AC 2009-2044: AN UNDERGRADUATE ANALYSIS OF TWO DIFFERENT PHOTOVOLTAIC MODULE TYPES: A COMPARISON COMPLETED FOR AN INDUSTRIAL AFFILIATE

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Abstract

Rowan University is committed to giving its undergraduate students an early experience in real world situations. Through the participation of Industrial affiliates Rowan University is able to get their undergraduate students involved in the innovation of cutting edge renewable energy research. During the 2007-2008 academic year Kaneka Corporation of Osaka Japan, sponsored the installation of a Photovoltaic (PV) system located at the newly created South Jersey Technical Park. This 1kW system utilizes Kaneka’s new amorphous-silicon photovoltaic modules, which are purported to being more efficient in higher temperatures. A comparison of these amorphous modules and an existing system of differing module types has been completed. This reference system being a 13.3kW array of single-crystalline modules located on the same roof, tilted at a comparable angle. Working in an engineering clinic environment modeled on the medical school model, students were to determine (if existent) the efficiency gains of the new amorphous type modules in contrast to the mono-crystalline modules on the same roof.

Background

The New Jersey state school Rowan University’s College of Engineering (CoE) has made a name for itself in large part due to working hand in hand with industrial affiliates from around the world. When the CoE was created thanks to a healthy endowment by an industry magnate, one of the most important aspects that the university wanted to integrate into its curriculum was a large amount of practical experience for its students. Not only would this keep things interesting but would also prepare them well for their future. The most important way this was done was by introducing what is now called the Engineering Clinic. This bases its idea on the medical school model by providing the necessary experience in a safe environment that will enable the participants to be fully capable of acting on their own in the real world, all the while providing a service to its affiliates. The details of the clinic are described in numerous papers1,2,3 so the sequence is not discussed here. In recent years many other papers have been written to demonstrate the usefulness of the clinic and to share many opportunities that students at this university have had to apply the clinic to innovative renewable energy and sustainability activities4-12. In late 2007 Kaneka Corporation of Japan approached the CoE to fund an experimental Photovoltaic system that incorporates their new amorphous silicon modules which promise lower losses of performance in higher temperatures when compared to conventional
solar modules. Seeing it as a great opportunity for an additional clinic project, Dr. Rowan along with his graduate student and four undergraduates added the project to their list of objectives. The first semester included the design and installation of the system including data collection for future analysis. In the fall 2008 semester, part of a clinic project entailed the analysis of the collected data to give an insight into the operational efficiency of the new module type versus two existing systems that utilize conventional multi- and single-crystalline technology.

Analysis

A large part of engineering entails the analysis and comparison of previously collected data, in order to give a greater understanding of improvements or changes that need to be made in the future. Without the scientific process of trying to understand the operation of any given system, significant advances in technology would not be made. Hence, it is an intricate part of the curriculum at the CoE and must be included in the clinic program for students to become proficient in all aspects of engineering. That is exactly what students have done in this part of the project, and on which this paper will focus.

Amorphous PV

The manufacturer claims that amorphous silicon cells will convert between four and six percent of incoming solar energy into usable power. Compared to mono- and poly-crystalline cells which most commonly range in the 12-17% efficiencies, amorphous types will at first glance seem inferior. However, due to several reasons this is not always the case. Their ease of manufacturing makes them less expensive per watt, but the nature of the thin-film method increases the overall area of the module per watt. A combination of these factors provides possibly the cheapest type of PV module that requires the most amount of space. The real advantage with these amorphous cells lies in their tolerance of heat. Normally efficiency drops immensely when module temperatures reach 30°C+, but amorphous cells do not suffer as greatly from increases in temperature as shown in the following section. If pertinent data can be collected on-site to help determine when - if ever - these module have an advantage, it can significantly help picking the right type for a new system.

