AC 2009-1093: USING ONE-DIMENSIONAL SOFTWARE TOOLS IN LOW-POWER AMBIENT ENERGY HARVESTING AND GENERATION SIMULATIONS

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Using One Dimensional Software Tools in Low Power Ambient Energy Harvesting and Generation Simulations

Abstract

One dimensional design, analysis and simulation software tools are used by professionals and educators globally, and thus the students are given the chance to familiarize themselves with the operation of analysis and simulation software packages. One of the major labor area for engineering and technology students is to use one of the simulation software tools for the analysis and simulation of engineering systems. Recently the use and development of educational software and simulation tools have been considerably increased for both undergraduate and graduate levels. Software tools developers started giving attention to reduce amount of expensive commercial testing equipments by software and simulation tools which gives the upfront analysis opportunity to industry. Many educational institutions prefer using software simulation tools instead of buying expensive test equipments for their laboratories, and research facilities. Taking engineering education into account, a demonstration mostly engages with process modeling, testing and simulation, imitated data acquisition and process control. For the demonstration purposes high level graphical user interface is required for providing efficient communications. The virtual applications may enhance both theoretical and hands-on experience of engineering technology students by supporting laboratory experiments as well.

MSC.Easy5 and LMS Imagine.Lab AMESim are some of the well known system modeling, analysis and simulation software tools that offer solutions to many problems in mechanical, thermal, hydraulics, pneumatics, electrical, control etc. areas. These practical software tools also help to improve learning speed and knowledge level of students in many engineering and technology subjects.

It is very helpful to use LMS Imagine.Lab AMESim and MSC.Easy5 one dimensional analytical simulation tools to test overall energy harvesting system and its components before implementation of the system. This paper presents a number of case studies used in applied class projects, laboratory activities, and research works for various levels from B.S. to PhD degree programs in electrical and mechanical engineering technology areas. Students have found the software tools helpful and user friendly in understanding fundamentals of physical phenomena in engineering and technology areas. In the case studies low power ambient energy harvesting systems were analyzed and simulated with real specifications of the overall components including gear ratios, generator units, electrical circuits, and battery units. The case studies include power scavenging from hydraulic door closers and fitness equipments through human power and using fiber composite bimorph to capture waste mechanical energy from human body. Testing the interoperability of all components by analyzing and simulating them reduced the redundancy of the energy harvesting systems after the implementation of the systems. In the design of the analytical simulation interfaces, the flexibility of the part modifications made it possible to change the parameters of the system for future researches.

1. Introduction

The engineering and technology software tools are used by professionals and companies worldwide, and thus the students are given the opportunity to familiarize themselves with the operation of software packages that most likely they will use after they join the workforce. A substantial portion of the classroom projects in engineering technology curriculum that require the use of advanced software tools has been increased in many higher institutions for both undergraduate and graduate levels.

Emerging virtual applications may enhance understanding both theoretical and applied experiences of engineering technology students by supporting laboratory experiments. Easy5, AMESim are some of the well known system modeling, analyzing, and simulation software tools that offer solutions to many problems in mechanical, hydraulics, pneumatics, electrical etc. controls areas. These virtual tools also help to improve learning pace and knowledge level of students in many applied subjects.

Computer aided engineering education is a valuable solution for increasing the quality of laboratory environments of engineering education courses. The classroom education, similarly to laboratory exercises, may be further visualized by introducing more advanced simulation tools in demonstration environment. Several case studies have been demonstrated using MSC.Easy5and LMS Imagine.Lab AMESim; a professional grade, integrated platform for 1D multi-domain system simulations.

The research was carried out to examine reliability of energy harvesting systems using one dimensional advanced software tools such as LMS Imagine. Lab AMESim and MSC.Easy5. The demonstration of human kinetic energy and its three different uses as ambient power source were investigated and tested with simulations. Three different energy scavenging techniques for low power portable and wireless electronic devices were examined. Human kinetic energy can be transferred in a number of ways so the main source was energized by human power to operate three ambient energy sources. These three forms of ambient energy sources (waste mechanical energy from hydraulic door closer, elliptical trainer, and human motions from shoe sole/insole such as walking or running) were converted to electrical energy and the energy stored in battery banks for use in the systems.

This paper presents a number of case studies used in applied class projects, laboratory activities, and doctoral research projects for B.S. and PhD degree program in electrical and industrial engineering technology areas. Many students have found the software tools helpful and user friendly in understanding fundamentals of physical phenomena in engineering and technology areas.

2. Characteristics of Energy Harvesting Sources

A hydraulic door closer was the first ambient energy source tested for this research. An energy harvesting system was graphically designed, simulated to capture and convert waste mechanical rotations from a hydraulic door closer. For this purpose, a hydraulic door closer as a potential mechanical energy supply was obtained from the Physical Plant at the University of ……………….. For the hydraulic door closer human presence was required to open the door.

A second ambient energy source of human power was elliptical trainer. One of the most commonly used source of human energy applications is propelling bicycles (fitness or regular) and that can generate electricity to power peripherals such as electronic display panels of the bicycle. An appropriate energy harvesting and storage system was graphically designed and simulated to investigate reliability of the fitness bicycle as an ambient energy source.

The third source of harvesting environmental energy was waste energy from human walking/running activities and was studied using piezoelectric fiber composites which are capable of generating/producing electricity from vibrations. The reason for choosing ceramic piezoelectric materials to capture tensions and vibration from the motion is the nature of the piezoelectric material which is capable of converting vibrations into electric current. The piezoelectric fiber composites were graphically inserted into shoe insoles where a significant amount of tensions, stresses and vibrations occurs when a person walks or runs.

Based on the ambient energy source characteristics, electric energy conversion and storage circuit specifications were inserted into a circuit and a storage modules for low power electronic applications. These sources were characterized according to energy harvesting (scavenging) methods, power and energy density.

Typical component specifications, such as electric generator, motor, gear sets, piezoelectric element, electronic part and storage device modules were inserted into modules to simulate energy harvesting systems. It was expected that the proper choice of these materials would develop an efficient energy harvesting device. Figure 1 shows a block diagram of the three different experimental energy harvesting systems with the matching order in simulation interface.

