AC 2007-507: SOLAR ENERGY: INNOVATIVE, APPLIED RESEARCH PROJECTS FOR THE SUSTAINABILITY OF DEVELOPING COUNTRIES

Olivia Dees, Middle Tennessee State University
OLIVIA DEES is a Graduate Research Assistant for the Masters of Science in Professional Science (MS-PS) degree program at Middle Tennessee State University. She has a B.S. in Plant Biology with a minor in Environmental Science and Technology, and is currently pursuing a MS-PS degree with a concentration in Biotechnology.

Saeed Foroudastan, Middle Tennessee State University
Dr. Saeed D. Foroudastan is the Associate Dean of the College of Basic and Applied Sciences and Professor of Engineering Technology. He received his B.S. in Civil Engineering (1980), his M.S. in Civil Engineering (1982), and his Ph.D. in Mechanical Engineering (1987) from Tennessee Technological University. Professor Foroudastan's employment vitae includes: Assistant professor of Mechanical Engineering for Tennessee Technological University, Senior Engineer, Advanced Development Department, Textron Aerostructures, and Middle Tennessee State University. Professor Foroudastan is involved with several professional organizations and honor societies, and has many publications to his name. He also holds U.S. and European patents.

Abstract

Renewable energy is becoming a more popular alternative to traditional energy sources due to issues concerning national security and the environment. Solar technologies are among many other products that are being created within the renewable energy sector on an unprecedented scale. In particular, solar energy is shown to be an ideal power source for the sustainability of developing countries. Its ever-increasing output efficiency and usefulness for a variety of locations make it an optimal choice for every region. Students from universities around the globe may be taught about solar technologies in order to facilitate important advancements for the needs of their countries.

The intrinsic qualities of solar design afford it great utility for the following reasons: 1) most developing countries are located in remote regions with optimal access to the sun’s rays, 2) traditional energy sources in developing countries harm the health of humans and exploit the ecosystem, 3) rising global independence of fossil fuels has encouraged the use of alternative energy, which will also increase competition and lower the costs of solar power, 4) solar photovoltaic systems are relatively affordable as well as applicable to single homes and entire villages alike, which is ideal for many families living in remote locations, and 5) passive solar design is inexpensive, provides renewable energy through precise building design, and may be coupled with solar panels to achieve maximum energy efficiency.

The previously mentioned topics will be addressed to exemplify why solar power is the best choice for sustainable, renewable energy in developing countries. The purpose of this is to support the future implementation of innovative, applied research projects within the engineering and engineering technology disciplines of international universities. This paper includes an example of a model program for student participation in hands-on, competitive research projects using solar energy. An increase in the number of students who are learning this necessary technology and its practical applications helps to ensure a decrease in future global energy needs.

Introduction

The increasing availability of cheaper solar energy resources is helping Third World countries to develop in a more sustainable manner. Research within this industry continues to increase the efficiency of solar photovoltaic (PV) systems, increase the competition between manufacturers, and lower prices for consumers. Although solar power is not the only renewable energy source able to be used today, its practicality for sun-belt areas which have less wind and water resources make it a superlative choice for most developing countries. The mounting practicality and availability of this energy source has encouraged various organizations and governments to install PV in developing countries through sustainable energy projects.

The versatility of solar energy is exemplified through its various applications for single houses, entire electrical grids, and even automobiles. Buildings which are supplemented with PV panels
may also be connected to a local utility grid for energy credits. Because solar energy is both adaptable and ideal for suiting the many needs of a developing country, experimental solar vehicle projects may be implemented in the universities of developing countries to promote this source of fuel for transportation purposes. This energy source may become a replacement for oil which is expensive and in short supply within these countries. The design of solar vehicle projects at international universities would encourage engineering technology students to create practical solutions to this growing problem.

Background

Solar energy is a promising technology for the generation of electricity in remote locations of the earth near the equator and along vast expanses of desert. Solar photovoltaic (PV) systems are able to maximize the potential of energy production in these settings where resources such as water and biomass are scarce. This renewable energy source provides developing countries the opportunity “to generate clean power anywhere on the planet, in a way that promotes local self-reliance and cultural autonomy, even as rural communities become more integrated into the global economy.”

Most homes and villages in developing countries derive their energy from sources such as charcoal, wood, kerosene, diesel, and batteries due to the unavailability of a clean, renewable energy source such as solar power. Charcoal and fuelwood are “the main sources of energy for heating and cooking for roughly half the world’s population. Within a few decades one-fourth of the world’s population in developed countries may face an oil shortage, but half the world’s population in developing countries already faces a fuelwood shortage.” Pollution from the fumes of kerosene lamps and small diesel generators cause serious health problems. “The World Bank estimates that 780 million women and children breathing kerosene fumes inhale the equivalent of smoke from 2 packs of cigarettes a day. Kerosene lamps are also a serious fire hazard in the developing world, killing and maiming tens of thousands of people each year.”