Module temperature and loss factors

Since module temperatures will not always be available before the installation of such a system, it is important to note any correlation between them, ambient temperature and insolation. There are many other meteorological and environmental factors that can influence any direct connection between variables, ranging from precipitation and humidity to wind or overcasts. Naturally one of the strongest of these will be the wind speed at a given site. It’s ability to cool the modules is a major factor, but only basic data for the surrounding area was found – which does however give at least a small insight into its effect. Comparisons of various data were done for the months of May through September 2008, starting with the most intuitively straightforward correlation of ambient and module temperatures. A simple best fit confirms the
assumption with $R^2$ values ranging from .8 to .85. Figures 1&2 give example graphs of the ambient and module temperatures measured at the site for the Months of May, July and September.
Figure 1. Module vs. Ambient Temperatures for the months of May and July

Figure 2. Module vs. Ambient Temp for September

Figure 3. May through September
When calculating the correlation for all summer months, there is still relatively good $R^2$ of about .68 (Figure 3).

As stated previously one of the most important factors that affect the temperature (and with that performance) of solar modules, is the airflow around them. With only average daily and not hourly wind data available from a nearby town, this data may only be used to verify a visual trend of any impact stronger winds may have on module temperature. Figure 4 gives an example of this data, the trend-line creating a very clear divide on high insolation days, between higher winds (red- above 2.65m/s) and lower winds (blue- less than 2.65m/s). This did not hold up for some other months, as seen in Figure 5. While seemingly random, all high winds for the month($\geq$3m/s – Figure 6) did correlate to lower temperatures (though not vice versa). This is expected to be due to the necessity for much stronger winds in order to cool the modules when ambient temperatures and insolation are very high.

![Module Temp. vs. Insolation (May)](image)

**Figure 4.** Module $^\circ$C vs. Insolation with high (red) and low (blue) winds.

This same data for the entire summer reveals that for average to high amounts of insolation (.6 – 1.5 kWh/m$^2$) high average wind speeds of at least 3m/s always provide for the lowest module temperatures, and low average wind speeds always provide for the highest module temperatures (Figure 7). This is a very straightforward but important thing to note, and should be an important factor in selecting the specific type of module for your location. By taking a close look at high insolation levels, it can be seen that the module temperature can vary by...
as much as 40°C. The next section shows that this can make a world of difference in the efficiency of the crystalline modules – and may cut into amorphous performance gains in high insolation areas.

![Module Temperature per Insolation, with Wind speed noted](figure7.png)

**Figure 7.** Module Temperature per Insolation, with Wind speed noted

### Efficiency

After this short introduction on the impacts of various factors on module temperatures, a comparison of the significance these effects can have on performance follows. As noted earlier in the paper, poly and single crystalline modules suffer in performance with an increase in module temperature (see Figures 8-11). Since amorphous modules are not as affected by high module temperatures, they manage to perform better per watt. These gains are represented in terms of a percentage calculated by simply dividing the difference of the two kWh/kW ratings by the rating of the crystalline module. Figure 8 gives a graph of this relationship for the month of May.

![Amorphous Gain vs. Module Temp. (May)](figure8.png)

**Figure 8.** Amorphous gain over single-crystalline modules

By plotting the production multipliers for each of the systems, it becomes very clear that the amorphous modules have the upper hand between ca. 11am and 4pm. These hours of the day are incidentally also the
period within which the capability to produce the most amount of energy is the highest, since they correspond to
the times of the maximum solar window perpendicular to the panels. Figure 9 gives a glimpse of some very hot
days, from July 15-22.

Figure 9. Comparison of kWh/kW for both systems

Even in the relatively cool month of May, gains of approximately 15% are not uncommon. After having
computed these same values for June and July, the hottest months of the year, that the 25% mark is almost
reached. What this essentially means is that the amorphous modules not only outperform the single-crystalline
modules, but by almost a quarter of their rated power. Of course this is no true “gain” as the Kaneka modules
never increase in efficiency, but the effect is nonetheless the same since their competitors fall far behind. Figure
10 shows the data for June and July, when compared to module temperature.

Figure 10. Amorphous modules’ gain in terms of module temperature.