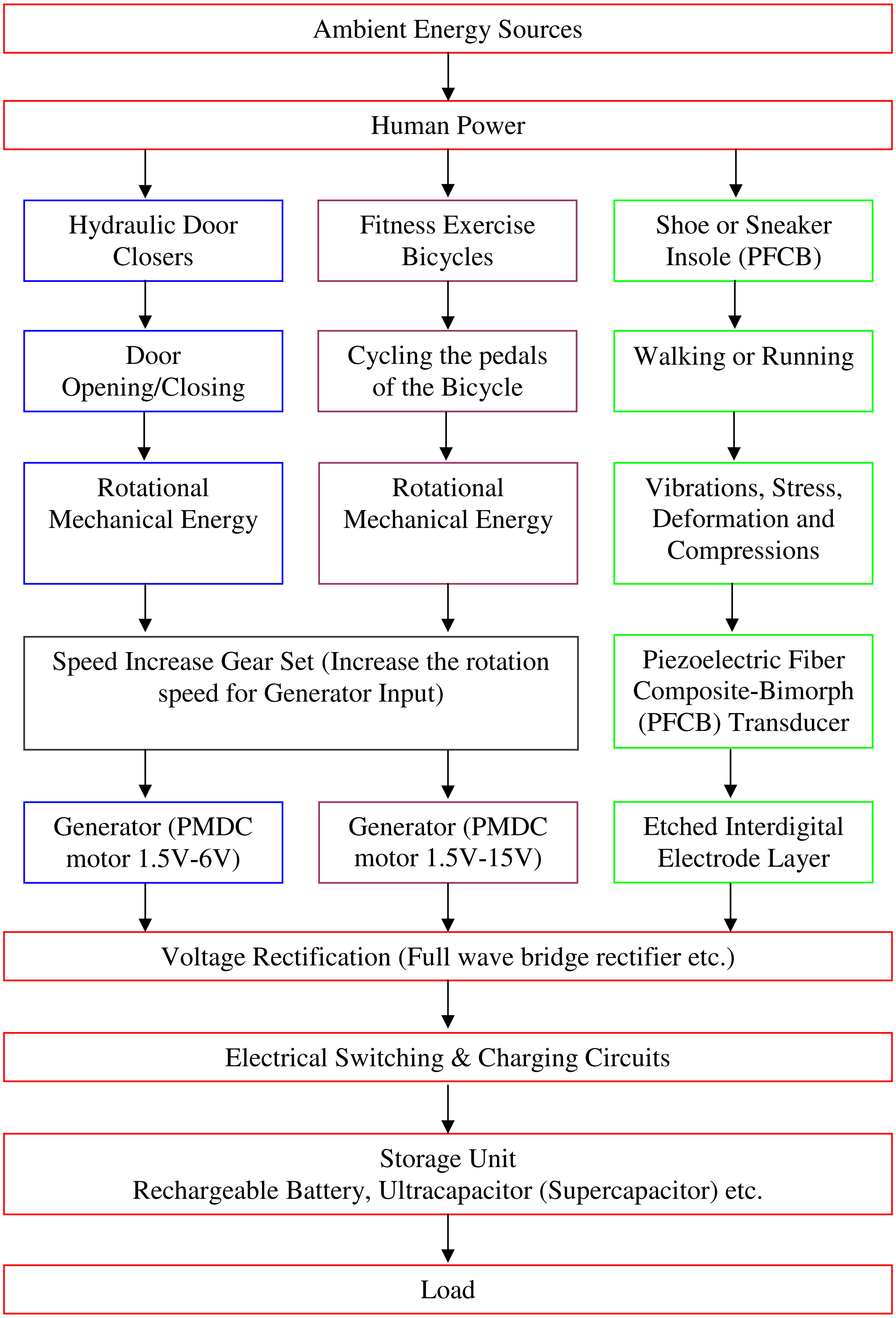

Figure1: Block diagram of experimental energy harvesting systems

3. Hydraulic Door Closers

The first phase of door hydraulic system operations is generally activated by human power; the second stage is the closing phase that is controlled by a spring and a hydraulic damping mechanism. The waste mechanical energy was converted into electrical energy using appropriate device modules and provide energy to low power electronic devices and applications such as security alarms, exit signs, or wireless security cameras. Overall simulations including all the modules necessary for the system were conducted using the MSC.Easy5 ® analysis and simulation interface.[1] MSC EASY5 is an engineering analysis and simulation software package originally created by Boeing Inc. and currently owned by MSC Software Inc. The analysis results indicate the speed of the gear set reaches its expected performance.

3.1 Overall System Analysis and Simulation with MSC. Easy5

The overall energy harvesting system with real specifications data of speed increase gear sets, generator unit, energy conditioning circuit, and battery simulations were conducted using the MSC.Easy5 ® advanced simulation and analysis tool. Specifications and characteristics of the generator unit, and battery were taken from manufacturer datasheets in order to be consistent with the future experimental implementation. In the following paragraph overall system analyses with MSC. Easy5 are explained in detail. The analysis results were compared with outputs in order to measure if efficiency of the system reached expected performance.

The MSC. Easy5 engineering analysis system was the base system for overall analysis of the generator unit, gear train, battery unit, battery controller/power converter, and bus connector units. The above components were required for the system analysis and were available within the MSC. Easy5 Ricardo Power Train library-version 5.1 (PT). The library components were MO-Motor (Generator), BA-Battery, BC-Battery controller/Power converter, and BX-Bus Connector. The parameters and specifications were studied separately to be consistent between the connections of the components. The Ricardo PT library had general components and general specifications were input by the software company automatically. General specifications of the PT library modules were intended for high power applications such as automobile technology, mechanical and electrical systems and hybrid vehicles. Therefore all specifications of the generator, battery, and gear train were altered according to manufacturer specifications of components purchased for the energy harvesting system. Also, the idea of the hydraulic door closer energy harvesting system model was represented on the MSC. Easy5 interface. Initially, it was assumed that the door was opened 30 times (each door opening is 180°, i.e. half cycle) in a minute which is 15 rpm. The specific gear train increased the speed from 15 rpm to 5160 rpm to meet input requirements of the generator unit for consistent electricity generation through a DC electric motor. The interface of the overall analysis is shown in Figure 2. The system was run 3600 seconds/hr and after running test results for input speed, output speed, and state of the battery charge in the analysis were indicated in Figures 3, 4, and 5 respectively.

