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14. ABSTRACT
**The renewable power industry is rapidly growing today and is in need of much data to augment the advancement of the field. Photovoltaic technology, while making substantial improvement over the last 60 years, still has some significant hurdles to overcome. When shading, dust, or damaged cells reduce the power output of one panel, the traditional series-parallel configurations make it so every panel in series with that lower current panel, will also have its current lowered; this lowers the overall power output of the array significantly. Advancements in configurations and converters could change this phenomenon and dramatically increase a solar array?s ability to produce power. The arrangement discussed in this thesis incorporates the author project managing a team of electrical engineers endeavoring to help resolve this dilemma by designing and deploying a sensor array, collecting data, and sharing this data with fellow graduate researchers whose other works explore ways to alleviate these hurtles. This author?s work combines this technical interest with an appetite for behavioral research as the project team members are introduced to a Maslovian approach to project management. This approach combines Maslow?s needs hierarchy with prosocial behavior theory to encourage team members to motivate themselves and build self-confidence. The experience and conclusions made from this work will hopefully have a positive impact on photovoltaic technologies, project management approaches to team motivation, and the humanistic community as a whole.**

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MANAGING A SOLAR SENSOR ARRAY PROJECT:

ANALYZING INSOLATION & MOTIVATION

by

BETH A. YOUNT

A THESIS

Presented to the Faculty of the Graduate School of the

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Approved by

Jonathan W. Kimball, Advisor
Scott E. Grasman, Advisor
Steven Corns

**PUBLICATION THESIS OPTION**

The 3rd section of this thesis has been prepared in the style utilized by the 2011 IEEE Green Technology Conference and the 4th section has been prepared in the style utilized by the International Journal of Project Management. The conference paper contained an error in referencing the insolation data as taken in June when the data was actually recorded in July. The error has been corrected in this thesis even though the conference paper, with the error, was already published and presented at conference in Baton Rouge, Louisiana on April of 2011. The Journal paper will be submitted for publication in July of 2011.

**ABSTRACT**

The renewable power industry is rapidly growing today and is in need of much data to augment the advancement of the field. Photovoltaic technology, while making substantial improvement over the last 60 years, still has some significant hurdles to overcome. When shading, dust, or damaged cells reduce the power output of one panel, the traditional series-parallel configurations make it so every panel in series with that lower current panel, will also have its current lowered; this lowers the overall power output of the array significantly.

Advancements in configurations and converters could change this phenomenon and dramatically increase a solar array's ability to produce power. The arrangement discussed in this thesis incorporates the author project managing a team of electrical engineers endeavoring to help resolve this dilemma by designing and deploying a sensor array, collecting data, and sharing this data with fellow graduate researchers whose other works explore ways to alleviate these hurtles. This author's work combines this technical interest with an appetite for behavioral research as the project team members are introduced to a Maslovian approach to project management. This approach combines Maslow's needs hierarchy with prosocial behavior theory to encourage team members to motivate themselves and build self-confidence. The experience and conclusions made from this work will hopefully have a positive impact on photovoltaic technologies, project management approaches to team motivation, and the humanistic community as a whole.

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This project would not be possible without the assistance of Dr. Jonathan Kimball, Electrical Engineering research advisor and Dr. Scott Grasman, Engineering Management academic advisor. They have provided a unique opportunity to combine the study of project management with applications of electrical engineering. A thanks also goes out to Dr. Steven Corns for serving on my thesis defense committee. The Energy Savings Store, a small business based in Kansas City and St. Louis, Missouri was also a contributor to this project.

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I would like to thank Dr. Benjamin Dow and Dr. Ray Luechtefeld for their thoughtful insights into the world of project management and organizational theory. Also, I would like to thank my family for their continuous love and support.

**DISCLAIMER**

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# NOMENCLATURE

| Symbol | Description |
|---|---|
| $n$ | Diode Quality Factor = 1.6 |
| $k$ | Boltzmann's Constant = $1.38x10^{-23}$ |
| $T$ | Temperature in Kelvin |
| $q$ | Charge of an Electron = $1.60x10^{-19}$ |
| $I_0$ | Diode Dark Saturation Current |
| $I_L$ | Current due to Photons or Sunlight |
| $I_{SC}$ | Short Circuit Current |
| $V_{OC}$ | Open Circuit Voltage |

## SECTION

# 1. INTRODUCTION

The field of renewable energy is growing quickly due to the impact of fossil fuels on the environment and the current economy. All areas of renewable energy are being pursued and solar technology is no exception. Photovoltaic (PV) cells have increased their efficiency over the years, but little has been done with configuration technology to increase the overall output of solar arrays. Shading and damage to cells in series-parallel topologies cause a lot of lost power; not just from the affected cell, but also from every cell in series with the affected cell. The lost power that may be regained by improving configuration technology could rival that which has been gained by increasing the efficiency of the cells themselves. Collecting insolation data from sensors placed as an array contributed valuable information that can be used to advance solar technology.

To this end, a team of engineers was formed to improve PV configuration technology. Just as in any project, motivation was an important factor in getting the team to complete the tasks successfully and on schedule. There are many different theories on how to motivate engineers during a project, however, this author decided to explore a more humanistic approach to project management using the theory of prosocial behavior to encourage team members to self-motivate. When workers can self motivate, the potential for micromanagement from the project manager or the dependency from the worker are easily prevented and a healthier project can be achieved.

## 1.1. PROJECT TEAM

The project team was comprised of seven electrical engineering students. There were three graduate and four undergraduate students all researching photovoltaics for Dr. Jonathan W. Kimball in the Missouri S&T electrical engineering power lab. For the purpose of this thesis and this project in particular, the author was the project manager, while Dr. Kimball served as program manager.

The graduate students were Jordan Henry, Zachary Johnson, and Nisha Nagarajan. Henry's and Johnson's contributions to the project were to design and build a new type of switched capacitor converter that would enable the implementation of parallel configured solar arrays [1]. Nagarajan's work on the project was to develop a graphical user interface (GUI) using the data that the author collected [2]. This GUI would generate predictive reports of energy outputs in various scenarios given inputs such as solar panel model, converter make and model, number of panels, solar sun eye photos, etc. Nagarajan and the author collaborated to write a paper that has been submitted to the Journal of Renewable and Sustainable Energy and is presently under review [3]. This collaboration paper was also a part of Nagarajan's thesis [4].

The undergraduate researchers on the team consisted of Jie Zhao, Jason Dickherber, Glenn Shanks Jr., and a fourth undergraduate researcher position that was filled by several students at different periods of time. This rotating position, hereto referred to as the forth undergraduate, was first filled by Rudolph Schmitz, then by Karl Mainsah, and last by Ben Orr. There was also a high school senior named Flora Xiao, who programmed MATLAB[1] to graph the downloaded sensor data. Zhao programmed all the data acquisition systems (DAQs) and was responsible for making sure the DAQs were talking to the sensors out in the field. Dickherber worked on the design of the sensor circuit board (It should be mentioned here that Chris Baker also worked on the design of the sensor circuit but graduated before the project really got started.) Shanks and the fourth undergraduate were the engineers who helped with whatever tasks arose at any given time.

[1] MATLAB is a registered trademark of The MathWorks, Inc.

## 1.2. THESIS OVERVIEW

The remainder of this introduction section will be the literature review where the works of other researchers will be discussed. Since the fields of photovoltaic and project management research do not typically overlap, they have been separated in the literature review to facilitate their discourse. Subsequently, there is a paper that has been published for the 2011 IEEE Green Technologies Conference on pages 5-18 [5], then a second paper that is presently being submitted to the International Journal of Project Management on pages 19-27. Following these papers, there is the thesis conclusion, bibliography, and vita respectively.

