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PVT: A PHOTOVOLTAIC/THERMAL CONCENTRATOR TOTAL ENERGY SYSTEM

DRAFT FINAL PHASE 1 PROJECT REPORT

BUILDING OPPORTUNITIES IN THE U.S. FOR
PHOTOVOLTAICS (PV:BONUS) TWO

UNITED SOLAR TECHNOLOGIES, INC

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Photovoltaic-Thermal (PVT): A Solar Concentrator Total Energy System

PV BONUS Two Phase 1 Contract Completion Report

Introduction

United Solar completed its Phase 1 report and its proposal for Phase 2 of the PVBONUS Two program at the end of March 1998. At the same time, it also completed and submitted a proposal to the California Energy Commission PIER program for additional funding to cost-share development and testing of a pre-production model of the PVT-14. It was unsuccessful in both of these proposed efforts. While waiting for the proposal decisions, work continued in April and May to analyze the system design and component decisions described below.

This document is a final summation report on the Phase 1 effort of the PVBONUS Two program that describes the key technical issues that United Solar and its subcontractor, Industrial Solar Technology Corporation, worked on in preparation of a Phase 2 award. The decisions described were ones that will guide the design and fabrication of a pre-production prototype of a 1500:1 mirrored concentrator with gallium arsenide cells when United Solar resumes its development work. The material below is organized by citing the key components that underwent a design review, what the company considered, what was decided, the name of the expected supplier, if not to be produced in-house, and some information about expected costs. The cost figures given are usually budgetary estimates, not the result of firm quotations or extensive analysis.

Technical Review Decision Process

Recall that the PVT-14 system consists of a mirrored parabolic concentrator and a receiver that produces electricity and collects and delivers thermal energy using back cooling and an infrared radiation filter in front of the cells. In December 1997, one of the first steps United Solar took under the PVBONUS Two contract was to review the technology as built and tested under the California Energy Commission ETAP program. The review created a matrix and organized discussions on each of the key system components. This work organized the tasks taken under Phase 1 of the contract and led to the technical profile drawn of the pre-production prototype proposed for Phase 2 funding. The following sections summarize key technical considerations and design decisions made.

1.0 Component: Receiver Thermal Mass.

Problem / issue addressed: The California ETAP proof of concept receiver was cast in copper. The casting process produced porous, unworkable material.

We considered casting the thermal mass in a vacuum so that outgassing would eliminate the porosity problem. This was found to be too expensive. It appeared we would face a fivefold

increase in price and have no guaranties that the problem would be completely eliminated. Using that style of thermal mass also requires costly precision machining.

We decided against casting in favor of a manifold system. Although the solid cast body acts as a protective thermal mass in a situation where a catastrophic cooling failure will eventually occur, it only does so for a minute or two, given the level of energy it "sees." This is not good enough for the PVT cell array, which require 100% protection for up to at least 10 minutes.

The solid thermal mass adds a good deal of weight to the receiver as well, which makes handling riskier. A manifold system is much lighter, and modular. The drawbacks include: Less thermal mass, more o-ring seals, more parts in general, and alignment issues. Performance of a modular manifold system will not be any better in terms of overall system efficiencies, however, the ease of handling, assembly, leakage, repair, modifications, and accessibility to the inner components means a significant time and cost savings advantage. The manifolds can be made in any shop with a lathe and a milling machine. Expected component cost:

- a. For the pre-production prototype -- \$200 per manifold (four per receiver)
- b. For modest production 100 to 1000 dishes -- \$135
- c. In full production -- \$50

2.0 Component: Pre filter tubes/Lenses

Problem/issue addressed: Lens integration in the receiver.

The lenses used in the proof of concept receiver created most of the problems in our proof-of-concept fabrication and testing effort. Dimensional inconsistencies made it impossible to seal all 32 tubes simultaneously. Even designing and fabricating custom gaskets for each individual tube proved inadequate to clear the hurdle.

We considered a precision made blown tube, but that still left us with an expensive lens and locked us into a cumbersome sealing dilemma. We decided to abandon the compression lens configuration altogether and go with a modular manifold system. Like the power bars (cells mounted on substrates), it is important to be able to install and remove each individual lens in case of breakage or modification. This new system will allow that to be done. The initial cost of the lenses are twice the price, but they will hold water easily with the use of o-ring seals, and the ability to just plug them in one at a time will greatly reduce the labor involved in the receiver assembly and repair.

