SIMPLIFIED METHOD OF ENCAPSULATING FRAGILE PV CELLS FOR COTTAGE INDUSTRY PRODUCTION OF PHOTOVOLTAIC MODULES

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ABSTRACT

More than two decades ago, Richard Komp developed methods of manufacturing PV modules without using the encapsulation systems that need special, complex laminating machines. This led to the development of photovoltaics as a cottage industry where people, including villagers in the developing world could make and install their own PV systems, bypassing the need to purchase PV modules made in the developed world and keeping their money in their locality. However, the introduction of thinner, more fragile PV cells has required modifications to this simple encapsulation technique; and more recently; the step drop in the price of finished modules has led to a careful reassessment of the costs and methods used in these techniques. This work, the details of which are given in this paper has been successful and cottage PV module manufacturing is still a viable option for developing countries.

1. INTRODUCTION

Over one half of the people living in the rural areas of developing countries have no access to utility grids. Photovoltaic (PV) electricity is often the most ideal solution to the problem of furnishing these people with electricity but the PV systems are generally far too expensive for the average rural peasant to afford, and an entire infrastructure needs to be created for the installation and maintenance of these systems. One possible solution to this problem is to teach the peasants how to build and install their own PV systems.

Over the years since commercial photovoltaic (PV) modules have been sold, various methods of manufacturing "homemade" PV modules have been tried. These have ranged from simply gluing PV cells to boards to more complex systems which included transparent plastic cover sheets and aluminum frames, to using various plastic encapsulants to imbed the PV cells. Most of these systems failed early on, caused by problems of differential thermal expansion to delamination of the module and corrosion of the contacts and solder joints from rain water leaking into the finished modules. Finally a method of encapsulation was developed that used a two part room temperature curing silicon resin encapsulant behind a glass front cover. This process requires no complex laminating machine and no electricity and produces PV modules or professional quality that will last for decades. This led to the start of a cottage industry of producing PV modules in developing countries, since it did not require a large capital investment or complex machinery to produce high quality modules that could be sold with 20 to 25 year guarantees[1].

However, this encapsulation process required relatively thick (300 micron or more) single or polycrystalline silicon PV cells and a considerable amount of the expensive silicone resin. As the photovoltaic industry migrated to thinner PV cells and the far more fragile ribbon grown PV cells became available, the encapsulation process became more difficult to implement successfully. One of us Marco Antonio Perez a Nicaraguan peasant landmine victim working in his remote village workshop, developed a variation of this encapsulation process that used a paper backing and turned the process upside down, with the glass cover being the last thing to be laid on the top of the layers of encapsulation materials. Capillary action draws the silicone resin into the paper resulting in a completely sealed module using only half the pervious amount of the expensive silicone. This previously reported work[2] has now been extended and simplified over the last three years as the cottage PV module assembly work has been taught in a number of developing countries including Nicaragua, Mexico, Peru, Chile Haiti, Mali west Africa, India, Pakistan and Rwanda east Africa, as well as in the United States and Canada[3]. In a number of these locations, the actual peasants involved in the cottage industries have developed their own procedures for manufacturing the PV modules and these improvements have been incorporated into the process when workshops in new locations have started up. In addition, follow-up visits between the groups have spread these improvements back to the earlier facilities. This paper shows and analyses several of these new encapsulation techniques, as well as giving some details of the costs of the finished modules; and social structures created in the different locations to produce a sustainable cottage workshop to build, install and maintain the PV systems.

Fig 1 Marco Antonio Perez teaching the first PV module assembly workshop in Haiti in November, 2003. This workshop used the thicker and stronger Astropower single crystal photovoltaic cells.

2. THE MODULE ASSEMBLY PROCESS

2.1 Details of the Basic Encapsulation Process

This method, developed in Nicaragua, by Marco A. Perez, Dr. Richard Komp, S. Kinne and the Grupo Fenix, for use in the field, to allow for secure sealing of cells and PV modules while away from standard power sources and without expensive laminating machines.