## 1.3. LITERATURE REVIEW

**1.3.1. Photovoltaics.** In the power industry today, renewable energy is an enterprising niche. While each type of renewable technology has its advantages and disadvantages, solar arrays are the easiest for consumers to attain and install for everyday use. Virtually anyone can buy solar panels at their local hardware store, so “Do It Yourselfers,” can install a solar array on their own home over a long weekend given the proper training [6]. This attainability compels us to put the development of photovoltaics at the forefront of renewable energy research.

Photovoltaic research on isolation as it varies across an array has only been done in simulation in the past. Modeling and simulation of PV arrays are quite common ways to estimate how cell characteristics will react to various illumination conditions [7][8][9]. The National Renewable Energy Lab is analyzing solar radiation data and its relation to weather patterns. One of their works is the National Solar Radiation Data Base, where one can find an extensive record of the typical meteorological data from years 1961 to 1990 [10][11]. Sandia National Laboratory has also published IEEE papers related to quantifying solar irradiance as it relates to monitoring the effectiveness and development of PV arrays out in the field for performance rating [12]. Sandia uses monitoring to study the various losses that take place throughout an array such as wire resistance, wind speed and direction, inverter efficiency, maximum power point tracking efficiency, incompatibility of system components, etc. [13]. PV models based solely on datasheet values are the basis and title of a paper published by Teodorescu and Rodriguez [14].

**1.3.2. Project Management.** The traditional approach to project management is that scope, time, and cost are the triad that a project is built upon, quality being based in the middle of the triangle [15]. Money was believed to be the prime motivator for employees, and while money is the easiest way to reward successful employees, there have been many studies to prove that money is not the prime motivator of individuals when they are working in groups [16]. Behavioral theory says that project management is much more that a quality triangle, the workers need to feel important and satisfied. Project managers need to be people managers, helping workers attain their needs, allowing motivation through goal setting [17]. Maslow's hierarchy pyramid, in Figure 1.1, illustrates this idea as the need levels describe the workers as they move up the pyramid.


Figure 1.1. Maslow’s Hierarchy of Needs Pyramid

A worker must satisfy his physiological needs of food and water before he will seek safety. Once his hunger and thirst is satisfied, he will seek a safe place to sleep, work, and live. After these levels are consistently met, he is motivated to find people to relate with; seeking a sense of belonging and trust, to fulfill his social needs. At the next level, he seeks esteem and respect from his colleagues. His colleagues motivate him and he reciprocates. He will fluctuate for many years between these upper levels before he may reach self-actualization. Here, he can work to his full potential and create, without self-doubt. At this, the highest level, he sees the big picture and does not stumble over small details that caused so many problems in the past [18].

Maslow's theories meld well with those of prosocial behavior. Prosocial behavior refers to voluntary acts that are for the benefit of a group or an individual [19]. A prosocial worker improves her self-confidence, sense of purpose, and gains the esteem of others in a way malevolent acts could never achieve; therefore, prosocial behaviors are necessary to complete Maslow's pyramid. As a worker makes her way up the pyramid, the project manager should get to know her background, her strengths, and her progress up the pyramid. Knowing each member of the project team should be a priority of the project manager [20]. The project manager then can apply this knowledge toward motivating the team. One step further would be to utilize prosocial behavior to encourage team members to motivate themselves [21]. Understanding the feelings and emotions of the team members, can also help project managers predict future outcomes, such as personal conflicts or a reductions in quality [22].

# PAPER

## I. QUANTIFYING INSOLATION IN MULTIPLE SHADING SCENARIOS

### ABSTRACT

This study seeks to quantify how much insolation varies over the span of a typical photovoltaic array. A solar sensor array was constructed and deployed at three locations where environmental conditions vary from full sun to highly restricted sunlight. Data was recorded at each location and then analyzed to find the effects of shading. In traditional series-parallel photovoltaic systems the total power output of the system is highly dependent on the full insolation of every cell. One cell with low insolation properties will drag down the current of an entire series string. Analysis of the sensor array data has shown that insolation varies substantially, even on an unshaded site. These findings should help, along with future research, to demonstrate the necessity of eliminating series strings from PV systems to increase energy production.

### I. INTRODUCTION

Solar power technology has been around for decades. Some progress has been made with solar panels allowing them to be lighter and easier to use, but the technology still has numerous pitfalls. One significant disadvantage of the present technology is that solar panels must be placed in a series-parallel configuration in order to produce a high enough voltage and a large enough power output to service any given customer. With this series-parallel configuration, when one cell is shaded or damaged, the overall power output of the solar array will be disproportionately reduced.

The sensor array in this project was designed to study the changes in solar insolation over an area roughly the size of a 3-kW series-parallel solar array. With the insolation data taken from the sensor array, converter technologies may be designed to work with parallel solar panels to alleviate the shortcomings of traditional series-parallel topologies [1].

## II. THEORETICAL BACKGROUND

In traditional series-parallel solar arrays, panels are placed in series strings to increase the voltage at the output, while strings are placed in parallel to increase the current available at the output. Combined, this increases the overall output power of the system, allowing the array to tie to the power grid or to its own power island. However, since many of these cells are in series, factors like dust, shading, and damaged cells cause a disproportionate reduction of power output because these factors cause a cell to produce less current or none at all. Since current in a series string is constant, when one cell's current decreases the entire series string current must decrease to match it, lowering or completely eliminating the string from contributing to the output of the series-parallel array [2].

In order to study the effects of insolation, one must study the solar cell's output in different conditions. The typical way this is done is by finding open circuit (OC) voltage and short circuit (SC) current for a given cell during a range of solar radiation exposures. The current from a cell in ideal conditions can be calculated as

$$I = I_L - I_0 \left( e^{\frac{qV}{nkT}} - 1 \right) \tag{1}$$

When determining short circuit current, setting cell voltage to zero in the exponent of equation (1) gives

$$I_{sc} = I_L \tag{2}$$

This means that the SC current is directly proportional to the cell's irradiance [3]. On the other hand, setting cell current to zero in equation (1) gives

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_{sc}}{I_0} + 1\right) \tag{3}$$

Equation (3) shows that the open circuit voltage is only logarithmically dependant on illumination. Then equation (3) can be solved for $I_0$, resulting in

$$I_0 = \frac{I_{sc}}{\left[e^{\frac{qV_{oc}}{kT}}\right] - 1} \tag{4}$$

Putting the results of equation (4) along with measured data for equations (2) and (3) back into equation (1), the I-V curve of a cell will have its two axis points. To determine an I-V point on the curve somewhere near the maximum power point (MPP), a load test was developed; a load line was interpolated based on the mid-most point on the I-V curve. To determine the MPP, a continuously irradiated cell would have a resistive load increased from zero (a short circuit) to a very high value (an open circuit); the point on the curve that maximizes V x I is also the point at which the cell can deliver maximum power to the load at that level of irradiation [4].

To study shading, a sensor array was designed that would simulate a PV array of the same approximate size. The sensor array was set up in three different locations. These locations were chosen because each had different shading profiles. This sensor array provided data on the effect shading has on insolation across the span of the array, at varying temperatures, and at different amounts of sun exposure due to location. This data could also be used to compare cells in series-parallel configuration versus parallel configuration. While studies similar to this may have been simulated on a computer [5][6], this type of study has never been done before using a sensor array, collecting data out in the sunlight just as one would a true PV array.