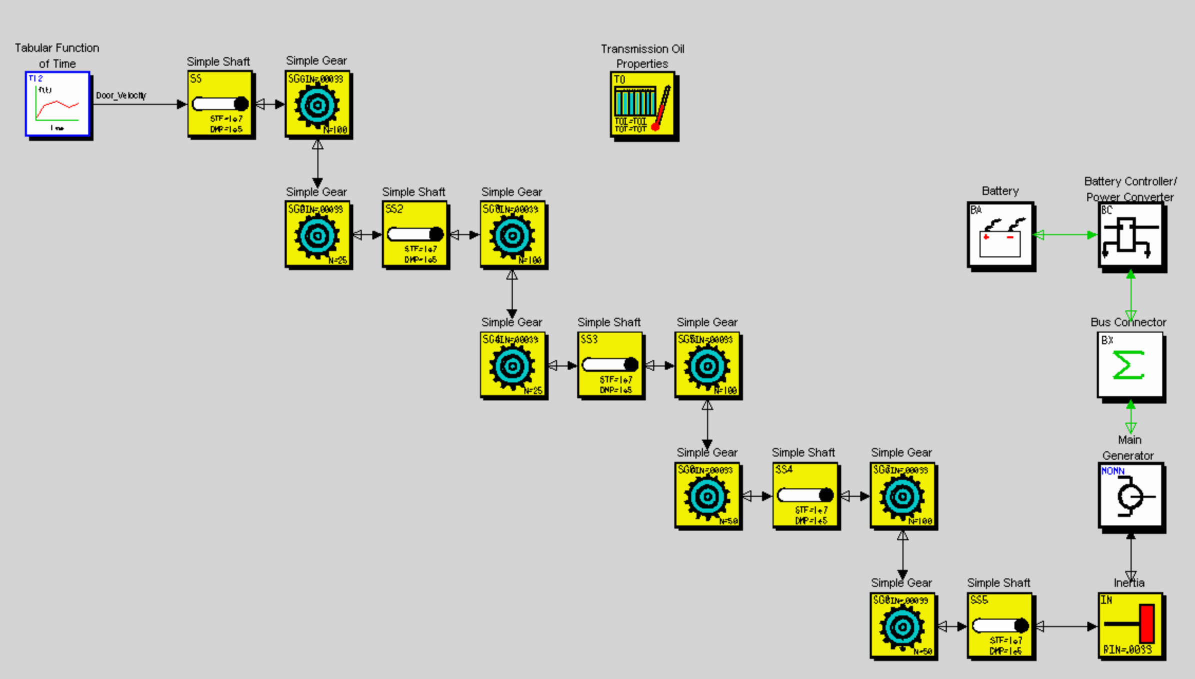

Figure 2: The MSC. Easy5 model analysis & simulation interface

Input speed of the gear train analysis for the gear box depends on initially 15 rpm and is shown in Figure 3. Figure 4 shows the result of the output speed in gear train analysis. Each of the plots for the speed increase shows increase at the first and last shafts within the given time period. By changing the gear and shaft positions, speed can be decreased or increased if the generator unit and the battery specifications are changed.

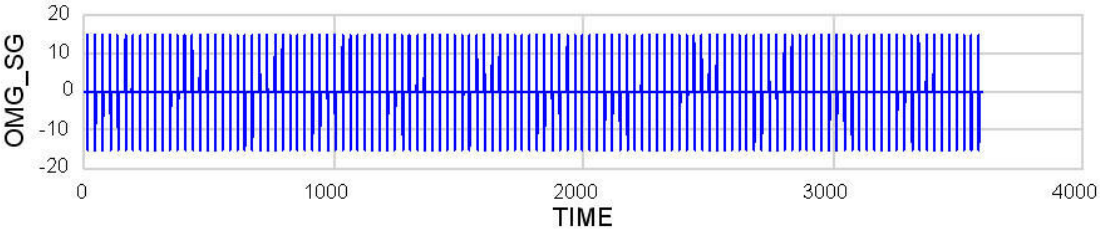

Figure 3: Initial speed in the gear train analysis & simulation for 1:344 ratio

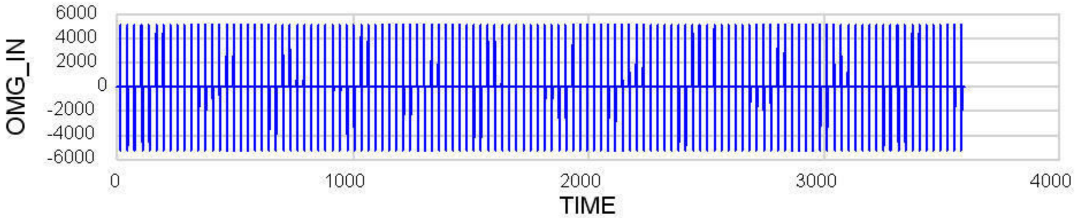

Figure 4: Output speed in the gear train analysis & simulation for 1:344 ratio

The output plots show the consequent increase of speed from 15 rpm to 5160 rpm at 1:344 speed ratio. Once this input speed is applied to the generator unit the state of battery charge starts to increase consequently. The overall system is run for one hour to see if battery capacity is increasing. Simulation results showed that it takes approximately 16 hours to charge a fully discharged battery. The state of the charge of the battery unit is shown in Figure 5. The system should run about 16 hours in order to receive a fully charged phase of the battery. However, depending on battery characteristics, charging time may change.

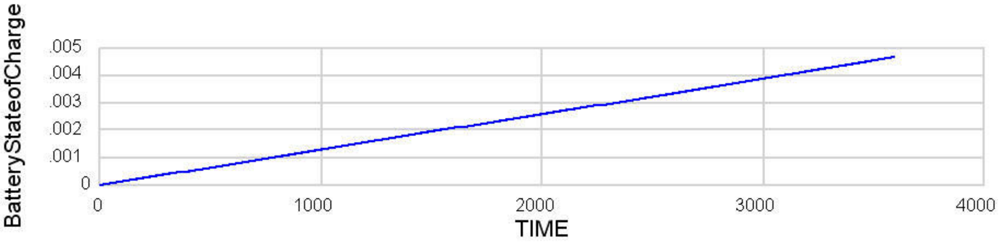

Figure 5: Battery state of charge with 1:344 ratio

Also, the simulation analysis was conducted to study the battery state of the charge ratings with 1:64 gear ratio gearbox. It was expected that the charge time would be increased before the MSC Easy5 analysis of the system. As expected the charging time of the same battery was increased because of the low gear ratio. Input and output speeds of the gear train with 1:64 ratio was shown in Figure 6, and 7 respectively. Initial speed of the gear train was configured as 15 rpm and the output speed reached 960 rpm as an input speed to the generator unit.