Performance will be the same optically, which is all that matters with this particular component. Rayotek of San Diego, assures us that these lenses can be made repeatedly with tight tolerances. As was mentioned, these will be expensive in small quantities -\$95 each, as compared to \$40 each for the proof of concept design.

Expected component cost:

- a. For the pre-production prototype -- \$95
- b. For modest production 100 to 1000 dishes -- \$50
- c. In full production -- \$35

3.0 Component. Seals

The seals used in the first proof of concept receiver were compression seals. All of the lenses were compressed between an upper and lower disc with flat gaskets contacting the lens ends. As was mentioned previously, this led to some rethinking in the plumbing department. Our second proof of concept receiver incorporated o-ring seals. 64 to be exact. No leaks were detected during any of the testing of this 2nd unit. The manifolds will consist of a flat disc with 32 radial holes in it, each with 2 O-ring grooves per hole. Both the power bars and lenses will plug into their respective manifolds and be sealed with redundant o-rings.

O-rings are extremely resilient to pressure changes and movement. They are also cheap and readily available in standard and metric sizes. High temperature o-rings, capable of 200 degrees C, can be bought in any quantity for as little as 10 cents apiece. The manifolds will require 270 o-rings.

4.0 Component. PV Cells

Problems encountered on our PV cells included: poor metalization; weak grid lines; and basic cell design. The original concentration ratio we expected was 1000X. We wound up with over 1500X. Since these cells were not designed to operate in that flux regime, most of the problems we experienced can be directly attributed to the higher irradiation. The cells that survived the initial 'burn in' showed no other signs of degradation afterwards. We looked at a variety of options for the next phase of cell. Those include: Grid design; thickness; size; chemistry; single vs. dual junction; double buss bars; shape; and metalization.

We decided to go with a thinner, double buss bar, rectangular cell with improved metalization designed for 1500X. Dual junction cells have higher efficiencies but are also higher priced. NREL has graciously agreed to supply 2 cells for testing. These tests will determine the final details on the preferred cell. The high intensity seen by the cells requires a double bus bar to enhance 'sweeping' of the electrons into the take off leads which route the electricity to the inverter. This complicates things somewhat in isolating the positive from the negative leads, but the modular design should significantly ease electrical routing problems in the cramped spaces. The exact specifics of the cell are yet to be determined, but given Tecstar's expertise, a suitable cell will be designed to perform under the expected conditions. Initial low quantity cost/cell is \$40 per square centimeter. Eventually that should drop to \$20 and quite possibly less. These costs are difficult to pinpoint at this stage.

Expected component cost:

- a. For the pre-production prototype -- \$40 / cm²
- b. For modest production 100 to 1000 dishes -- \$20 to \$30 / cm²
- c. In full production -- \$20 / cm²

5.0 Component: Cell Connectors

Wire mesh was welded to the cell bus bar and then soldered to a circuit board, which in turn, had a series of plugs soldered to it. Each cell could be individually monitored or bypassed. Electrically isolating each pair of cells provided great flexibility in our testing efforts. This is

one area which is difficult to improve on. There were no problems associated with this component.

The modular system is designed so that each electrical plug seats in a ring under the coolant manifold as the power bar is inserted into that manifold. The electrical ring is co-aligned with the manifold and contacts it thermally to provide cooling in case of resistance heating. This system is much easier to make but the ability to isolate each individual cell group is sacrificed. The component will perform as well as the proof of concept component. This component can be made in house or by any electrical circuit board manufacturer. Alignment of the female sockets which accept the male electrical plugs will be crucial.

Expected component cost:

- a. For the pre-production prototype -- \$25 per board
- b. For modest production 100 to 1000 dishes -- \$15 per board
- c. In full production -- \$5 per board

6.0 Component: Power Conditioner

Problem / issue addressed: Power conversion located at the dish

Trace Engineering supplied the 32-volt conditioner for our proof of concept receiver and agreed to design a boom mounted inverter for our pre production prototype. The obstacle to power conditioning lies in size. It is hard to invert 3 kilowatts of electricity with a compact, lightweight inverter. If we are to shorten the distance between the receiver and inverter, which is desirable, it is necessary to mount the conditioner somewhere on the dish.