## III. EXPERIMENTAL SETUP

The sensor array was designed to simulate a typical residential roof-mounted 3kW photovoltaic array. The sensor array needed to be hinged with adjustable legs, so the array could be tilted to different angles similar to a traditional PV array. For this project the sensor array was only utilized at 0 and 26 degrees from horizontal; 26 degrees is the pitch of a typical household roof [7]. Estimates for the sensor array dimensions were based on research into the popular solar panels used today. Since only the dimensions of the average 3-kW PV system were of interest, maximum power ratings at standard testing conditions were used while sizing the array. The Kyocera KD135GX 125-W was the main panel model that was used as a reference while estimating panel and system sizing; it measures 1500mm long x 668mm wide x 46mm thick [8]. The Sharp ND-123UJF 123-W panel measuring 662mm x 1499mm x 46mm and the Solar World SW175 175-W panel measuring 1610mm x 810mm x 34mm were also considered in determining the size of the array [9] [10]. These and other solar panel models were referenced because their names are recognizable in the solar power industry. The popular choices for residential PV system installations were twenty 175-W PV panels or 24 125-W PV panels; 20 to 24 panels in a series-parallel configuration would make a footprint of 220 to 270 sq ft depending on panel models, manufactures and styles [11]. Since the average footprint was 245 sq ft, the decision was made to make the sensor array 10 ft x 17.5 ft; this would simulate a system with 24 125W PV panels. The twenty-four sensors boxes were spaced 2.5 feet and 5 feet apart in order to simulate placing the boxes in the center of each solar panel. The boxes used were plastic polycarbonate, weatherproof, and clear-covered, measuring 4 inches wide by 4 inches long by 2 inches deep. The sensor array dimensions and placement of the boxes and other equipment are shown in

Figure 1 below (not to scale). Steel Unistrut was selected as the building material because of its ease of use and availability.

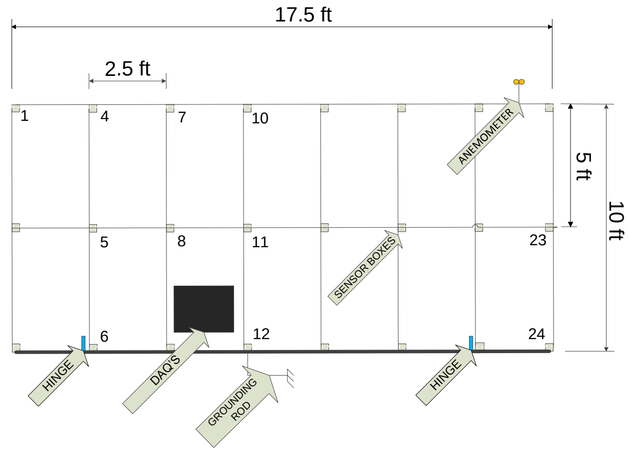


Figure 1. Sensor Array Dimensional Diagram

An anemometer was used to measure the effects of wind speed on solar sensitivity, since wind has an effect on panel temperature as temperature and humidity change. The anemometer on the sensor array was an Inspeed Vortex wind sensor [12], mounted on the top right corner of the array away from where it might cause unintentional shading.

Cat5e cabling with RJ-45 terminations was used for all communication of data throughout the array. The Data Acquisition Systems (DAQs) were R-Engine-A programmable controllers manufactured by Tern, Inc. [13]. Each DAQ has twenty-four 12-bit and sixteen 16-bit analog to digital channels (ADCs), and each solar sensor box requires 4 ADCs. So, 3 DAQs were needed for the 24 sensor boxes because each DAQ could only be interfaced with eight sensor boxes. Early testing showed the 12-bit channels to have better performance than the 16-bit channels. Therefore, the outputs of the three circuit tests (OC, SC, and load test) were fed to the more stable 12-bit channels, while the temperature data was fed to the 16-bit channels. A converter board was used to transfer the RJ-45 terminations into ribbon cable connections allowing data to interface with the DAQs. The DAQs triggered the circuit board to send sensor data every 2 seconds. The data then was saved on compact flash cards in CSV format. A rough analysis was then done with Microsoft Excel and a detailed analysis was performed using MATLAB[2].

Each sensor box contained a circuit board that connects to a 9V battery, a solar sensor, and the cat5e cable used to communicate with the DAQs. The solar sensors were 0.5 V 100 mA solar cells measuring approximately 1 inch (2.5 cm) square. The sensor data included: temperature, short circuit test, load (or 1/R) test, and open circuit test. The temperature sensor was an LM34 surface mount IC that measured the Fahrenheit temperature inside each 4 x 4 box. This temperature sensor was ± 3º F accurate or better at 10 mV per °F during testing. This LM34 was to give an idea of when the temperatures were rising and falling inside the sensor box, so temperature effects on the solar sensors could be followed. The short circuit test indicates the amount of sunlight reaching the solar sensor, while the open circuit test relates mainly to the temperature of the cell itself and gives open circuit voltage. The load test gives an indication of a measurable point near the cell's maximum power point (MPP). Figure 2 is a rough sketch of the 3 test circuits the sensor board contains.

[2] MATLAB is a registered trademark of The MathWorks, Inc.

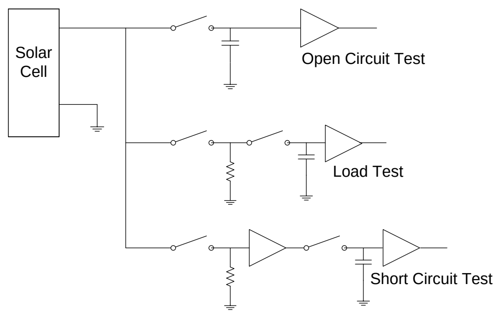


Figure 2. Solar Sensor Board

These short circuit, load, and open circuit tests allow for the analysis and derivation of the complete I-V curve, including an estimate of the MPP, such as the one seen in Figure 3.

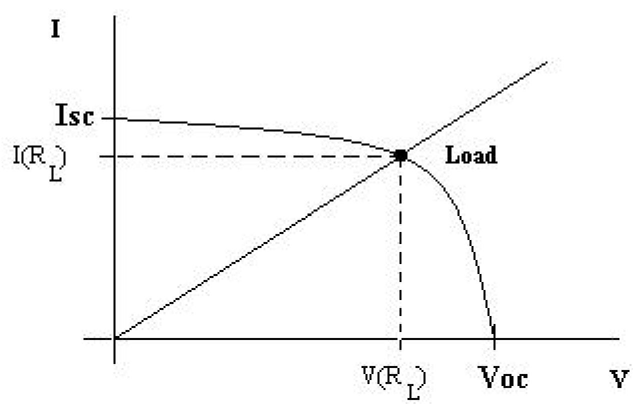


Figure 3. Example I-V Curve with a Load Line

This data was sent back to the DAQs and stored on compact flash cards that were downloaded periodically for analysis. The analysis that leads up to the MPP curve will be discussed in sections IV and V.

The array was deployed, with the DAQs recording data, for a week to 10 days in both the 0 and 26 degree positions at each site. A Solar Pathfinder was used to scout for sites that have full sun, partial shading, and predominant shading.

## IV. EXPERIMENTAL DATA

The sensor array data collection started at the location called the Burn Pit, a location that was completely open to sunlight for all daylight hours. The array was laid flat, set at 26 degrees from parallel to the ground facing south, and set at 26 degrees from parallel to the ground facing west for a week each. Every 2 seconds, the temperature, open-circuit voltage, measured load, and short-circuit current for each sensor was measured and recorded as previously mentioned and transferred to sets of Excel files to be examined (Please see "IV. Data Processing and Results").

The sensor array was then moved to a very shaded area called Norwood, where it was laid flat, facing south, then set at 26 degrees from parallel to the ground for a week each. Again, the temperature, open-circuit voltage, measured load, and short-circuit current for each sensor was measured and recorded every 2 seconds and transferred to sets of Excel files.

