From 79-974), including all supporting documents and payments as described in the Application.

b. A completed *Expanded Net Energy Metering (NEM) Supplemental Application (Form 79-998)*
c. A signed and completed *Interconnection Agreement (Form 79-978)*
d. A copy of the Customer-Generator's final inspection clearance from the governmental authority having jurisdiction over the Generating Facility. Such approval shall not be unreasonably withheld. **PG&E shall have the right to have representatives present at the Commissioning Test as defined in Rule 21**. Customer-Generator shall notify PG&E at least five business days prior to the initial testing.

Electric Rule No. 21
Both Standard NEM and Expanded NEM customers must adhere to the requirements set forth by PG&E's *Electric Rule No. 21*.

PG&E's *Electric Rule No. 21* describes the various interconnections, operating, and metering requirements for Generating Facilities to be connected to PG&E's Distribution System. For a complete list of General Rules, Rights, and Obligations, please refer to *Section B of Electric Rule No. 21*. A copy of *Electric Rule No. 21* can be obtained from the PG&E corporate website. The key requirements related to this project are listed below.

Section B – Rule 1: Authorization Required to Operate. A Producer must comply with this Rule, execute an Interconnection Agreement with PG&E, and receive PG&E's express written permission before Parallel Operation of its Generating Facility with PG&E's Distribution System. PG&E shall apply this Rule in a non-discriminatory manner and shall not unreasonably withhold its permission for Parallel Operation of Producer's Generating Facility with PG&E's Distribution System. (11)

Section B- Rule 5: Design Review and Inspections. PG&E shall have the right to review the design of a Producer's Generating and Interconnection Facilities and inspect a Producer's Generating and/or Interconnection Facilities prior to the commencement of Parallel Operation with PG&E's Distribution System. PG&E may require a Producer to make modification as necessary to comply with the requirements of this Rule. PG&E's review and authorization for Parallel Operation shall not be construed as confirming or endorsing the Producer's design as or warranting the Generating and/or Interconnection Facilities' safety, durability or reliability. PG&E shall not, by reason of such review or lack of review, be responsible for the strength, adequacy or capacity of such equipment. (11)

Section B – Rule 6: Right to Access. A Producer's Generating Facility and Interconnection Facilities shall be reasonably accessible to PG&E personnel as necessary for PG&E to perform its duties and exercise its rights under its tariffs approved by the Commission, and any Interconnection Agreement between PG&E and the Producer. (11)

AC Disconnect Switch Requirement (12)
Effective November 21, 2006, PG&E customers installing inverter-based systems will no longer be required to include an AC disconnect switch when the facility has a self-contained electric revenue meter (ie. 0-320 amp socket-based meter or 400 amp K-based meters).
Since our design will be utilizing inverter/micro-inverter technology, it is important to consider the implementation of the AC Disconnect Switch. It is recommended that that AC disconnect switches be implemented in addition to the meters above as an additional safety precaution. The use of an AC Disconnect Switch also provides the additional benefit of allowing PG&E to isolate the customers

generator from the utility's distribution system without having to interrupt service to the customers facility or residence. Since reliability is priority in this project, the implementation of the disconnect switch is essential.

PG&E Contact Information (8)
Have further questions regarding the interconnection process or guidelines? Feel free to contact PG&E NEMS hotline via the contact information provided below.

E-mail: gen@pge.com
Phone: 415-972-5676

Underwriters Laboratory (UL)

Underwriters Laboratories (UL) is an independent product safety certification organization that test products and sets standards and for public safety. They report the overall quality to ensure safety of products for both commercial and industrial use. Since the EHFEM project involves modifying a UL listed exercise machine, it must be determined if the end-product with the modifications still complies with UL requirements. UL listed products are in accordance with applicable requirements before shipping from the manufacturer. Thus, if a UL listed product is modified, "UL is unable to determine if the product continues to comply with the safety requirements used to certify the product without investigating the modified product". Therefore, the Authority Having Jurisdiction (AHJ) must determine if any modifications are still acceptable under UL requirements. If the modifications are significant enough, the AHJ must also determine if a UL Field Engineer Service Member is needed to evaluate the modified product. In short, use of UL Recognized Components does not necessarily mean the end-product is UL Listed. However, UL certified retrofits can be used to possibly circumvent the reevaluation process.

If implemented with a micro-inverter, the EHFEM modified exercise machine must comply with UL 1741 standard. Listing UL 1741 involves the implementation of "inverters, converters, controllers, and interconnection system equipment for use with distributed energy resources" with "utility interactive (grid-connected) power systems". The following are criteria listed in UL 1741:

- **1.1** – Utility-interactive inverters, converters, and ISE are intended to be operated in parallel with an electric power system (EPS) to supply power to common loads.
- **1.2** – Test procedures for equipment interconnecting distributed resources with electric power systems must conform to the standards of IEEE.
- **1.5** – Installation must be in accordance with the National Electric Code, NFPA 70.

Potential Funding

Additional funding is needed to support the additional research, development, and implementation cost of the EHFEM project. There are many state and federal programs which aim to support the development and growth of renewable energy generation. However many of these renewable initiative programs are geared towards the specific growth of solar and wind generation. This section investigates several different renewable generation initiative programs in an effort to find additional funding sources for the EHFEM project.

California Energy Commission

The California Energy Commission (CEC) funds alternative energy programs through various programs administered by the CEC Research, Development, and Demonstration Division. Particular programs of interest are as follows:

Public Interest Energy Research – PIER

The Public Interest Energy Research (PIER) program is administered by the Research, Development, and Demonstration Division (RD&D) of the California Energy Commission (CEC). The PIER program supports the development of energy technologies through distribution of research grants and development contracts. The PIER Program awards up to $62 million dollars towards public energy research annually. (13)

Applying for PIER Funding

The RD&D division distributes funding in the form of grants or contracts. In order to qualify for such grants or contracts, the project being investigated bust adhere to the following criteria:

1. The project shall be environmentally safe.
2. The energy solution or service must be affordable and reliable.

To apply for PIER funding, Cal Poly needs to submit a Request for Proposal (RFP) to the CEC and receive it's approval. Once funding is approved, the RD&D Committee will review funding on an annual basis and continue to fund the project if deemed feasible after the budget review. (13)

Please contact the CEC Energy Generation Research Office for further information and guidance regarding the funding for renewable energy generation and technology research. Please contact Gerald Braun at the CEC for further information regarding the grant and contract approval process. (14)

Gerald Braun
Energy Generation Research Office, Renewable Energy Technologies
E-mail: gbraun@energy.state.ca.us
Phone: 916-653-8906

Energy Innovations Small Grant – EISG

The Energy Innovations Small Grant program is a sub-division of the PIER program. EISG provides up to $95,000 for hardware projects and $50,000 for modeling projects to small business, non-profits, individuals, (and of particular interest to Cal Poly) academic institutions (15).

Applying for the EISG Grant

The EISG Grant Application Cutoff date has already passed for the 2010 year. The application process started on December 11, 2009 and commenced on February 9, 2010. The application process for the 2011 funding cycle will most likely start towards the end of 2010 as well (early December 2010) and commence early 2011. Please visit the EISG website listed below and select the Electric Program solicitation for future application dates.

Energy Innovations Small Grant Program: http://www.energy.ca.gov/contracts/smallgrant/index.html

The submitted documents and proposal will be evaluated once they have been submitted by the cutoff date. The CEC states that it typically takes five to six months after the cutoff date to evaluate and approve the proposals. As soon as the grant agreement is fulfilled by a Program Administer, one may start working towards the development of the project. The projects are typically required to be completed within a 12-month time frame after receiving grant approval.

EISG Requirements

The proposal submitted to the EISG program must meet all of the following criteria to be eligible for funding:

a. The proposed work must advance science or technology not adequately addressed by competitive and regulated markets.
b. Propose an original innovative solution to a significant energy problem.
c. Propose work that is still in the proof-of-concept phase.
d. Address a California market need.
e. Provide a clear potential benefit to California Electricity ratepayers.
f. Target one of the PIER R&D areas listed below:
    1. Industrial/Agriculture/Water End-use Efficiency
    2. Building End-use Efficiency
    3. Environmentally Preferred Advanced Generation
    4. Renewable Generation
    5. Energy-Related Environmental Research
    6. Energy Systems Integration

The following information provides Cal Poly's support for Requirements A through E listed above. The EHFEM project does not yield high levels of generation. However, when implemented on a large scale, the project yields enough energy to power small parts of exercise facilities while reducing the amount of wasted heat dissipated by ceramic coils. The EHFEM projects makes California ratepayers more conscious of the cost and work related to their energy consumption. When using an EHFEM exercise machine, the user is able to see how much energy their hard work generates during their exercise session. This may make the user more conscious of the efforts needed to generate energy that heats the water for their extra long showers or run the air conditioner on an extra warm day. If rate payers become more conscious and develop a personal connection with their energy consumption, rate payers may consider more energy efficient alternatives thereby reducing the demand for non-renewable energy procurement.

In addition to satisfying requirements A through F, the Cal Poly EHFEM project satisfies requirement F by targeting the Renewable Generation PIER R&D area.

In summary, the EHFEM project satisfies requirements A through F in the following ways:

a. The EHFEM project investigates the unique idea of harvesting energy from everyday human activity while increasing energy awareness amongst the average consumer.
b. While it is important to generate clean energy, it is equally if not more important to address the growing need to conserve energy as well. While other sources of renewable generation satisfy the clean generation criterion, none of them manage to establish a direct connection between energy generation and the end user. The EHFEM proposes a clean way of generating energy while addressing the expanding need to conserve energy.
c. Various aspects of the EHFEM are still in the process of research and development while others are working towards prototype implementations. Cal Poly aims to have a working model of the concept by the grand re-opening of the REC center in the year 2011.
d. California develops the largest amount of clean technology in the nation. As leaders and innovators in the clean technology revolution, it is vital that we continue to emphasize not only the importance of sustainable resources, but the importance of sustainable practices as well. Consumer interactions with everyday EHFEM technology is an example of both sustainable generation and practice and will aims to lay the groundwork for greater sustainable practices in the lives of the average consumer.
e. When rate payers become more conscious of their energy consumption, they may consider more energy efficiency alternatives and promote the development of other clean technology implementations thereby reducing the demand for non-renewable energy procurement.
f. The EHFEM project targets two of the PEIR R&D areas.
    i. Building End-Use Efficiency: Reduces buildings dependency on grid generated energy while also decreases the amount of heat dissipated into the recreational facility. The reduction of disspated heat will also reduce the demand of the buildings HVAC system.
    ii. Renewable Generation – the EHFEM system generates 100% clean energy.

For further information regarding the Grant Application process, please refer to the Grant Application Manual Enclosed in Appendix ___. An up to date version of the Grant Application Manual can be obtained from the EISG website as well.

The Green Initiative Fund (TGIF)

The Green Initiative Fund is a proposed grant making fund that if enacted, can help fund possible student-led sustainable project here at Cal Poly. A proposed increase of $5 in tuition fees can approximately allow $300,000 for funding of these projects per year. Some of these projects include, “renewable energy, energy efficiency building retrofits, water conservation measures, sustainable transportation, expanding recycling/composting and fund sustainability internships” (16).

However, because this grant is still in its proposal phase, there is no actual funds available as of yet. If on the other hand enough support is garnered for this proposed fund, the EHFEM project can be further financed through this.

Sponsorships

The unique concept behind the EHFEM projects makes it ineligible for many of the national and state incentive programs available today. Most of the state and national incentive programs are geared towards more commercial types of alternative energy generation such as solar and wind generation. For a list of approved funding programs, please refer to the *Potential Funding* section of this document.

It may be necessary to seek funds from private contributors in an effort to meet the financial demands of the EHFEM project. One may consider contacting Cal Poly alumni in hopes of obtaining financial support or seeking donations from companies in exchange for acknowledgement for their contribution.

Current Commercial Products

ReRev

ReRev, short for Renewable Green Revolution is a Clearwater, Florida based company started by 23-year-old Hudson Harr. It is a subcompany of Harr's main venture SunQuest in solar thermal (3). The company aims to retrofit ellipticals to generate electricity to be connected to the grid. The company has chosen to use Precor ellipticals which have an integrated generator to power the user interface. The excess power generated is loss through two parallel 20 ohm resistors. ReRev has developed the idea of using the dissipated energy and harvest it to be fed into the grid. Instead of connecting wires to the resistors, the wires are connected to other units and then into an inverter.

As of April 2010, ReRev has installed a total of 250 machines on 17 campuses throughout the United States. The first and largest installation in California is at California State University, San Bernardino with 20 machines installed in August 2009 (3).

A phone conversation with ReRev indicates that their modifications do not void any Precor warranty or UL listing. The retrofit does not alter the exterior dimensions of the exercise machine as well (17). The system utilizes a 6kW central wind inverter design with 600Vdc input and 240Vac, split phase - single phase (17). The inverter has a display that shows the power output of the system for the day and total in kWh. The system also includes a single AC disconnect for the whole system.

The company offers a full turnkey system which includes design, installation, materials, and maintenance training. They also offer a 5 year warranty on all equipment related to the retrofit and installation (17). The expected life span of the system is not changed and should last the same as the OEM model. A typical installation of 10-15 machines cost approximately $12k - $16k (3).

ReRev U.S. Patent Application

Application Number: 20090315336 (18)
On December 24, 2009, ReRev filed for a patent with the US Patent & Trademark Office. The patent aims to protect the intellectual property obtained during the development of ReRev's Renewable Energy Generation System. This section aims to address any similarities between ReRev's design and the EHFEM design. A complete version of the ReRev U.S. Patent Application can be seen in Appendix G or obtained from the US Patent & Trademark Office Database using the application number listed above.

Claims
Excerpt from Claim 1: "A diode in each feed line to allow current flow from the generators to allow current flow from the generators to the primary feed line and to preclude any back flow; a regulator coupled to each feed line adapted to regulate the voltage of each machine and to maintain such voltage at a constant level."

- The diode serves as a protection mechanism for the exercise machine. The hardware within the elliptical is expensive and susceptible to damage from reverse current flow from the grid. The diode on each feed line ensure that current only supplied to the grid from the generator while preventing the grid from supplying current to the generator.
- The term "regulator" refers to a DC-DC converter used to maintain a constant voltage at each node.

Excerpt from Claim 2: "Main circuit breaker panel also adapted to terminate current flow through such facility to terminate power to the transformer and machines as well as other electrical powered devices in the event of a short circuit or overload."
Excerpt from Claim 3: "The output end of the secondary cable coupled to the input end of the inverter, an AC disconnect along the secondary electrical cable between the inverter and the main breaker panel, the AC disconnect under the control and discretion of a user and adapted to terminate the flow of current from the main breaker panel to the inverter and combiner/controller and generators.

- The Cal Poly design also utilizes an AC disconnect to increase safety and reliability of the system during utility maintenance. The Cal Poly design uses a utility lockable AC disconnect which provides both the user and the utility with access to the AC disconnect while providing them with visual confirmation as well.

Excerpt 1 from Claim 5: "Each feed line adapted to regulate upwardly and downwardly the voltage of each machine and to maintain such voltage at a constant level, 50 volts in the preferred embodiment, regardless of the input work from the user at a machine."

- The EHFEM design utilizes DC-DC converters to maximize power point tracking and output power efficiency of the inverter.

Excerpt 2 from Claim 5: " A combiner/controller along the primary electrical cable between the inverter and the feed lines, the combiner/controller adapted to combine the current from the generators being fed to the inverter."
Excerpt 3 from Claim 5: "the transformer output in the preferred embodiment being 50 volts at 0.3 amps to insure that the inverter stays online and synchronized to the grid with minimum loss."

- Each node maintains a constant voltage to ensure maximum power point tracking in both the ReRev and EHFEM design.

Summary of the Invention

Excerpt from [0012]: "A diode is provided in each feed line. The diode further precludes any back flow of current from the primary feed line to the generators."

Excerpt from [0013]: "The regulator is adapted to regulate upwardly and downwardly the voltage of each machine…The regulator is also adapted to allow the current contribution of each machine to vary as a function of the input work from the user at a machine."

Excerpt from [0015]: "The combiner/controller is provided along the primary electrical cable between the inverter and the feed lines."

Excerpt from [0046]: "Considering that the machine's load is dependent upon the inverter's dynamic loading, there must always be a 'grid' connection for the users to experience resistance."

- The inverter serves as the load for each of the elliptical within the EHFEM and ReRev systems. The load enables the system to draw current and therefore generate power. The size of the load does not significantly change the "resistance" the user feels from the torque of the generators. However, the dynamic loading of the inverter may account for the slight change in user experience as described in CSUSB review of the ReRev system.

Excerpt from [0048]: "The system negates the need for batteries, in the preferred embodiment, and utilizes the building's load as resistance to the users. It uses this dynamic load to optimize each machine creating an identical user experience to the machine's previous state."

[0050]: "The user experience does not vary from day to day and is independ of the number of machines in use.

Excerpt from [0051]: "Each unit operates on the same parallel circuit but is not affected by neighboring machines."

- The design protected by the U.S. Patent Application refers to a parallel central inverter system.