Solar PV produces no carbon dioxide (CO$_2$) emissions and offsets approximately 6 tons of CO$_2$ emissions over a span of twenty years. Improving market conditions and advances in technology are creating a sustainable market for solar energy. Over the past decade, the following has taken place:

- Compound annual growth rate (CAGR) of industry revenues have been averaging more than 40 percent.
- Solar power capacity continues to increase at a rate of 2GW per year
- Reductions in the cost of PV average 6 percent annually.
- PV cell efficiency has increased from 14 to 20 percent

The price of solar energy will continue to drop from its current rate of 20 cents per kwh. Once it reaches 10 cents per kwh, solar energy will become competitive with other renewable energy sources.

Solar Home Systems (SHSs), installed by organizations such as the Solar Electric Light Fund (SELF), are 12-volt direct-current (DC) stand-alone systems that use PV to electrify small rural homes. Each SHS includes a PV module, battery, charge controller, wiring, fluorescent lights, and outlets for other appliances. See Figure-1 in the Appendix for a model of a SHS. Today,
more rural populations in developing countries are finding this type of off-grid solar PV more affordable. Market studies conducted in India, China, Sri Lanka, Zimbabwe, South Africa, and Kenya over the past five years show that approximately five percent of most rural populations are able to pay cash for a SHS, 20-30 percent can afford a SHS with short or medium term credit, and 25 percent can afford a SHS with long term credit or leasing.

Passive solar design can be coupled with solar PV for maximum energy efficiency. Passive solar design is a very inexpensive and efficient type of solar collection and conversion of low-temperature heat. Sunspaces, greenhouses, and energy-efficient windows are well known examples. An energy efficient home can cause a dramatic reduction in annual electricity usage as well as the size of the PV system needed to source the energy. While results of field and laboratory testing show that the average lifetime of a 1-2 kW PV module is more than 20 years, a passive solar home may extend the lifetime of a module by reducing the frequency of its usage.

Introduction to solar vehicles

Solar energy addresses a global need to counteract a diminishing supply of fossil fuels. In addition to housing, it also exhibits great potential for supplying the power needed for transportation. Higher oil prices have hit developing countries much harder than it has industrialized nations. Up to 90 percent of the export earnings of some developing countries are used to pay for imported oil for power generation. Therefore, a sustainable energy source for urban transport systems is becoming a higher priority in developing countries. Solar energy can help these countries save capital and invest in other areas such as health, education, economic development, and industry.

“As the countries in the developing world rapidly motorize, the increasing global demand for fuel will pose one of the biggest challenges to controlling the concentration of greenhouse gases in the atmosphere.” Transportation accounts for 25 percent of greenhouse gas emissions worldwide, making transportation efficiency a critical part of the energy strategy for reducing greenhouse gases. In general, there are four options for improving transportation sustainability: 1) improve or change vehicle technology, 2) change how vehicles are used, 3) reduce the size of vehicles, or 4) use different fuels. A combination of these options is likely to be met in order for all societies to drastically reduce energy consumption and greenhouse gas emissions.

“A solar car is an electric vehicle powered by solar energy obtained from solar panels on the surface of the car.” Currently, solar cars are not a practical form of transportation because most have been developed for the purpose of competition. Racing teams have focused on optimizing functionality rather than passenger comfort. A solar car called "The Power of One," however, may soon be seen on Canada’s roads if granted the right to drive alongside traditionally-fueled vehicles.

Components of a solar vehicle

A good array is able to produce over 2 kilowatts (2.6 hp) at noon on a bright day. Energy production depends on the type of material, capacity of the array, weather conditions, and
positioning of the sun. The most common types of solar cell technologies used for solar vehicles today are polycrystalline silicon, monocrystalline silicon, or gallium arsenide.\textsuperscript{11}

The electrical system is a very important element of the solar vehicle. The battery pack is similar to a gas tank in a normal car in that it stores power for future use. Types of batteries commonly used in solar cars include lead-acid batteries, nickel-metal hydride batteries (NiMH), nickel-cadmium batteries (NiCd), lithium ion batteries, and lithium polymer batteries. Voltage ranges between 84 and 170 volts.\textsuperscript{11} Electricity is monitored and regulated by the car’s power electronics, which include the following:

- Peak power trackers—manage power provided by the solar array, maximize power to store excess in the motor, and protect batteries from overcharging
- Motor controller—manages electricity going to the motor by reading the signals coming from the accelerator
- Data acquisition system—monitors the entire electrical system.\textsuperscript{11}