Finally, the sensor array was moved to a grassy open area called The Puck, where buildings obstructed the array only in morning and evening. Facing south, the array was laid flat, and then set at 26 degrees from parallel to the ground, for a week each. The temperature, open-circuit voltage, measured load, and short-circuit current for each sensor were measured and recorded every 2 seconds and transferred to sets of Excel files.

Of the data recorded, a mostly-to-fully sunny day was selected from a set of data recorded with the sensor array at 26 degrees. Sensors 6, 10, and 23 were selected for their positions on the array and analyzed in detail. Also, sensors 4 through 12 were analyzed for a further demonstration of variation across the array.

## V. DATA PROCESSING AND RESULTS

Using MATLAB[3], the sensor data from a sunny day at the Burn Pit along with an estimate of peak power was plotted in one graph while the Current vs. Voltage and Power vs.

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[3] MATLAB is a registered trademark of The MathWorks, Inc.

Voltage curves were plotted over time. Resistance was ignored and the diode quality factor *n* was set to 1 in order to process the data.

Figure 4 contains several views of the data from three sensors spread across the sensor array for one particular sunny day in July. In all cases, the sensor data has been averaged over one minute. The current is in milliamps and voltage is in millivolts. The first row shows I-V curves over time and the second row shows P-V curves over time. The characteristics were estimated from curve fits using the three test points described above (measured open, short, load data). The third row shows the raw data, plus an estimate of the peak power at a given time on the same day. Although, the short circuit current increases in the middle of the day, the temperature (T) variation causes a decrease in open circuit voltage, for an approximately flat power capability. The fourth row of Figure 4 is zoomed versions of the third row, showing only short circuit current (indicating insolation) and peak power capability. In the first portion of this time window, sensor 6 has a longer slope than the other two sensors; this is probably due to an obstruction, such as a building, blocking the sun just after sunrise. Then after a portion of time where all three sensors are uniformly insolated, random shading starts to occur, probably due to clouds. Notice that the magnitude and shape of the insolation-time characteristic is different among the three sensors. Shading on sensor 6 occurs much more frequently than on the other two, and there are some differences between sensors 10 and 23 visible around t = 900 min.

On the last page, Figure 5 shows graphs of sensors 4 through 12 placed on the page in the same way the sensors laid on the actual array structure itself (see Figure 1). The differences in $I_{sc}$ and estimated MPP are of particular interest. This represents a six sensor span of the array measuring 7.5 ft by 10 ft. Each graph shows the raw sensor data over time for each sensor. Each sensor is only 2.5 ft apart horizontally and 5 ft apart vertically, yet there are quite remarkable differences in insolation in these relatively short spans of space. It shows significant variance in insolation and power from sensor to sensor.

## VI. CONCLUSIONS

This paper details an ongoing project to quantify insolation variation. Although insolation is somewhat uniform during clear conditions, shading of the array varies both over time and with sensor location across the span of the array. Data has been gathered at 3 sites over a 5 month time span; to date, over 2 GB of data has been gathered. The data reported in this paper is representative of a clear, unshaded site, yet significant insolation variation is still observed. Nagarajan's research [1] incorporates the entire collection of data to simulate solar arrays in various series-parallel and parallel topologies in order to demonstrate the differences between topologies in various scenarios. Future work will utilize the data from the sensor array at the 3 locations to analyze the covariance of each sensor's short circuit current as it varies across time. These works will potentially produce further indications on how parallel PV array topologies may mitigate the effects of insolation variations.

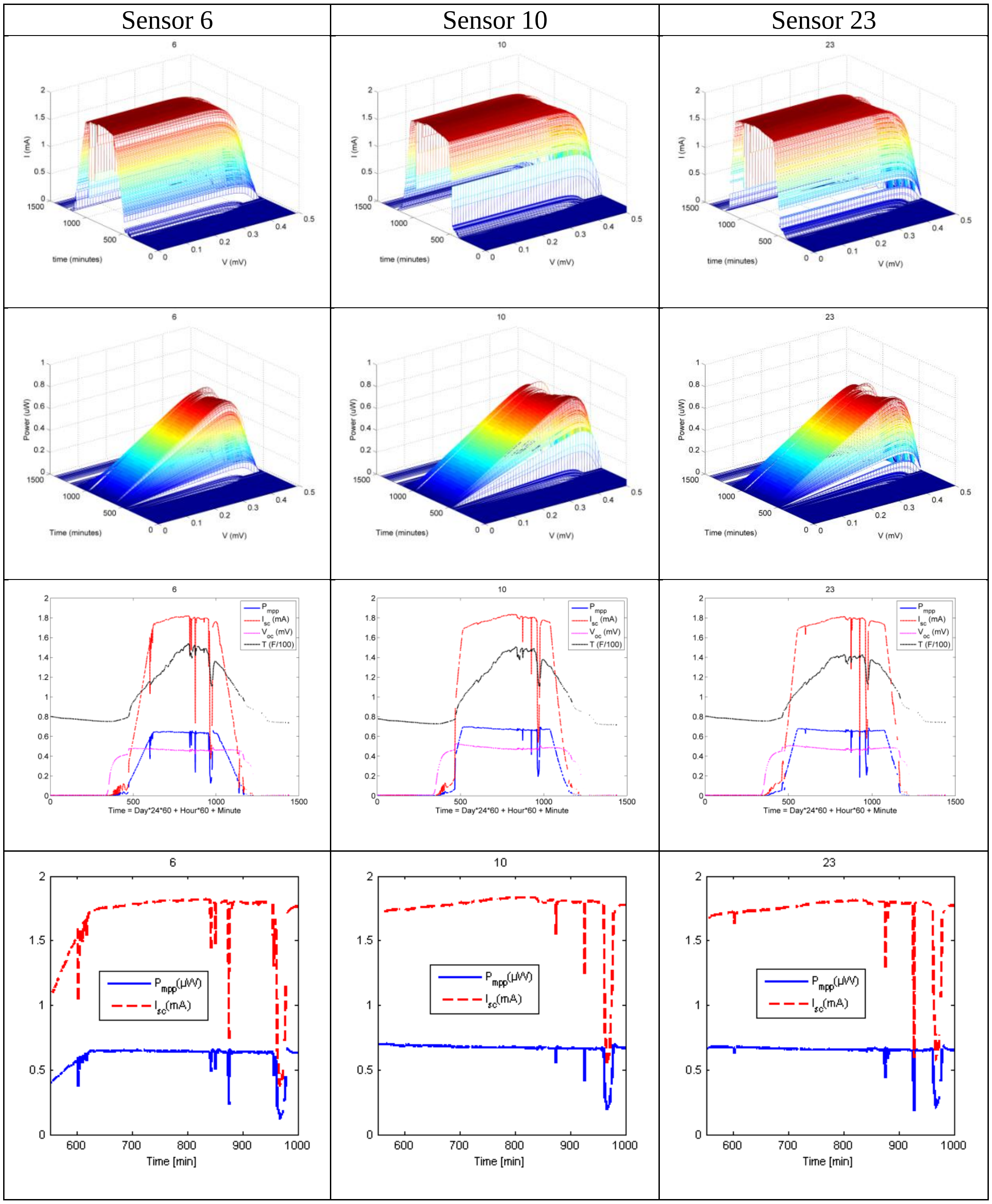


Figure 4. Burn Pit Data for 24 July 2010: Current-Voltage Characteristic, Power-Voltage Characteristic, and Raw Sensor Data Graphs with Estimated Maximum Power