Fig 2 Soldering the PV cell strings in Rwanda, Africa

After soldering PV strings for the easy to handle 60W module, the encapsulation of the strings, using Dow Sylgard 184 kit, is the next step. We may configure cells in four strings of 9 cells (when using tempered glass), or three strings of 12 cells (for window strength glass).

On a flat, level surface, the base working layer of six sheets of newsprint or 2 to 3 cm thick, flexible Styrofoam board is used to cover the glass dimension area, plus about 10 cm all around. Then a 2 to 3 mil (50 to 75 micrometers) thick polyethylene sheet is laid down, about the same size as the backing cushion and taped to secure. A layer of vinyl (polyvinyl chloride) plastic (clear or colored), is then put on top of the polyethylene plastic. This may be a table cloth type material or clear window sealing vinyl, which will be the final backing of the finished PV module. The area is then covered with (usually white) 20# bond paper (we use a roll wider than the module, when available). This will allow the encapsulant to be absorbed around the cell strings to the back of cells with a capillary action during curing process.

The soldered strings (series connections), are laid onto the paper, with alternating ends (pos., neg., pos., neg.), for final wiring in series as well. This will give the 18V, rated output, to enable 12V charging, when the PV module is used alone or in parallel with other modules in an array. The strings are placed as close together on the paper sheet as possible, without touching each other and centered within the penciled glass outline. The ribbon-tabbing ends are fitted through small (1/4”) slits, cut in the paper (approx. ¼” from end of each string), so the final soldering may be done after the encapsulation process.

Fig 3 Mixing the two part Sylgard 184 silicone resin to encapsulate a 30 watt PV module in Mali, Africa.

The positioning of the strings is checked once again and approx. 200 ml of liquid silicone kit is mixed in paper cup or other container. This is mixed with pouring action between two cups and then poured onto cells, as well as between each string. Another application of approx. 200 ml of the Sylgard kit is mixed and poured onto and between strings. The paper cups may be used to gently spread the encapsulant over the area evenly. Allowing the silicone to sit uncovered for approx. 15 – 20 minutes seems to let air escape from the curing Sylgard. You can see that the table or surface is level as the Sylgard settles. The glass is cleaned with window cleaner and dried on the side to be put on to the Sylgard, then placed gently onto the assembled materials, exactly within the penciled in area. The air space will seem to have large air bubbles that will slowly move toward the edges of the glass and out of the liquid space. Pressure is applied to help the air escape and a 10 Kg or more weight is placed on top of the glass with a cardboard cushion between the weight and the glass. This is left on the level surface, with the weight to help the air bubbles escape during the one to two day curing process. The temperature and humidity will determine the time necessary for the curing. The warmer the room, the less time required for Sylgard curing. In tropical conditions of 28 to 35º C, the modules are completely cured overnight.

After the Sylgard has set up, the module is ready to be taken out of the laminating station and cleaned of excess silicone. The black 3 mil plastic is removed, and the vinyl and paper backing sheets are trimmed back to the glass edges. The 60W module is now ready for the testing, final wiring, framing and junction box installation. Normally, the frame is made from some locally available aluminum extrusion (usually a U channel about 4 cm in height by 1 cm or more in width), with the corners fastened together by aluminum blind rivets. In addition to gluing the frame on the module with 100% silicone caulk, a second small 1x1 cm aluminum angle is fastened inside the four frame sides to mechanically pin the laminated module into the frame.

Fig 4 Pedro Sanchez installing the extruded aluminum frame on a 60 watt PV module in Peru. He used the vinyl poster announcing the PV course as the backing sheet.

Sometimes, instead of an actual junction box, a simple European style terminal strip is mounted one end of the frame. This arrangement is particularly useful in tropical countries where moisture building up in the warm junction box leads to corrosion problems. For small 12 and 24 volt systems, the open terminal strips are not a shock hazard.

