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Diagnostic Test Report on Florida Power Corporation's 15-kWp Amorphous Silicon Photolvotaic System

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Diagnostic Test Report on Florida Power Corporation's
15-kWp Amorphous Silicon Photolvotaic System

Florida Power Corporation (FPC) owns and operates a 15-peak-kilowatt (kW_p) amorphous silicon photovoltaic (PV) system at its Econ substation in Orlando, Florida. The PV system, commissioned on August 23, 1988, was designed to generate power that would be injected directly to the FPC electric grid. The *Solar Progress Generating Station* was developed as part of FPC's interest in new power generation technologies. The PV system design and installation was a collaborative effort among FPC, the Florida Solar Energy Center (FSEC), Sandia National Laboratories (SNL), and the Electric Power Research Institute (EPRI).

In March 1999, FPC informed FSEC that the PV system was off-line and its operation could not be restarted. FPC requested that FSEC conduct diagnostic testing to assess system status and make recommendations for corrective actions. FSEC researchers made a site visit to the PV system on April 20, 1999 and conducted the system inspection and testing. This report summarizes the test results, system status and corrective actions needed to restore the system to its full operational status.

Existing System

The existing PV array is comprised of 640 ARCO Solar (now Siemens Solar) G4000 amorphous silicon thin-film modules. The system consists of five subarrays of 128 modules, each arranged in sixteen columns and eight rows, as seen in Figure 1. In each subarray, the modules are connected in series strings of sixteen groups of eight parallel-connected modules, for a nominal operating voltage of 240 volts dc. The output of each subarray is connected to an Omnion 20-kilowatt (kW) three-phase power conditioning unit (PCU). The PCU is located in a small control building approximately 100 feet east of the southernmost subarray, as depicted in Figure 2.

Figure 1. Solar Progress photovoltaic array.

Figure 2. Control building.

Operational Status

At the time of the site visit the system was inoperative, and it could not be readily determined how long the system had been off-line.

System Check Out

Initially, a visual check of the Solar Progress system was conducted, including an inspection of the modules, wiring, inverters and other associated equipment. Significant physical damage to two modules was immediately observed. The probable cause of the damage was the development of a virtual short-circuit condition between the PV cell and the grounded module frame, characterized by high leakage current and possibly resulting in an electric arc. The condition was such that catastrophic damage to the module glass and plastic junction box occurred, as illustrated in Figures 3 and 4.

Figure 3. Damage to the module surface.

Figure 4. Damage to the module junction box.

The visual inspection of the modules indicated some level of physical damage in all five subarrays. The damage to the modules could be described as: 1) minor - chalking or corroding module frames, 2) severe - cracked module glass, extensive corrosion, and/or water present in the module, and 3) catastrophic failure of the module and materials. At least fifty-five of the 640 modules suffered from some level of damage: firty-six had minor damage, seven had severe damage, and two suffered catastrophic damage.

No physical damage was observed on the inverter, wiring, or the structural components. There was some corrosion of the metal combiner boxes mounted on the support structure at the east end of each subarray.

An attempt was made to restart the inverter but it was not successful. The inverter indicated "over temperature" fault condition associated with a temperature sensor reading out of range. This fault condition was probably caused by a failed temperature sensor. The diagnostics of the inverter failure were beyond the scope of this inspection.

System Testing

A PV curve tracer was used to obtain current and voltage measurements and to develop current vs. voltage (I-V) curves for each subarray. The I-V curves were used to assist in the determination of the peak power output for each subarray and for the entire system. Also determined from the I-V curve testing was the fill factor value for each subarray and the complete array. (The fill factor is the ratio of the maximum power to the product of the short-circuit current and the open-circuit voltage.) Fill factor is an operating characteristic that indicates relative performance of the array, and a low fill factor can indicate problems with the array [FF= Pmax/(Isc x Voc)].

Table 1. Summary of IV Curve Test Results

Subarray	Peak Power kW (DC)	Fill Factor
1	1.7	40
2	1.4	35
3	1.8	40
4	1.7	40
5	1.7	40

Test results for the entire array indicated that the peak power of the array was approximately 8.3kW dc and the fill factor was 37. The low values recorded for subarray 2 were primarily the result of major damage to modules. The poor performance of the subarray has a significant impact on the performance of the entire array.

