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Power Options for Wireless Sensor Networks

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Abstract –
To combat the security threats of the 21st century it has become increasingly necessary to protect ever-remote terrain with wireless sensor surveillance. These systems must be self-sustaining to ensure they are constantly operational. Sandia developed a software simulation tool to validate a variety of renewable energy sources for commercial needs. While this software is heavily used in industry it has yet to be fully applied to wireless sensor networks. Based on simulated solar energy yields two different solar energy systems were designed, built, and deployed to the field. In the time since the solar energy power supplies were deployed zero hours have been spent on maintenance and it was not necessary to replace a single battery.

Index Terms — Wireless Sensor Networks, Solar Power, Unattended Ground Sensors.

I. INTRODUCTION

Photovoltaic (PV) power supplies for use with wireless sensor networks were designed and implemented by Sandia National Laboratories. Advanced photovoltaics, (PV) coupled with rechargeable batteries, provide continuous power for both the wireless sensors and remotely located video assessment equipment. The PV power supply is scalable in size, depending on the system energy requirements and the expected solar resource at the intended geographical location. A PV system performance model was used to optimize both the solar array size and the required battery capacity for each application. Several design objectives were addressed, including: long-term autonomous operation, smaller batteries, and lower cost sensor networks.

The PV performance model used to optimize the system design provided an accurate simulation of the expected energy available from the array of solar cells. Simulations include detailed performance characteristics of the high-performance solar cells and provide hourly estimates for voltage, current, and power from the array. The National Solar Radiation Database provided hourly solar resource and meteorological conditions based on thirty year averages for each site considered. Different PV array orientations (horizontal, vertical, tilted) significantly influence the annual energy available, therefore different possibilities are being considered in the simulation. The system design goals were to have enough PV energy available to fully recharge the battery during typical sunny days, and to have sufficient battery capacity to ensure 24-hr operation during extended periods of stormy weather. A detailed energy balance was conducted to account for the expected load (power) profile of the system, as well as parasitic energy losses in the system components. Successfully achieving the system design goals resulted in a power supply, which provided independent operation and dramatically reduced the need for battery maintenance or replacement.

II. POWER SOURCE SELECTION

Wireless intrusion detection and assessment equipment is typically deployed in locations where utility-based power is unavailable. Historical solar and climate data from the US National Solar Radiation Database and the US National Oceanic and Atmospheric Administration information, combined with the equipment's continuous power load, allows for selection of a power supply concept. The concept may be a single energy-scavenging device (solar, wind, hydro) combined with traditional battery energy storage, or may require a combination of multiple energy scavenging devices.

III. WIRELESS INTRUSION DETECTION EQUIPMENT

A. *Sensor Node Equipment Definition*

Sandia National Laboratories has deployed wireless intrusion detection sensor node units which are capable of powering a 1.3Watt, 12 Volt Direct Current (DC) continuous load in Albuquerque, New Mexico. The solar power supplies are large enough to provide power to externally connected mono-static microwave sensors, active infrared beam-break sensors, seismic sensors, and magnetometers, as well as a long-haul wireless radio. The sensor nodes transmit detection events along with state-of-health messages to a command center receiver located several miles away.

Fig. 1 shows a sensor node with a solar panel and lead-acid battery supplying power to mono-static microwave sensors, seismic sensors, and a long haul-wireless radio. This sensor node unit was deployed approximately three miles from the command center.

Fig. 1. Deployed Wireless Intrusion Detection Sensor

B. *Sensor Node Power Supply Model*

Solar panels that are rated for this amount of power are somewhat difficult to find in industry. Due to a rather limited market, the sensor node's power supply was built around a single 10W (rated) photovoltaic panel. The solar arrays deployed as part of this project are constructed with durable glass covers with metal frames.

Since the solar panel was already selected, the modeling and simulating was somewhat constrained. The following section will calculate power outputs for the sensor node's PV power supply under a variety of conditions and installed in a variety of locations.

C. *Sandia's Photovoltaic Modeling Tool*

Sandia developed a modeling tool that was validated by industry and is now commercially available [1]. The model utilizes model specific solar panels and thirty years of historical data to build an empirical model of the photovoltaic power supply. This simulation tool is different than others on the market since it uses 'real' solar panels from manufacturers to build the empirical model. Other simulation tools use only the label or the solar panel's surface area to estimate power output. Often there are differences in conversion efficiencies and output voltage levels from manufacturer to manufacturer. Since model specific solar panels are used to populate the simulation database, the modeling tool is often less cumbersome and more accurate than generic simulation tools.

D. *Sensor Node Simulation*

The sensor node's (SN) photovoltaic power supply was simulated in twelve locations throughout the United States to validate its performance in these environments. With only a single exception, the Pacific Northwest Rain Forest, the solar panels were able to provide at least 1W of continuous power to the sensor node for the entire year. Fig. 2 shows the results of this analysis.