The goals of a solar vehicle designer include minimizing drag, maximizing exposure to the sun, minimizing weight, and making the vehicles as safe as possible. For this purpose, composite materials such as carbon fiber, kevlar, and fiberglass are widely used in solar cars. Carbon fiber and kevlar structures can be as strong as steel with considerably lighter weight. Foam and honeycomb are the most widely used filler materials. Epoxy resins then bond all of these materials together.\textsuperscript{11} The design of the chassis should maximize strength and safety, while keeping the weight as high as possible. The three main types of chassis are:

- space frame—“uses a welded or tubed structure to support the body which is a lightweight composite shell attached to the body separately and the loads,”
- semi-monocoque or carbon stream—uses composite beams and bulkheads to support the weight and is integrated into the belly with the top sections often being attached to the body,”
- monocoque—uses the body of the car to remove the weight.”\textsuperscript{11}

Solar vehicle competitions

Many universities are now offering special design courses to introduce students to solar-powered vehicles. Some also form their own student teams to build a solar car for entry in an international design competition. A competition on this level is beneficial for the following reasons:

- Contributes to the development of electric vehicle technology, solar energy, and alternative transportation
- Increases public awareness of the need for environmentally clean transportation systems
- Students develop important engineering knowledge and experience by designing, fabricating, and racing the vehicles
- Practical, real-world engineering design and fabrication projects enhance career direction and employment opportunities for students
- Solar car competitions promote outreach and student recruitment efforts, as the fun and success of the projects encourage young students to study engineering technology
- Students from any university realize they can compete and win against some of the most prestigious universities in the world
Reputation and recognition is built for the university

Solar car races, often referred to as “rayces,” are becoming more and more popular every year. The two most widely recognized solar car races are the World Solar Challenge and the North American Solar Challenge. Both university and corporate teams are able to compete within these races. While corporate teams gain publicity, student teams gain valuable experience in “designing high technology cars and working with environmental and advanced materials technology.”¹¹ The World Solar Challenge has promoted sustainable transportation since 1987, when it first invited engineers and scientists from around the world to design and construct solar-powered vehicles capable of traveling 3000 km across Australia. The newest generation of solar cars includes six square meters of solar collectors, driver access and egress unaided, upright seating position, and many new safety requirements.¹³

The Formula Sun Education Foundation awards grants for solar panels to some teams entering the Solar BikeRayce USA.¹⁴ The Solar BikeRayce USA is an international closed-course race held each summer in Kansas. The objectives of this competition are to stimulate interest in science and technology and to promote energy efficiency and the use of renewable energy sources.¹⁵ Some solar cell companies such as Astro Power, BP Solar, Photon Technologies, and SunCat Solar will often provide technical information on their websites, and will provide teams with sample or broken cells for practice.¹⁵

There are many different options for the construction of a solar vehicle, and no single way to build it. The solar vehicles entering the Solar BikeRayce USA are classified as S Class. An S Class vehicle must have a functional electric propulsion system, battery, and solar array, using no other source of energy other than the battery and solar array. The size of the solar array and the dimensions of the vehicle are subjected to limitations for use on the track. Teams may choose one battery from the following types: Sealed Pb-acid, NiMH, NiCad, or Li Ion/Li Ion Polymer/Li Ion Alloy batteries. The S Class solar vehicle also must exhibit roll over protection for the driver, meaning that it must have sufficient strength to help protect the driver in the event of a roll over and should shield the driver from the incidental movement of body and chassis parts.¹⁵

MTSU’s solar vehicle projects

Two professors at Middle Tennessee State University, Dr. Cliff Ricketts and Dr. Saeed Foroudastan, have each conducted independent research projects utilizing solar energy. Each project has obtained positive results, and may contribute to the near future of solar automotive technology.

Dr. Ricketts, an Agricultural Education professor, has been researching and building alternative fuel vehicles for 25 years. In 1991, Dr. Ricketts “set the world record for speed for hydrogen-powered cars at 108.4 miles per hour.”¹⁶ The car is featured by a newspaper article in Figure-2. His career with alternative fuels began with ethanol and methane engines, and now includes a solar hydrogen vehicle fueled by sunshine and water.

The PV panels positioned next to Dr. Ricketts’s building store solar power in the grid line of the local electric service. PV installations which are tied to a utility grid are beneficial because
excess solar power can be sold back to the utility. The panels have stored as much as 10,000 kW in the grid bank, and can potentially provide enough “fuel” for a 70-mile trip. This grid-stored solar energy can be re-harvested later for such applications as fueling a solar car, much like the gas at a gas pump. For long-distance capability, Ricketts utilizes hydrogen power. His Nissan truck’s hybrid engine uses hydrogen, which is made from water. The hydrogen is produced by the following steps:

1. Solar panels provide power generation for a hydrogen electrolysis unit
2. Electrolysis purifies water and separates the hydrogen from the oxygen
3. Hydrogen is displaced into a metal hydride tank to solidify
4. Hydrogen is then converted to a gaseous state through a process which will allow the hydrogen to be used directly by the truck.

