Minimizing Instrumentation and Control Costs for Concentrated Solar Power Projects

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Introduction

Scaling up a concentrated solar power plant from 30-60 MW to 300 MW+ results in substantial technological and cost challenges in the area of instrumentation and control. These challenges are a direct result of the high number of solar collector assemblies (SCAs) and the large amount of acreage that a Concentrated Solar Power Plant occupies. This paper will concentrate on solar plants utilizing parabolic trough SCA technology.

For example, input/output (I/O) count associated with the solar section of a nominal 300 MW plant with no thermal storage exceeds 24,000. Total length of cable and conduit is measured in hundreds of miles.

Due to the plant scale and size, conventional power plant approaches (and thinking) would be prohibitively expensive. Creative approaches and proven new technologies must be utilized to minimize the installed cost. Total installed I&C cost even with creative approaches is in the $ 75 MM to $ 100 MM range.

We will review the economics of various approaches:

- Conventional approach of hardwiring 24,000 I/Os to a centrally located DCS
- Semi-conventional approach of hardwiring 24,000 I/Os to a number of remote DCS cabinets.
- Local network controllers with multi-mode optical fiber communications with hubs/load centers
- Local network controllers combined with the stepping motor controls, with multi-mode optical fiber communications with hubs/load centers.
- Local network controllers, combined with the stepping motor controls, powered by Solar PV and a battery, with multi-mode optical fiber communications with the hubs.
- Local network controllers, combined with the stepping motor controls, powered by Solar PV and a battery, with wireless communications with the hubs.

This paper compares different methods of minimizing the instrumentation and control costs and hopefully will provide some useful insights for the benefit of the growing solar power industry.

I&C Scope of Work

For a nominal 300 MW plant that includes thermal storage, one has to control over 3,500 solar collecting assemblies plus a conventional power plant. For the purposes of this paper we will concentrate on the solar part – costs and technological solutions for conventional power plants are well known. Within the solar control portion we will further concentrate on economical solutions for the repetitive and massive task of solar assemblies control.

Each SCA is positioned by a single reversible gear pump or motor, rated 0.5 to 0.75 Hp but with only ~ 10% duty cycle. Depending on supplier, its length is 96 to 100 meters (over 300 feet), with the total area of the solar field for a nominal 300 MW facility with thermal storage exceeding 1,500 acres.

Each solar assembly has the following I/O count:

- Two solid state "dry" raise/lower outputs to the motor.
- One solid state "dry" output to the stowage lock-dog solenoid (interrogated by the solenoid).
- One input from an inductive proximity switch to monitor the position of the stowage lock-dog.
- One analog input from an angle sensor
- One analog input from a solar flux sensor
- One analog input representing thermal fluid temperature
- One fail-safe digital signal (enable/trip)

In summary, there are five digital and three analog I/O for each SCA.

The most critical command is a trip command (in the case of approaching bad weather) to store all solar assemblies in a safe position.

Practical Installation Alternatives

Let us first clarify "the installed cost of I&C" – it includes the cost of instrument hardware, the cost of DCS (including configuration services), the cost of cable/fiber/conduit and, last but not least, the cost of installation. The rule of thumb for I&C is that the installation cost is

66% or greater of the total (which is a polite way of saying that installation cost twice as much as hardware). This is true even in non-union states where most of the concentrated solar power plants are being built.

By the way, reduction in installation cost cannot be achieved at the expense of reliability. One cannot push the envelope in wireless technology because this is a power plant. Let us consider all practical alternatives, including uneconomical ones.

Scaling Up is Hard to Do

Conventional approach of hardwiring 24,000 I/Os to a centrally located DCS would be a huge waste of copper, conduit, installation labor, DCS equipment, configuration and commissioning labor. Amount of fossil power expended on materials and installation will make for a very long payback from renewable solar power. Our rough estimate for the conventional approach is about $200,000,000. In other words, this approach is hopeless and some innovation and risk taking is a must.

Semi-Conventional Approach

Semi-conventional approach would involve hardwiring 24,000 I/Os to a number of remote DCS cabinets. It would make sense to locate these cabinets in the load centers that supply power to the positioning motors.