Upon investigation, we found that there are no small and light weight inverters on the market at this time. (Trace makes a micro-sine unit for 100 to 120 watt flat plate PV panels. These are too expensive at this time to consider using an array of them) We decided to approach Trace about the possibility of designing a more compact 48 volt inverter which we could mount near the receiver. Forty-eight volts is more standard and a higher voltage allows a smaller wire gauge. We learned that Trace was already working on a new inverter that uses 3 smaller transformers to do the job of a single heavier transformer. This allows for some dimensional flexibility which will facilitate positioning on the dish. A smaller profile makes it easier and possible to mount the inverter on the receiver boom. A shorter run for the DC wires coming off of the receiver means smaller gauge wires and more power is delivered.

It was decided it makes sense to go with a higher voltage inverter and to stick with a reliable trade name. The trade-off guiding the decision was that servicing the inverter will be more difficult and it will add weight to the dish support system, but the lower line losses offset the added weight and servicing drawbacks. This component should perform adequately and continued development of inverter technology should lower its cost and improve capabilities. Trace Engineering supplied the power conditioner for our proof of concept receiver and agreed, had we won Phase 2, to design a boom-mounted inverter for the pre production prototype.

Expected component cost:

- a. For the pre-production prototype -- \$2500
- b. For modest production 100 to 1000 dishes -- \$1500
- c. In full production -- \$900

7.0 Component: Fail safe protection

The problem / issue addressed: Inevitable catastrophic power failure and receiver melt down.

We looked at a battery backup system that would supply power to the tracker and drive motors. The BSAR tracking system we used has thermally triggered off-sun circuits built into it which read signals from thermistors (heat sensors) mounted on the receiver. When the temperature goes beyond a pre-determined point, the tracker logic takes over, the dish goes off sun and into a stow position. This system is highly effective as long as the power is on. However, a mechanically triggered backup is obviously needed, in the event of a power outage.

What did we decide? The added production costs for a battery backup system were unacceptable, and it did not offer protection in the event of a motor failure. Finally, a spring loaded, thermally activated stainless steel shield was decided on for catastrophic failure protection. Even though this device adds more parts and costs to the system, the price of the PV cells dictate the requirement to do what it takes to protect them in the inevitable worst case scenario. In reality, the shield mechanics are very low "tech" and will easily pay for themselves each time they spring into action.

This solution should provide adequate shielding for hours, depending on the thickness of the shield. The shield will be attached to a collar that can slide on the boom. A spring will be in constant tension drawing the shield towards the boom, but the shield collar will be held in place by a small plastic rod with a low melting temperature. An insulated thick copper wire attached to the receiver is inserted into the base of the rod. As the receiver heats up, the heat is quickly transmitted down the wire and melts the plastic rod thus releasing the collar. The shield then springs up over the receiver to provide complete shading.

UST will fabricate the protective shield system. Expected component costs are:

- a. For the pre-production prototype -- \$300
- b. For modest production 100 to 1000 dishes -- \$75
- c. In full production -- \$25

8.0 Component: Boom

Although the newly designed space frame concentrator is completely different, integration of the proof of concept boom system to the new geodesic space frame will require very little engineering. Space requirements inside the boom and cost of materials became key design drivers. The proof of concept unit showed that we could use more space for plumbing and electric runs. The only difference on the new space frame is that the boom will not rotate.

The new boom specifications call for a 5" thinner walled tube.

UST will supply this component. Expected costs are:

- a. For the pre-production prototype -- \$25
- b. For modest production 100 to 1000 dishes -- \$25
- c. In full production -- \$25

9.0 Component: Absorption Chiller to Convert Thermal Output

The cogeneration concept is enhanced if the thermal output can meet a high cost energy load. Cooling is a logical choice and the system should be capable of generating 24,000 Btu's per hour for thermal use. The issue is finding a suitable small scale absorption chilling interface. The only small scale absorption chiller available is likely to be one in development by Energy Concepts Corporation, its VX GAX system. This is a high efficiency chiller that is a good thermal match with our system. Yazaki's smallest chiller absorption chiller for solar is a single effect 7.5 ton unit that is too large for one dish to power alone.