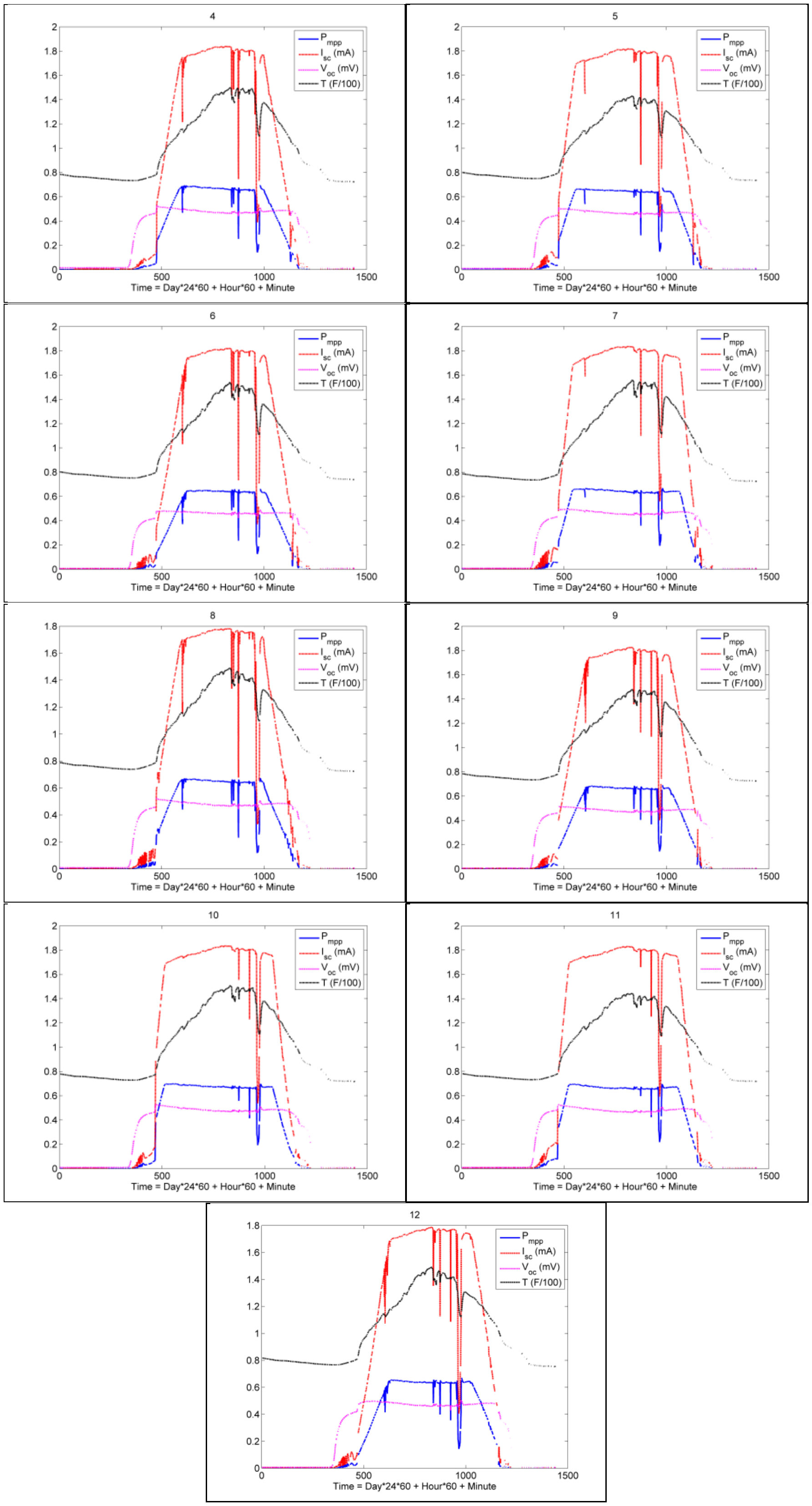


Figure 5. Burn Pit Data for 24 July 2010: A Six Sensor Span of the Array Shows Significant Variance in Insolation and Power

**REFERENCES**


[1] N. Nagarajan and J. Kimball, "Development of a GUI for parallel Connected Solar Arrays," Power and Energy Conference of Illinois, Feb 2011.

[2] R. Messanger, J. Venture, *Photovoltaic Systems Engineering, 2nd ed.*, New York: CRC Press, 2004.

[3] D. Sera, R. Teodorescu, and P. Rodriguez, "PV panel model based on datasheet values," IEEE International Symposium on Industrial Electronics, pp. 2392-2396, June 2007.

[4] T. Esram, P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," IEEE Transactions on Energy Conversion, vol. 22, pp. 439-449, June 2007.

[5] H. Kawamura, K. Naka, N. Yonekura, S. Yamanake, H. Ohno, and K. Naito, "Simulation of I-V characteristics of a PV module with shaded PV cells," Solar Energy Materials & Solar Cells, vol. 75, pp. 613-621, 2003.

[6] H. Patel and V. Agarwal, "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics," IEEE Transactions On Energy Conversion, vol. 23, pp. 302-310, March 2008.

[7] Bob Solger, The Energy Savings Store, personal communication.

[8] http://www.kyocerasolar.com/pdf/specsheets/KyoceraSolar_KD135GX_Web.pdf. last accessed May 2011.

[9] http://www.pvsolarmodules.com/sharp.html. last accessed May 2011.

[10] http://www.wholesalesolar.com/pdf.folder/module%20pdf%20folder/SW165175185.pdf. last accessed May 2011.

[11]http://www.worldofphotovoltaics.com/vbnews.php?do=viewarticle&artid=26&title=photovoltaic-companies. last accessed May 2011.

[12] http://www.inspeed.com/anemometers/Vortex_Wind_Sensor.asp. last accessed May 2011.

[13] http://www.tern.com/portal/content.asp?contentid=689. last accessed May 2011.

## II. PROJECT MANAGEMENT: GUIDING WORKERS TO MOTIVATE THEMSELVES

### ABSTRACT

Project managers are continuously looking for ways to motivate their workers. However, no manager can motivate workers more than workers can motivate themselves. Although some have postulated that self-interest is the strongest motivator, Maslow's pyramid demonstrates that individuals also need the acceptance and esteem of others to reach self-actualization (the highest level of being). To gain this respect, one must engage their intrinsic prosocial behaviors, working toward the well-being of the group in order to improve one's own status. This paper discusses how prosocial behavior and task management can be used by project managers to inculcate team members to motivate themselves to become more effective and efficient workers. The authors undertook a thirteen month solar sensor array project with a seven engineer team to study the validity of these motivational theories in practice.

### 1. INTRODUCTION

Project management is a complex combination of both managerial capabilities and leadership skills. Project managers must be able to adjust to the many different situations and the varied personalities that they will encounter during their career. They must be able to change as the situation and people necessitate (Fisher, 2010). This paper describes a project for which the second author was the program manager and the first author was the project manager. The project team was composed of seven electrical engineers, and the project lasted for over thirteen months in a university setting. The project manager not only studied the ways one could motivate a project team, but also designed and deployed a fairly large sensor array, that had to be moved and maintenance at three locations around campus. This paper analyzes the impact of a real working project into these learned management skills.

## 2. BACKGROUND

This project began in August 2009, a month before the first author was brought on-board as project manager. The Leonard Wood Institute had already approved a proposal written by the program manager. The goals had already been established and some tasks had already been assigned to the engineers on the project by the program manager. The engineers were comprised of three graduate and four undergraduate student electrical engineers. The project's overall goal was to devise a way to make solar energy a more flexible technology. The project manager's job was to design a sensor array as well as manage the seven engineers, making sure the project met specifications and deadlines. More specifically, along with the typical project management duties, the project manager focused on team motivation.