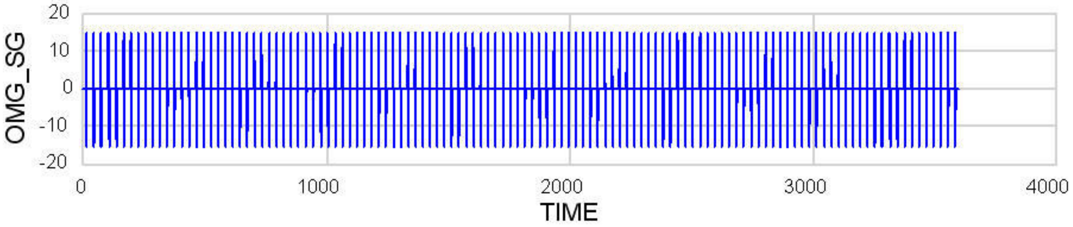

Figure 6: Initial speed in the gear train analysis & simulation for 1:64 ratio

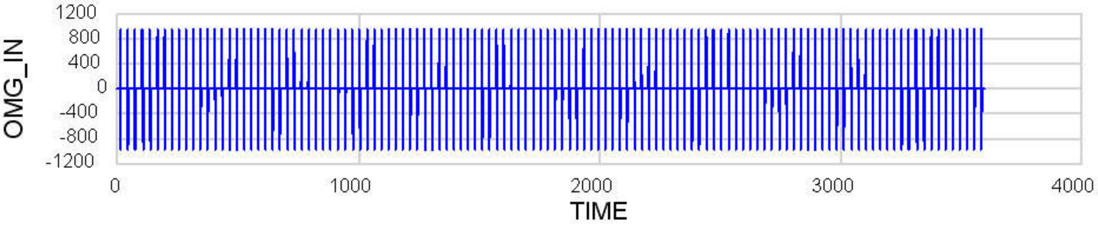

Figure 7: Output speed in the gear train analysis & simulation for 1:64 ratio

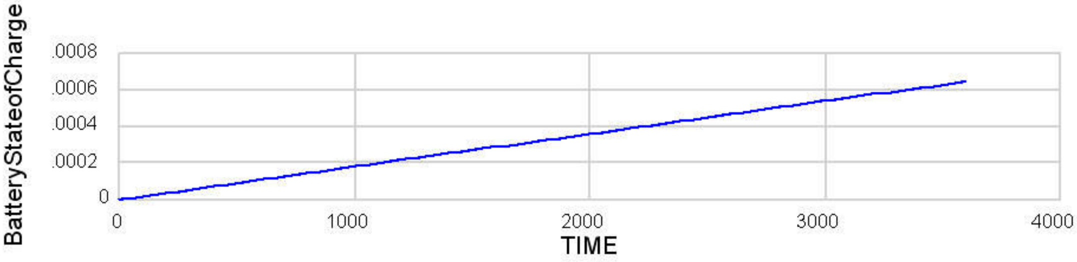

Figure 8: Battery state of charge with 1:64 gear ratio

The battery charging graph in Figure 8 shows the consequent increase of the battery capacity at the 1:64 speed ratio. The overall system is run for one hour to see if battery charging is increasing. Simulation results at the 1:64 ratio showed that it takes approximately 140 hours to charge a fully discharged battery. Thus the 1:64 ratio is not feasible to use with this method to power a low power electronic application. The system would need to be run for 140 hours in order to achieve a fully charged phase of the battery.

4. Fitness Equipments

Human kinetic energy can be extracted and transferred to small scale power applications in few different ways. For example moving bicycles are most commonly operated by human kinetic energy, but can also be used to extract energy by powering hand-crank tools. In this section of the paper an energy harvesting system from human kinetic energy was presented using one dimensional analytical simulation software tool is named LMS Imagine. Lab AMESim. For this purpose the rotating pedal parts of the elliptical trainer were investigated for appropriate waste mechanical energy capturing and conversion system.

A human powered pedal generator can be a perfect solution to power a fitness equipment display, hence eliminating conventional battery power and its regular maintenance. Not only does the display get powered but also different applications such as a small radio, or digital embedded heartbeat reader can be powered at the same time. The average continuous power which can be generated by pedaling the fitness bicycle can be adjusted through changing the generator unit (DC motor) and energy harvesting circuit. The graphical modules of gearset and generator unit were placed at the appropriate place inside the pedal system in LMS Imagine. Lab AMESim graphical interface. It was a design issue to place the gearset and the generator where the most rotation is occurring during pedaling the elliptical trainer. The power output of the generator unit was directly proportional to the effort put into it but the output power of energy harvesting circuit was a fixed voltage to avoid damaging the storage device. So the amount of electrical power that can be generated by the human powered generator is determined by the energy available to turn the pedals. The stronger the human power, the more electrical power which can be generated and stored. The produced DC power can also be used for different applications even for AC appliances by using a DC-AC inverter connected to a storage unit for a stable AC output. If an average person is expected to produce sustainable 100-1500 Watts then charging a battery with average 50mA current will be enough to charge a battery or a capacitor to power a low power electronic device.

4.1 Overall System Analysis and Simulation with LMS Imagine. Lab AMESim

In the “LMS Imagine. Lab AMESim” advanced simulation tool the overall energy harvesting system was analyzed and simulated with real specifications of the overall components including wheel ratios, generator, circuit, and battery unit. Initially the simulation was conducted using W_{OUT}=1800rpm input velocity for the generator input to a Barber-Colman PMDC brushless generator with AC output 6VAC out at 1800rpm and five units of 1.2V rechargeable batteries connected in series to reach 6V which is needed to power the elliptical trainer’s electronic panel. The AMESim simulation interface was depicted in Figure 9 with all modules.