We decided we will collaborate with Energy Concepts to develop a small scale dish/chiller interface. We submitted a proposal to NREL in October 1997 to collaborate on matching the GAX to the dish thermal output profile, but were not successful in winning a contract.

Efficiency was the driver in the decision to go with the VX GAX. It is nearly double the efficiency of the Yazaki unit, but the interface engineering will require about \$80,000 to \$100,000 in effort to accomplish. (Details are summarized in the above mentioned proprietary proposal) The VX GAX small unit is in the later stages of development and could be deployed in convenience stores if Energy Concepts is successful with a proposed demonstration project. It will be expensive during its early commercialization stage and will have to prove its performance in the field. Higher temperature input capability and lower volumes of water needed from the dish should yield high efficiencies and plenty of cooling for a small building. It is too early to provide specifications for this system and to estimate costs per unit.

10.0 Component: Back up power

Problem / issue addressed: Power outages

United Solar considered several options for back up power for the dish. We decided to integrate a battery pack into the dish counter weight. In case of an outage, the battery pack capacity would have sufficient energy to operate the dish for 3 days without being recharged. A simple recharger working off the AC or DC output from the dish would extend this capability indefinitely.

Batteries are usually located in a building or small utility shed. Since it is necessary to counter weight the dish, it makes sense to use ancillary components to do the job. Exposure to the elements becomes an issue here, but proximity to the dish outweighs the cost of making the water proof battery pack container, and it eliminates the need to add materials strictly for weight considerations. As long as the batteries are kept out of the sun and rain the back up power should operate uninterrupted.

What are the new specifications? To be determined based on load calculation and testing of the prototype. Any number of companies can supply a suitable battery.

Expected component cost:

- a. For the pre-production prototype: \$250
- b. For modest production 100 to 1000 dishes: \$150
- c. In full production: \$45

11.0 Component: Ground anchoring the concentrator

Problem / issue addressed: Wind loading.

Forces created by winds as low as in speed as 25 mph can be formidable. The proof of concept dish had a base that could withstand 100 mph quite easily. The new space frame configuration presents some new problems in this area.

We investigated and analyzed a single pylon versus ground screws at the ends of three radially placed I- beams. We decided to use a single pylon. The pylon will be one of two designs depending on location and available materials: either a concrete pylon will be poured, or a one-foot steel I-beam will be driven into the ground. The trade-offs guiding the decision were costs and availability of concrete and I beams. In order to withstand 25 mph wind speeds, sufficient rigidity is needed to prevent oscillation of the dish while operating. Any oscillation will significantly affect performance so it must be avoided.

The current specifications are: 12" concrete pylon, or a 12" I beam

Expected component costs are:

- a. For the pre-production prototype -- \$135
- b. For modest production 100 to 1000 dishes -- \$75
- c. In full production -- \$50

12.0 Component: Receiver Cooling System/Heat Exchanger

Problem / issue addressed: Design of receiver cooling system/heat exchanger

Given the design cell array/receiver operating temperature, we considered using the proof-of-concept design, which is a tied loop system that directs the cooling fluid through the prefilter lenses in front of the PV array then to the back side of the cells. Given the fact that the cell performance is inversely proportional to cell temperature, it became apparent that decoupling the cooling loop and untiing the cells from the lenses was an option that should be considered in the receiver module design. A further consideration was the temperatures that would be preferred for operating a VX GAX chiller.

The decision was made to decouple the cells from the lenses. The trade-offs guiding the decision turned out to be the advantage of opening up new possibilities for higher temperature interfacing

with thermal loads like a VX GAX cooling system. In addition, electrical efficiency would rise if the system could maintain cell operating temps below 50 degrees C. At the same time we can supply a flow of 165 degree C water for a hotter running chiller. It will require more plumbing lines and complicate the utility routing, but will most likely extend the life of the cells and definitely increase their performance. This redesign should improve the performance of the proof-of-concept receiver.

The new specifications will require two cooling loops instead of one, and an extra pump. United Solar will develop the heat exchanger and cooling system as part of the receiver module design and fabricate this component.