With a lighter vehicle and more sophisticated equipment, his hybrid hydrogen truck could travel 300 miles. Ricketts plans to make a 600-mile trek across Tennessee. “Making the trip across the state on only sun and water as the power sources should, I believe, have as much impact as the Wright Brothers flying the first airplane,” Ricketts said. “My hope is that we make this an annual event, and every year, somebody will do it faster, more efficiently and more economically. If we show it can work, due to supply and demand, it’ll get cheaper.” He receives annual funding from the Tractor Supply Company and Middle Tennessee State University. “With the right amount of funding, Dr. Ricketts is sure he can prove hydrogen’s pertinence to the automobile industry.” “Solar hydrogen,” he says, “is the future of cars.”

Dr. Foroudastan, a professor of Engineering Technology, has supervised MTSU’s solar vehicle team for several years. The Solar Raider, a race cart-style solar vehicle built by students from the ground up, is modified each year by a team of young engineers for greater efficiency in an upcoming competition. It is powered by both solar and battery power, which can reach speeds up to 60 kM/h for distances of 100 kM. The Solar Raider has competed in the annual Solar Bike Rayce USA for several years with great results. The vehicle won first place for the 200 meter sprint race and 100 kilometer race in 2003. In 2004, it won second and third place in the respective events. Figure-3 features the 2004 Solar Raider. The 2006 prototype, shown in Figure-4, includes “a super-lightweight, low drag carbon fiber body, efficient NiMH batteries, and advanced power management and remote monitoring systems.” It features increased aerodynamics and efficiency with flexible solar panels. The new and improved solar vehicle is scheduled for a race during the upcoming summer of 2007.

A model program for other universities

Innovative, applied research projects such as the Solar Raider may be adopted by universities in developing countries to help promote solar energy for transportation. Solar vehicle projects allow students to learn about the processes of design, construction, and competition. The competitive portion of the project is usually the reason why students get involved with the project in the first place. Competition serves as an incentive to not only finish the project, but also to design and construct the vehicle well so that it can win the race. The project can supplement existing coursework or even be used to create a new course. Research-based course curricula benefit student learning by reinforcing classroom principles throughout the various stages of a project.
At MTSU, the Experimental Vehicles Program (EVP) is a model program for student participation in hands-on, competitive research projects. The EVP is comprised of mini-teams, each with at least one upper division and one lower division student. Upper division students mentor lower division students, and practice valuable skills such as leadership and project management. Lower division students gain valuable insight from a more experienced student. Each student is also able to learn and practice many other skills such as teamwork, budgeting, computer design, and machining. The EVP garners strong support and participation from the students every semester. During the entire school year, the students work on the project so that it may enter the annual international solar vehicle competition every summer. The Solar Bike Rayce USA is a valuable opportunity for students to apply themselves and reap the rewards of their hard work. This type of competition also carries prestige on a resume. Every EVP team member has experienced great success with employment upon graduation. Similar success rates may be expected of universities which adopt a project such as the solar vehicle.

The Third World Academy of Sciences (TWAS) is an organization that, like many institutions supporting science and renewable energy, provides universities with the necessary funding to bring their projects into fruition. TWAS is an autonomous international organization that represents the best of science in developing countries and does the following:

- Promotes scientific excellence for sustainable development by supporting fellowships and grants
- Provides research facilities for developing countries
- Facilitates contacts between individual scientists and institutions in developing countries
- Provides developing countries with free access to scientific literature

The best research units in developing countries are selected by TWAS to receive grants for the promotion of scientific research which will help solve major problems in the Third World. Not only is funding for scientific research and the promotion of renewable energy garnered from such institutions as TWAS, industries also welcome the opportunity to sponsor solar car teams. This win-win situation for the university and industry is one that the EVP at MTSU has tested and now promotes.

With the help of funding, many universities in developing countries may participate in a solar vehicle competition. If Engineering Technology students within these universities begin to build innovative, applied research projects such as the solar car, they may also lead to the development of better ways to harness this energy for transportation. This would benefit the people of their countries, who suffer from high oil prices.

Conclusion

Various international, governmental, and non-governmental organizations have funded renewable energy projects in developing nations. Solar energy has transformed the lives of millions, and will sustain the lives of many more once it reaches more competitive levels with other renewable energy sources. Engineering Technology students in developing countries have the opportunity to participate in the application of solar energy to the transportation industry. Students enjoy solar vehicle projects because of the challenge, the cutting-edge technology, and the element of competition. An increase in the number of students who are learning the practical
applications of this necessary technology will help secure future global energy production. This paper encourages all universities to participate in an international solar vehicle competition.

Bibliographic Information


Figure 1. Model of a SHS (www.self.org)

Figure 2. World Record in Hydrogen Car Race
Figure-3. Solar Raider in 2004

Figure-4. Prototype for Solar Raider in 2006