Summary

Many of the topics listed within the ReRev Patent Application correlate with the findings obtained throughout the EHFEM Project's independent research. The design portrayed in the ReRev patent differs from those implemented at other recreational facilities (such as the system implemented at CSU San Bernadino). The EHFEM team proposes more efficient alternatives to the ReRev design while using similar tools such as the AC disconnect diode protection, and DC-DC converters. Please refer to ReRev's patent application for further information or investigation. It is advised that further teams investigate patent laws to prevent patent infringement in the future.

The Green Revolution

The Green Revolution is a company that retrofits cardio exercise equipment, including ellipticals, cross-trainers, stepping machines, stationary and recumbent bikes, to generate electricity. Jay Whelan, founder and CEO of The Green Revolution, started the company after working out at a gym and realizing the potential of harnessing the wasted energy being dissipated into heat. Tested on all leading brands of Group Cycling bikes, The Green Revolution Technology has been designed to fit existing fitness equipment without modification. The energy created from the output of the bikes are connected to the power grid through a grid-tied inverter.

Human Dynamo

The Human Dynamo is a "compact and efficient full body cardio machine" that is used to produce clean and efficient energy (19). Henry Works, the company that is developing this product, is currently working on two ways to deliver energy from their exercise machine. An "off grid" system would charge batteries to power an inverter to make 120 volts AC.   A "grid tie" system would be wired directly to the electrical panel. The Human Dynamo uses a 200 Watt generator for a 12V battery system, but it does not include an AC inverter to provide feedback to the grid.

Cal Poly Senior Project Products

Over the past few years, Cal Poly students have been working on modifying exercise machines that can generate electricity to be sent back into the grid. Students have been working on prototypes for a recumbent bicycle and an elliptical that produces DC power. All projects related to the EHFEM is listed below:

1. Vann Chau, Jennifer Roecks, Sean Spurr, & David Webb, *Exercise bike power generator*, Senior Projects 07-0508 and 07-0930, Thesis (B.S.)—California Polytechnic State University, 2007.

2. Zachary R. Goldstein, Sean A. Gouw, & Alexander J. Clarabut, *Exercise to grid II : rowing*, Senior Project 08-0556, Thesis (B.S.)—California Polytechnic State University, 2008.

3. Rogan Guild, Kevin Kinoshita, Sameer Pangrekar, & Stephen Queen, *Harvesting energy from an elliptical machine*, Senior Project 08-0610, Thesis (B.S.)—California Polytechnic State University, 2008.

4. Jared Rounsevell, Claire Shubert, Matt Snitowsky, & Andy Wong, *Harvesting human exercise power at the Cal Poly Rec Center: exercise bike power generator II*, Senior Project 09-0855, Thesis (B.S.)—California Polytechnic State University, 2009. Available: http://digitalcommons.calpoly.edu/mesp/13/.

5. Jonathan Chan, Chris Cinkornpumin, Michelle Lum, & Jonathan Yuen, *Energy harvesting from exercise machine (EHFEM) self-generating elliptical machines*, Senior Projects 09-0654 and 09-0840, Thesis (B.S.)—California Polytechnic State University, 2009. Available: http://digitalcommons.calpoly.edu/eesp/12/.

6. Henry Ureh & Chris Henry, *DC-DC converter for harvesting energy from an exercise bike*, Senior Project 09-0848, Thesis (B.S.)—California Polytechnic State University, 2009. Available: http://digitalcommons.calpoly.edu/eesp/20/.

7. Brendan Cullen Asche, *Near real-time exercise machine power statistics reporting*, Thesis (M.S.)—California Polytechnic State University, 2010. Available: http://digitalcommons.calpoly.edu/theses/241/.

Bicycle Generator

Mechanical engineering students started the bicycle project in 2007. Several students have been working on revising the bicycle since its origination to meet specifications set forth at the beginning of the project. The students retrofitted a Star Trac recumbent bike to deliver power to the Morningstar ProStar 12V 30 amp charge controller which would then go to a battery. The mechanical engineering group was able to successfully create a working prototype of the recumbent bike. To better improve the efficiency of the implementation, a group of electrical engineering students took on completing a dc-dc converter for the exercise machine. The final design and implementation of the dc-dc converter is still in progress as of May 2010. Although the bike generator is almost complete, it will not be considered for this project because it has not been implemented with an inverter for the power to be connected to the grid.

Elliptical Generator

The elliptical was modified by a group of electrical engineering students as their senior project. Precor ellipticals have an internal generator, which is able to produce DC electricity from the movement of the pedals. The power generated is used to power the display. The excess power is dissipated through resistor coils as heat. Instead of sending the power to the resistor coils, the students have taken the DC power and input it to a micro-inverter to be sent back into the grid. The system includes a dc-dc converter before the inverter to ensure the input voltage is within the inverter operating range. The group was not able to find an effective dc-dc converter to be used with the system. The elliptical is able to work with an old Wilmore dc-dc converter but the converter does not fit the size constraints of the system. Another group of Cal Poly students has started looking into a better approach for this implementation starting Spring 2010.

Current Commercial Implementations

Oregon State

Overview

Oregon State University is one of the first universities to implement energy harnessing elliptical machines that directs generated power back into the grid. The technology used for the system comes from the company ReRev. The system contains 22 elliptical exercise machines, two inverters, AC and DC wiring, and a display computer. At most, each elliptical can produce up to 400 watts; however a more realistic output is around 25-100 watts sustained.

Installation

Every elliptical exercise machine has the DC generation capacity out of the box. Using ReRev's inverter technology, OSU retrofitted the elliptical exercise machines' DC wiring output to ReRev's inverters, which was in turn connected to the buildings electrical panel. Under floor conduits were used to provide a cleaner and more aesthetic installation.

Funding/Cost

Their project was funded from three main sources: a grant from the Energy Trust of Oregon, from the OSU Student/Incidental Fees Committee (a student body governing student fee rates and how that money is spent), and from the Recreational Sports department. The total cost of the project was in the price range of $17k-$19k.

Email with Brandon Trelstad

The following is an excerpt from an email conversation with Brandon Trelstad, Sustainability Coordinator at Oregon State University. Questions were asked regarding their experience with ReRev.

<u>Safety</u>

1. Does the system used in the design adhere to all UL standards? Is the equipment UL listed?

My understanding is that the equipment is UL listed.

2. What safety measures are taken into account throughout the design and implementation process?

The installation consists mostly of low voltage DC wiring, which poses lower personal safety risks than higher voltage AC. Wires are protected throughout (AC and DC) and connections covered. At no point should a human be able to contact the wires, let alone any uninsulated conductors. Where the inverter is hooked to the AC system, the wiring and protection is typical of a solar inverter you'd find in a residential installation.

<u>Technology/Design</u>

1. What type of equipment was purchased from ReRev?
Inverter, wiring, connections.

2. Is a battery utilized in the design?
No.

3. How is an individual unit connected back into the AC grid?
Units are grouped together in no more than 20 elliptical units. They are then wired to an inverter which converts DC off the ellipticals to AC that can be fed into the building electrical system.

4. How much additional size does the retrofit add to the exercise machine footprint? None.

5. Does the user experience any change to the workout experience after the retrofit?
Not really. Some people have said the resistance is different for a given level (number) than it used to be, but that is not a widely held opinion. Either way, resistance can still be adjusted to get the workout one desires.

6. What is the average output of a single machine? The entire system?
Hard to know at this point, I've not studied all the output data. We're seeing about 10-20 watts/machine during the typical workout and we have a total of 22 machines hooked to two inverters.

<u>Maintenance/Support</u>

1. What are the warranty terms for the entire system?
ReRev offered a 5 year warranty on everything. I can send you the warranty documents if you'd like.

2. What are the warranty terms for the individual units within the system?
The warranties on the Precor ellipticals is unchanged after the inverter-bound wiring is hooked to them.

3. What type of service plans and technical assistance does ReRev offer?
Not sure on a written service plan, but they have offered some troubleshooting during this first year. Since we were one of their first large installations, and the largest in the world for about a year, they wanted to make it a success for us and them so they were pretty responsive to our inquiries.

4. Does the company provide maintenance training?
Yes.

5. What is the life expectancy of each unit?
If you mean the elliptical, you'd have to check with Precor. The ReRev inverter should last at least 10 years, perhaps up to 20 years.

Cost

1. Cost breakdown?

These are estimates. Please let me know if you need more solid numbers. ReRev equipment package, including initial installation: $14,000. Electrical permits: ~$200. AC wiring panel connections and setup: ~$2000.

Contact Information (20)

Brandon Trelstad
E-mail: brandon.trelstad@oregonstate.edu

Texas State University

Overview

Texas State Student Recreation Center's Calories to Kilowatts program features 30 elliptical machines that convert human exercise into energy, which gets routed directly back into the university's power grid. This is currently the "Largest Human Power Plant in the World" and the first of its kind in the state of Texas. A typical 30-minute workout provides about 50 watt-hours of energy.

Installation

Similar to OSU's installation setup, the company ReRev came out and retrofitted each of the 30 elliptical exercise machines, connected them to the inverters, and then back into the power grid.

Funding/Cost

The cost of the project was $19,750 and funded by Texas State's Environmental Service Committee and the Department of Campus Recreation.
(21)

California State University San Bernardino

Overview

California State University San Bernardino (CSUSB) is the home of the first recreation facility within California to harvest energy from exercise machines. The CSUSB recreation facility currently houses twenty Precor Elliptical Fitness Machines retrofitted with ReRev technology. Nakamura, Arakaki, and Lawrence visited the CSUSB Recreation Facility on April 9, 2010 in an effort to develop a better understanding of the ReRev energy harvesting system. Lawrence also conducted a phone interview with Rick Craig, Director of Recreational sport at CSUSB, on April 5, 2010. Details regarding the information obtained from the phone interview with Rick Craig and the trip to San Bernardino will be discussed in the following sections.

Phone Interview with Rick Craig

A transcript of the telephone conversation between Lawrence and Craig will not be provided within this section. Instead, summaries of the topics discussed are provided. Rick Craig is the current Director of the CSUB Recreational Facility and the CSUSB Department of Recreational Sports. Craig also worked for Cal Poly Recreational Sports prior to the construction of the original REC Center.

Question 1: How long did it take ReRev to retro-fit all twenty of the Precor Elliptical Machines?

ReRev was able to retro-fit each of the machines within a single business day. During the initial construction of the facility, Craig had additional conduit put in place for Ethernet cables. Craig envisioned future exercise machines with internet connectivity and had the extra conduit put in place to accommodate future advancement in exercise machine technology. However, many of the exercise machines with internet connectivity nowadays are also cable of connecting to the internet via a wireless protocol. With this in mind, Craig decided to use the vacant conduit space to run the necessary wiring for the ReRev system. The existing conduit space made the installation process quick and easy.

Question 2: Do students have a preference between retrofitted and OEM machines?
All of the Precor Elliptical exercise machines within the CSUSB exercise facility have been retrofitted with ReRev technology. Elliptical machines have always been popular amongst the athletes at CSUSB. Therefore, no significant change in usage occurred after the implementation of the ReRev technology. However, many of the students did inquire about the amount of power generated during their individual work out. Unfortunately, the CSUSB system is only capable of displaying generation information for the system as a whole. The system is currently incapable of determining generation statistics for the individual user. Craig suggested that Cal Poly incorporate a feature that calculates the generation for each node in the EHFEM design.

Question 3: Is there any difference in performance between OEM and retrofitted Precor Elliptical Machines?
The elliptical machines retrofitted with ReRev technology perform differently than its OEM counterpart. An athlete on a retrofitted machine will experience less resistance than its OEM counterpart when operating the retrofitted machine within the 1 through 8 resistance level range. Resistance levels 9 through 11 tend to be more vigorous than that of their OEM counterparts. Resistance levels 12 and above on the retrofitted machine seems to be equivalent to an OEM elliptical machine. The performance evaluation is not based off user experience rather than an analytical comparison of the OEM and retrofitted machines.

Question 4: How was the project funded? Did CSUSB receive any donations or funding from renewable energy incentive programs?
CSUSB did not seek for donations or apply for funding from any renewable energy incentive programs. The ReRev retro-fit was paid for in full by excess money allocated to Recreational Sports through student use fees.

Question 5: Do the machines actually generation 100W per hour? What is the payback period for the ReRev system?
Most users do not generate the maximum power output of 100 watts per hour. According to Craig, the average user generates much less than that. Since CSUSB's system is incapable of calculating the generation at each node, Craig was unable to provide the actual average generation per machine. However, generation statistics show that the system as a whole will take about 12 to 14 years to break even.

Question 6: Did ReRev provide you CSUSB with maintenance training?
The lead of the CSUSB maintenance team participated in the installation of the ReRev system. The ReRev team was informative and addressed any questions CSUSB had during the installation process. In addition to answering any on site questions and concerns, the ReRev team does provide formal maintenance training in addition to a maintenance service plan and warranty.

Contact Information
Rick Craig
Phone: (909) 537-7142

E-mail: craig@csusb.edu

Site Visit

During the site visit, we walked through the exercise room with the exercise machines where we were able to examine their machine layout and wire management. The system uses speaker wires with special clips to connect several machines together. There are two rows of machines with each row creating one string. One string consists of 14 machines in series while the other has 6 machines in series. The two strings are feed into a 6kW power one Aurora wind inverter in a nearby electrical closet. The output of the inverter is connected to a Square D fused AC disconnect before being connected to the recreation system panelboard. According to Rick Craig, the system generates approximately 8-10kwh per day. Since the installation of the system, users have generated 229kWh over 3334 hours. The estimated payback time of the system approximated by Craig is 14 years.

Pictures from CSUSB Visit

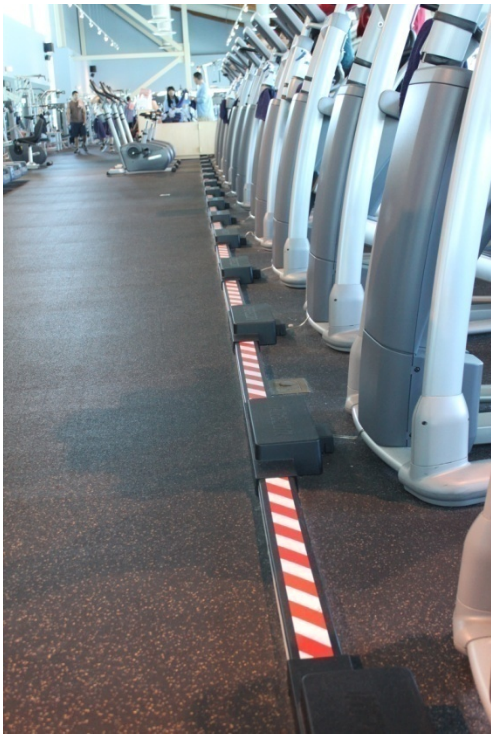

Figure 4: Formation for String of Ellipticals

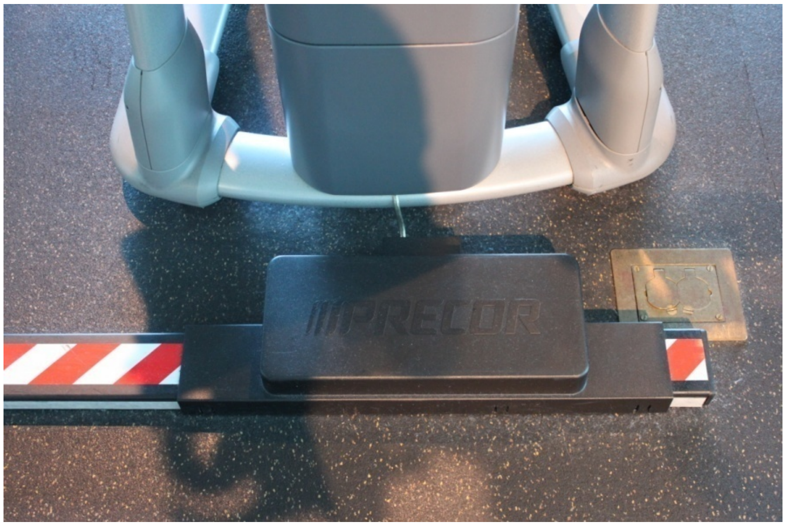

Figure 5: Connection box for single elliptical machine to line bus

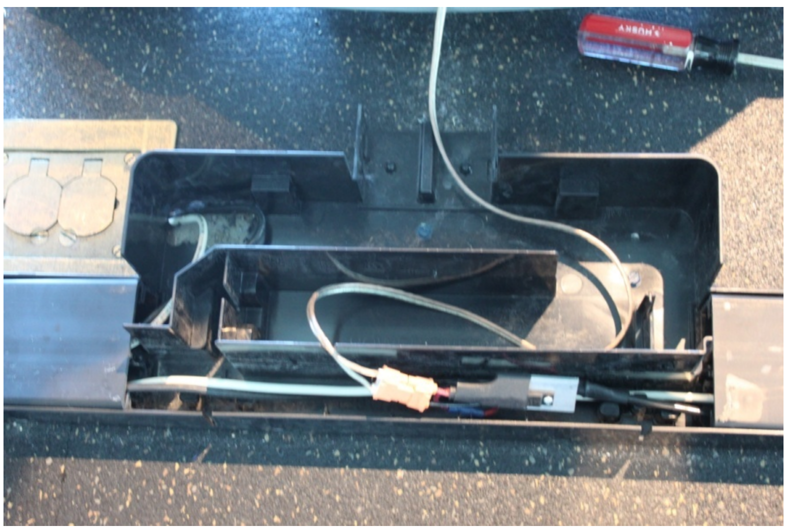

Figure 6: Inside of connector box

Figure 7: AC Disconnect in Equipment Room

Figure 8: Wind Inverter for AC grid intertie

Cal Poly Cardio Machine Usage

The Cal Poly Rec Center is opened between the hours of 6:00am and 12:00am, Monday thru Friday, 8:00am to 10:00pm on Saturdays, and 8:00am to 12:00am on Sundays. This amounts to 18 hours of operation per day during the week and 30 hours of operation on the weekend. Rec Center Facilities Manager, Eric Alexander has provided data on the cardio usage in the Rec Center for Fall 2009 and part of Winter 2010. The data shows how many people used a particular type of cardio machine per day. By analyzing the data, an average of 9 people are on the available 16 ellipticals. This results in a 57% usage of the ellipticals per hour. This number will be used in a later approximation of energy generation for the elliptical system. Note: the number of hours per day was adjusted based day of the week.