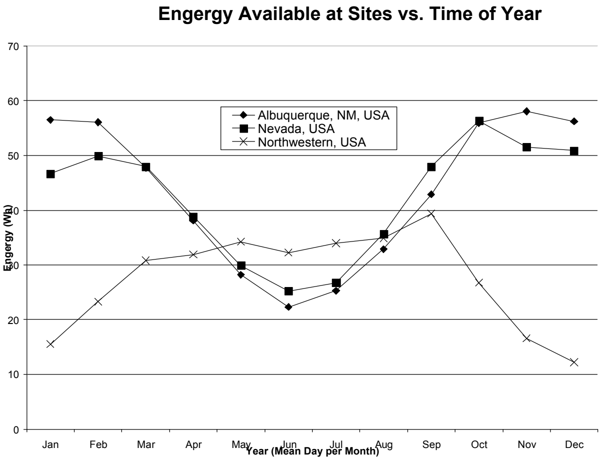

Fig. 2. *Calculated Watt-hours (Wh) for a solar array power units located in Albuquerque, Nevada, and the Pacific Northern part of the USA.*

The SN solar (or PV) energy-power supply works well and has required no maintenance during its time in the field. The small PV-power supply supports a continuously connected load of 1.3W. The SN utilizes a 12V, 12Amp-hour, sealed lead-acid battery to store the solar energy during the day and releases the energy back to the SN at night. In the future, thin-film cells may be incorporated into the packaging of the SN. Fig. 3 shows the continuous power load a solar panel can support when installed in Albuquerque, NM.

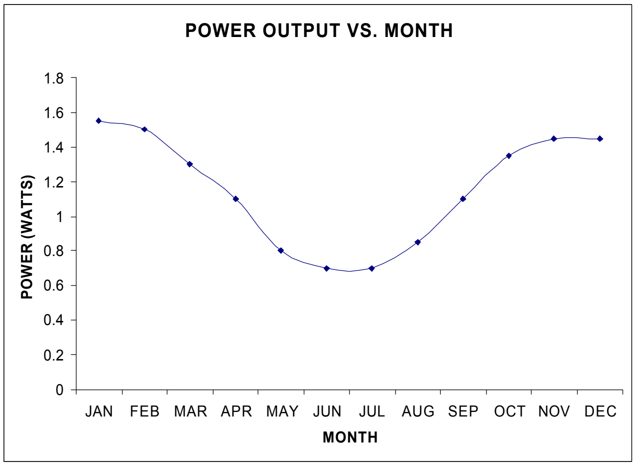

Fig. 3. *Calculated power output for a SN unit located in Albuquerque, NM with the panels facing south.*

E. *Solar Array Output versus Orientation*

The following analysis provided estimates of the daily average energy available (Wh) for each month of the year for three different array orientations (horizontal, vertical, latitude tilt angle). For varying application sizes, the energy values determined for the 100-cm2 array can be scaled up or down in proportion to the array area and to the cell efficiency. Fig. 4 illustrates the influence of array orientation and season on the daily energy for one site, Albuquerque, NM. Calculated daily average energy available from a 100-cm2 array of silicon solar cells oriented three different ways is also shown.

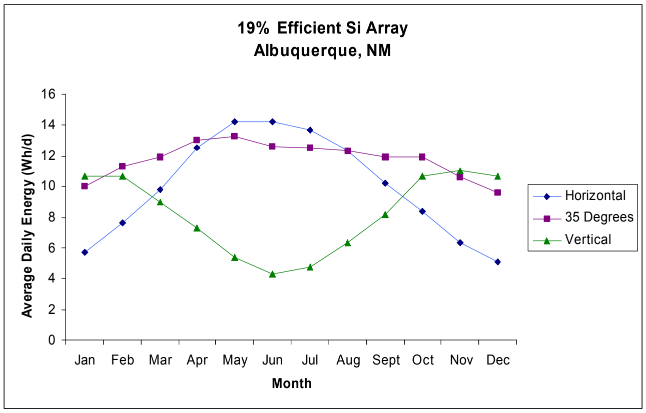

Fig. 4. Calculated daily average energy available in Albuquerque, NM.

IV. WIRELESS ASSESSMENT EQUIPMENT

A. *Assessment Node Equipment Definition*

The wireless assessment equipment Sandia National Laboratories deployed in 2005, utilized Internet Protocol (IP) based imagers and high-end commercial off-the-shelf, ad-hoc, mobile radios to transmit snapshot and streaming images several miles in rugged mountainous terrain. The photovoltaic power supplies were designed to provide 30W of continuous load DC power during all seasons when it was installed in Albuquerque, NM, as shown in Fig.5. Simulation results suggest that the solar energy system is suitable to provide at least 30W of power in most locations throughout the US.