Expected component costs are:

- a. For the pre-production prototype -- \$95
- b. For modest production 100 to 1000 dishes -- \$65
- c. In full production -- \$30

13.0 Component: Thermal piping

Problem / issue addressed: Mechanical integrity of the fluid lines.

With a decoupled lens and cell cooling loop, maintaining a good insulation barrier between the hot and cold lines carrying fluid to the cell cooling side and the prefilter lens manifolds, and keeping the two separate loops thermally isolated becomes an important consideration. The crux of the problem is located in the dish boom. A mechanical issue also is involved, because the lines must be flexible to follow the dish tracking path. United Solar considered using live swivel joints versus flex hoses. It was determined that live swivel joints would be ideal for this application. Flexhoses work in many applications but restrict some movements.

A key trade-off guiding the decision was restrictions in the degree of rotation that made it impossible to go with the less expensive flex hoses. Our new system requires 360 degrees of rotation in two axes. Live swivels, like those found on large cranes, provide continuous rotational freedom. The disadvantage is cost. Live swivels, although very common and proven, still come at a high-price. It is possible to reduce the price by using plastics instead of solid steel or stainless steel. It is also necessary in our case to use a material which is thermally non-conductive. Provided we use a material such as nylatron or graphite, the live swivels will perform without leaking or thermal crossover.

For the new system, the specifications will call for four ports on each live swivel that allow two separate loops. Two brush rings will supply the electrical conduction.

Beavis Machine of Tacoma, Washington will supply the prototype units, but eventually, these will have to be made by UST to bring the cost down. Expected component costs are:

- a. For the pre-production prototype -- \$1000
- b. For modest production 100 to 1000 dishes -- \$340
- c. In full production -- \$190

14.0 Component - Fluid pumps

Problem / issue addressed: Power for fluid pumps

With a decoupled fluid loop for the prefilter and the cell back cooling, the receiver will require separate fluid lines and two pumps. Considering whether they should be DC powered pumps or AC powered, we decided to use DC powered pumps since they can operate directly off of the battery pack. Several trade-offs were involved. First, DC pumps are easier to adjust and are compatible with direct battery power. This would increase the system safety factor in the event of a power outage from the grid. Further, using DC power for the pumps eliminated the need to invert a portion of the DC output from the receiver, which would slightly reduce the load on the inverter and raise overall system efficiency a slight amount.

The revised specifications for the fluid pumps for the receiver are: two D.C. powered, 0.5 -1.5 gallons per minute capacity operating at 30-60 psi. Any number of manufacturers can supply the pumps. Estimated component costs are:

- a. For the pre-production prototype -- \$85
- b. For modest production 100 to 1000 dishes -- \$55
- c. In full production -- \$45

15.0 Component -Freeze protection

Problem / issued addressed: Location in freezing climates.

It is necessary to consider locations where freezing conditions exist during winter. Three choices investigated were using a resistance receiver heater, a constant fluid circulation, and an ethyl or glycol alcohol/water mix. It was decided that ethyl alcohol was the clear winner for freeze protection. It is optically compatible with the secondary concentrator pre-filter lenses and it is unlikely that a dish will be installed in a region where temperatures will be low enough to freeze an ethyl alcohol/water solution. Resistance heaters are too inefficient, and running a circulation pump also meant increased parasitic losses.

A key trade-off considered was whether an alcohol mixture would hinder optical performance. It turns out that it doesn't affect performance of the prefilter and at the same time it is inexpensive and readily available. Another tradeoff concerns the drop in specific heat of an alcohol/water mix compared to water and the impact on the pumping load to remove heat from the receiver. These considerations were minor compared to the cost of the other two options for freeze protection.

The initial specification is a 1:3 alcohol-to-water ratio should give us optimum performance. The cost is incidental. A more important consideration will be periodic maintenance to assure that the ethyl or glycol level is maintained properly.

16.0 Component -Weatherization

Problem / issue addressed: Rusting, seizing, and structural degradation.

With regard to weatherization and the mechanical effects of oxidation, United Solar also considered the cosmetics or appearance of the system. Galvanized tubing and zinc plated fasteners were looked at, along with stainless steel fasteners. Aluminum tubing was also considered.