Chapter 4 Design and Implementation

While the project was originally set up to retrofit both ellipticals and bicycles, our group decided to focus on a system with only ellipticals. Since most of our research has been directed towards elliptical generators and the Cal Poly senior project elliptical has been designed to feed into the grid, our group has gained a better understanding of the operation of the elliptical and how to extract power from it; therefore, better capable to design a full system.

Characterizing the Elliptical

Elliptical Operation

The elliptical uses the rotations from the pedals to run a six-phase synchronous generator. The six phase AC generator connects directly to a PCB board within the elliptical which converts the AC power to DC power. The DC power is then used to temporarily charge a battery and power the control panel of the Elliptical. The remainder of the unused DC power is dissipated across the power resistors within the elliptical chassis.

Purpose of Resistive Load

The resistive load is essential to elliptical operation. The resistive load allows for the system to draw current effectively enabling the system to dissipate power. The ability to dissipate power allows the user to manipulate the "user resistance", effectively the torque of the motor. The relationship between power, torque, and speed is represented analytically by Equation 1 where P_{out} , τ_{ind}, ω_{speed}, represent the output power of the elliptical, the induced torque of the motor, and the rotational speed of the generator respectively.

$$P_{out} = \tau_{ind} \times \omega_{speed} \text{ (Equation 1)}$$

Without a resistive load, the system is incapable of drawing current, therefore incapable of generating power. If the elliptical is incapable of generating power, P_{out} is effectively equal to zero. If $P_{out} = 0$, then manipulation of the torque or rotational speed of the generator remains constant. Therefore, if the elliptical system has no resistive load, the user will be unable to manipulate the torque of the motor or change the level of experienced resistance during their athletic activity.

Dynamic Resistive Loading of Inverter

The EHFEM model harvest energy from the elliptical machines by replacing the resistive coils within the elliptical machines with the dynamic load of the inverter. The input impedance of the inverter is seen by all of the machines within the EHFEM system and is uniform amongst these machines. The uniform resistance allows for consistent operation and user experience throughout the system. Since the elliptical now has a load to dissipate power, the user is capable of manipulating both the torque and rotational speed of the generator in proportion to the power generated by the user.

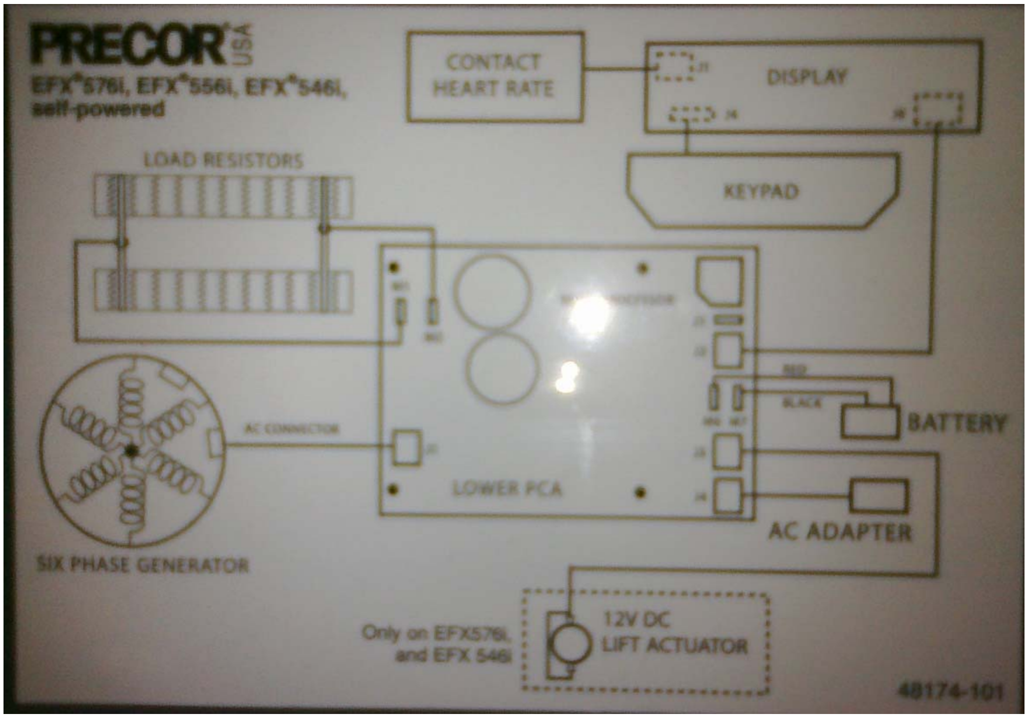

Figure 9 Precor Elliptical Schematic

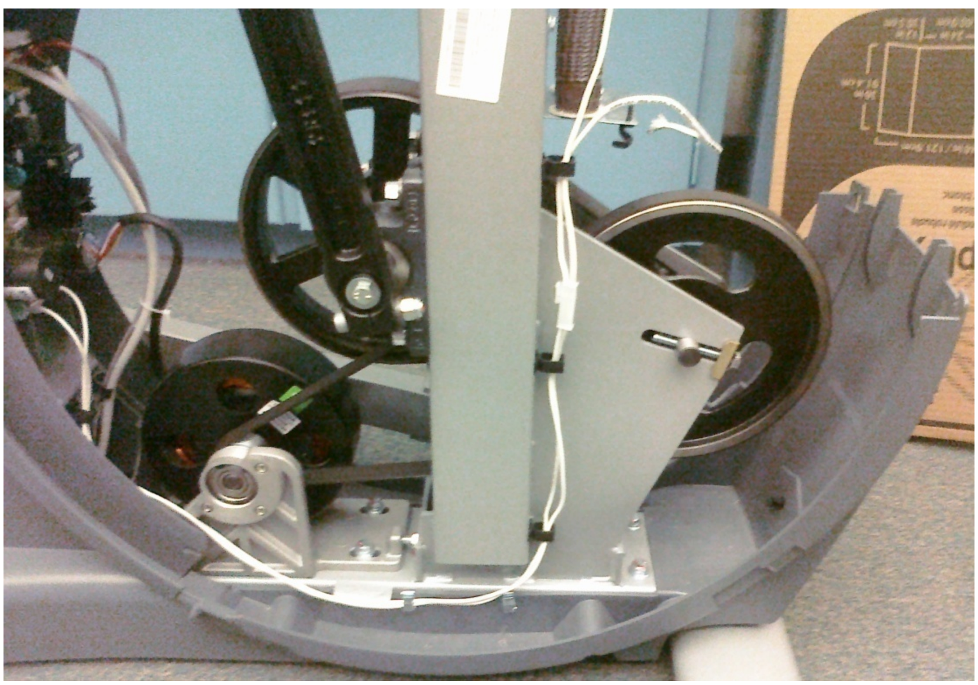
Figure 10 Precor Elliptical Pulleys and Generator

Figure 11 Precor PCB Board, one function is to convert from AC to DC

Figure 12 Elliptical Load Resistors, Two Parallel 20 Ohm Resistors

Testing

To determine an estimate of the power output by the elliptical, each group member performed a test on the elliptical. Two multimeters were used to measure the current through and voltage across the load resistors on the elliptical. Measurements were taken as the resistance was increased from 1 to 20 with constant strides per minute for the most part. The chart below shows a graph of the power output by each member. The full set of data can be found in Appendix F: Elliptical Testing.

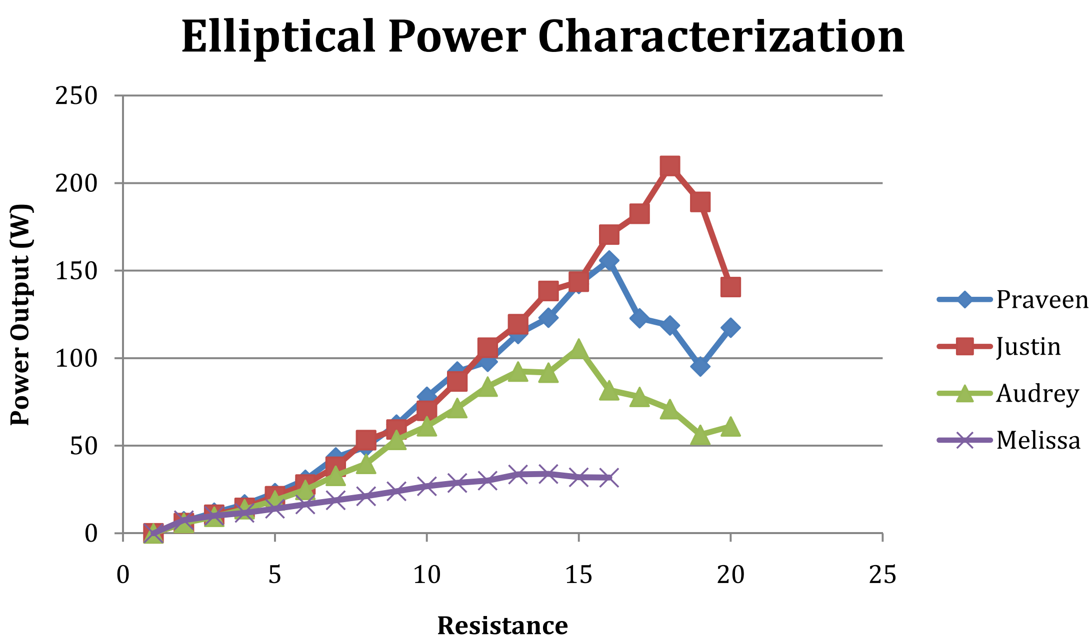

Figure 13 Elliptical Power Output Testing

The graph above shows some interesting characteristics about the power output in relation to the resistance. For all members, the power increased as the resistance increased up until about a resistance of 15. After a resistance of 15, the power output drops because as the resistance increases, the user has a more difficult time keeping a steady pace. A slower pace causes a decrease in the rotations for the generator, which will result in lower voltage and current readings at the load resistor.

The power measurements taken from this test does not correctly reflect the actual power to be distributed to the grid. This is because equipment such as dc-dc converter and inverters were not connected to the machine. Each of these components has an efficiency of less than one that would reduce the effective power from the elliptical to the grid.

Two members also tried to simulate the settings of a normal workout to determine the kilowatt-hours produced by a single person during a workout. Each member set the elliptical to a resistance they would likely choose to workout at and kept constant strides per minute. Each member did a five-minute workout with another member taking measurements every 30 seconds. By using an extrapolation of this data, an estimate for the amount of kilowatt-hours can be made for a typical workout.

Table 2 Typical Workout Power Output

	Praveen	Audrey
Resistance	12	10
Strides/Min	132	120
Average Power (W)	112.56	56.61
Watt-Hours (Wh)	93.80	47.18

As seen in the table above, a workout can generate powers between 50 and 100Wh. These are the numbers we have used in our power estimation.

Design Overview

The exercise areas in the renovated Rec Center are divided into two areas, one on the first floor and the other on the second floor. Since the machines are on two different floors, it will be difficult to connect all the machines together. Therefore, two points of interconnection points, one on each floor will be chosen. Each connection point will need an inverter and AC disconnect. After looking over the floor plan and electrical plans from the contractor, panel __ for floor one and panel __ for floor two will be used. To see the location and availability of each panel, see

Appendix B: Rec Center Layouts.

With an estimate of 40 machines for the entire system, each floor will be estimated to house 20 machines. Therefore, a design will be created for a 20 unit system, which will be duplicated for the other floor with the exception of the panel. Each machine is estimated to average 100W, while it has been seen that students can generate over 200W as seen in Figure 13 Elliptical Power Output Testing. The inverter is sized according to 200W per machine. Therefore, for a 20 unit system, a 4kW inverter rating is needed.

The following sections will show the various designs investigated during this project.