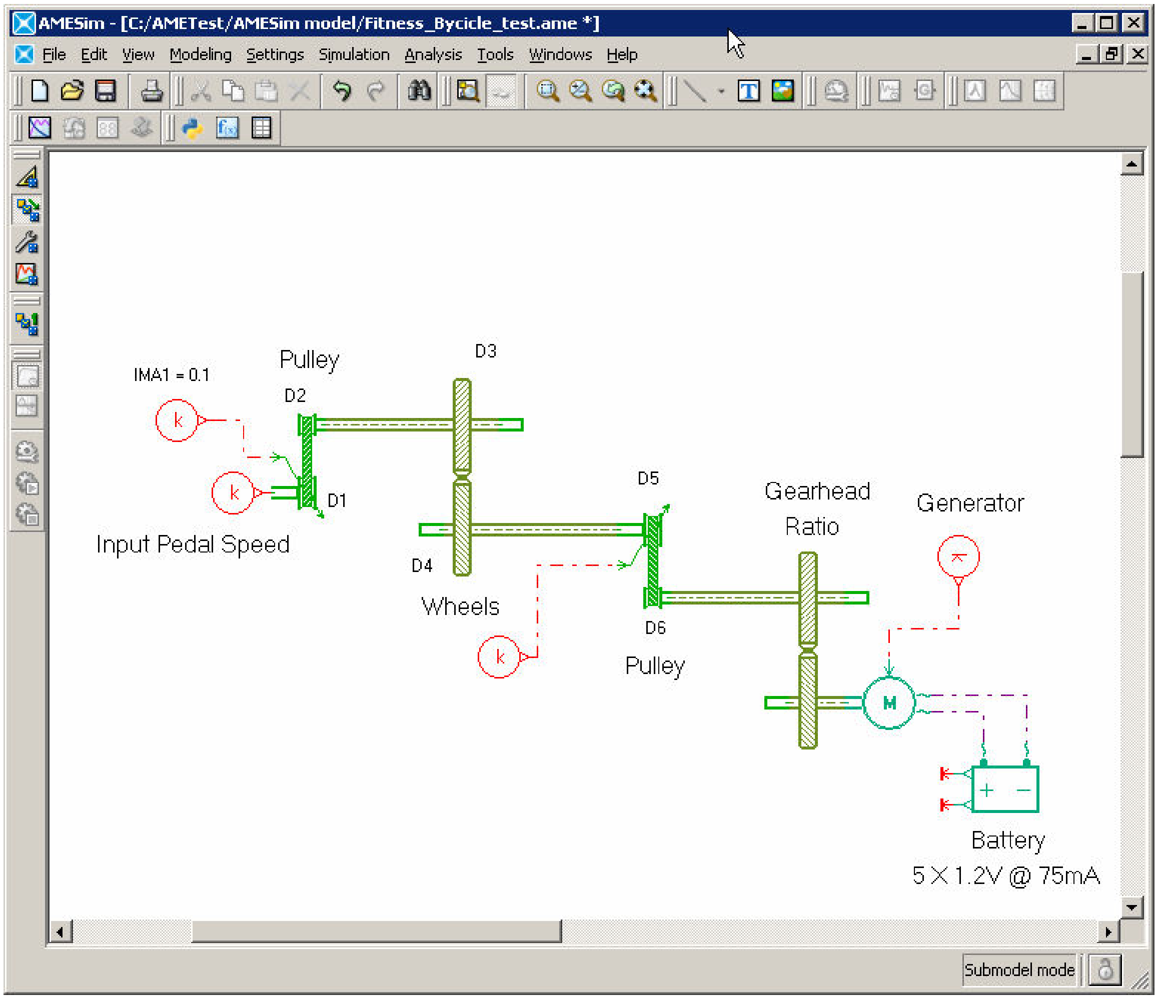

Figure 9: AMESim energy harvesting simulation interface

For each component, the specifications were entered into proper component tables for accurate simulation results. At this point, it was very critical to enter proper specifications for the component modules because of their interoperability. It was observed that if one of the simulation modules is specified incorrectly it would have affected the overall simulation and other modules. It was very challenging to figure out the meanings of the variables and parameters of the generator and battery units in the AMESim library. The specifications of the library elements were programmed for the high voltage applications such as hybrid vehicles or power trains of high horse power applications. All parameters and variables of the generator, circuit and battery units were altered for low power application. The output power of the generator is calculated and applied to one of the circuit modules that is not shown in simulation interface. The power output of the generator is applied to the battery terminals through the circuit module using k constant specifications. As mentioned above, the output speed of the system was 1800rpm as an input speed to the generator unit. The system simulations were conducted and the critical simulation plots are showed in the Figures 10, 11, and 12 respectively. The simulation analysis was run for 14 hours for all the components to observe if the batteries are charged at a given time. The battery state of charge graph is shown in Figure 13 to point out the time it takes to charge a specific rechargeable battery. As plotted in Figure 13 there is a consequent increase while the generator unit is producing energy at the constant voltage and current levels.

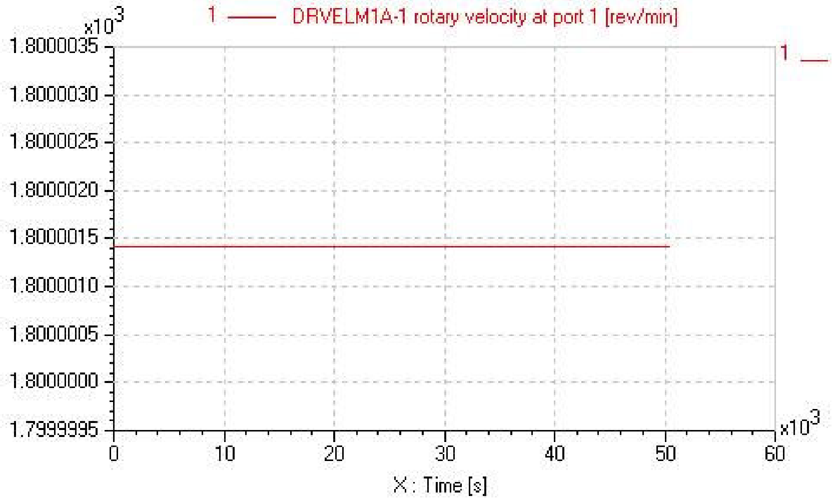

Figure 10: Input mechanical speed of the generator

In Figure 10, the output speed of the generator energy harvesting system is shown. This speed can be changed if the overall ratio of the mechanical system is altered. In the simulation plot, 1800rpm is constant but in real life, a case of this speed has the possibility to change any time depending on the person during a workout.

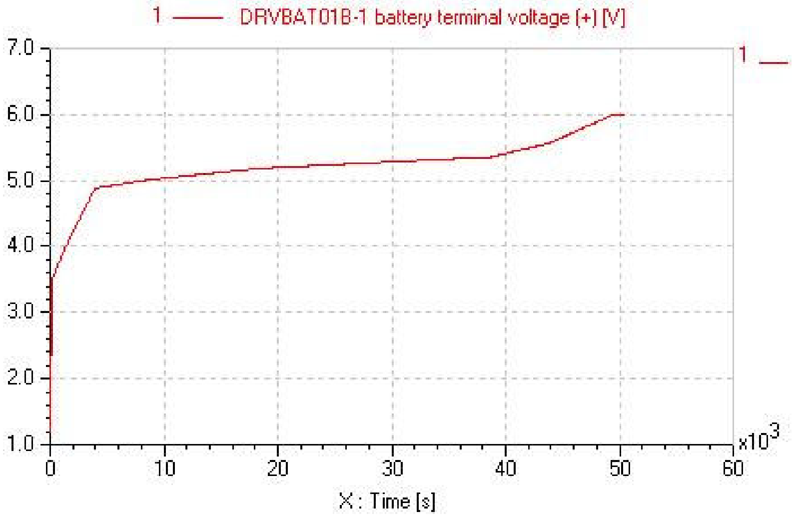

Figure 11: Battery charging voltage

Figure 11 and 12 show the battery charging voltage/current which are regulated by a battery charging circuit. Five units of 1.2V rechargeable batteries are integrated into the simulation interface in series to reach 6V for the battery charging purpose. Beside 75mA current is supplied to the battery terminals as specified in the battery data sheets. In fact the voltage and current levels are produced by the generator and automatically applied to the battery terminals due to component interoperability.

In Figure 13 the battery state of the charge is depicted. As aforementioned the system was run 14 hours to comply with a standard battery charge time as specified in the data sheet. As is shown in Figure 13 the battery is being charged linearly if the fully discharged battery is put in the system. After 14 hours the capacity stays flat not charging until the battery starts lose energy with a load.