2.2 <u>Variations on the Module Encapsulation and Assembly Methods</u>

The different groups which have started the cottage PV module making workshops have developed variations on the original procedure, and these important developments have spread from one group to another as they see the advantage in the changes.

2.2.1 <u>Haitian Revisions</u>

For instance Jean Ronel Noel and Alex Georges of the Enersa group in Haiti pioneered the use of surprisingly heavy weight, up to 50 Kg, as well as the method of spreading the liquid silicon from the center of the modules to edges to remove the trapped air.

The Enersa factory was completely destroyed in the recent earthquake in Haiti, but all the participants and their families survived, and they saved some of the production tools and are setting up production as soon as donated PV cells arrive. All the solar street lights they had installed in the Port au Prince area survived and became the center of impromptu refugee camps, even before any outside help arrived.

Fig 5 Low-tech laminating system using heavy weights, developed by Enersa in Haiti.

2.2.2 Changes Developed in Peru

Pedro Sanchez Cortez of Solartec in Peru and Richard Komp developed the technique of including the vinyl backing sheet in the original encapsulation step and soldering together and testing all the strings in the module before encapsulation. This leads to a finished module ready for framing and installation of the junction box or terminal strip, and a more professional looking, more reliable module with fewer assembly steps and a lower cost.

2.2.3 Changes Made in Rwanda

In Rwanda, aluminum extrusions for the module frames are unavailable so the group of genocide survivors had a local carpenter assemble frames from locally cut tropical hardwood. Since silicone caulk adhesive is also unavailable, they also used locally made putty to hold the laminated modules into the wooden frame. This group has also now started their own solar enterprise, which they are calling Radiant Horizon.

Since many of the locations where we have introduced the cottage PV modules assembly procedure are some distance from the utility grid, and many of the others have a very unreliable grid with many hours of unpredictable blackouts; we designed the assembly equipment to be solar powered. At first, we would bring to the location two 30 to 40 watt PV modules made in Nicaragua by the Grupo Fenix and use those to power the tools but for the last 3 years, we have simply bought two 12 volt truck batteries (the closest thing to deep-cycle batteries available in most developing countries) and would use them to make two 60 watt PV modules. The challenge is to finish the modules before the batteries are badly discharged and install them on the roof of the cottage workshop to continue work.

Fig 6 Testing the strings of PV cells for a 30 watt module in Karachi, Pakistan, prior to encapsulation. The two 60 watt PV modules in the background power the cottage workshop.

3. PV MODULE INSTALLATION AND REPAIR WORK

The cottage PV module enterprise not only has to manufacture the modules but they also have to learn how to design, install, maintain and repair the entire PV systems[3]. When we are arranging to go to a developing country to start the PV module workshop there, we try to arrange some customers ahead of time, for the finished product. In addition, it is usually necessary to install the first finished modules on the workshop, so the group gets practice in installation before meeting their first outside client.

Fig 7 Cottage industry group in India installing a pole mount PV system at a "green" resort near Mumbai.

Quite often, there will be PV systems already installed by outside non-profit groups (NGOs) on nearby community buildings like health clinics, and these systems usually need maintenance work, or are not working at all, since the NGO had made no provision for repair and maintenance. These make excellent teaching opportunities for the cottage industry group, and they also can often get a contract for future maintenance of the system. We have repaired systems that had not been working for years, simply by fixing a corroded or broken wire, which took the group fifteen minutes to troubleshoot.

Fig 8 Richard Komp helping the Radiant Horizon group find the problem (a broken wire) on a non-functional PV array on a health clinic in Rwanda.