ReRev Central Inverter Design

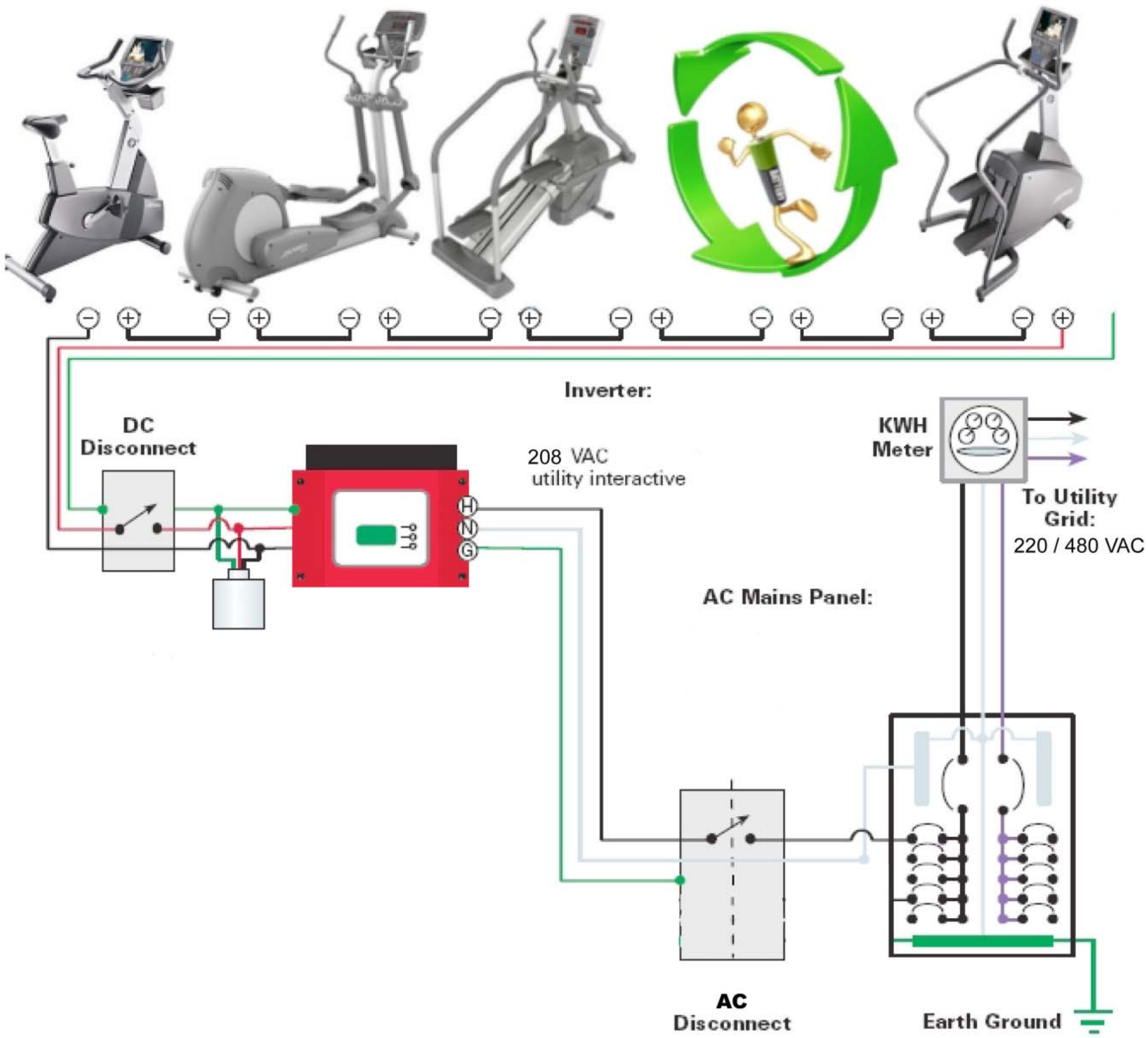

Figure 14 ReRev Schematic courtesy of ReRev

Cal Poly Central Inverter Design

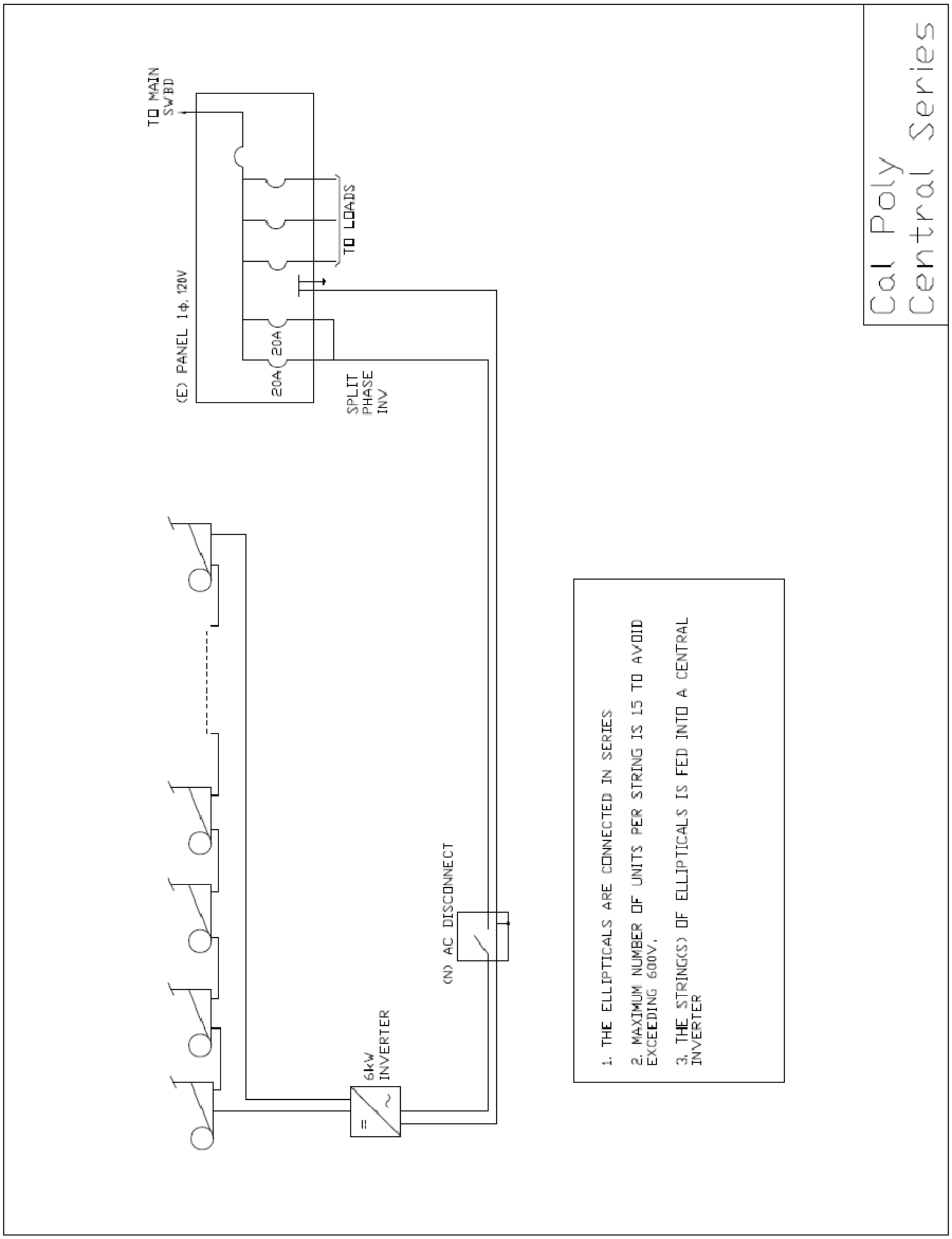

Figure 15 Central Series Implementation

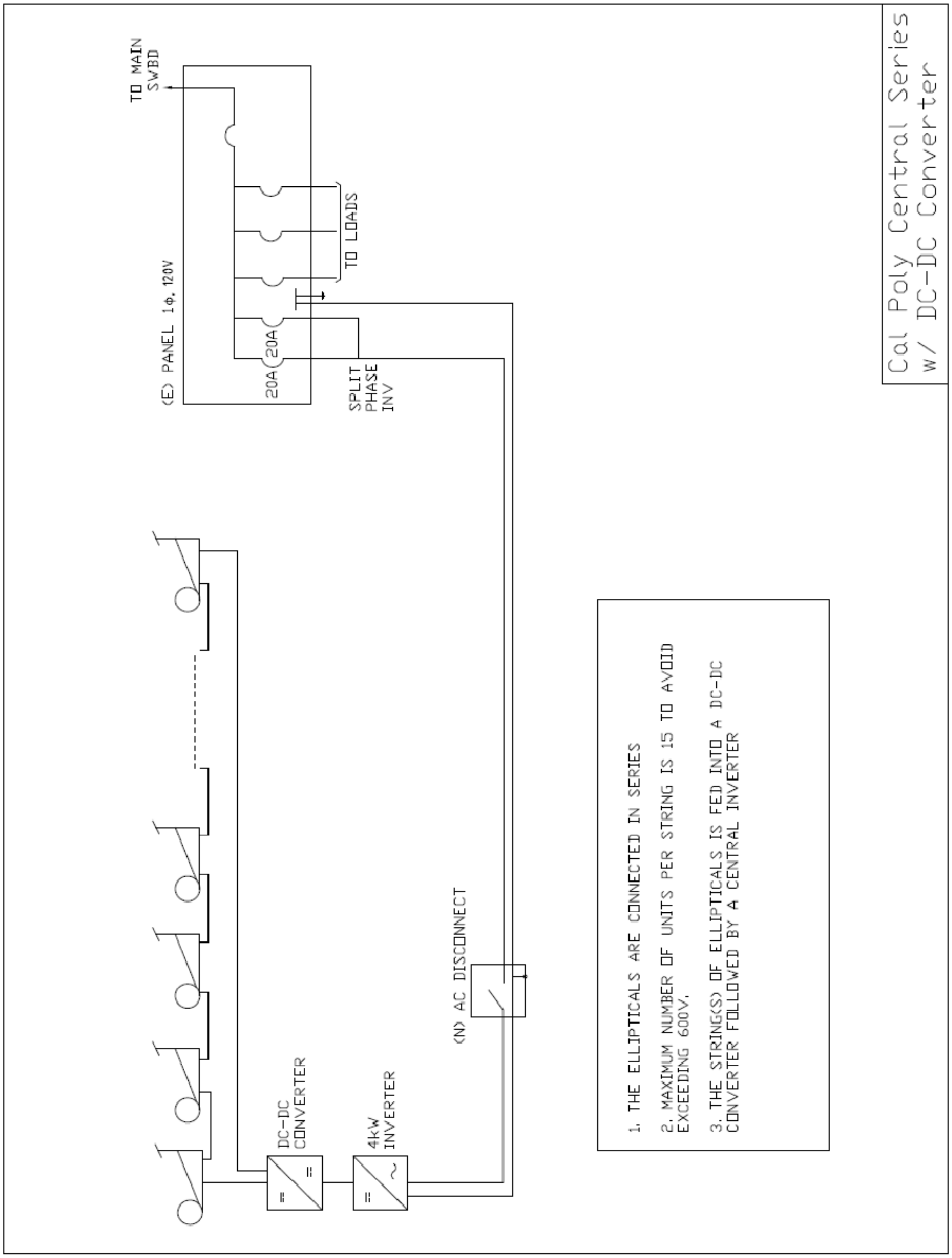

Figure 16 Central Series Implementation w/ DC-DC Converter

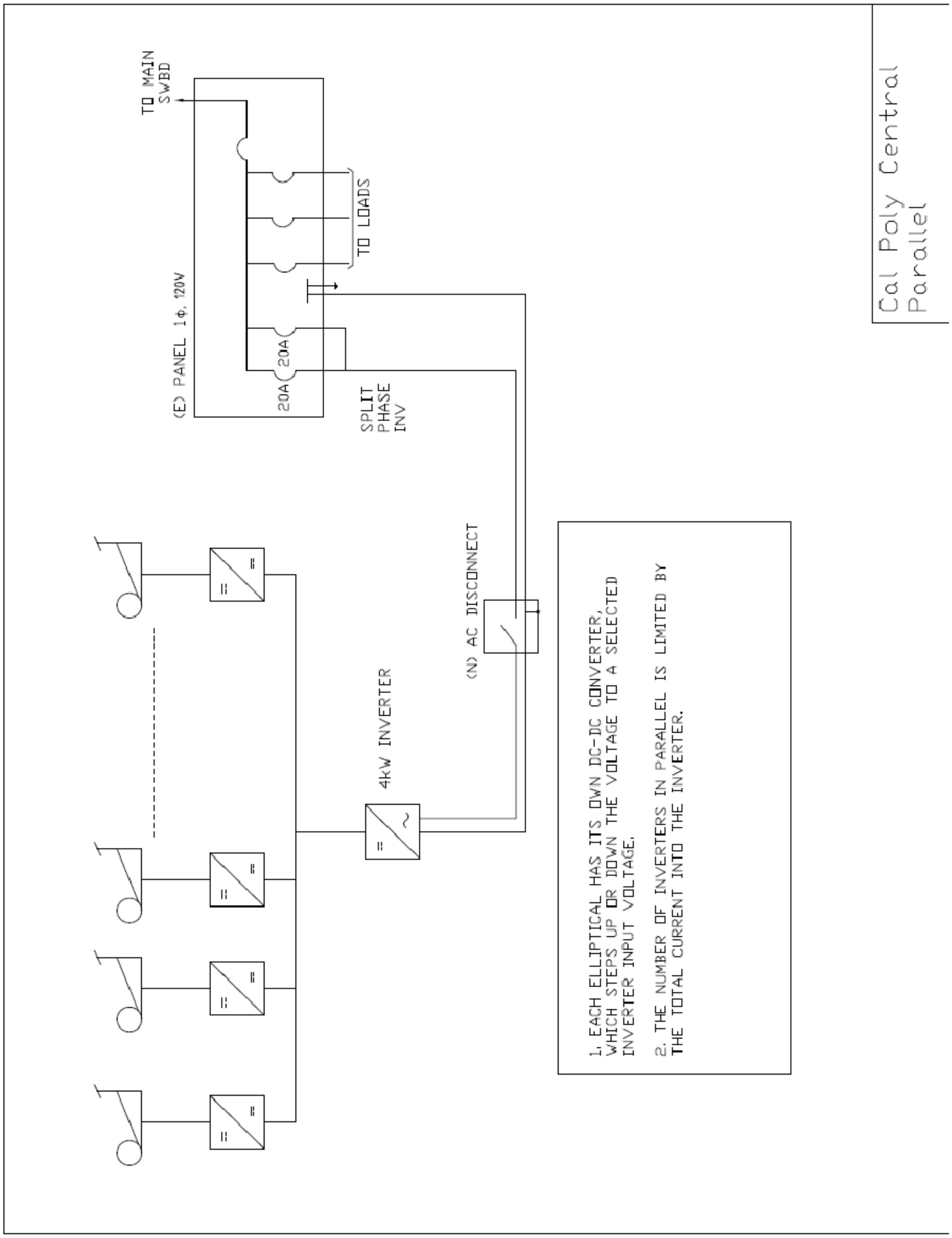

Figure 17Central Parallel Implementation

Cal Poly Micro Inverter Design

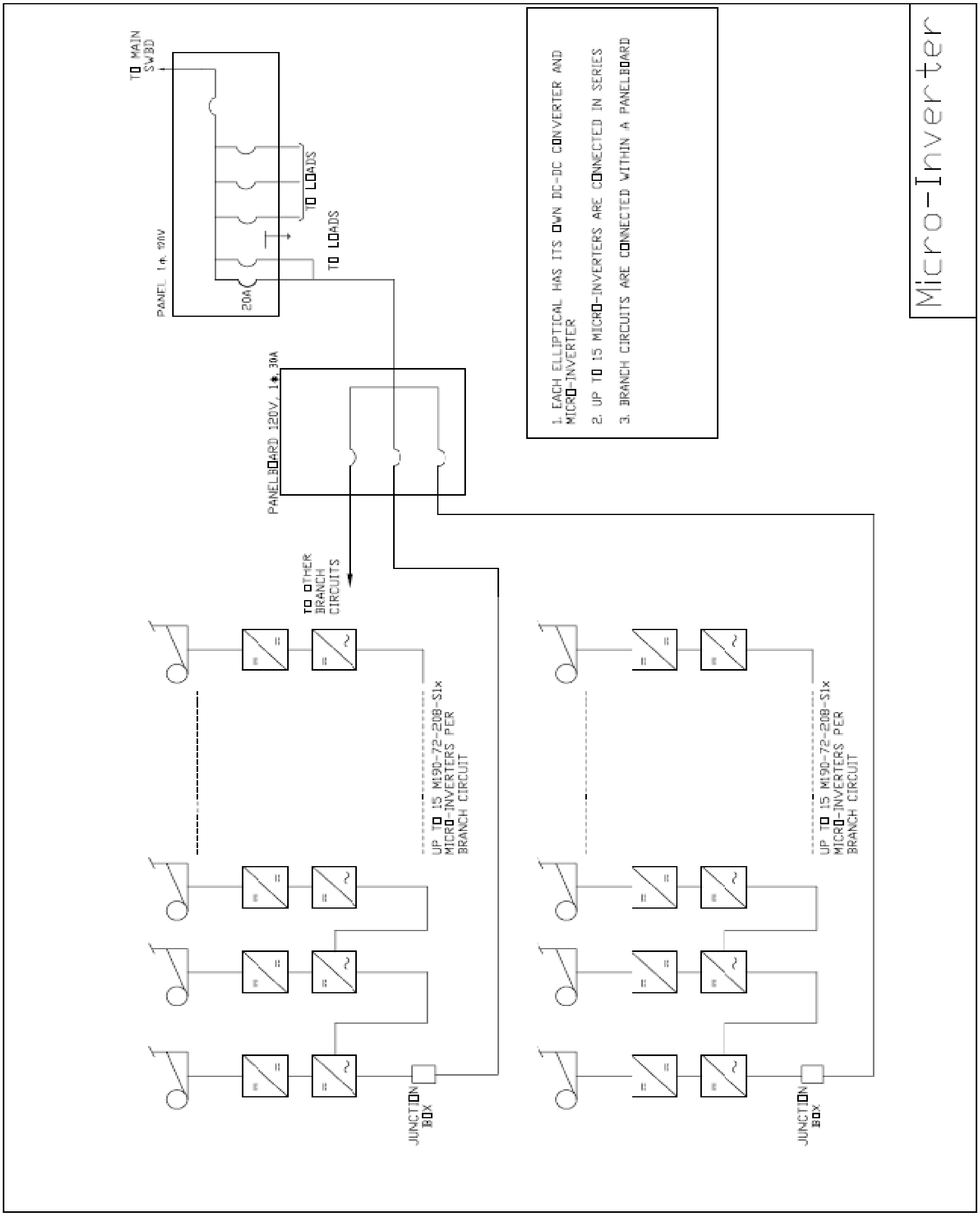

Figure 18 Cal Poly Micro-Inverter Design

Micro vs Central Inverter

The alternative energy market offers two techniques for converting DC to AC in a system. The first option is a central inverter in which multiple units connected in strings are tied in parallel into the inverter through a bus bar. The second option is the use of several micro-inverters, which connect to individual units to convert DC to AC for each unit.

The main functions of the inverter are to convert DC to AC and perform power point tracking on the array to maximize power output. Power point tracking for photovoltaics works based on a modules IV curve. It is important to the function of the inverter to extract the maximum amount of power from a fluctuating array. The tracking system works by using the IV curves for a photovoltaic module and finding the optimal operating voltage, Vmp (22). It is uncertain if this same concept is applicable to exercise machines since the machines have a different IV characteristic.

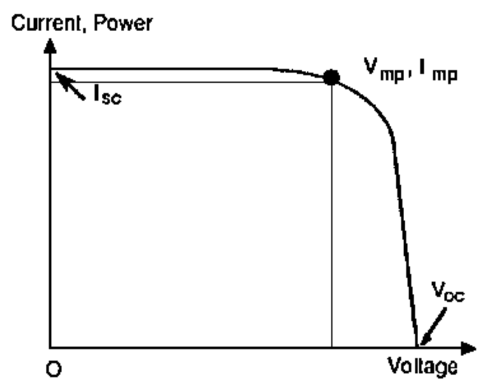

Figure 19 Solar IV Characteristic Curve courtesy for engnet.anu.edu

Central Inverter

The central inverter has been the stakeholder in the alternative energy field in the past and still very prominent in present projects. The main advantage for using central inverters is that there are fewer components needed. With fewer components there is a smaller probability of failure, which increases reliability and reduces maintenance. It has been argued that central inverters make a system easier to troubleshoot since it has a centralized location of maintenance (23). At this time, central inverters also appear to be more economical than micro-inverters as there are fewer components and more cost-effective to manufacture especially for large scale projects (23).

In recent years, there have been several technological advancements, which have increased the efficiency of central inverters. Central inverter companies, such as Satcon have implemented better electronics to allow for better power point tracking even with significant module mismatch (23). Satcon claims that two different types of modules can be used in a system and connected to the same inverter without negatively affecting the output. Other companies such as eIQ Energy have worked with central inverters to increase the efficiency of the system by creating DC-DC converters to standardize the voltage level output of the panels to the desired inverter input (23). The addition of the DC-DC converter decreases the balance of system cost by reducing the amount of equipment such as the combiner box.