The sensor array design aspect of the project entailed 24 sensor boxes arranged in a manner that would simulate a 3-kW solar array found on a typical house. Each box contained a solar and temperature sensor supplying data back to data acquisition units that recorded the data from all the boxes continuously for about a week, to be downloaded later for analysis. The solar data sent was open circuit (OC), load (1/R), and short circuit (SC) readings, which give an indication of the solar cell's maximum power point (MPP). An analysis of this data would be used to quantify the way clouds and other obstructions vary the sun's intensity across the array (Yount et al., 2011). This data could be used to advance solar technology. Below, in Figure 1, includes a drawing of the sensor array (not to scale) and an example MPP graph. $V_{oc}$ is open circuit voltage and $I_{sc}$ is short circuit current in the MPP graph.

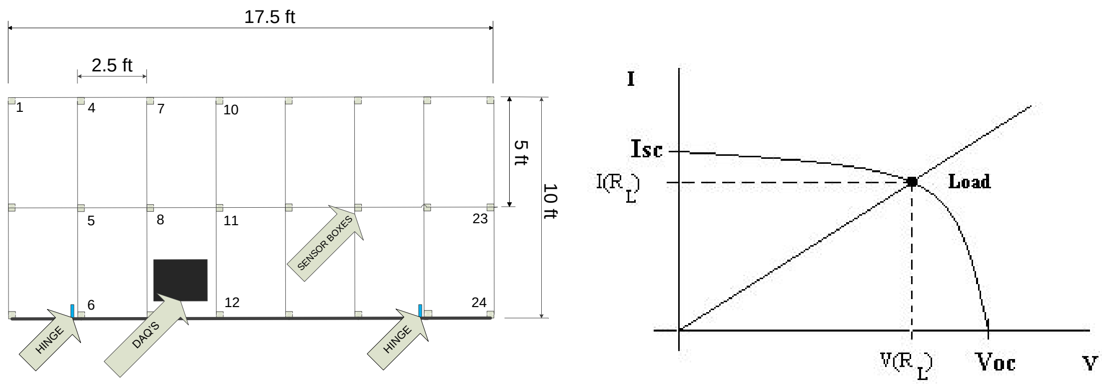


Figure 1. Sensor Array Architecture and MPP Graph

## 3. LITERATURE REVIEW

Many confuse prosocial behavior with altruism. Altruism is behavior that benefits the recipient at a cost to the actor (Waal, 2008). Prosocial behavior usually benefits both the actor and the recipient. Prosociality may involve the exchange of goods, services, or information in the form of helping, sharing, or communicating (Warneken and Tomasello, 2009). For example, teaching and leading others towards their goals can be considered prosocial behavior.

Cooperation is an essential part of prosocial behavior (Waal and Suchak, 2010; Melis and Semman, 2010; and Jaeggi et al, 2010). Most animals engage in this behavior in the interest of reciprocity, they help and share with others when they can see the beneficial outcomes for both themselves and the recipient (Waal and Suchak, 2010). The propensity toward prosocial behavior is a natural phenomenon. Jaeggi et al. (2010) have observed that humans have a strong sensitivity to the percieved presence and size of an audience. Melis and Semmann (2010) concur, saying that societal norms caused a more refined order of prosociality; reward, punishment and reputation building have become a cornerstone for the stability of human societies. In order to hold relationships, individuals must maintain not only reciprocity and cooperation, but also relatedness, benevolence, and willingness to contribute to the group with which we belong. Therefore, the evolution of humans into societal living has motivated us into prosocial behaviors.

Over the past few decades, experiments involving primates and young children have proven prosocial behavior to be an inherent behavior. Experiments conducted by Svetlovs et al (2011), explicitly show that children as young as 12 to 14 months old exhibit prosocial behavior, even though at this age they do not yet know how to anticipate another's needs (they do not know how to read social cues). The need for us to be prosocial is instinctive, not just out of empathy, but out of mutual benefit and cooperation for the better good, for ourselves and our society.

Abraham Maslow (1943) established a prominent theory of motivation with his needs hierarchy. According to Maslow's theory, once the basic needs of food, shelter, and security are maintained; an individual strives for belonging. A sense of acceptance in a group, such as a project team, is part of the belonging needed in the 3rd level of this hierarchy. Once team members feel accepted, they can move on to seek esteem, recognition, and respect from others in order to feel confidence in themselves. Then finally, the team members can feel a sense of purpose as they contribute more creativity to the project. The self-actualization level can only be achieved if team members are doing work in which they can reach their highest potential. Figure 2 demonstrates a little more of the model. Extrapolation of this theory indicates that serving others is important for reaching each level of the pyramid since it creates an opportunity to receive the help, acceptance, and recognition that is necessary to achieve the level of self-actualization.

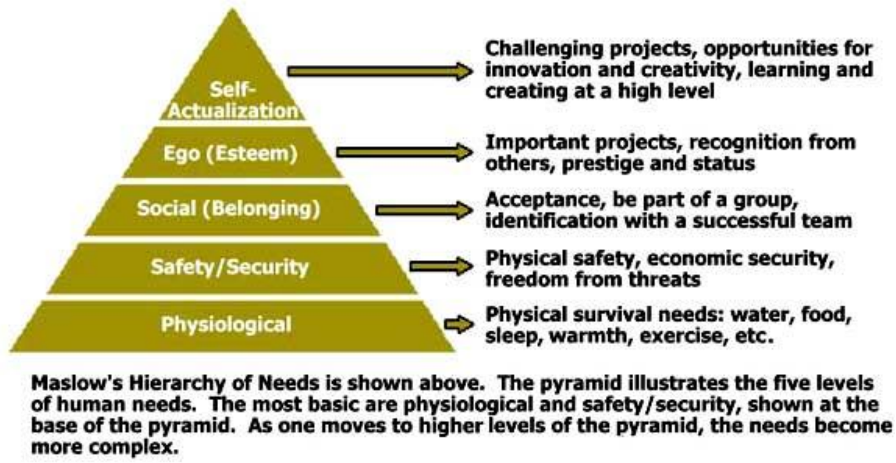


Figure 2. Maslow's Hierarchy of Needs Pyramid (UTAS, 2010)

According to Claude Graeff (1983), performance is a product of motivation times ability. The task of placing people in a position where they will be the most successful is important to a team member's self-motivation. If a team member feels effective and vital to the project, he will feel compelled to do more for the project, for the company, and for the community. This is part of prosocial motivation. Once a worker feels like she is making a meaningful contribution, she will want to contribute more. Self-interest has traditionally been seen as the primary motivator of individuals within a group. Although self-interest is usually associated with selfishness, prosocial behavior and self-interest can be complementary (Grant, A. and Berg, J., 2010). Prosocial behavior can be inspired by self-interest; one gets contentment from helping others, thus satisfying the base needs for security, affiliation, and recognition identified by Maslow. There is much satisfaction to be found in serving others and in creating a greater good. When workers are self-motivated, they are more likely to take initiative, accept negative feed-back, grow in creativity, and perform better, leading to greater productivity.

Fisher's research (2010) indicates that interpersonal skills are a prevalent factor in worker performance, both individually and as a group. Understanding the behaviors of others, being able to lead and influence others, and being culturally aware, genuine, and exceptional at problem resolution are all qualities that project managers should posses to be the most effective at managing people. Gillard and Price (2005) agree as they observed that successful project managers must be able to build comradery while understanding the individual differences among workers in diverse and constantly changing environments. Leadership skills must be delicately balanced with social skills that will allow the project manager to work well with both subordinates and executives. An effective project manager is a coach of sorts, nurturing individuals toward their full potential, finding each worker's best skills, and encouraging performance growth. When a project manager is present, they are there to encourage feedback, address performance issues, and motivate workers toward self-improvement and creativity. The project manager can create team cohesiveness by facilitating group discussions which will naturally build trust, emphasize common interests, and promote free communication. Peters and Austin (1985) call this approach management by walking around (MBWA). By being present, she may engage their prosocial tendencies to foster cooperation and collaboration towards a common goal. When a project manager positions herself in an office, away from the project, she discourages communication and becomes disassociated from project workers.