4. THE COTTAGE INDUSTIRY AS A SUSTAINABLE BUSINENSS, FINANCIAL CONSIDERATIONS

In order for the cottage PV module industry to be successful, it must ultimately be financially sustainable without subsidies. This means that, first the cost of the finished PV module has to be competitive with the commercially sold modules in the area, and second, there has to be a customer base that can afford to purchase the products. In developing countries, there are three classes of customers:

1. NGOs that wish to install PV systems in places like community centers, health clinics and schools but who wish to keep as much of their development funds circulating in the client country, and who also wish to have a local partner to install and maintain the systems.
2. Businesses who wish to have a reliable source of electric power for their establishments in areas with frequent brownouts and power failures. This same class of new middle class people will also often want similar solar uninterruptable power systems in their homes.
3. The poor peasants who live in rural areas not served by electric utilities. These are the largest group of potential customers, but they generally can't afford to purchase even a small PV lighting system without some sort of microloan arrangement.

The small cottage PV module assembly and installation businesses that have been started as a result of our work, have usually been successful in getting some sort of cooperative microloan arrangements with a financial partner, but in all cases, the cash flow from the first two classes of customers, who have either the cash or the credit resources to pay in cash for their systems, is what allows the small solar businesses to by the materials and produce the PV systems for the poor peasants.

With the worldwide recession and the steep decline of the price of PV modules, the cottage PV workshops have had to take a careful look at their costs for all the materials, not simply the cost of PV cells, which have now dropped to less than $1 per watt. Susan Kinne and Richard Komp have worked with Marco Antonio Perez and Mauro Perez to get the price of all the materials to manufacture a 60 watt PV module down to $97 ($1.62 per watt); cheap enough so that they can compete with the imported Chinese PV modules and still pay a decent wage and a obtain good profit for their work. Similar costs of materials were obtained in other countries like Peru, Rwanda, India and Pakistan.

John Burke, working with the Addicts Rehabilitation Center (ARC) in Harlem NY has also been able to produce PV modules at a competitive price for off-grid camps in Maine, but the ARC group is not allowed to sell the modules in Manhattan since they aren't certified. However, they have been working with Underwriters Laboratory to see if they can get some sort of certification

Fig 9 Removing the bubbles from a module being encapsulated at the Addicts Rehabilitation Center in Harlem New York.

Fig 10 Testing the first PV module made in Chile, at the Universidad de Concepcion

Fig 11 Women in Mexico learning how to build a 30 watt PV module at the Villa Energia cooperative they started.

5. CONCLUSIONS

We have shown that it is possible to set up cottage industries in developing countries that will build photovoltaic modules and will design, install, maintain and repair photovoltaic systems.   Some of the cottage industries that have been operating for some years, such as Suni Solar in Nicaragua and Afriqpower in Mali, have become large, almost conventional solar distributer-installers with the ability to handle large government projects and systems paid for by outside non-governmental organizations (NGOs). Other groups are just starting and will need careful nurturing for several years as they develop.

We have also shown that it is possible to produce quality PV modules at a price that competes with the new low prices of the imported modules, and at the same time furnishing a good living for the entrepreneurs and workers in the developing countries.

6. REFERENCES

(1) Richard Komp, Elieneth Lara; “Photovoltaics as a Cottage Industry”, 2nd Sustainable Resources Conference, Univ. of Colorado, Boulder CO (2004)

(2) F. Dross, Marco Lopez, Mauro Lopez, A. Smith, D. Elis, A. Labat, R. Raudez, A. Bruce, S. Kinne, R. Komp; “Capillarity Solar Cell Encapsulation: A New Vacuum-free, Cost-effective Encapsulation Technique Compatible with Very Thin String Ribbons” 21st European Photovoltaic Solar Energy Conference, Dresden, Germany (2006)

(3) Richard Komp, Susan Kinne, Maria Teresa Castillo, Peter Sundberg, José Luis Vilches, Alexis José Martinez. “Off-Grid Photovoltaic Rural Electrification in Northern Nicaragua”, 2nd International Conference on Rural Electrification, Havana, Cuba (2003)

(4) Richard J. Komp, PRACTICAL PHOTOVOLTAICS, aatec Publications, Ann Arbor MI. (1981) Revised 3rd Edition (2002)