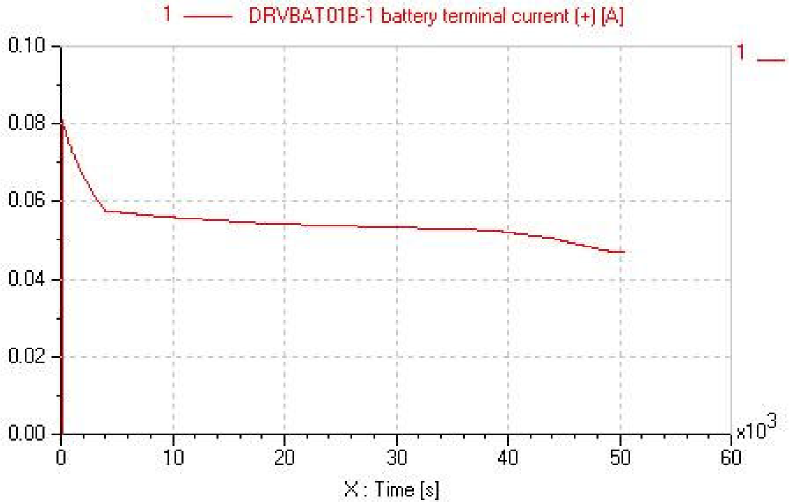

Figure 12: Battery charging current

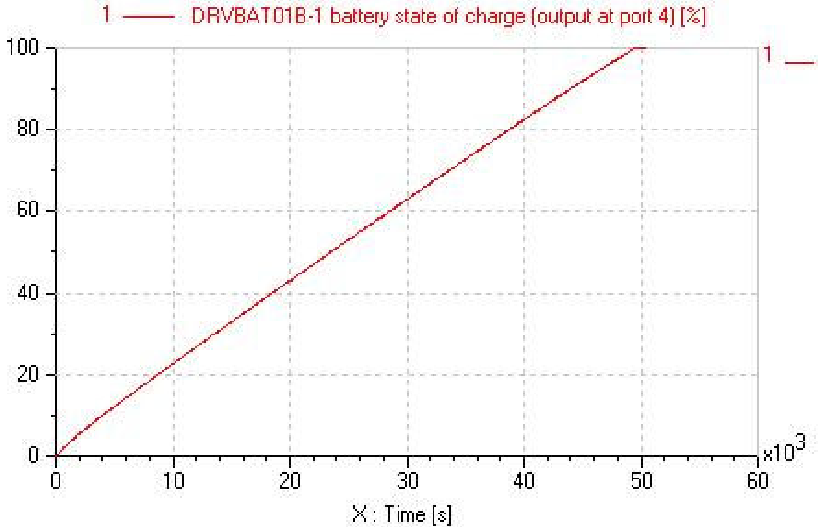

Figure 13: Battery state of charge

5. Piezoelectric Fiber Composites

The use of Piezoelectric elements has not been very successful for energy harvesting systems even though there have been many research studies in this area. It does not mean PZT materials are not capable of energy harvesting, but more advanced piezoelectric materials are needed to increase the efficiency of ambient energy harvesting systems. ACI (Advanced Cerametrics Incorporated) very recently has developed Piezoelectric Ceramic Fiber Composite (PFC) energy harvesting systems.[2,3] This recent development was recognized by R&D Magazine providing the “2007 R&D 100 Award” which is given to the top 100 new products from around the world every year. The PFC (Piezoelectric fiber composite) consists of uniquely flexible ceramic fiber capable of capturing waste ambient energy from mechanical sources such as vibrations. This new product functions between ambient vibration sources and electrical circuit with the storage device to convert vibrations into electrical energy. This unique development by ACI allows powering some applications without the need for conventional battery power such as wireless sensors, transmitters, microcircuits, smartcards, cell phones, and other handheld devices.

5.1 Piezoelectric Fiber Composite Characteristics

The Piezoelectric active fiber composites (AFC) are made by ACI (Advanced Cerametrics Incorporated) from a uniquely-flexible ceramic fiber that was able to capture wasted ambient energy from mechanical vibration sources and convert it into electric energy. The piezoelectric fiber composites’ fiber spinning lines are capable of generating electricity when exposed to an electric field. In PFCB (piezoelectric fiber composite bimorph) architecture the fibers that are suspended in an epoxy matrix and connected using inter-digitized electrodes create an active fiber composite (AFC). It is already known through tests by the manufacturing company that thin fibers with a dominant dimension, a length and very small cross-sectional area are capable of optimizing both the piezo and the reverse piezo effects. The amount of energy produced by mechanical to electrical energy conversion through the PFCB is much better than that compared to other piezoelectric materials according to the ACI’s internal studies.

In this section an investigation into the improvement of an energy harvesting system performance and efficiency using a piezoelectric fiber composite bimorph (PFCB) is considered. The PFCB characteristics and properties were intensively studied in order to design an efficient energy harvesting system for further study. Since cycle durability of fiber composites was determined by the manufacturer, the life cycle test of the PFCB material is ignored in this simulation research. Manufacturer cycle tests showed that fiber composite materials are extremely durable, able to handle one billion cycles without any degradation of properties, and efficiently, to generate constant continuous power. A photograph of the PFCB with the inter-digitized electrodes to align the field (energy harvesting circuit) with the fibers is shown in Figure 14.

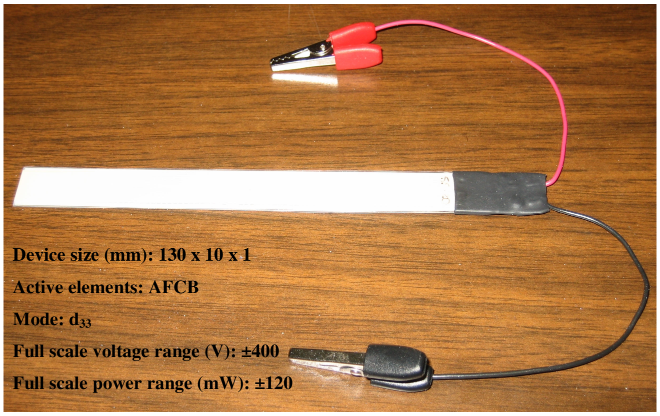
Device size (mm): 130 x 10 x 1
Active elements: AFCB
Mode: d_{33}
Full scale voltage range (V): ±400
Full scale power range (mW): ±120

Figure 14: The photograph and basic specifications of the PFCB

5.2 Overall System Analysis & Simulation with LMS Imagine. Lab AMESim

LMS Imagine Lab AMESim advanced simulation tool was used to analyze and simulate the overall energy harvesting system with actual component specifications including the piezoelectric fiber composite bimorph, shaker or vibration environment (Shoe sole/insole with

PFCB attached) and storage unit.[4] The simulation was conducted using a spring and damper system to manage vibrations and frequency levels when an input force was applied on the tip of the PFCB. A velocity sensor was placed between the mass and spring-damper to read the velocity of the system while the PFCB is being vibrated. Also a mass-friction was attached to the middle of the PFCB to represent added mass values on the tip of the product. Additionally a displacement sensor was placed between the mass and the PFCB to measure the vibration distances when a force was applied to the PFCB. The rest of the modules in the simulation interface are the calculation tools and data table connections to manage control between the components such as reading magnitude of vibration, the power specifications of the PFCB, the time taken for the PFCB vibrations to decay, and the battery charging measurements. All the module specifications were derived both from the PFCB and battery datasheets. The AMESim advanced analysis and simulation interface is depicted in Figure 15 with all modules included.