The load centers will provide a shelter for remote DCS cabinets. Electrical installation pays for the cable tray costs. Digital I/O cables can use the electrical cable trays. Analog I/O cables would need their own cable tray. As you can see, there is a lot of free riding here. However the cost is still staggering.

The number of load centers defines the number of remote DCS cabinets. If we have 60 load centers, each remote will control 50 solar assemblies and will have 400 I/Os. There will be a need to install 300 miles of 14 conductor digital cable and 300 miles of 5 twisted pair cable. There still will be a need to configure and maintain 24,000 data points. Commissioning costs would be substantial. Our rough estimate for this semi-conventional approach is about $130,000,000.

Our Favorite Approach for 2008-2009

Use local controller to perform all local control and communicate via multi-mode optical fiber (100BASE-FX) with one of 60 network hubs/load centers. Preferably one cable (AC power and multi-mode optical fiber) will be pulled for each controller.

This provides an almost complete free ride on electrical installation, except for the incremental cost of multi-mode optical fiber and local cable runs. Installed costs of $40,000,000 (300 miles of 14 conductor digital cable and 300 miles of 5 twisted pair analog cable are eliminated. Installed cost of 60 remote DCS cabinets (~$6,000,000) is eliminated. Of course the installed cost of 3,000 Network Controllers (~ $15,000,000) must be added. We should note that the Network Controllers are available from at least three major DCS vendors.

Network Controllers (NC) have the following attributes:

- Provides Process Control
- Has Local I/O
- Has Ethernet Network Connection built in
- Directly communicates to the network with standard Internet Protocols
- Directly serves Operator Graphics, Faceplates, Tuning Panels, Trends and Reports using HTML over the network

Use of the network controller with direct support of HTML-based Graphics provides a means of commissioning the mirror controls locally, without connection to the control center. The system will use NC graphics in the control center and only map points to the DCS as required for control intervention, Track/Off, and Trouble alarms. Should operational or diagnostic information be needed from the NC, the graphics would be served directly by the NC at the Control Room Operator Stations . A Historian would collect data needed for performance monitoring directly from the NC.

The above 3 techniques would eliminate a significant amount of configuration at the Central Control Room for Graphics, I/O point mapping etc.

It also eliminates the large bandwidth in communications to the DCS since from an operational perspective most data is served only as needed. This will be quite important for the next step – wireless communications.

Our Favorite Approach for 2010-2013

Pretty much the same as above, except:

- transition from a reversible gear pump to a low power stepping motor (good for reducing cost of the positioning devices and quite important for the next step – wireless communications).
- Customize and combine the network controller with the stepping motor controls. Use the same enclosure.

This approach will eliminate 3000 local cable runs (two solid state “dry” raise/lower outputs to the motor) and 18,000 terminations and significantly reduce device costs for the positioning devices and network controllers. It is an overkill to use a general purpose network controller for 8 I/Os. We estimate that this customization can reduce the overall installed cost by $ 10 MM to $15,000,000 or better.

Minimizing Electrical Installation Costs

The next big savings will come from eliminating AC power supply to the stepping motors and the network controllers (NC) and instead using Solar PV and a battery. This is no longer hard to do.

Stepping motor power requirement is 0.75 Hp at the most, most probably 0.5 Hp, with a duty cycle of only 10%. Therefore we will use 60 w of continuous power as a power budget for the stepping motor.

A new generation of low power controllers uses only 3 Watts of power. With careful selection of low power Fiber Media Converters, sensors and latch solenoid, we can use 50 w of continuous power as a power budget for the rest of the local control system. A Solar PV power supply of 120 w is quite do-able.

The savings from the elimination of 56 out of 60 load centers and 300 miles of power supply cable (and associated cable trays, etc.) is on the order of $ 20 to $25,000,000.

We will have to add the cost of running multi-mode optical fiber to each controller (we no longer will have a free ride with power supply cable) and the cost of 56 enclosures for the network hubs, but these additional costs are only a fraction of savings in the electrical installation budget. To eliminate these costs, we have to make the next step – wireless communications.