The converter also reduces the amount of wiring needed since it allows for maximum use of the wire ampacity without worrying about voltage drops.

There are some limitations on the use of central inverters. One of the most prominent disadvantages of using a central inverter is the use of a single maximum power point tracking for an entire array (24). Conditions across a system may vary causing a fluctuation in the output of each unit therefore making it difficult for the inverter to execute maximum power point tracking. The output of the inverter is therefore degraded even if only a small portion of the system is affected. Another argument against central inverters is their single point of failure. If the inverter unit is disabled, the entire array attached to it will not be functional. Also, central inverters require a large amount of space and usually need a separate equipment facility created to house it.

Micro-Inverters

Micro-inverters have emerged as a new technology fighting to replace the central inverter. Micro-inverter advocates have argued many good points including increased efficiency of the overall system. Although micro-inverters have been around for a while, they have not been successful since they have not been able to reach the efficiency, reliability and cost advantage of current commercial products. The company enPhase, established in 2008, has begun offering micro-inverters comparable to central inverters. The main advantage offered by micro-inverters is their ability to perform maximum power point tracking on the individual level therefore optimizing energy harvesting of the entire system (24). Also, individual units will not negatively impact the output of another unit in the event that one unit is inoperative. Instead of having the whole system shut down, only one micro-inverter will be out and can be replaced at anytime.

The balance of materials is also affected with the use of micro-inverters. Micro-inverter eliminates the need for strings and therefore combiner boxes and DC disconnects (24). It has been claimed that micro-inverters offer a much safer approach since each unit deals with smaller voltages and power.

With all the good that comes with micro-inverters, there are some drawbacks to this approach. The cost is major factor in determining which technology is more advantageous. Currently, the cost of the enPhase inverter, which outputs 190W is approximately $200 (25), while the cost of one Satcon 500kW inverter is about $171,000 (26). To create the same amount of power, the system would need 2632 micro-inverters, which amounts to $526,316. There is an obvious cost disadvantage for larger systems. Even for smaller systems, a SMA 5kW inverter costs $3,398 (25) and for an equivalent system using enPhase inverter, the cost would be $5,400. As the system size decreases, the cost benefits of using micro-inverters are more reasonable.

Another argument against micro-inverters is their lack of test in real life implementations. Micro-inverters have not been installed in the field long enough to determine their true reliability or life expectancy. Another concern is maintaining hundreds or thousands of micro-inverters instead of maintaining one component. The locations of the inverters are within the array, which could sometimes be hard to access.

Wind Inverter Consideration

The above discussion was based on knowledge of solar inverters. For this application, it is possible to use wind inverters; therefore, it will be beneficial to discuss the use of a wind inverter for this project. Wind inverters are generally not offered in smaller sizes since wind turbines are built for larger amounts of power. Knowing this, the wind inverter shall only be considered in the central inverter implementation.

The most critical difference between the wind and solar inverters are the way they execute maximum power point tracking. To perform the maximum power point tracking function, inverters use the IV curve of the PV module or speed-power curve of the wind turbine to determine the optimal operating point. The figures below show the difference in the IV characteristics of a PV module and wind turbine. The wind turbine power output is determined by the speed of the wind, similar to the power output of the elliptical is dependent on the users speed.

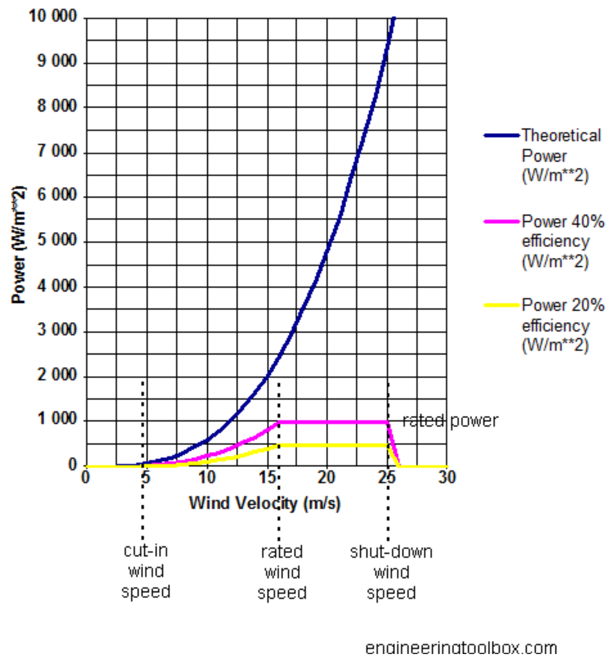

Figure 20 Wind Power Characteristics courtesy of EngineeringToolBox.com

Inverter Selection for Cal Poly Recreation Center

There are advantages to both the central and micro-inverter for the energy harvesting from exercise machine project. The best approach to implement at the Cal Poly Recreation Center is the simplest approach. After thorough investigation of the two options, the central inverter offers a simpler design with sufficient efficiency and the more cost-effective implementation.

The central inverter eliminates the use of the DC-DC converter needed to operate the enPhase mirco-inverter. The inverter also eliminates the need for multiple AC connections into the existing equipment. All the DC outputs of the machines are combined in the central inverter. Since there is less equipment such as inverters and dc cabling, the central inverter implementation is more cost effective for a system of our proposed size.

The only concern with implementing a central inverter is maintenance availability. In order to do maintenance on a single unit, all units must be taken out of service. The next section of this report will investigate methods to solving this solution.

Based on the characteristics of solar and wind turbines, the exercise machines match more closely with the wind characteristics. The power tends to ramp up from zero somewhat linearly as resistance and speed increase. At some point the user has a set resistance with varying speed, which will produce a fairly constant power output.

A central inverter without a DC-DC converter will yield the highest efficiency. The purpose of the DC-DC converter is to set the input voltage to the inverter to be within the maximum power point range. However, there is very little gain in the inverter efficiency with the DC-DC converter yet there is power loss due to the efficiency of the DC-DC converter being less than one. The machines can be connected in series to reach within the range of the MPPT easily and therefore, gain sufficient inverter efficiency.

In conclusion, the design for the Rec Center should utilize a central wind inverter without a DC-DC converter to connect the DC power to the grid.

Safety/Maintenance Concerns

It will be desirable to perform maintenance on a single machine when it is inoperable. Therefore, a method must be devised to safely remove a machine without adversely affecting the other machines. One way to do this would be to bypass a machine when it needs to be removed, similar to bypass diodes in solar modules. To implement this plan, a small switch can be installed in parallel to each unit, which will allow current to flow through a path around the inoperable machine. A second switch can be implemented in the series path of the machines to ensure the machine is completely disconnected from the other machines.

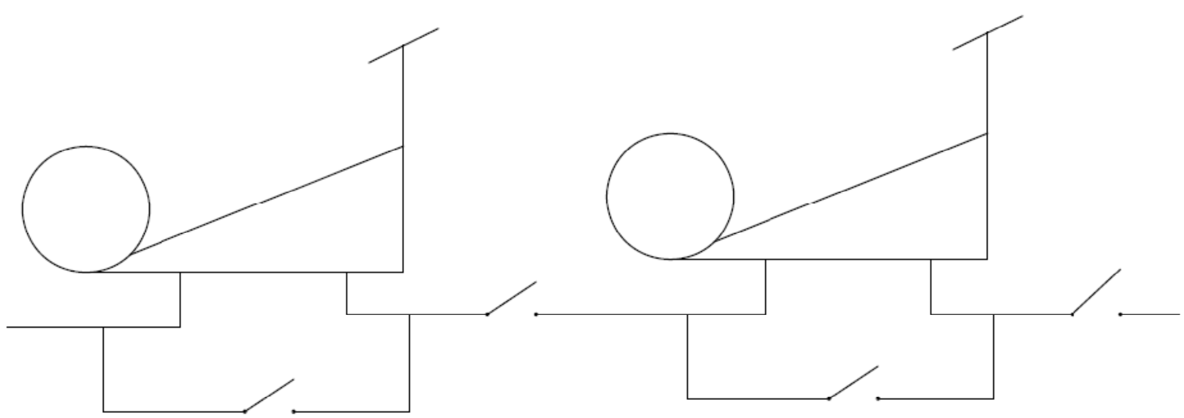

Figure 21 Unit Protection with Switches

Inverter Options

Finding different options for the wind inverters proved to be a difficult task, as not many choices are available for systems as small as the EHFEM project requires. However, two companies within the U.S. have been found to manufacture and sell wind inverters that meet our projects inverter requirements. Table 4 shows a summary of each wind inverter choice.

Table 3: Inverter Options Summary

Company	Model	Max Input Power (W)	Max Output Power (W)	CEC Efficiency (%)	UL/IEEE Compliant	Warranty	Price
Power-One	PVI-4.2-OUTD-W-US	5300	5100	96	YES	10-year limited standard warranty	$3,145
SMA-America	WINDY BOY 5000US	4820	4600	96	YES	5-year warranty, optional 10-year	$3,153.02

Decision Matrix

The various parameters for each system were determined by information from another source or our group experience. To determine the overall efficiency, the various efficiencies of the system's components were multiplied. Central inverters had an efficiency of 96%, while the micro-inverter had an efficiency of 95%. DC-DC converters were estimated to have an efficiency of 80%, while series wiring had an efficiency of 97% and parallel had an efficiency of 99%. The only thing that changes is the 97% for the series wiring efficiency.

Table 3 shows our decision matrix for the different possible systems to be implemented at the Rec Center. Five different systems were compared using this matrix, each being described according to a respective category. The main comparison dealt with either using a main central inverter, or using several micro-inverters in the proposed system. From the Micro-inverter vs. Central Inverter section, it was concluded a central inverter system would be the best choice. For the decision on either going through ReRev or in-house, the main concern was efficiency of each system. By doing in-house, we can increase efficiency in areas ReRev's system may have overlooked. Also, costs may be less going with an in-house design. The last two designs involved implementing a DC-DC converter to optimize the inverters' efficiency by inputting the optimal input voltage for optimal output.

	ReRev	**Cal Poly Micro-Inverter Design**	**Cal Poly Central Inverter Series Unit Design**	**Cal Poly Central Inverter w/ DC-DC Converter Design**	**Cal Poly Central Inverter Parallel Unit Design**
Technology/Design (25%)					
Overall Efficiency	93.12% [25]	75.24% [15]	93.12% [25]	74.5% [12]	76.03% [18]
User Experience	Resistance Levels 1 through 8 are distorted [17]	Goes from one extreme to another; very easy at low levels and extremely hard at high levels [15]	Resistance different from OEM [10]	Resistance different from OEM [10]	Resistance different from OEM [10]
Space Requirements	No additional exercise footprint; space needed for inverter & AC disconnect [15]	Footprint depends on location of micro-inverter & dc-dc converter; space needed for junction box, panelboard & AC disconnect [7]	No additional exercise footprint; space needed for DC disconnect, inverter, & AC disconnect [13]	No additional exercise footprint; Space needed for DC-DC converter, DC disconnect, inverter & AC disconnect [10]	Foot print depends on location of DC-DC converter, space needed for DC disconnect, inverter, & AC disconnect [8]
Type of Inverter	Wind[10]	Solar [7]	Wind [10]	Wind [10]	Wind [10]

	ReRev	Cal Poly Micro-Inverter Design	Cal Poly Central Inverter Series Unit Design	Cal Poly Central Inverter w/ DC-DC Converter Design	Cal Poly Central Inverter Parallel Unit Design
Inverter Implementation	Central [10]	Micro-inverter [7]	Central[10]	Central [10]	Central [10]
Inverter Efficiency	96% [10]	95% [8]	96% [10]	96% [10]	96% [10]
Unit Implementation	Several ellipticals connected in series into strings [10]	Each ellipticals has an inverter, inverters are connected in series [6]	Several ellipticals connected in series into strings [10]	Several ellipticals connected in series into strings, each string has a dc-dc converter [9]	Each ellipticals has a dc-dc converter, connected to a bus then to the inverter [7]
Technology/Design Score	87	65	88	71	73
Maintenance/Support (20%)					
Reliability	No reported incidents [40]	No fully functioning prototype [20]	No prototype but similar to ReRev design [32]	No prototype [27]	No prototype [20]
Level of Maintenance	Single inverter to be maintained; single machine maintenance requires entire string to be shut down [20]	[X] Micro-inverters & dc-dc converter will need to be maintained; single machines can be isolated [17]	Single inverter to be maintained; switches will be implemented to allow for isolation of a single machine [30]	Single inverter & DC-DC converter to be maintained; switched to be implemented to isolate a single machine [30]	Single inverter to be maintained, multiple dc-dc disconnect to be maintained; each machine can be isolated [27]
UL Listing/Warranty	All UL listings/warranties are upheld [20]	Possible UL listing needed, need to check with Precor about warranty,15 yr inverter warranty [13]	UL listing should be upheld; check with Precor warranty, 5 yr inverter warranty [20]	Possible UL listing needed, check with Precor warranty, 5 yr inverter warranty [10]	Possible UL listing needed, check with Precor warranty, 5 yr inverter warranty [10]
Maintenance Precautions	(1) AC disconnect [6]	(1) AC disconnect, protection within panelboard [7]	(1) DC disconnect, (1) AC disconnect, switches to isolate machines [10]	(1) DC disconnect, (1) AC disconnect, switches to isolate machines [10]	(1) DC disconnect and (1) AC disconnect [8]
Maintenance/Support Score	86	57	92	77	65
Safety (30%)					

	ReRev	Cal Poly Micro-Inverter Design	Cal Poly Central Inverter Series Unit Design	Cal Poly Central Inverter w/ DC-DC Converter Design	Cal Poly Central Inverter Parallel Unit Design
Safety & Adherence	Company works closely with local utility to build in accordance to pertinent codes, all components are off-the-shelf and UL listed	Design has been examined to follow all safety standards	Design has been examined to follow all safety standards	Design has been examined to follow all safety standards	Design has been examined to follow all safety standards
Safety Score	100	100	100	100	100
Cost (25%)					
Bill of Materials	(1) inverter (1) AC Disconnect	(X) Inverters (X) DC-DC Converters (1) AC Disconnect (1) Junction Box (1) Panelboard	(1) Inverter (1) AC Disconnect (80) Switches	(1) Inverter (1) AC Disconnect (1) DC-DC Converter (80) Switches	(1) Inverter (X) DC-DC Converters (1) DC Disconnect (1) AC Disconnect
Retrofit Cost	$12k - $16k for 10-15 machines [30]	$10,800 for 10-15 machines [50]	$4625 for 10-15 machines [100]	$4875 for 10-15 machines [90]	$8575 for 10-15 machines [60]
Cost Score	30	50	100	90	60
Total Score	76.45	70.15	95.4	85.65	76.25

Table 4: Decision Matrix

Cost Benefit Analysis

The cost of the EHFEM implementation and recovery of such costs are important factors to consider when selecting the appropriate final design for the Cal Poly Rec Center. This section investigates the cost of the various implementations discussed throughout the document.

Initial Cost and Payback Analysis

Table 5 Initial Cost Analysis for 15 Units

Initial Costs (15 units)															
	ReRev			Cal Poly Micro-inverter Design			Cal Poly Central Inverter Design			Cal Poly Central w/ DC-DC Design			Cal Poly Central Parallel Design		
Parts list	#	$/unit	total	#	$/unit	total	#	$/unit	total	#	$/unit	total	#	$/unit	total
Switch				0	0	0	30	10	300	30	10	300	0	0	0
Inverter				1	20	3000	1	26	2625	1	26	2625	1	26	2625

				5	0			25			25			25	
DC-DC converter				15	250	3750	0	0	0	1	250	250	15	250	3750
AC disconnect						0	1	100	100	1	100	100	1	100	100
DC disconnect						0	1	100	100	1	100	100	1	100	100
Wiring						2000			1000			1000			2000
Panel board				1	2000	2000			0			0			0
Junction box				1	50	50			0			0			0
Total			**$16,000**			**$ 10,800.00**			**$ 4,125.00**			**$ 4,375.00**			**$ 8,575.00**

Table 5 portrays the initial cost of each system investigated throughout the EHFEM Up scaling project. The cost of each system portrayed in Table 4 is based off a 15 unit implementation. Nakamura, Arakaki, and Lawrence attempted to obtain accurate estimates from reliable sources throughout the cost analysis. Unfortunately, the group was unable to obtain certain prices from facility officials before the end of the quarter. Therefore, the costs for wiring has been estimated for 1000 feet (2000 feet for parallel and micro-inverter designs) at the wholesale rate of $1.00/foot for 14 gauge wire rated at 20A. ReRev was unable to provide information regarding their bill of materials. The cost of their system is based off values obtained from ReRev for systems consisting of 15 ellipticals.