In the cost and performance tradeoff, galvanized steel tubing was found to be rigid enough and has a long enough life span for our needs. The life span of zinc plated fasteners is also acceptable.

Price was the deciding factor in the decision to avoid aluminum. Even though aluminum has a superior strength to weight ratio, and can be anodized to last without oxidizing, the constant upward price creep of aluminum in general makes aluminum less attractive for the long run. Galvanized steel tubing is relatively cheap, easy to get, has an acceptable price, and is easy to work with. The geodesic structure also lends itself to less rigid materials as the rigidity is incorporated into the geodesic shape. Zinc plated fasteners are inexpensive and are very resilient to harsh environments. The galvanized tubing should have a life span of at least 25 years.

For the geodesic frame design, the new specifications would call for: 2.5" diameter tubes x .80 wall thickness. Any steel distributor can supply the material. Expected component cost is:

- a. For the pre-production prototype -- \$4.10/foot
- b. For modest production 100 to 1000 dishes NA
- c. In full production NA

17.0 Name: The component -Azimuth and Zenith Joints

Problem / issue addressed: Overall drive system was effective but not esthetically pleasing.

The original dish concentrator structure used for the proof-of-concept needed to be replaced by something that would do the same job and be esthetically pleasing. We discovered and researched a 1970s NASA tracking support mechanism that accomplished azimuth and zenith tracking with one single moving arm. It was clear that a geodesic structure would be lightweight, strong, and more esthetically pleasing than our proof of concept dish, a robust but relatively crude design. The NASA innovation should provide a more accurate platform from which to work. We will use a modification of the NASA patent to perform azimuth and zenith tracking.

What trade-offs guided our decision? Esthetics were a key factor in deciding on this system. However, it is a very simple system mechanically. The difficulties are mainly routing problems. This is why we require live swivels. They are costly but not overly complex. This system also forces us to redesign some of the tracking logic. It should make things simpler but the tracker/drive motor interface changes will be expensive. Once a suitable fix is made, the tracker price will drop dramatically.

How will the component perform? It should be much more accurate. Specifications for the system still need to be worked out in detail. Industrial Solar Technology will contribute its expertise in concentrator fabrication to prepare the specifications for the new structure.

Expected component cost is:

- a. For the pre-production prototype \$3000
- b. For modest production 100 to 1000 dishes \$900
- c. In full production \$525

18.0 Component - Primary optics

Problem / issue addressed: Cost effective, highly accurate and reflective facet material that will resist weathering.

Developing a low cost, plastic based concentrator reflective film has been a DOE goal for more than a decade. United Solar started with an in house super plastic forming technique to form aluminum or steel and then coat it with a reflective material. For the ETAP concentrator we stretched formed our own reflective dish gore sections, but applied ECP 305+ film to them. The aluminum panels we fabricated for the proof of concept were extremely light weight and easy to handle but were not resilient to the weather. The lamination process of the aluminum was responsible for some deformation in the panels which led to a decrease in performance. The ECP305+ from 3M is no longer made, and the SA 85 film has shown durability but the reflectance penalty is too large.

For the PV BONUS prototype we began to investigate using glass in the United Solar stretch forming machine with a slightly different technique and it appears that, for the near term, glass mirrors are the answer. Glass is rather heavy if it is thick enough to hold an accurate shape, which makes it difficult to produce large panels and handle them safely. SAIC has succeeded in applying thin film glass to steel substrates for its dish Stirling concentrator and the glass industry seems to be making progress on thinner, more flexible glass reflectors. Still, SAIC's glass is applied in fairly small segments. Our panels have much more contour than the SAIC reflective panels, consequently, we decided to break the panel up into four pieces, and make four small facets instead of one large one.

The trade off for using smaller pieces is that it requires more parts. On the other side, the accuracies and ease of handling are greatly improved. Working with small pieces is much easier and safer. The major draw back to this route is the amount of standoffs needed to hold the facets to the frame, however, each facet can now be focused and pointed to improve flux density consistency. Other positives are that reflectance should actually be better and the glass facets will be much more resilient to cleaning and handling. They should also weather better.