Wireless Communications

This last step seems to offer less net gain and present more difficulties than the one preceding it. The preceding step (eliminating AC power supply) is a necessary precondition to even consider wireless. As long as multi-mode optical fiber can get a free ride on the power supply cable, there is no room for wireless.

It would be nice to have an overall strategy for future projects that incorporate wireless, provided it is a cost effective alternative and will meet the new FERC CIP requirements going into effect in 2010.

There are many questions that need to be answered:

- What type of technology should be used for the local wireless modem?
- What would be the power requirement be for the wireless modem?
- What radius distance from the network cabinets to the control cabinets will provide reliable communications?
- How is FERC CIP cyber security met using wireless in this communication approach? How can secure communications be maintained?
- What are the costs for a control radio/modem and network hub wireless equipment?
- What are the licensing issues and costs for the technology
- What are the commissioning time duration and costs associated with the proposed technology, network and control cabinets?
- What environmental issues will affect reliability (temp, moisture, power disruption etc.)?

Solar mirror control NCs require Ethernet (TCP/IP) addressing with a low data rate (command and control information, reasonably latency-tolerant). The network hubs (NH) require Ethernet addressing but significantly higher data rates due to the attached video cameras and the hub's functioning as the NC aggregation points. We envision eight (8) NHs deployed in the field to which optical fiber will be connected (for backhaul to the DCS).

The wireless systems to be connected to the NCs will be solar powered (photovoltaic). The wireless system must be FERC CIP compliant (or is it?).

Discussions with NIST and NSA officials during the first week of November 2008 indicate that the 2010 version of FERC CIP will recommend that only low power 802.11-based devices be used – not 802.15.4-based – for government installations. While not ratified, we feel that this singular point tips the entire network topology to be 802.11-based.

From a wireless communications perspective, it is worthwhile noting that an 802.11-compliant access point provides a coverage that is approximately 50m in radius. Note that numerous organizations report exceptionally long distance 802,.11-based wireless communications – far exceeding 50m.

There are three performance metrics that are intertwined: data rate (throughput), distance/Received Signal Strength, bit error rate. Consider the case of communications between an 802.11-access point (AP) and a 802.11 client device. In this situation, for a fixed transmit power and receiver sensitivity, the client's received power decreases as the distance between the AP and client increases. The data rate, for a fixed bit error rate, is dependent on the received signal strength (the higher the RSS, the less the number of errors).

Typical power consumption for the 802.11 client devices is <5W at 24 VDC (well within solar powering capabilities). Power consumption is not a problem. The 50m communication radius is a problem. We estimate that 900+ 802.11 APs (Receivers) will be required because of it.

This number of 802.11-APs would require a substantial amount of fiber/cable to be run unless we use a wide bandwidth larger RF footprint wireless technology to cover the thermal solar field. This can be provided by the 802.16 (or similar wireless broadband technology) wireless cloud.

The communication to the transceiver 802.16 to/from 802.11AP devices is based on non-line-of-sight (NLOS) operation. The size of each 802.16 footprint is a few kilometers in radius. This will allow the 802.11 APs to have easy wireless connectivity to the backhaul network without requiring fiber or other forms of wired connectivity.

The bottom line – it can be done. Whether or not it will be economical is a different issue.

We have three questions/approaches we would like to pose:

1. Since this is a commercial application, do we even need to comply with the 2010 version of FERC CIP regarding use of only the 802.11-based devices? This requirement seems to be a major obstacle to wireless connectivity implementation.
2. Even if we are stuck with the 802.11-based devices, can we increase the coverage radius since the data traffic from Network Controller to/from DCS is very modest. What would be the max distance to ensure 30 seconds response time?
3. We suggest that until FERC CIP cyber security requirements are finalized, wireless is not an option, but a 3-5 year goal.

Summary

We outlined an attractive approach using local Network Controllers that can be executed today. The next step of using Solar PV and a battery to provide power to the solar assemblies controls is not far fetched. We hope our paper will inspire somebody to do it.

The idea of combining the network controller with the stepping motor controls should draw attention of a large DCS vendor since it will give them a competitive advantage. Finally, we remain ambivalent regarding wireless communications.

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