Table 6 Cost Analysis for 40 Unit System

Initial Costs (40 units)															
	ReRev			Cal Poly Micro-inverter Design			Cal Poly Central Inverter Design			Cal Poly Central w/ DC-DC Design			Cal Poly Central Parallel Design		
Parts list	#	$/unit	total	▯	$/unit	total	#	$/unit	total	#	$/unit	total	#	$/unit	total
Switch				0	0	0	80	10	800	80	10	800	0	0	0
Inverter				40	200	8000	2	3145	6290	2	3145	6290	2	3145	6290
DC-DC converter				40	250	10000	0	0	0	3	250	750	40	250	10000
AC disconnect						0	2	100	200	2	100	200	2	100	200
DC disconnect						0	2	100	200	2	100	200	2	100	200

Wiring						4000			2000			2000			4000
Panel board				2	2000	4000			0			0			0
Junction box				2	50	100			0			0			0
Total						**$ 26,100.00**			**$ 9,490.00**			**$ 10,240.00**			**$ 20,690.00**

Table 6 portrays the initial cost of each system investigated throughout the EHFEM Up scaling project. The cost of each system portrayed in Table 5 is based off a 40 unit implementation. Nakamura, Arakaki, and Lawrence attempted to obtain accurate estimates from reliable sources throughout the cost analysis. Unfortunately, the group was unable to obtain certain prices from facility officials before the end of the quarter. Therefore, the costs for wiring has been estimated for 1000 feet (2000 feet for parallel and micro-inverter designs) at the wholesale rate of $1.00/foot for 14 gauge wire rated at 20A. ReRev was unable to provide information regarding their bill of materials. The cost of the ReRev system has been omitted from the 40 unit analysis. Please refer to Table 5 for information regarding ReRev system implementation cost.

Table 7 Payback Analysis for 15 Unit and 40 Unit systems

	Payback					
		ReRev	Cal Poly Micro-inverter Design	Cal Poly Central Inverter Design	Cal Poly Central w/ DC-DC Design	Cal Poly Central Parallel Design
	Efficiency	0.93	0.75	0.93	0.75	0.76
15 units	Annual Revenue ($)	448.85	362.74	448.85	359.17	366.41
	System Cost ($)	16000.00	10800.00	4125.00	4375.00	8575.00
	Payback period (years)	35.65	29.77	9.19	12.18	23.40
40 units	Annual Revenue ($)		967.31	1196.92	957.80	977.08
	System Cost ($)		26100.00	9490.00	10240.00	20690.00
	Payback period (years)		26.98	7.93	10.69	21.18

Table 7 portrays the payback period for each of the proposed implementations. The annual revenue of each system is determined by the amount of power generated during the average school year (Fall, Winter, and Spring Quarters) and omits data obtained from off peak times such as summer quarter, holidays, etc.

Systems comprised of 15 units or below have difficulty achieving the payback requirement of 8 years. However, as the size of the system increases, the ability to achieve the payback requirement becomes more realistic. The cost of implementing an additional unit to the system is relatively small in comparison the initial cost of the central inverters while the savings from the generated electricity significantly increase the systems annual revenue.

Please keep in mind that the data portrayed in Tables 5, 6, and 7 are based on peak period of generation only (Fall, Winter, and Spring Quarters of the academic school year). The data does not incorporate the savings incurred from generation during the holidays, summer quarter, and other off peak seasons of the year. The generation from those periods will further reduce the payback periods portrayed in Table 7.

Calculations

The values portrayed in Tables 1 and 2 were obtained using the following methods and equations.

Annual Revenue

The annual revenue for each system is determined using the following equations:

$$Annual\ Weekend\ Revenue = \frac{30\ hours}{weekend} \times \frac{32\ weekends}{academic\ year} \frac{\$0.116}{kWh} \times \frac{0.075W}{unit} \times number\ of\ units$$

$$Annual\ Weekday\ Revenue = \frac{18\ hours}{day} \times \frac{5\ days}{week} \times \frac{32\ weeks}{academic\ year} \times \frac{\$0.116}{kWh} \times \frac{0.075W}{unit} \times number\ of\ units$$

$$Total\ Annual\ Revenue = Annual\ Weekend\ Revenue + Annual\ Weekday\ Revenue$$

At one hundred percent efficiency, the average Annual Weekend Revenue, Annual Weekday Revenue, and Total Annual Revenue for a system comprising of 15 ellipticals is:

$$Annual\ Weekend\ Revenue = \frac{30\ hours}{weekend} \times \frac{32\ weekends}{academic\ year} \frac{\$0.116}{kWh} \times \frac{0.075W}{unit} \times 15\ units = {\$120.53}/{year}$$

$$Annual\ Weekday\ Revenue = \frac{18\ hours}{day} \times \frac{5\ days}{week} \times \frac{32\ weeks}{academic\ year} \times \frac{\$0.116}{kWh} \times \frac{0.075W}{unit} \times 15\ units = {\$361.58}/{year}$$

$$Total\ Annual\ Revenue = Annual\ Weekend\ Revenue + Annual\ Weekday\ Revenue = {\$120.53}/{year} + {\$361.58}/{year} = {\$482.11}/{year}$$

The California Public Utilities Commission (CPUC) reports and average rate of $0.1116/kWh for large industrial/commercial buildings over the last 10 years. The average rate was used to determine the annual revenue.

System Costs

The system costs used for the payback analysis were determined during the cost analysis portrayed in Table 1.

Total Annual Revenue per Implementation

At 100 percent efficiency, each system is capable of providing an average output of 75 Watts/hour. The 75 Watts/hour average is based off the statistical data portrayed in the *Elliptical Characterization* section. The Annual Revenue portrayed in Table 2 is based off the calculated efficiency of each system. The annual revenue portrayed in Table 2 is determined using the following equation in accordance with the values obtained from the *Total Annual Revenue* equation:

$$Total\ Annual\ Revenue\ Per\ Implementation = Total\ Annual\ Revenue\ \times System\ Effeiceincy$$

Payback Period

The payback period effectively portrays how long it will take for Cal Poly to recover the costs of implementing the EHFEM system. The payback period is determined using the following equation:

$$Payback\ Period\ (number\ of\ years) = \frac{System\ Costs}{Total\ Annual\ Revenue}$$

Energy Calculations

The following tables summarize the predicted electricity to be generated from the ellipticals. To accurately predict the amount of energy, the results from our elliptical tests and Rec Center Usage data was used to calculate energy produced. Since, one user produced 50Wh in one workout while another produced 100Wh, our final numbers are based on an average of the users outputs. Also, to take into account the efficiencies of the various electronics between the elliptical output and grid, an efficiency factor of 75% was applied to our measured results.

Table 8 Energy Calculation Factors

# of ellipticals	40
Elliptical Usage each hour	57%
# of ellipticals used/hour	22.8
School Weeks	32

Table 9 Calculation of Predicted Generated Electricity from Ellipticals

Watt-hour/Workout (Wh)	50	75	100
Effective Power to Grid per Machine (Wh)	37.5	56.25	75
Power/Day per Machine (kWh)[weekdays]	0.675	1.0125	1.35
Power/Day per System (kWh) [weekdays]	15.39	23.085	30.78
Power/day per Machine (kWh) [Saturday]	0.525	0.7875	1.05
Power/Day per System (kWh) [Saturday]	11.97	17.955	23.94
Power/day per Machine (kWh) [Sunday]	0.6	0.9	1.2
Power/Day per System (kWh) [Sunday]	13.68	20.52	27.36
Power/Week per System (kWh)	102.6	153.9	205.2
Power/School Year per System (kWh)	3283.2	4924.8	6566.4

The table above shows that the system could potentially produce about between 3.28MWh and 6.67MWh per year. These numbers vary significantly since they are based on the highest and lowest amount of predicted energy generation per workout. Our system will be advertised to generate 4.92MWh a year, which is the average power between the two extremes.

Externalities

Externalities are an economic side effect, wherein its results are not fully accounted in dollars. It not only affects direct participants, but also third parties as well. An externality can be either positive or negative, also known as a benefit or a cost. In this section, both positive and negative externalities will be discussed as part of the Cost Benefit Analysis.

Positive Externalities

"A positive externality exists when an individual or firm making a decision does not receive the full benefit of the decision. The benefit to the individual or firm is less than the benefit to society" (27).   The following are some examples of external benefits resulting from implementation of the EHFEM system at the Cal Poly Rec Center.

One of the main goals that our project seeks to achieve in the long run is the effect of reduced carbon emissions. This can be accomplished when excess generated power from the exercise machines offsets power usage, thereby decreasing power generation from the utilities, which may utilize coal/oil generation. The external benefit that results from reducing carbon emissions is the increase in better environmental welfare. With an increase in environmental welfare, a multitude of benefits arise. These benefits include the extended lifetime of some limited resources for future generations or also better air conditions, which can decrease health risks from pollution.

Another positive externality of implementing such a system at Cal Poly is knowledge spillover, which can lead to the exploitation of information and in turn better technology. When inventions or information are discovered or made more available, people besides the ones who invented or possess the information can now take advantage of this new technology. With more competitors exploiting a closed technology, new innovations and better technology can be achieved. Like an open market, the market itself can benefit from competition. This externality is closely related to the next external benefit, the "tipping point".

By implementing this system at Cal Poly's Rec Center and showing that different parties may benefit from it, this can cause a "tipping point" where it leads to an increase in usage and wider acceptance from everyone. Similar to the knowledge spillover externality, universal usage and general acceptance can lead to better products and better technology. With the increase in competition in the market, the market can look forward to change and innovation.

Another externality that arises from implementing the EHFEM project is more people are exercising; therefore society will have an increase in healthier people. With better health come lower health costs, higher qualities of life, healthier lifestyles, increased life expectancy, and a better overall feeling of well-being. Healthier people can greatly benefit society in many ways. For instance, a healthier society means a more productive society.

Negative Externalities

"A negative externality occurs when an individual or firm making a decision does not have to pay the full cost of the decision. If a good has a negative externality, then the cost to society is greater than the cost consumer is paying for it" (28). The following are some examples of external costs resulting from implementation of the EHFEM system at the Cal Poly Rec Center.

One example of a possible negative externality is pollution. Even though the goal with this project is to decrease pollution by generating clean energy, the cost, materials and energy required to produce the materials needed for our project may be greater than the output of our project. This external cost from pollution can lead to rising medical expenses, decreased life expectancy, and for those who live near these plants that produce the materials, a reduction in visual appeal of the area. This reduction in aesthetic appeal can reduce property values for some homes.

Another negative externality that may happen is an increase in energy usage due to users thinking they are producing more energy from the exercise machines. If there is an increase in energy consumption, the project may lose its affect in offsetting some part of the energy consumption. With the increase of energy usage, more generation may be required by utilities, which in turn increases the burning of fossil fuels for the excess generation.

Chapter 5 Conclusion

The complexity of this project has grown during its progression. In an effort to upscale the system, a thorough investigation of a single unit was performed. As more details were unveiled about the operation of the elliptical, more questions arose about the operation and how it affects the energy harvested. The system is quite complex and may require more examination; however, our group has grasped the basic operation of the elliptical. A thorough understanding of elliptical operation enables the engineer to create a more efficient design.

After much consideration, the single central inverter with series machines design similar to ReRev's design was chosen as the best implementation. This implementation provides the best efficiency because it minimizes the electronics between the elliptical output and grid. Since there is only a small amount of power to work with, a majority of it needs to be transferred to the grid to get a practical amount of power. Our design also incorporates a safety and maintenance feature to isolate machines when inoperable. The idea is to add two simple switches, one between each machine and one in shunt to each machine. The switches direct the path of current around a machine when it needs to be disconnected. The Cal Poly Central Inverter EHFEM design is the most efficient and maintenance-friendly design available.

The proposed design also offers the most cost-effective implementation. The overall retrofit cost for 40 units is about $10,000. Since the energy harvesting machines will help offset electrical utility usage for the Rec Center, the rate of return is approximately 8 years. The equipment purchased for the initial retrofit cost can be used again when the elliptical machines are upgraded to newer models. Therefore, the retrofit equipment including the inverter, disconnects, and wiring is a one time cost and should operate for at least 10 years or longer.

Recommendations

Arakaki, Nakamura, and Lawrence have designed the most efficient scaled system design. The next step involves looking into an individual unit for a higher efficiency. Our group suggests future students working on the EHFEM project to investigate more into the operation of the elliptical. Re-designing the integrated power electronics of the elliptical trainer may result in greater efficiency. The Precor elliptical investigated throughout the project requires a small battery to power the user interface after the user stops pedaling. The user interface only needs to stay on for a couple minutes, especially if the data is accessible online as the new models boast. Another problem encountered was the change in user resistance when multiple machines were connected in a system. An explanation needs to be found on why this happens and how it can be avoided. In the end, it seems that creating a new elliptical design with energy harvesting in mind may be the best solution for increasing the efficiency of this project.

Appendix

Appendix A: Elliptical Datasheets

Please obtain the elliptical data sheets from the Precor website listed below.

EFX-534i Self Powered Elliptical
Source: http://www.precor.com/pdf/tech/Spec-Sheet_na534i_en.pdf

EFX-532i Self Powered Elliptical
Source: http://www.precor.com/pdf/tech/Spec-Sheet_532i_en.pdf

AMT-100i
Source: http://www.precor.com/pdf/tech/Spec-Sheet_amt100i_en.pdf

Appendix B: Rec Center Layouts

Please obtain floor plans for the Rec Center Expansion from following source:

Calpoly Rec Center Expansion Timeline
Source: http://www.asi.calpoly.edu/RCFP_timeline

Appendix C: Rec Center Electrical Plans

Please contact Cal Poly Facilities for Rec Center Electrical Plans

Appendix D – Rec Center Usage Data

Fall 2009 Cardio Usage Stats by Machine:

Date	Treadmills (13)	Elliptical (16)	Stepmills (7)	Upright Bikes (10)	Recumbent (10)	Rowers (4)	60 Machines
10/7/2009	181	212	30	76	57	22	
10/8/2009	153	149	35	68	53	15	
10/9/2009	129	126	27	36	31	13	
10/10/2009	65	90	14	32	8	5	
10/11/2009	84	106	14	27	21	8	
10/12/2009	171	194	46	82	73	10	
10/13/2009	149	133	30	44	28	11	
10/14/2009	157	181	32	68	50	16	
10/15/2009	160	172	38	45	61	21	
10/16/2009	104	148	16	44	28	12	
10/17/2009	58	76	20	22	10	8	
10/18/2009	108	151	13	40	32	10	
10/19/2009	130	152	35	50	49	8	
10/20/2009	199	207	33	75	51	23	
10/21/2009	173	199	28	78	59	17	
10/22/2009	173	175	34	73	49	25	
10/23/2009	131	147	21	37	30	11	
10/24/2009	66	83	10	20	12	4	
10/25/2009	89	119	13	35	26	11	
10/26/2009	180	217	34	80	72	25	
10/27/2009	159	150	44	50	45	13	
10/28/2009	162	178	50	71	42	12	
10/29/2009	144	158	35	57	43	15	
10/30/2009	104	131	24	34	26	9	
10/31/2009	56	73	13	23	13	7	
11/1/2009	72	79	13	26	15	4	
11/2/2009	187	208	37	71	57	11	
11/3/2009	198	182	34	58	47	12	
11/4/2009	164	208	49	66	50	14	
11/5/2009	161	177	48	55	51	16	
11/6/2009	140	166	27	55	27	10	
11/7/2009	94	87	21	38	10	6	
11/8/2009	99	126	17	43	27	6	
11/9/2009	163	208	49	80	53	11	
11/10/2009	163	208	48	89	56	26	
11/11/2009	111	153	32	40	32	6	Vets Day
11/12/2009	152	202	33	63	58	13	
11/13/2009	163	198	40	48	36	16	
11/14/2009	88	106	22	`29	20	9	
11/15/2009	82	131	25	43	22	4	
11/16/2009	218	211	45	77	73	16	
11/17/2009	127	185	32	58	42	14	
11/18/2009	143	185	31	72	43	13	
11/19/2009	110	128	24	46	21	10	
11/20/2009	88	129	30	48	32	8	
11/21/2009	75	92	32	26	9	5	
11/22/2009	85	92	12	32	24	11	
11/23/2009	93	139	27	45	19	3	
11/24/2009	57	73	18	16	21	4	
11/25/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	
11/26/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	
11/27/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	
11/28/2009	5	13	2	2	3	0	
11/29/2009	53	83	13	19	8	5	
11/30/2009	156	195	43	54	61	8	
12/1/2009	162	189	50	60	50	12	
12/2/2009	184	219	37	72	49	13	
12/3/2009	146	196	45	48	43	8	
12/4/2009	271	104	190	49	40	14	

12/5/2009	75	76	14	17	15	6	
12/6/2009	100	108	35	28	20	7	
12/7/2009	113	109	21	34	21	5	
12/8/2009	138	160	30	45	25	15	
12/9/2009	153	154	25	51	20	13	
12/10/2009	111	112	28	33	21	8	
12/11/2009	76	78	12	21	13	53	
12/12/2009	23	25	17	20	3	4	winter break
12/13/2009	34	34	2	8	3	2	winter break
12/14/2009	54	58	4	14	9	0	winter break
12/15/2009	48	59	15	17	7	2	winter break
12/16/2009	39	47	9	18	21	1	winter break
12/17/2009	32	34	6	11	8	1	winter break
12/18/2009	31	36	2	8	9	0	winter break
12/19/2009	23	26	1	7	9	1	winter break
12/20/2009	24	25	3	4	5	2	winter break
12/21/2009	19	35	5	11	7	1	winter break
12/22/2009	21	37	5	2	7	1	winter break
12/23/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	winter break
12/24/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	winter break
12/25/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	winter break
12/26/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	winter break
12/27/2009	17	20	4	2	3	0	winter break
12/28/2009	20	23	4	7	9	1	winter break
12/29/2009	29	22	6	9	5	1	winter break
12/30/2009	25	19	4	8	4	0	winter break
12/31/2009	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	Fall total
Total	8500	9696	2067	3141	2312	763	26479
Avg/Day	109.0	124.3	26.5	40.8	29.6	9.8	340.0