Other performance issues rely on a project manager's ability to manage scope, time, and budget constraints. These are the three foundations on which a project manager forms their project structure (PMI, 2008). If not monitored, scope creep can be a significant problem because time, budget, and personnel are finite resources. Time is used most effectively if tasks are planned carefully in advance. Based on the scope of a project, the project manager must divvy up tasks among team members, utilizing their skills and time to finish tasks efficiently and effectively. When team members are strategically tasked where their particular talents lie, then their successful accomplishment of each task will motivate them to become creative and contributory to the project as a whole. Therefore, the effective distribution of tasks among personnel should be a major priority of the project manager because it is key to the successful completion of a project.

## 4. OBSERVATIONS AND DISCUSSION

For the project discussed here, the customer was the Leonard Wood Institute, a nonprofit organization affiliated with Fort Leonard Wood that receives funding from the Army Research Office. The project had a thirteen month deadline. They contracted the team to deliver a graphical user interface (GUI), data, and conclusive graphs by September 2010. The general tasks, budget, and resource pool had already been established by the program manager; therefore, the project manager's first job was to take the general tasks and assign them to team members.

The tasks were vague in the original Gantt chart, so they needed to be refined into more specific tasks. The project manager needed to know which team members would be able to perform the tasks best and the reasonable lengths of time in which they could be finished. Keeping in mind each individual's particular strengths and specialties, interviews were conducted to assess the refinements needed on the Gantt chart. The the original Gantt chart was then updated, assuring that deadlines could still be met. This was an important first step to ensuring the specific tasks had been assigned to the team members that could best accomplish them. Also, interviewing the team members forced them to think about their tasks and what process they would have to go through to accomplish them. This in turn, caused them to make plans of how to complete the more complicated tasks and let them come up with more realistic time estimates.

As the project progressed, the project manager continually reassess the Gantt chart's accuracy, updating it quarterly. If a task had taken longer than anticipated, the another future task had to be completed faster than planned in order to keep the project on schedule. For example, when circuit board testing took longer than anticipated, the length of time the sensor array would stay at each site was shortened. The data acquired was still adequate to establish the necessary analysis, and the project was put back on schedule.

The sensor circuit board design for this project had been completed on schedule; however, the testing proved to be a challenge. The sensor board testing was completed by undergraduate researchers and sometimes needed the assistance of more senior researchers. The testing procedure entailed calculating the Thevenin equivalent circuit of the solar cell used in each sensor box, building this equivalent circuit on a breadboard, then measuring the open circuit, load circuit, and short circuit portions of the sensor board using three different types of metering instruments to calculate percent errors and identify any design flaws. A digital multimeter, oscilloscope, and data acquisition unit (DAQ) was chosen for the three types of metering instruments.

The challenge came when the undergraduates tried to calculate the Thevenin circuit. They had a miscommunication with the program manager and calculated the Thevenin equivalent of the sensor board's circuits instead of that of the solar cell. This error invalidated the first set of data, so before further testing could take place, the managers had to clear up the confusion about the testing procedure. Once the Thevenin circuit problem was corrected, the entire testing procedure had to be started over again. The new results were still outside the 2% error parameters that were required, so the project manager became further involved in the testing process. The project manager sat down and tested some boards with the team members. Upon doing this, the high error was found in how the undergraduates were reading the oscilloscope. The settings on the oscilloscope were not at optimal, so a precise reading was impossible and therefore causing the large error percentages.

The help provided to the inexperienced researchers is an example of how MBWA and keeping communications open helps a project team work more effectively. However, to avoid fostering dependency, the project manager must not take over the task. Rather a manager must simply show how a process is performed and then step back to allow the team member to do it themselves. This approach instills both trust in management and increases the team member's self-esteem and creativity. This is an example of prosocial behavior in that the team members must be given tasks that they are capable of performing, even if they do not yet recognize their own capabilities. When team members complete a task they did not know they could do, their success motivates them to try new things, be creative, and contribute more readily to the team.

About halfway through the project, the program manager brought to the attention of the project manager a concern that the team members were not working enough hours. The researchers were not fulfilling their agreed upon working hours per week. Several vacation breaks were approaching, and if the team members took time off during these breaks, the project would fall behind. So, a meeting was called to determine why tasks had been delayed and what could be done. The project manager expected to hear complaints of poor communication and lack of understanding tasks, but this was not the case. Some team members wanted more structure, more deadlines in the form of further breakdown of tasks on the Gantt chart. People need deadlines so that they can cross tasks off a list and feel a sense of accomplishment. Each task they accomplish gives them motivation to accomplish more and aim toward greater challenges in the future. However, too many deadlines can be counterproductive; team members must learn how to set deadlines for themselves so they do not become dependent on the manager. Team members need to set some of their own goals, otherwise they may become stagnate. Learning to set goals will encourage team members to push the envelope and creating new ideas.

Fearing that the team would become too dependent and not wishing to micromanage the project, the project manager opted to be present in the lab more frequently and for longer periods of time. This would allow the team members to ask the project manager questions when need be; if someone really needed to know what to do next, they could ask. This relates to the project manager's discovery of the importance of presence.

The project manager noted a clear difference in performance and attitude toward the project when present in the lab among the team members. When management was not present, team members gave the project a low priority. When the project manager started coming to the lab and staying there most of the day, the team members were eager to ask questions, order parts, and work on the project in general. The availability of the project manager encouraged more open communication of technical problems and deadline concerns. It also gave the project manager more opportunities to offer encouragement and guidance. If a solution was needed, the project manager did not resolve it for them, but gave them suggestions or pointed them to a source where they could find the answer; watching to make sure they go down the right path towards a solution. The presence of the project manager also build comradery and trust. The development of open communication permitted encouragement and the discussion of concerns on a day-to-day basis; rather than delaying such communication until the weekly evaluation, which was the norm in this academic environment.

## 5. CONCLUSION

This project manager found that the importance of presence was paramount. She had an office in another building, but if she had spent more time there instead of being present in the lab, where the work was actually being done, the project and the problems that arose would not have been managed as quickly. Although one can manage a project from an office, the project suffers. The primary victim being communication, it is also quite difficult to motivate a team when you are not present among them.

A good project manager who wishes to motivate his team must assign project tasks to the team members with the most appropriate skills and work with them to ensure efficient and effective project completion. As discussed with Maslow’s pyramid, self-actualization can only be achieved if team members work on tasks that allow them to reach their full potential. Assigning personnel to tasks where they do not succeed, is not only counter-productive for the project, but also frustrates the capabilities of the workers.

The observations discussed in this paper support the contemporary wisdom that managing people and behaviors is the real foundation of successful project management. Project managers must first know their team's personalities and needs; only then can they get the most productivity out of their workers that will perpetuate and grow, because workers that motivate themselves cultivate success.

**REFERENCES**

de Waal, F., and Suchak, M., 2010. Prosocial Primates: Selfish and Unselfish Motivations. Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 365, No. 1553, pp. 2711-2722.

de Waal, F., 2008. Putting the Altruism Back into Altruism: The Evolution of Empathy. The Annual Review of Psychology, 59: 279-300.