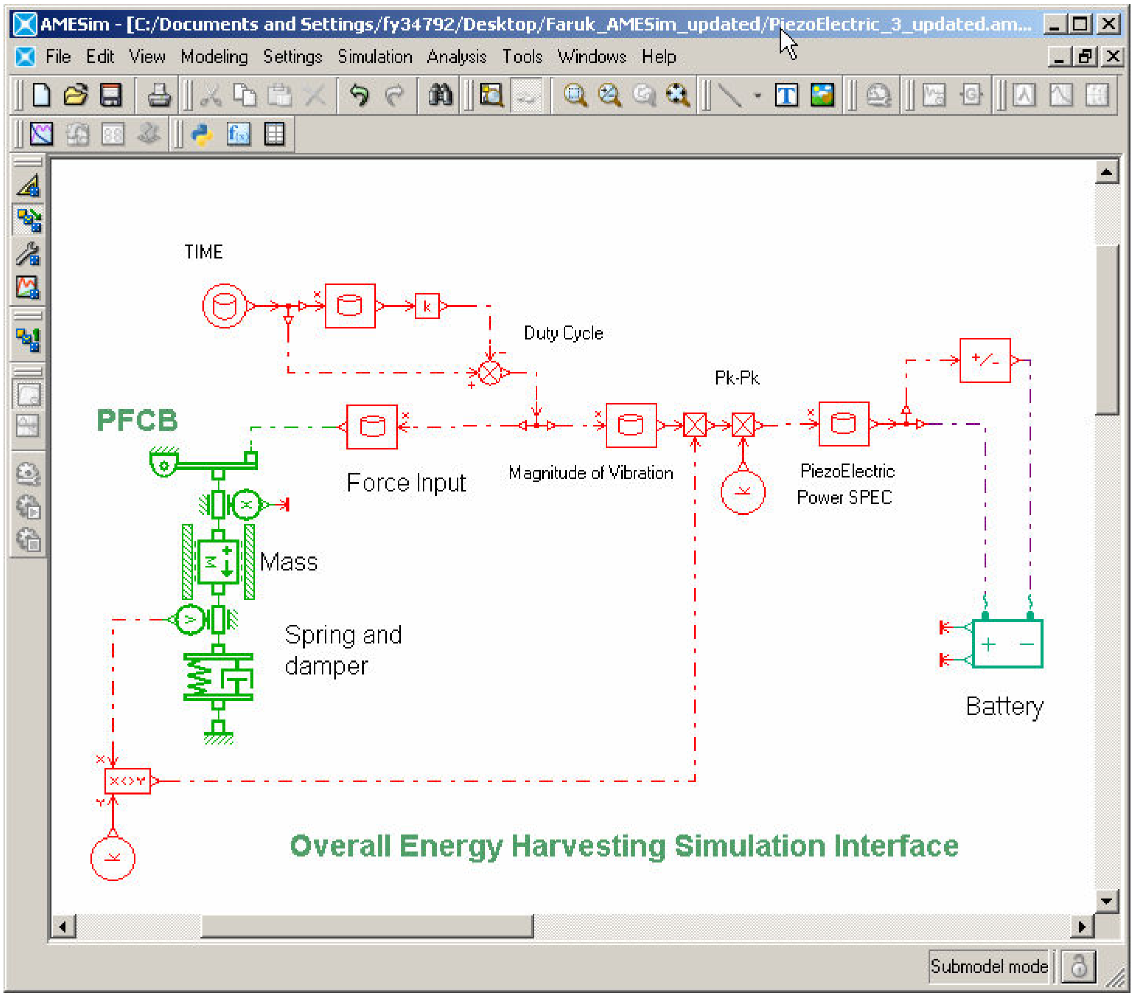

Figure 15: Overall energy harvesting simulation interface with PFCB using AMESim

For the each module, the default values of the components were altered by entering new specifications into proper component tables for the precise simulation results. Precise specifications for each module were essential. If one of the simulation modules had gotten the wrong specification or data set it would have affected the other modules and eventually affected overall simulation results. In AMESim, the specifications of the library modules were programmed for high voltage applications that required the reasonably to make intensive examination of the module characteristics in order to change the parameters for the low power applications. All parameters and variables of the modules were altered according to the low power energy harvesting application purposes.

The basic working principle of the system starts with the input force representing foot steps of the person. The force module flicks the PFCB every two seconds to induce and cause vibrations on PFCB for each foot step. Then the PFCB starts shaking according to the specifications of the mass and spring/damping modules. The graph of input force that represents the average walking of a person is shown in Figure 16.

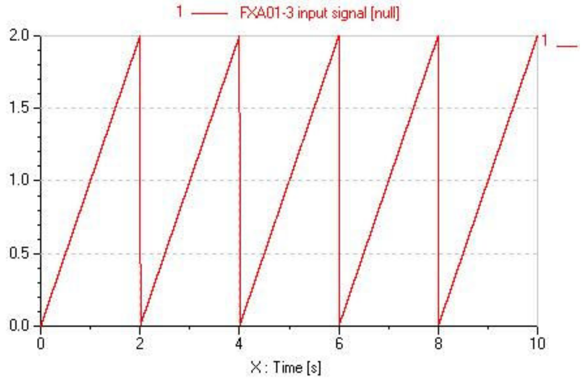

Figure 16: Input force to induce vibration on the PFCB every two seconds

Once the input force is applied to the PFCB, it starts shaking and produces vibrations. The vibrations are then captured and processed by the displacement sensor module which is represented by the “X” under the PFCB module on the simulation interface. There were a lot of sinusoidal signal outputs coming from the displacement sensor which made it difficult to count peak-to-peak signal outputs. For this reason a magnitude of vibration module was placed to calculate each signal’s peak-to-peak power output in order to supply accurate charge parameters to the battery module. Both the output signals from the PFCB through the displacement sensor and the magnitude of vibrations are graphed together and shown in Figure 17, representing the observed magnitude of the signal when a force was applied.

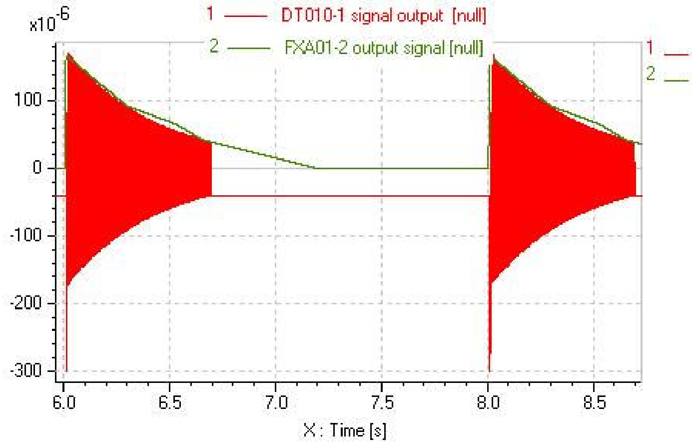

Figure 17: Signal output from the PFCB and peak-to-peak magnitude of vibrations

As indicated in Figure 17 the borders of the signals from PFCB were captured and calculated by the magnitude of vibration sensor multiplying by two (in order to include negative and positive cycles). Electrical specifications of the PFCB were derived from its datasheet and evaluated using Microsoft Excel to provide accurate power characteristics depending on the vibrations to the battery terminals in order to observe battery charging time. The evaluated specifications of the PFCB were entered into a table which was connected to the piezoelectric power spec module on the simulation interface. This module converted the input mechanical vibration energy into electrical power in order to provide accurate charging voltage/current level to the battery module. The evaluated specifications of the PFCB are listed in Table 1.