Winter 2010 Cardio Usage Stats by Machine:

Date	Treadmills (13)	Elliptical (16)	Stepmills (7)	Upright Bikes (10)	Recumbent (10)	Rowers (4)	60 Machines
1/1/2010	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	winter break
1/2/2010	26	41	8	14	9	1	winter break
1/3/2010	60	68	6	22	9	1	winter break
1/4/2010	174	199	53	73	72	22	
1/5/2010	184	216	45	83	73	25	
1/6/2010	155	216	48	77	69	18	
1/7/2010	193	205	62	83	89	15	
1/8/2010	134	154	34	61	37	10	
1/9/2010	98	113	26	31	23	6	
1/10/2010	102	123	22	42	20	8	
1/11/2010	217	263	67	134	95	30	
1/12/2010	182	195	54	92	74	16	
1/13/2010	209	246	60	124	103	25	
1/14/2010	175	213	50	100	74	26	
1/15/2010	131	171	31	60	52	17	
1/16/2010	113	113	14	53	19	4	
1/17/2010							
1/18/2010	150	139	29	54	34	17	
1/19/2010	205	219	57	120	86	21	
1/20/2010	161	195	43	74	55	25	
1/21/2010	183	218	60	121	72	23	
1/22/2010	158	188	98	109	78	25	
1/23/2010	107	119	22	41	21	12	
1/24/2010	114	143	20	58	27	13	
1/25/2010	166	199	47	104	70	15	
1/26/2010	190	250	49	112	91	24	
1/27/2010	155	162	31	73	51	16	
1/28/2010	165	221	52	86	52	17	
1/29/2010	155	162	31	73	51	16	
1/30/2010	103	135	28	45	72	8	
1/31/2010	141	135	17	46	26	10	
2/1/2010							
2/2/2010							
2/3/2010	207	255	59	110	82	17	
2/4/2010	168	186	35	61	51	15	
2/5/2010	161	170	36	89	38	17	
2/6/2010	117	143	32	71	32	9	
2/7/2010							
2/8/2010							
2/9/2010							
2/10/2010							
2/11/2010							
2/12/2010							
2/13/2010							
2/14/2010							
2/15/2010							Presidents Day
2/16/2010							
2/17/2010							
2/18/2010							

Table 10 Elliptical Usage at Rec Center

Date	Elipticals(16)	Usage/Hour	Percent of Ellipticals Used
10/7/09	212	11.77777778	73.61111111
10/8/09	149	8.277777778	51.73611111
10/9/09	126	7	43.75
10/10/09	90	6.428571429	40.17857143
10/11/09	106	6.625	41.40625
10/12/09	194	10.77777778	67.36111111
10/13/09	133	7.388888889	46.18055556
10/14/09	181	10.05555556	62.84722222
10/15/09	172	9.555555556	59.72222222
10/16/09	148	8.222222222	51.38888889
10/17/09	76	5.428571429	33.92857143
10/18/09	151	9.4375	58.984375
10/19/09	152	8.444444444	52.77777778
10/20/09	207	11.5	71.875
10/21/09	199	11.05555556	69.09722222
10/22/09	175	9.722222222	60.76388889
10/23/09	147	8.166666667	51.04166667
10/24/09	83	5.928571429	37.05357143
10/25/09	119	7.4375	46.484375
10/26/09	217	12.05555556	75.34722222
10/27/09	150	8.333333333	52.08333333
10/28/09	178	9.888888889	61.80555556
10/29/09	158	8.777777778	54.86111111
10/30/09	131	7.277777778	45.48611111
10/31/09	73	5.214285714	32.58928571
11/1/09	79	4.9375	30.859375
11/2/09	208	11.55555556	72.22222222
11/3/09	192	10.66666667	66.66666667
11/4/09	208	11.55555556	72.22222222
11/5/09	177	9.833333333	61.45833333
11/6/09	166	9.222222222	57.63888889
11/7/09	87	6.214285714	38.83928571
11/8/09	126	7.875	49.21875
11/9/09	208	11.55555556	72.22222222
11/10/09	208	11.55555556	72.22222222
11/11/09	153	8.5	53.125
11/12/09	202	11.22222222	70.13888889
11/13/09	198	11	68.75
11/14/09	106	7.571428571	47.32142857
11/15/09	131	8.1875	51.171875
11/16/09	211	11.72222222	73.26388889
11/17/09	185	10.27777778	64.23611111
11/18/09	185	10.27777778	64.23611111

11/19/09	128	7.111111111	44.44444444
11/20/09	129	7.166666667	44.79166667
11/21/09	92	6.571428571	41.07142857
11/22/09	92	5.75	35.9375
11/23/09	139	7.722222222	48.26388889
11/24/09	73	4.055555556	25.34722222
11/25/09	closed		
11/26/09	closed		
11/27/09	closed		
11/28/09	13	0.928571429	5.803571429
11/29/09	83	5.1875	32.421875
11/30/09	195	10.83333333	67.70833333
12/1/09	189	10.5	65.625
12/2/09	219	12.16666667	76.04166667
12/3/09	196	10.88888889	68.05555556
12/4/09	104	5.777777778	36.11111111
12/5/09	76	5.428571429	33.92857143
12/6/09	108	6.75	42.1875
12/7/09	109	6.055555556	37.84722222
12/8/09	160	8.888888889	55.55555556
12/9/09	154	8.555555556	53.47222222
12/10/09	112	6.222222222	38.88888889
12/11/09	78	4.333333333	27.08333333
1/4/10	199	11.05555556	69.09722222
1/5/10	216	12	75
1/6/10	216	12	75
1/7/10	205	11.38888889	71.18055556
1/8/10	154	8.555555556	53.47222222
1/9/10	113	8.071428571	50.44642857
1/10/10	123	7.6875	48.046875
1/11/10	263	14.61111111	91.31944444
1/12/10	195	10.83333333	67.70833333
1/13/10	246	13.66666667	85.41666667
1/14/10	213	11.83333333	73.95833333
1/15/10	171	9.5	59.375
1/16/10	113	8.071428571	50.44642857
1/17/10			
1/18/10	139	7.722222222	48.26388889
1/19/10	219	12.16666667	76.04166667
1/20/10	195	10.83333333	67.70833333
1/21/10	218	12.11111111	75.69444444
1/22/10	188	10.44444444	65.27777778
1/23/10	119	8.5	53.125
1/24/10	143	8.9375	55.859375
1/25/10	199	11.05555556	69.09722222
1/26/10	250	13.88888889	86.80555556
1/27/10	162	9	56.25

1/28/10	221	12.27777778	76.73611111
1/29/10	162	9	56.25
1/30/10	135	9.642857143	60.26785714
1/31/10	135	8.4375	52.734375
2/1/10			
2/2/10			
2/3/10	255	14.16666667	88.54166667
2/4/10	186	10.33333333	64.58333333
2/5/10	170	9.444444444	59.02777778
2/6/10	143	7.944444444	49.65277778
2/7/10			
AVERAGE		9.091312057	56.82070035

Appendix E: Survey

EHFEM Implementation Survey

Survey Performed By: Company

Date: Total Score

Safety

1. Does the system used in the design adhere to all UL standards? Is the equipment UL Listed? 1 2 3 4 5

2. What safety measures are taken into account throughout the design and implementation process? 1 2 3 4 5

Total Weighted Points = ____ x (0.30)=____

Technology/Design

1. What type of inverter technology is used to convert DC power generated from the machine to AC power (standard or micro, off shelf, single or three phase, voltage and power ratings)? 1 2 3 4 5

2. Is a battery utilized in the design? 1 2 3 4 5

3. How is an individual unit connected back into the AC grid? 1 2 3 4 5

4. How much additional size does the retro-fit add to the exercise machine footprint? 1 2 3 4 5

5. Does the company sell a single retrofitted unit or only full systems? 1 2 3 4 5

6. Does the user experience any change to the workout experience after the retro-fit (i.e. Are the resistance levels comparable to the factory settings?) 1 2 3 4 5

Total Weighted Points:____ x(0.25)= ____

Maintenance/Support

1. What are the warranty terms for the entire system? 1 2 3 4 5

2. What are the warranty terms for the individual units within the system? 1 2 3 4 5

3. What type of service plans and technical assistance do you offer?	1	2	3	4	5
4. Does the company provide maintenance training?	1	2	3	4	5
5. What is the life expectancy of each unit?	1	2	3	4	5

Total Weighted Points = ____x(0.20) = ____

Cost

1. What is the cost of a single unit? Is there a bulk price?	1	2	3	4	5
2. What is the cost of the whole system?	1	2	3	4	5

Total Weighted Points = ____x (0.25)=____

Overall Score

To calculate the total score, take the sum of the total weighted points listed in each section above.

Appendix F: Elliptical Testing

Table 11 Praveen's Elliptical Test Results

Resistance	Strides/Min	Voltage	Current	Power
1	128	0	0.01	0
2	128	8.14	0.85	6.919
3	128	10.64	1.11	11.8104
4	1280	12.73	1.3	16.549
5	128	14.83	1.55	22.9865
6	128	17.68	1.73	30.5864
7	128	19.73	2.2	43.406
8	134	22.3	2.22	49.506
9	130	24.36	2.55	62.118
10	130	27.76	2.81	78.0056
11	130	30.4	3.04	92.416
12	122	31	3.16	97.96
13	120	33.4	3.41	113.894
14	120	34.2	3.6	123.12
15	120	37	3.85	142.45
16	122	41.9	3.72	155.868
17	90	35.8	3.43	122.794
18	90	34.7	3.42	118.674
19	90	32.4	2.94	95.256
20	90	35.7	3.29	117.453

Table 12 Audrey's Elliptical Test Results

Resistance	Strides/Min	Voltage	Current	Power
1	126	0	0	0
2	110	7.61	0.78	5.9358
3	110	9.81	0.97	9.5157
4	110	11.61	1.19	13.8159
5	110	13.53	1.39	18.8067
6	110	15.82	1.57	24.8374
7	110	17.98	1.83	32.9034
8	110	19.96	1.99	39.7204
9	110	23.31	2.29	53.3799
10	110	24.66	2.48	61.1568
11	110	26.04	2.75	71.61
12	110	28.9	2.9	83.81
13	110	29.72	3.11	92.4292
14	100	29.8	3.08	91.784
15	96	33.2	3.18	105.576
16	85	29.3	2.79	81.747
17	84	27.347	2.85	77.93895
18	74	25.44	2.79	70.9776
19	68	22.98	2.45	56.301
20	68	25.55	2.39	61.0645

Table 13 Justin's Elliptical Test Results

Resistance	Voltage (V)	Current (I)	Power (W)
1	0	0	0
2	7.8	0.75	5.85
3	10.4	1.02	10.608
4	11.9	1.22	14.518
5	14.5	1.46	21.17
6	16.4	1.7	27.88
7	19.3	1.97	38.021
8	24.4	2.18	53.192
9	24.4	2.43	59.292
10	26.5	2.64	69.96
11	29.1	2.98	86.718
12	32.5	3.26	105.95
13	34.4	3.47	119.368
14	37.2	3.72	138.384
15	39.8	3.61	143.678
16	40.9	4.17	170.553
17	41.1	4.44	182.484
18	45.7	4.59	209.763
19	43.8	4.32	189.216
20	37.8	3.72	140.616
			110-130 strides/min

Table 14 Melissa's Elliptical Test Results

Resistance	Voltage (V)	Current (I)	Power (W)
1	0	0	0
2	7.56	0.76	5.7456
3	10	1.02	10.2
4	11.67	1.17	13.6539
5	14.07	1.43	20.1201
6	16.5	1.66	27.39
7	18.9	1.87	35.343
8	21.2	2.11	44.732
9	24	2.4	57.6
10	26.9	2.68	72.092
11	28.8	2.89	83.232
12	30.1	3.02	90.902

13	33.6	3.23	108.528
14	33.9	3.45	116.955
15	32	3.37	107.84
16	31.8	2.94	93.492
17			0
18			0
19			0
20			0
		100-120 strides/min	

Table 15 Praveen 5-minute Workout Test

5 min interval				
Resistance	12			
	Strides/Min	Voltage(V)	Current (A)	Power(W)
1	130	33.7	3.41	114.917
2	132	33.1	3.38	111.878
3	130	33.7	3.29	110.873
4	132	33.4	3.35	111.89
5	130	32.4	3.38	109.512
6	132	33.5	3.41	114.235
7	134	33.7	3.38	113.906
8	134	33.4	3.39	113.226
9	134	33.6	3.37	113.232
10	134	33.4	3.35	111.89
			Average(W)	112.5559
			Wh	93.79658333

Table 16 Audrey's 5-minute Workout Test

5 min interval				
Resistance	10			
	Strides/Min	Voltage	Current	Power
1	120	22.57	2.31	52.1367
2	122	23.81	2.39	56.9059
3	122	23.87	2.41	57.5267
4	120	23.23	2.32	53.8936
5	120	23.71	2.39	56.6669
6	120	23.42	2.42	56.6764
7	118	23.36	2.38	55.5968
8	120	24.03	2.42	58.1526
9	122	24.14	2.48	59.8672
10	122	24.27	2.42	58.7334
			Average(W)	56.61562
			Wh	47.17968333

US Patent & Trademark Office
Patent Application Full Text and Image Database

(**1** of **1**)

United States Patent Application	***20090315336***
Kind Code	**A1**
Harr; Hudson Worthington	**December 24, 2009**

Renewable energy generation system

Abstract

A plurality of exercise machines each have a generator with a rotating element for creating a current flow. A primary electrical cable is between the input and output ends. A plurality of feed lines couple an associated generator with the primary electrical cable. A diode is in each of the feed lines. Current is allowed to flow from the generators to the primary feed line and any back flow is precluded. A regulator coupled to each feed line is adapted to regulate the voltage of each machine and to maintain such voltage at a constant level. An inverter is coupled to the primary electrical cable. A combiner/controller along the primary electrical cable between the inverter and the feed lines is adapted to combine the current from the generators being fed to the inverter.

Inventors: **Harr; Hudson Worthington**; *(St. Petersburg, FL)*

Correspondence Name and Address: **MICHAEL J. COLITZ, JR.**
640 Douglas Avenue
DUNEDIN
FL
34698
US

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Claims

1. A renewable energy generation system comprising:a plurality of exercise machines, each having a generator with a rotating element for creating a current flow;a primary electrical cable between the input and output ends;a plurality of feed lines coupling an associated generator with the primary electrical cable, a diode in each feed line to allow current flow from the generators to the primary feed line and to preclude any back flow;a regulator coupled to each feed line adapted to regulate the voltage of each machine and to maintain such voltage at a constant level;an inverter coupled to the primary electrical cable; anda combiner/controller along the primary electrical cable between the inverter and the feed lines, the combiner/controller adapted to combine the current from the generators being fed to the inverter.

2. The system as set forth in claim 1 and further including:a main circuit breaker panel coupled to a source of potential of a facility housing the system, the main circuit breaker panel adapted to monitor current flow through a facility housing and power the transformer and the machines as well as other electrical powered devices, the main circuit breaker panel also adapted to terminate current flow through such facility to terminate power to the transformer and machines as well as other electrical powered devices in the event of a short circuit or overload.

3. The system as set forth in claim 2 and further including:a secondary electrical cable coupled to the main breaker panel, the output end of the secondary cable coupled to the input end of the inverter, an AC disconnect along the secondary electrical cable between the inverter and the main breaker panel, the AC disconnect under the control and discretion of a user and adapted to terminate the flow of current from the main breaker panel to the inverter and combiner/controller and generators.

4. The system as set forth in claim 1 and further including:a display screen on each exercise machine adapted to provide a visual display of a plurality of factors being generated by a each particular user of each particular exercise machine at any given time during a particular exercise program.