The new specifications will require 92% reflectance and the high specular glass can provide to enhance accuracy. United Solar started working with Rayotek as its potential supplier. Expected component cost is:

- a. For the pre-production prototype \$6/square foot
- b. For modest production 100 to 1000 dishes \$4/square foot
- c. In full production \$2/square foot

19.0 Component - Drive Motors/gears

Problem / issue addressed: Back lash commonly associated with chains and worm drive systems, and gear reduction ratios.

There are a number of drive mechanisms that have been used in active tracking systems. We looked at hydraulic drives, cable drives, worm gear drives, chain drives, and out of phase worm gear drives. In order to achieve the least amount of slop or backlash, it was determined that the out of phase worm gear drives would provide the most stability and the most gear reduction or torque in a compact profile. This compact profile is necessary since the motors need to fit inside a 10" tube.

What trade-offs guided our decision? Chains are easy to work with and relatively inexpensive, but backlash is a problem. Worm drives have very high torque and acceptable gear reduction but they also have back lash in the direction opposite of travel. Hydraulic drives are outstanding but too expensive for our purposes, and they tend to develop leaks. Out of phase worm drives on the other hand have good torque and they hold positions well in both directions.

For the new concentrator design, the specifications are for a drive that provides 4 degrees of rotation/15 minutes. Industrial Solar Technology will provide its expertise to help develop the mechanical system. Expected component cost:

- a. For the pre-production prototype -- \$465
- b. For modest production 100 to 1000 dishes -- \$370
- c. In full production -- \$335

20.0 The component - Dish support carriage

Problem / issue addressed: Spacial accuracy, weight, wind loading, material cost, cost of construction.

This is an area that presented serious accuracy problems in the proof of concept dish. Having worked with geodesic structures in the past, we determined that it was necessary to go back to that configuration for many reasons: Spacial accuracy; weight to strength ratio; material costs; and ease of assembly. We designed a hexagonal geodesic space frame that will replace the frame that held the dish in the proof of concept version. Among the trade-offs guiding the decision were a significant savings in costs, both material and labor. A geodesic structure can be picked up and manipulated at any point as well, which lends itself to our unique tracking arm. For less money, we gain more rigidity, the ability to attach to it anywhere, and a system for which the construction takes little more than a hydraulic press and a drill press. The specification will center on a 3" galvanized tube to be used for the construction. Any steel distributor can supply the material. Expected component cost:

- a. For the pre-production prototype -- See previous section
- b. For modest production 100 to 1000 dishes -- Above
- c. In full production -- Above

21.0 Component - Overall control system

Problem / issue addressed: Interface of the current BSAR controls with the new tracking system.

The BSAR overall control system possesses what is essentially needed for the new tracking mechanism. It has the high wind stow input, the over temp stow input, and the cloud lock feature. For the prototype PV BONUS unit, we decided to contract with BSAR to make the necessary changes and improvements to its tracker/control system. System integration will require slight changes in the motor control circuitry, and a different stop switch for the stow command as the dish will be held at a different angle of operation with our new tracking arm. The main trade off was cost and expediency. It is easier to make the changes in the BSAR controller than to completely redesign a new controller interface. BSAR will create the modified specifications and supply the new unit. Expected component cost:

- a. For the pre-production prototype -- \$10,000
- b. For modest production 100 to 1000 dishes -- \$500
- c. In full production -- \$125

22.0 Component - Tracker control routine

Problem / issue addressed: 'False starts' on days too overcast for real energy collection.

This is an issue that the controller for the production prototype must solve. One option would be to install a low cost equivalent of a pyrometer to determine when the level of solar insolation was adequate to generate energy. A final decision on this aspect of the design has been postponed. In the near term, the testing prototypes will only be installed in areas where inclement weather is not really a concern and manual overrides will govern operation. An important testing element will be the effects of transient insolation conditions on the receiver and once this data is collected, the trade-offs will be conducted on measurement and control integration.

Conclusion

The 22 subsections above summarize the key component and design issues that United Solar and Industrial Solar considered during the Phase 1 work under PV BONUS Two. With the help of other companies selected to be a the team to take the PVT system to its next generation, many of the issues appear to be reasonably resolved and the company is prepared to proceed to completing a design for the new concentrator and receiver, conducting several component tests and fabricating the pre-production prototype.