Displacement Pk-Pk	Displacement Pk-Pk	Harvester Power	PFCB Power	PFCB Power	Charge Voltage	Current
mm	M	µW	µW	W	V	A
-4	-0.004	750	250.00	0.00025	1.2	0.000208
-0.5	-0.0005	750	250.00	0.00025	1.2	0.000208
-0.3	-0.0003	620	206.67	0.000207	1.2	0.000172
-0.1	-0.0001	270	90.00	0.00009	1.2	0.000075
-0.03	-0.00003	20	6.67	6.67E-06	1.2	5.56E-06
0	0	0	0.00	0	1.2	0
0.03	0.00003	20	6.67	6.67E-06	1.2	5.56E-06
0.1	0.0001	270	90.00	0.00009	1.2	0.000075
0.3	0.0003	620	206.67	0.000207	1.2	0.000172
0.5	0.0005	750	250	0.00025	1.2	0.000208
4	0.004	750	250	0.00025	1.2	0.000208

Table 1: Evaluated power specifications of the PFCB using Microsoft Excel

The simulation analysis was run one hour for all the components to observe if the battery was getting charged while PFCB was being vibrated. A 1.2V at 110mAh rechargeable battery module was integrated into the simulation interface. The voltage/current levels were applied to battery terminals by the piezoelectric power spec module according to the magnitude of the vibrations. The battery charge time may be changed any time and depends on the vibration time and frequency of the PFCB. The charging time calculated and simulated here is an estimate according to the input force module that flicks PFCB every two seconds to induce the vibrations. As aforementioned the system was run one hour to compare with the standard battery charge time as specified in the data sheet. The battery state of charge graph which is showed in Figure 18 indicates the time taken to charge a specific rechargeable battery. There is a consequent increase in battery capacity while the PFCB module is being vibrated by the input force producing energy at a constant voltage/current levels. In the graph, the battery is being charged linearly assuming the fully discharged battery is put in the system.

In one hour the battery is charged 4% by the current energy harvesting system from the PFCB. The charging time changes if one of the modules' specifications is either altered or improved. This simulation is designed to accept any modifications to fit any ambient energy environment through a PFCB.

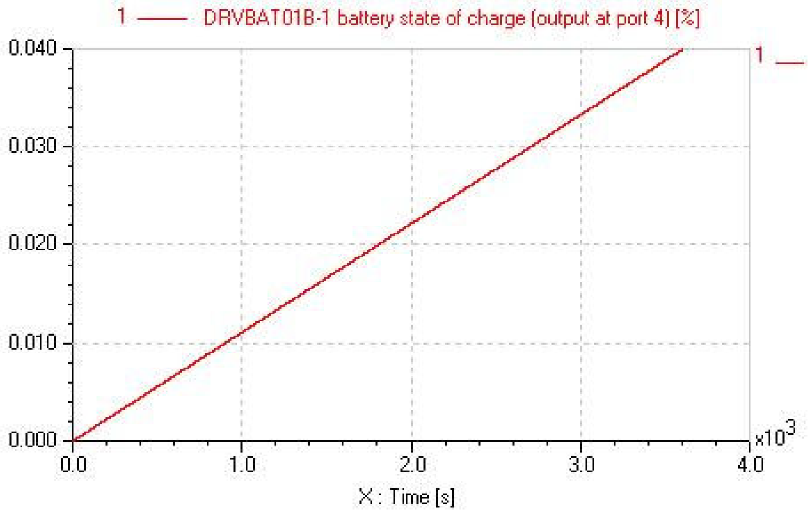

Figure 18: Battery state of charge in one hour

6. Conclusion

Many students have found the software tools very helpful and user friendly in understanding fundamentals of physical phenomena in engineering technology areas. A number of students have used their knowledge and experience with the aforementioned software tools as a valuable bridge to many internship and part-time student positions in local electronics and manufacturing industries. Our industrial advisory board members have repeatedly mentioned their satisfaction with our students and their valuable experience on digital modeling and simulation tools.

For the analytical simulation of the overall energy harvesting systems LMS Imagine Lab AMESim and MSC Easy5 one dimensional analytical simulation tools were used before the implementation of such systems. Easy5, an engineering analysis system, served as a software tool to simulate and analyze energy harvesting from the hydraulic door closer. Since Easy5 was a graphics based software tool, the overall energy harvesting system from the hydraulic door closer was modeled, simulated, and designed dynamically to permit changing the component variables easily. The specifications and working characteristics of the generator unit, and storage units were derived from the manufacturer datasheets. The system was very useful to observe both mechanical and electrical energy flow parameters from the source until the battery reached a state of charge.

For the fitness bicycle and PFCB energy harvesting systems, the AMESim one dimensional advanced engineering analysis and simulation tool was used for overall energy harvesting systems. All the simulation components for both systems were successfully derived and altered according to the manufacturer data sheets of the parts from the AMESim internal libraries. The analyses and simulations with real specifications of the overall components including wheel ratios, generator, circuit, piezoelectric fiber composite, spring and damping system, force and battery were successfully conducted resulting in applicability of the such systems.

The physical implementations of the simulation systems were conducted as a separate research after all simulations were complete. The parts were ordered according to the specifications were used in one dimensional simulations tools in this research. All three experimental systems were built and tested in Electronics, Production, and Welding laboratories. Undergraduate and Graduate students are majoring in Electrical and Information Engineering Technology, Manufacturing Design, Industrial Technology etc. were involved in design, building and testing processes of the overall energy harvesting systems. The analysis and simulation results then were compared with experimental test results to measure weather the efficiency of the Easy5 and AMESim for generating proper results were the same. The experimental and simulation outcomes were almost same as the result of the energy harvesting system. The detailed physical implementations of the systems will be shared with the academia and industry with separate publication having link with this research.

Moreover, In the AMESim and Easy5 simulation tools every component of the energy harvesting systems was included as separate modules. Checking the interoperability of all components by analyzing and simulating them reduced the redundancy of the energy harvesting systems after the development of the systems physically. In the design of the analytical simulation interfaces, the flexibility of the part modifications made it possible to change the parameters for future research. In both AMESim and Easy5 designs, the ambient energy source and related modules can be adjusted or modified easily to improve or change the energy harvesting system. The viability of the modules can be measured by simulating each module independently to adjust component specifications before the physical system developments and part ordering process. The analytical simulation allowed the researcher to find out the parameters needed to produce results after the long time test application. Incorporating the analytical simulation and physical development of the energy harvesting systems allows the researcher to investigate the system both analytically and physically and to make comparisons. The contributions of these software tools to the classroom environment were extraordinary especially where the physical development of the systems are not possible or expensive. Also both AMESim and Easy5 can be programmed to measure efficiency of the different ambient energy sources before the actual physical development of the energy harvesting systems.

References

1. MSC.Easy5 General Documentation (2004). MSC. Software Corporation, Bellevue, WA.
2. ACI, Advanced Cerametrics Incorporated. (2009). Retrieved January 17, 2009, from http://www.advancedcerametrics.com/pages/energy_harvesting_components/
3. Advanced Cerametrics Incorporated. (2009). Retrieved January 16, 2009, from http://www.advancedcerametrics.com/
4. LMS Imagine.Lab AMESim. (2009). Retrieved December 12, 2009, from http://www.lmsintl.com/imagine