5. A renewable energy generation system for capturing energy generated through the use of exercise machines and for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, ecologically friendly, power conserving, grid-tied, and economical manner, the system comprising, in combination:a plurality of exercise machines chosen from the class of exercise machines including elliptical machines, climbers, treadmills, bikes and like machines, each exercise machine having a generator with a rotating element, each rotating element adapted to be rotated through the exercising activities of a user for creating a current flow;a primary electrical cable having an input end and an output end with an intermediate extent between the input and output end;a plurality of feed lines, each feed line coupling an associated generator with spaced regions on the intermediate extent of the primary electrical cable, a diode in each feed line to allow current flow from the generators to the primary feed line and to preclude any back flow of current from the primary feed line to the generators;a regulator coupled to each feed line adapted to regulate upwardly and downwardly the voltage of each machine and to maintain such voltage at a constant level, 50 volts in the preferred embodiment, regardless of the input work from the user at a machine, the regulator also adapted to allow the current contribution of each machine to vary as a function of the input work from the user at a machine;an inverter having an input end and an output end, the input end of the inverter coupled to the output end of the primary electrical cable, a transformer coupling the inverter to a 120 volt AC source of potential for powering the inverter;a combiner/controller along the primary electrical cable between the inverter and the feed lines, the combiner/controller adapted to combine the current from the generators being fed to the inverter;a main circuit breaker panel having a first end and a second end, the first end of the main breaker panel coupled to a source of potential of a facility housing the system, the second end of the main breaker panel coupled to the output end of the inverter, the main circuit breaker panel adapted to monitor current flow through a facility housing and power the transformer and the machines as well as other electrical powered devices, the main circuit breaker panel also adapted to terminate current flow through such facility to terminate power to the transformer and machines as well as other electrical powered devices in the event of a short circuit or overload, the transformer output in the preferred embodiment being 50 volts at 0.3 amps to insure that the inverter stays online and synchronized to the grid with minimum loss;a secondary electrical cable having an input end and an output end with an intermediate extent between the input and output end, the output end of the secondary electrical cable coupled to the input end of the main breaker panel, the input end of the secondary cable coupled to the output end of the inverter, an AC

disconnect along the secondary electrical cable between the inverter and the main breaker panel, the AC disconnect under the control and discretion of a user and adapted to terminate the flow of current from the main breaker panel to the inverter and combiner/controller and generators; anda display screen on each exercise machine adapted to provide a visual display of a plurality of factors being generated by a each particular user of each particular exercise machine at any given time during a particular exercise program, such factors including user-watts, voltage, peak amps and peak watts.

Description

BACKGROUND OF THE INVENTION

[0001]1. Field of the Invention

[0002]The present invention relates to a renewable energy generation system and more particularly pertains to capturing energy generated through the use of exercise machines for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, ecologically friendly, power conserving, grid-tied, and economical manner.

[0003]2. Description of the Prior Art

[0004]The use of renewable energy generation systems of known designs and configurations is known in the prior art. More specifically, renewable energy generation systems of known designs and configurations previously devised and utilized for the purpose of generating power through known methods and apparatuses are known to consist basically of familiar, expected, and obvious structural configurations, notwithstanding the myriad of designs encompassed by the crowded prior art which has been developed for the fulfillment of countless objectives and requirements.

[0005]By way of example, U.S. Patent Application Publication Number US 2002/0147079 published Oct. 10, 2002 to Kalnbach relates to a Human Generated Power Source.

[0006]While this device fulfills its particular objectives and requirements, the aforementioned patent does not describe a renewable energy generation system that allows for capturing energy generated through the use of exercise machines for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, eclogically friendly, power conserving, grid-tied, and economical manner.

[0007]In this respect, the renewable energy generation system according to the present invention substantially departs from the conventional concepts and designs of the prior art, and in doing so provides an apparatus primarily developed for the purpose of capturing energy generated through the use of exercise machines for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, eclogically friendly, power conserving, grid-tied, and economical manner.

[0008]Therefore, it can be appreciated that there exists a continuing need for a new and improved renewable energy generation system which can be used for capturing energy generated through the use of exercise machines for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, eclogically friendly, power conserving, grid-tied, and economical manner. In this regard, the present invention substantially fulfills this need.

SUMMARY OF THE INVENTION

[0009]In view of the foregoing disadvantages inherent in the known types of renewable energy generation systems of known designs and configurations now present in the prior art, the present invention provides an improved renewable energy generation system. As such, the general purpose of the present invention, which will be described subsequently in greater detail, is to provide a new and improved renewable energy generation system and method which has all the advantages of the prior art and none of the disadvantages.

[0010]To attain this, the present invention essentially comprises a renewable energy generation system. First provided is a plurality of exercise machines. The exercise machines are chosen from the class of exercise machines. The class of exercise machines includes elliptical machines, climbers, treadmills, bikes and like machines.

Each exercise machine has a generator. The generator has a rotating element. Each rotating element is adapted to be rotated through the exercising activities of a user. In this manner a current flow is created.

[0011]A primary electrical cable is provided. The primary electrical cable has an input end. The primary electrical cable has an output end. The primary electrical cable has an intermediate extent. The intermediate extent is provided between the input and output end.

[0012]Provided next is a plurality of feed lines. Each feed line couples an associated generator. Spaced regions are provided on the intermediate extent of the primary electrical cable. A diode is provided in each feed line. The diode allows current flow from the generators to the primary feed line. The diode further precludes any back flow of current from the primary feed line to the generators.

[0013]A regulator is provided next. The regulator is coupled to each feed line. The regulator is adapted to regulate upwardly and downwardly the voltage of each machine. The regulator is further adapted to maintain such voltage at a constant level, regardless of the input work from the user at a machine. In the preferred embodiment, the constant level is 50 volts. The regulator is also adapted to allow the current contribution of each machine to vary as a function of the input work from the user at a machine.

[0014]An inverter is provided. The inverter has an input end. The inverter has an output end. The input end of the inverter is coupled to the output end of the primary electrical cable. A transformer is provided. The transformer couples the inverter to a 120 volt AC source of potential. In this manner the inverter is powered.

[0015]Next provided is a combiner/controller. The combiner/controller is provided along the primary electrical cable between the inverter and the feed lines. The combiner/controller is adapted to combine the current from the generators being fed to the inverter.

[0016]A main circuit breaker panel is provided next. The main circuit breaker panel has a first end. The main circuit breaker panel has a second end. The first end of the main breaker panel is coupled to a source of potential of a facility housing the system. The second end of the main breaker panel is coupled to the output end of the inverter. The main circuit breaker panel is adapted to monitor current flow through a facility housing and power the transformer and the machines as well as other electrical powered devices. The main circuit breaker panel is also adapted to terminate current flow through such facility. In this manner power to the transformer and machines as well as other electrical powered devices is terminated in the event of a short circuit or overload. The transformer output in the preferred embodiment is 50 volts at 0.3 amps. In this manner the inverter stays online and synchronized to the grid with minimum loss.

[0017]Further provided is a secondary electrical cable. The secondary electrical cable has an input end. The secondary electrical cable has an output end. The secondary electrical cable has an intermediate extent. The intermediate extent is provided between the input and output end. The output end of the secondary electrical cable is coupled to the input end of the main breaker panel. The input end of the secondary cable is coupled to the output end of the inverter. An AC disconnect is provided. The AC disconnect is provided along the secondary electrical cable between the inverter and the main breaker panel. The AC disconnect is under the control and discretion of a user. The AC disconnect is adapted to terminate the flow of current from the main breaker panel to the inverter and combiner/controller and generators.

[0018]Provided last is a display screen. The display screen is provided on each exercise machine. The display screen is adapted to provide a visual display of a plurality of factors being generated by a each particular user of each particular exercise machine at any given time during a particular exercise program. Such factors include user-watts, voltage, peak amps and peak watts.

[0019]There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows may be better understood and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject matter of the claims attached.

[0020]In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of descriptions and should not be regarded as limiting.

[0021]As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

[0022]It is therefore an object of the present invention to provide a new and improved renewable energy generation system which has all of the advantages of the prior art renewable energy generation systems of known designs and configurations and none of the disadvantages.

[0023]It is another object of the present invention to provide a new and improved renewable energy generation system which may be easily and efficiently manufactured and marketed.

[0024]It is further object of the present invention to provide a new and improved renewable energy generation system which is of durable and reliable constructions.

[0025]An even further object of the present invention is to provide a new and improved renewable energy generation system which is susceptible of a low cost of manufacture with regard to both materials and labor, and which accordingly is then susceptible of low prices of sale to the consuming public, thereby making such renewable energy generation system economically available to the buying public.

[0026]Even still another object of the present invention is to provide a renewable energy generation system for capturing energy generated through the use of exercise machines for converting such captured energy into electrical power to be used in driving associated machinery, such captured energy also adapted to be returned to a communal power source, all in a safe, ecologically friendly, power conserving, grid-tied, and economical manner.

[0027]Lastly, it is an object of the present invention to provide a new and improved renewable energy generation system. A plurality of exercise machines is provided. Each machine has a generator with a rotating element for creating a current flow. A primary electrical cable is provided between the input and output ends. A plurality of feed lines couple an associated generator with the primary electrical cable. A diode is provided in each of the feed lines. In this manner current is allowed to flow from the generators to the primary feed line but any back flow is precluded. A regulator is coupled to each feed line. The regulator is adapted to regulate the voltage of each machine and to maintain such voltage at a constant level. An inverter is coupled to the primary electrical cable. A combiner/controller is provided along the primary electrical cable between the inverter and the feed lines. The combiner/controller is adapted to combine the current from the generators being fed to the inverter.

[0028]These together with other objects of the invention, along with the various features of novelty which characterize the invention, are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and the specific objects attained by its uses, reference should be had to the accompanying drawings and descriptive matter in which there is illustrated preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029]The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

[0030]FIG. 1 is a perspective illustration of a first section of a power generating system constructed in accordance with the principles of the present invention.

[0031]FIG. 2 is a perspective illustration of a second section of a power generating system constructed in accordance with the principles of the present invention.

[0032]FIG. 3 is a plan view of a display screen of one of the exercise machines.

[0033]FIG. 4 is an electrical schematic illustration of the power generating system of the prior Figures.

[0034]The same reference numerals refer to the same parts throughout the various Figures.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0035]With reference now to the drawings, and in particular to FIG. 1 thereof, the preferred embodiment of the new and improved renewable energy generation system embodying the principles and concepts of the present invention and generally designated by the reference numeral 10 will be described.

[0036]The present invention, the renewable energy generation system 10 is comprised of a plurality of components. Such components in their broadest context include a plurality of exercise machines, a primary electrical cable, a plurality of feed lines, a regulator, an inverter and a combiner/controller. Such components are individually configured and correlated with respect to each other so as to attain the desired objective.

[0037]First provided is a plurality of exercise machines. The exercise machines are chosen from the class of exercise machines. The class of exercise machines includes elliptical machines 14, climbers 16, treadmills 18, bikes 20 and like machines. Each exercise machine has a generator 22. The generator has a rotating element 24. Each rotating element is adapted to be rotated through the exercising activities of a user. In this manner a current flow is created.

[0038]A primary electrical cable 28 is provided. The primary electrical cable has an input end 30. The primary electrical cable has an output end 32. The primary electrical cable has an intermediate extent. The intermediate extent is provided between the input and output end.

[0039]Provided next is a plurality of feed lines 36. Each feed line couples an associated generator. Spaced regions are provided on the intermediate extent of the primary electrical cable. A diode 38 is provided in each feed line. The diode allows current flow from the generators to the primary feed line. The diode further precludes any back flow of current from the primary feed line to the generators.

[0040]A regulator 42 is provided next. The regulator is coupled to each feed line. The regulator is adapted to regulate upwardly and downwardly the voltage of each machine. The regulator is further adapted to maintain such voltage at a constant level, regardless of the input work from the user at a machine. In the preferred embodiment, the constant level is 50 volts. The regulator is also adapted to allow the current contribution of each machine to vary as a function of the input work from the user at a machine.

[0041]An inverter 46 is provided. The inverter has an input end 48. The inverter has an output end 50. The input end of the inverter is coupled to the output end of the primary electrical cable. A transformer 52 is provided. The transformer couples the inverter to a 120 volt AC source of potential. In this manner the inverter is powered which keeps the unit online and grid synchronous.

[0042]Next provided is a combiner/controller 56. The combiner/controller is provided along the primary electrical cable between the inverter and the feed lines. The combiner/controller is adapted to combine the current from the generators being fed to the inverter.

[0043]A main circuit breaker panel 60 is provided next. The main circuit breaker panel has a first end 62. The main circuit breaker panel has a second end 64. The first end of the main breaker panel is coupled to a source of potential of a facility housing the system. The second end of the main breaker panel is coupled to the output end of the inverter via a standard wall plug. The main circuit breaker panel is adapted to monitor current flow through a facility housing and power the transformer and the machines as well as other electrical powered devices. The main circuit breaker panel is also adapted to terminate current flow through such facility. In this manner power to the transformer and machines as well as other electrical powered devices is terminated in the event of a short circuit or overload. The transformer output in the preferred embodiment is 50 volts at 0.3 amps. In this manner the inverter stays online and synchronized to the grid with minimum loss.

[0044]Further provided is a secondary electrical cable 68. The secondary electrical cable has an input end 70. The secondary electrical cable has an output end 72. The secondary electrical cable has an intermediate extent. The intermediate extent is provided between the input and output ends. The output end of the secondary electrical cable is coupled to the input end of the main breaker panel. The input end of the secondary cable is coupled to the output end of the inverter. An AC disconnect 74 is provided. The AC disconnect is provided along the secondary electrical cable between the inverter and the main breaker panel. The AC disconnect is under the control and discretion of a user. The AC disconnect is adapted to terminate the flow of current from the main breaker panel to the inverter and combiner/controller and generators.

[0045]Provided last is a display screen 78. The display screen is provided on each exercise machine. The display screen is adapted to provide a visual display of a plurality of factors being generated by a each particular user of each particular exercise machine at any given time during a particular exercise program. Such factors include user-watts, voltage, peak amps and peak watts.

[0046]The inverter's 120 volt wall plug-in power may be thought of in an auxiliary fashion serving only as backup to maintain the connection and circumvent the inverter's startup process so that array is live instantaneously when users get on the machines. Considering that the machine's load is dependent upon the inverter's dynamic loading, there must always be a "grid" connection for the users to experience resistance.

[0047]The secondary cable is only pertinent due to the amount of current flow which could reach 20 plus amps coming from the array. This requires a dedicated line to the system.

[0048]The system negates the need for batteries, in the preferred embodiment, and utilizes the building's load as resistance to the users. It uses this dynamic load to optimize each machine creating an identical user experience to the machine's previous state. The load to exercise equipment is optimized so users cannot discern which machines are hooked into the system and which are factory default stand alone units.

[0049]By using the building as the load directly, work is being performed to offset the power coming into the facility via the utility grid on a continual basis. This allows power to be sent to the building for immediate use while minimizing losses.

[0050]The user experience does not vary from day to day and is independent of the number of machines in use.

[0051]The system allows users to make current contributions to the building/grid without feedback between machines. Each unit operates on the same parallel circuit but is not affected by neighboring machines. The load experienced by the user is a constant independent of other machines' utilization.

[0052]As to the manner of usage and operation of the present invention, the same should be apparent from the above description. Accordingly, no further discussion relating to the manner of usage and operation will be provided.

[0053]With respect to the above description then, it is to be realized that the optimum dimensional relationships for the parts of the invention, to include variations in size, materials, shape, form, function and manner of operation, assembly and use, are deemed readily apparent and obvious to one skilled in the art, and all equivalent relationships to those illustrated in the drawings and described in the specification are intended to be encompassed by the present invention.

[0054]Therefore, the foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

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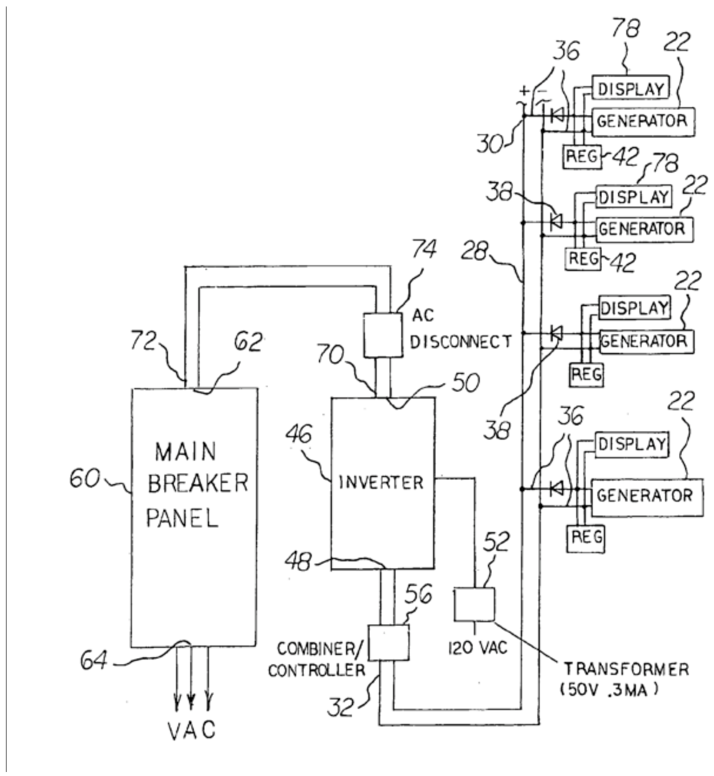

Figure 22 ReRev Patent Schematic

Appendix H: Inverter Datasheets

Data sheets for Power-One Aurora Wind Inverters and be obtained from the following website:

Source: http://www.power-one.com/renewable-energy/wind-inverters.php

Please obtain data sheets for the PVI-3.0, PVI-3.6, PVI-4.2, and PVI-6000.

Appendix I: NEM Fee Matrix

Please obtain meter re-programming fees from the PG&E file listed below.

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