Fisher, E., 2010. What Practitioners Consider to be the Skills and Behaviors of an Effective People Project Managers. International Journal of Project Management, doi: 10.1016/j.ijproman.2010.09.002

Gillard, S. and Price J., 2005. The Competencies of Effective Project Managers: A Conceptual Analysis. International Journal of Management, vol. 22, No. 1, pp. 48-53.

Graeff, C., 1983. The Situation Leadership Theory: A Critical View. Academy of Management Review, vol. 8, No 2, 285-291.

Grant, A. and Berg, J., 2010. Prosocial Motivation at Work: When, Why, and How Making a Difference Makes a Difference. in K. Cameron & G. Spreitzer (Eds.), Handbook of Positive Organizational Scholarship. New York: Oxford University Press.

Jaeggi, A., Burkart, J., and van Schaik, C., 2010. On the Psychology of Cooperation in Humans and Other Primates: Combining the Natural History and Experimental Evidence of Prosociality. Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 365, No. 1553, pp. 2723-2735.

Kirman, A., and Teschl, M., 2010. Selfish or Selfless? The Role of Empathy in Economics. Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 365, No. 1553, pp. 303-317.

Maslow, A., 1943. A Theory of Human Motivation. Psychological Review, pp. 370-396.

Melis, A., and Semmann, D., 2010. How is Human Cooperation Different? Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 365, No. 1553, pp. 2663-2674.

Peters, T. and Austin, N., 1985. A Passion for Excellence. Random House, New York.

PMI. 2008. A Guide to the Project Management Body Of Knowledge (PMBOK Guide), forth ed. Project Management Institute, Newton Square, USA.

Svetlova, M., Nichols, S., and Brownell, C., 2011 (in press). Toddlers' Prosocial Behavior: From Instrumental to Empathic to Altruistic Helping. Child Development. University of Pittsburg.

University Department of Rural Health, University of Tasmania, Australia (UTAS). 2010. Community Leadership in Rural Health. Maslow's Hierarchy of Needs Pyramid. last accessed May 1, 2011at http://www.ruralhealth.utas.edu.au/comm-lead/leadership/maslow-diagram.htm).

Warneken, F., and Tomasello, M., 2009. Varieties of Altruism in Children and Chimpanzees. Trends in Cognitive Sciences, vol. 13, No. 9, pp. 397-402.

Yount, B., Xiao, F., Zhao, J., and Kimball, J. 2011. Quantifying Insolation in Multiple Shading Scenarios. IEEE Green Technology Conference.

## SECTION

## 3. CONCLUSION

This thesis describes the plan and implementation of a solar sensor array project that spanned thirteen months and employed roughly seven engineers. A solar sensor array was designed and deployed to three locations to collect data and later downloaded for further analysis. This analysis has quantified the differences of insolation from sensor to sensor at any given time. The varying insolation is due to clouds shadowing one portion of the array but not another and these differences can be observed between sensors that are positioned next to each other. This lends itself to future work calculating the convergence of these quantifications. This sensor array still exists and collects more data for future analysis. These and other utilizations of the data collected should aid in the advancement of PV technology.

During this project, the prominent observation made as a project manager was the importance of presence. The prime objective was to motivate the team to reach all milestones on time while producing a quality end product (the sensor array and its data). However, this proved difficult when the project manager's office was in another building. Project management requires MBWA in order to grow people management skills. Once tuned-in to the team members needs, realizing each engineer was at a different level of experience and skill, being present in the lab was the best solution to most problems that arose.

# BIBLIOGRAPHY

[1] J.M. Henry and J.W. Kimball, "Practical performance analysis of complex switched-capacitor converters," *IEEE Transactions on Power Electronics*, vol. 26, pp. 127-136, January 2011.

[2] N. Nagarajan and J. Kimball, "Development of a GUI for parallel connected solar arrays," in *Proceedings of the Power & Energy Conference at Illinois (PECI)*, Feb. 2011.

[3] N. Nagarajan, B. Yount, and J. Kimball, "Use of a sensor array to quantify the effects of insolation on solar arrays," Journal of Renewable and Sustainable Energy. awaiting publication.

[4] N. Nagarajan, "Development of a graphical user interface for the study of parallel connected solar arrays," Thesis for her Masters in Electrical Engineering. May 2011.

[5] B. Yount, F. Xiao, J. Zhao, and J. Kimball, "Quantifying Insolation in Multiple Shading Scenarios," *IEEE Green Technology Conference*. April 2011.

[6] A. Crowe, "For DIYers, Solar Panels Come to Lowe's," last accessed May 2011 at http://realestate.aol.com/blog/2009/12/17/for-diyers-solar-panels-come-to-lowes/

[7] H. Kaqamura, K. Naka, N. Yonekura, S. Yamanaka, H. Kawamura, H. Ohna, and K. Naito, "Simulation of I-V characteristics of a PV module with shaded PV cells," Solar Energy Materials & Solar Cells. 2003. vol. 73, pp. 613-621.

[8] D. Nguyen and B. Lehman, "Modeling and Simulation of Solar PV Arrays under Changing Illumination Conditions," *2006 IEEE COMPEL Workshop*, Troy, NY, July 2006.

[9] H. Patel and V. Agarwal, "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics," *IEEE Transactions on Energy Conversion*, March 2008. vol. 23, NO 1, pp. 302-310.

[10] D. Renne, R. George, and M. Sengupta, "Recent Advances in Solar Resource Verifiability and Forecasting," *Utility/Lab Workshop on PV Technology and Systems*, Tempe, AZ 2010.

[11] National Renewable Energy Laboratory, National Solar Radiation Data Base, accessed May 2011. http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/.

[12] D. King, G. Galbriaith, W. Boyson, S. Gonzalez, A. Murry, J. Ginn, and W. Bower, "Array Performance Characterization and Modeling for Real-Time Performance Analysis of Photovolaic Systems," *4th World Conference on PV Energy Conversion*, Hawaii, May 2006.

[13] D. King, W. Boyson, and J. Kratochvil, "Analysis of Factors Influencing the Annual Energy Production of Photovoltaic Systems," *29th IEEE Photovoltaic Specialists Conference*, 2002.

[14] Teodorescu, D., and Rodriquez, "PV panel model based on datasheet values, " *IEEE International Symposium on Industrial Electronics*, 2007. pp. 2392-2396.

[15] PMI, "A Guide to the Project Management Body Of Knowledge (PMBOK Guide)," forth ed. Project Management Institute, 2008. Newton Square, USA.

[16] D. Pink, "Dan Pink on the surprising science of motivation," TED ideas worth spreading, last accessed on May 2011 at http://www.ted.com/talks/dan_pink_on_motivation.html.

[17] A. DuBrin, "Essentials of Management," eighth ed. 2009. South-Western Cengage Learning, Mason, OH. pp.375-383.

[18] A. Maslow, "Motivation and Personality," 2nd ed. Harper & Row, NY. 1970.

[19] N. Eisenberg and P. Mussen. "The Roots of Prosocial Behavior in Children," Cambridge: Cambridge University Press, 1989. ISBN: 0-521-33771-2.

[20] S. Adams and V. Anantatmula, "Social and Behavioral Influences on Team Process," Project Management Journal, 2010. vol. 41, No. 4, pp. 89-98.

[21] A. Grant and J. Berg, "Prosocial Motivation at Work: When, Why, and How Making a Difference Makes a Difference," in K. Cameron & G. Spreitzer (Eds.), Handbook of Positive Organizational Scholarship. New York: Oxford University Press. 2010.

[22] E. Fisher, "What Practitioners Consider to be the Skills and Behaviors of an Effective People Project Manager," International Journal of Project Management, 2010. doi: 10.1016/j.ijproman.2010.09.002.

# VITA

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