This drop in output on part of the single-crystalline type becomes even more evident as their efficiency is
graphed with respect to module temperatures. Their effectiveness in converting sunlight into power is evaluated
by taking the entire solar-incident area of each system and dividing the generated energy by this area. Since
hourly measurements of the incoming insolation are available, these two values can then be compared to
determine the average efficiency of each type. Figure 11 gives an example of one of these plots for the month of
July.
This same data was compiled for the entire summer, given in Figure 12. One immediately notices the large spread for the single-crystalline modules, whereas the amorphous’ efficiency stays within a relatively small range. With a maximum of 6.1% and evening out to around 5.8%, this accounts for only around a 5% drop in efficiency, whereas the crystalline modules dropped by close to 25%. This means 95% of the maximum efficiency is kept for the amorphous modules (5% drop) and 75% for the crystalline type (a 25% drop). A better argument for the use of amorphous modules in temperate to hot climate areas will be hard to find.
Final comments

Throughout the course of the analysis for this project amorphous silicon modules do indeed seem to hold true to their manufacturer’s claims. While the crystalline type generate more power and are more efficient with respect to their size, the energy output per watt is significantly better for the amorphous modules during times of high module temperatures. There are a few stipulations that need to be addressed, however. The SunTech-Power modules are tilted about 6° lower than the Kaneka modules, which will give them an advantage in terms of the available sun due to being more normal to the incoming solar radiation. Also, while the amorphous modules’ backs are covered by being mounted in SolarDocks, the crystalline modules have open backs which gives them an advantage in terms of airflow and cooling. Module temperatures were only measured on the amorphous modules, and not on the single crystalline system. This could translate into higher losses for lower module temperatures, in favor of the amorphous.

Graduate student:

This and many other such clinic projects can be quite rewarding for the graduate student involved. It generally is the case that the grad student will take the lead, acting as a sort of mid-level manager, to ensure that all objectives are completed. It gives some great insight into learning what works best when trying to motivate students while extracting as much useful work out of them as possible. With a large variety of interests, personalities and motivations found in students, leading such a team can range from frustrating to downright gratifying. With their motivated help, it is possible to accomplish a grand amount of deliverables that would otherwise take ages. I was very happy with the two students on this project, as they were a strong part of the team that delivered quality work from day one.

Undergraduate 1:

My work with Dr. Jansson and graduate student Ulrich on the Rowan Engineering Clinic study of PV cells has given me invaluable experience in real-world engineering practice. The collection and analysis of data from the PV systems has taught me a great deal about how this renewable energy technology works. By comparing two systems in a controlled environment our team was able to analyze the affect that various parameters such as wind speed, ambient temperature, and module temperature have on the energy production of different types of PV cells. This Clinic project has given me an understanding of how to properly run an experiment as well as how to analyze data.

Working on this Clinic project has given me much more than a grade, it has provided me with actual engineering experience before I have even graduated and entered the work force. This experience will stand out on my resume and separate me from students who have only studied what I have actually done. The PV project has exposed me to the design of technology that plays a vital role in environmental sustainability which is a huge global issue. Being acquainted with sustainable design and renewable energy will help me in my future as a civil engineer. My experience with renewable energy will make me much more marketable once I graduate. One of the reasons I chose Rowan over other schools is because of the Clinic portion of the curriculum that they advertised during their open house for prospective engineering students. Although I wasn’t sure what to expect from this program after being involved in several projects I understand just how such practical experience is valuable in dealing with real world issues.
Having the ability to access tools and work on projects at an undergraduate level, experience most would only get in a post graduate setting, has given me an edge over many others. Those wanting to pursue a career in energy systems like photovoltaics, such as myself, now have the ability to learn how to operate, install, and calculate data for this popular source of renewable energy. Not only have I gained this knowledge, but by working alongside those who have been in the field creating and maintaining tangible systems, I’ve had the opportunity to see what can affect them in the real world. Having this opportunity gave me the chance to see errors that occur and use divergent thinking processes to correct said errors, along with knowledge of what affects photovoltaics in terms of insolation, temperature, and wind speed to give a more hands on approach to learning. All in all, with the help of Rowan University and its’ affiliates at the Kaneka Corporation, many undergraduate students such as myself have an opportunity which most will never get, a chance to be in the field to learn, not just learning from the classroom.

References