Fig. 5. Assessment Equipment Solar Array Power Supply

The video assessment photovoltaic power supply utilized four Shell Solar SQ75W panels and two lead-acid batteries capable of supplying enough energy for 48 hours to compensate for extreme periods of low solar radiation. The design of this system was calculated and validated until performance was acceptable. The calculations were performed with the same simulation tool [3].

The solar panels have a total rated value of 300W, however, the panels typically only deliver this amount of power under ideal solar radiation levels. Dust and dirt on the panels, incidence angle with regards towards the sun, seasonal radiation levels, and the age of the panels all affect the power output of the solar panels. In addition to these factors, there are also inefficiencies when charging the batteries and when alternating current (AC) power is required to power equipment. These effects make this solar panel array capable of supporting a substantially smaller continuous power load.

B. *Simulated and Actual Performance Results*

Fig. 6 shows simulated power output for the photovoltaic and lead-acid battery power supply when deployed in Albuquerque, NM. Since August 2005, when the units were installed, they operated well including a week of poor weather conditions when there was two feet of snow as well as times with heavy rain.

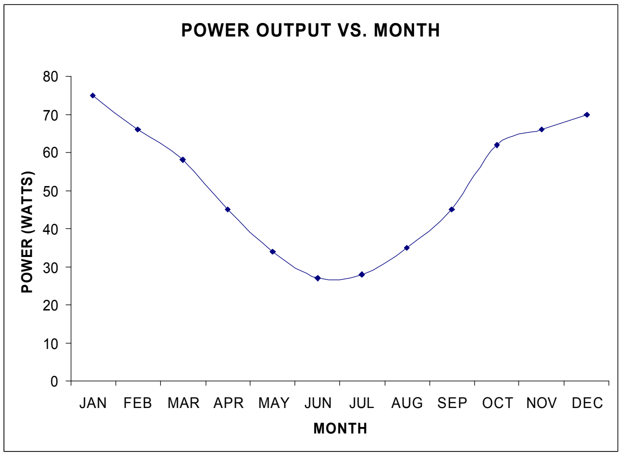

Fig. 6. Calculated power output for unit located in Albuquerque, NM with the panels facing south.

V. OTHERE RENEWABLE POWER RESOURCES

Sandia National Laboratories deployed this wireless sensor network in the desert of the southwestern United States. This particular area of the United States boasts an abundance of solar energy for harvest. Due to the constant presence of solar energy, other power sources are not necessary, nor are they feasible. For example, hydropower is virtually non-existent in the southwestern desert; therefore it would be impractical to consider hydro energy as a power source in this environment.

Although solar arrays worked well to power this wireless sensor network, there are other sources of renewable power that may need to be considered in some deployment locations. Two other popular ways to generate renewable energy are though harvesting water and wind energy by converting their kinetic energy into electrical energy. These power sources are sometimes used in combination with solar power. The renewable energy industry calls power supplies that harness more than one type of renewable energy source a hybrid system. However they may be also be used as stand-alone systems with proper design.

A. *Hydro Electric Power*

Hydropower (waterpower) harnesses the energy of moving or falling water. This is usually achieved in the form of hydroelectricity. Today there are several small (350-1,200W) commercial off the shelf (COTS) units that can be installed in streams and rivers. Since water is relatively predicable there is a decreased need for an energy storage media, such as batteries. In addition, there is often little to no environmental impact as water flow is relatively undisturbed with the introduction of these small devices.

The small physical size of a hydroelectric generator allows for installation of semi-covert video assessment and detection equipment. Water is a fantastic source of renewable energy and should be investigated when there are continuously flowing streams and rivers in a deployment area.

B. *Wind Power for Wireless Equipment*

Wind is also an excellent source of energy as it contains a significant amount of kinetic energy that can be relatively easily harvested to power wireless sensor network equipment. Large commercial wind generation facilities are typically connected to utility power as wind is difficult to predict and has a large variation in the amount of energy it can output. Due to the unpredictable power output a large battery bank is required to store energy during non-windy conditions. Wind is not ideal as stand-alone power system, however, it is often very successfully when used to supplement power output from solar panel arrays.

VI. CONCLUSIONS

A well designed power supply and intelligent power management can result in long-term autonomous operation, smaller batteries, minimize maintenance and lead to lower cost wireless sensor networks. Power management is extremely important when equipment must be self-powered and last for years without maintenance .

VII. REFERENCES

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[2] M. L. Garcia, *The Design and Evaluation of Physical Protection Systems*, Sandia National Laboratories.
[3] Maui Solar Energy Software Corporation, 810 Haiku Road #113 Box 1101, Haiku, HI 96708 USA

VIII. VITA

Bradley C. Norman is currently a Member of the Technical Staff at Sandia National Laboratories where he works on advanced physical security systems. Mr. Norman was the hardware design lead for the Advanced Exterior Sensor (AES) which is a multi-spectral imaging system. Recently, he was the hardware design lead for wireless intrusion sensors and investigated sensor deployment strategies for the Micro-Enable Virtual Perimeter Security Systems Project.