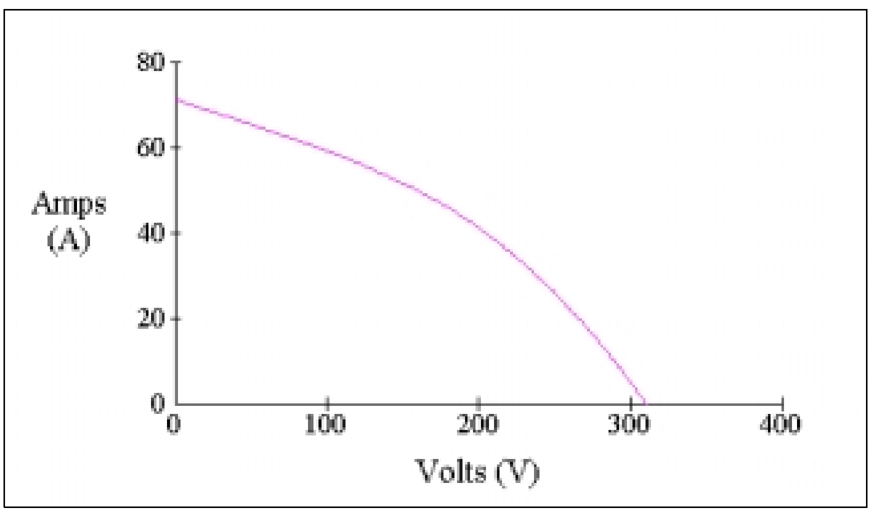

Figure 5. Complete array IV curve (peak power 8.3 kW, 37.3 fill factor.)

Summary and Recommendations

All five subarrays and the Omnion 20-kW inverter will need to be repaired in order for the FPC system to begin re-operation.

The following information is based on the limited investigation conducted during the site visit in April 1999, at which time the severity of all the problems could not be fully determined.

The ARCO/Siemens G4000 modules show significant signs of physical damage and performance degradation. The subarrays appear to be operating at about 55% of their nameplate rating. The full array power output of 8.3 kWp is within 10% of the array power (≈ 9 kWp) last measured by FSEC staff in 1992, which indicates the light-induced power degradation of the amorphous silicon modules had long been stabilized and the annual degradation was on the order of 1%. The array can never be returned to 100% of the installed capacity without completely replacing all of the modules. It may be possible to salvage some or even a large percentage of the modules, by individually testing them and eliminating the damaged or poorly performing modules. The acceptable modules could be consolidated and reconfigured into subarrays. This process would be time consuming and labor intensive and continued damage of more PV modules and additional failures cannot be avoided.

The IV curve tests show a very poor fill factor for all of the subarrays, indicating poor performance quality of the modules. Poor fill factor can also cause problems with the peak power tracking capabilities of the inverter.

The infrastructure of the PV system appears to be in good condition. It would be possible to remove the existing modules and retrofit new modules with only minor modifications. This would eliminate the expense of commissioning a new system or demonstrating a new technology.

In regards to this PV system at Econ substation, there are two options:

1. *Minimal Cost Option:* FPC can remove about sixty failed and defective modules from the array, rewire about 10% of the connections, and get the inverter repaired by Omnion Power Engineering Corporation. The estimated cost would be up to $5,000 for the inverter repairs, with three days labor for two technicians and one day of diagnostics for two professional staff members. The array power output will not decrease significantly as a result of this modification (less than 5% decrease).

   The array will need to be monitored periodically (bimonthly or quarterly) to diagnose leakage current, assure personnel safety, and minimize potential fire hazard. Progressively more modules will have high leakage current, corrosion (and possibly burn damage due to resulting electrical arc), and failures. The specific amorphous silicon technology used in the production of these modules is outdated now, so there won't be much useful technology-related information generated from this system.

   The existing PV system can provide useful information on grid interconnection issues and the impact of PV generation (including seasonal variation in amorphous silicon PV system output) on the utility demand profile, in addition to providing PV operational experience.

2. *Array Replacement Option:* This will require replacing all 640 amorphous silicon modules with about 35-kWp of crystalline silicon modules. All of the dc wiring and balance-of-system components will need to be replaced. The inverter will also need to be replaced with a larger 40-kW inverter, or it may be repaired and supplemented with an additional 20-kW inverter. The existing array support structure and most of the ac wiring may be retained and used for the new array and system. The total cost of this option is estimated at $200,000.