Cal Poly Sustainable Power for Electrical Resources (SuPER) Project

Solar 2008
San Diego, CA

PV System Performance

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Cal Poly SuPER Project

Outline:

• Background: rationale for project
• SuPER prototype development
• SuPER simulation model
• Applications of simulation
• Plans for field testing at Cal Poly Organic Farm
• Conclusion
Background - Electrification

- Electrification – National Academy of Engineering’s top engineering achievement for the 20th Century
- Estimated 2 billion people (1/3 of population) do not have access
  - Significant proportion of remainder does not have reliable access to battery or grid
Background – Solar Insolation

- Goal to provide electrical resources to people in underdeveloped countries
- Leapfrog technology – no need for 100 years of development
  - Example of cell phone
- Review of global insolation map
  - Poorest people ($1-2 a day income)
  - Within plus or minus 30 degree of latitude
    - Highest values of solar insolation (minimum W hr/sq m/day)
Background – DC Power

- Solar photovoltaic systems inherently DC
- History of DC (Edison) versus AC (Westinghouse and Tesla) at end of 19th and beginning of 20th century
  - DC versus AC for generation, transmission and distribution to loads
  - Initially, lighting was the customer load
  - Thomas P. Hughes; *Networks of Power: Electrification in Western Society, 1880-1930*; Baltimore: Johns Hopkins University Press, 1983
  - David Nye; *Electrifying America Social Meanings of a New Technology, 1880-1940*; MIT Press; 1990
Background – DC power loads

- Future lighting technology: DC LEDs
  - 60W incandescent bulb and 15W compact fluorescent bulb lumens
  - Equivalent to 1W LED technology, and improving
- Efficiency of electrical motors: few horsepower
  - Permanent magnet DC motors
- Electrical appliances
  - Computer: 50W laptop (DC)
  - TVs, radios use DC power
  - RV 12V DC market: kitchen appliances
  - Portable power tools – battery powered (DC)
- Computers: wireless connection
  - Internet, phone (voice over IP), TV, radio,
  - Education: MIT One Laptop per Child project - $100 laptop
Background: Overall Cal Poly SuPER System Goals

- Design lifecycle of 20 years
- Total Cost: less than $500 for 1 sq m PV module including battery replacements
- Mean time between failures (MTBF): 25 years
- Mean time to repair (MTTR): 1 hour
- Power depends on PV efficiency and battery storage capacity
  - Consideration of load utilization
Background: Initial Development

Plan

- Five years for completed design, development, and field testing
  - Includes business plan, documentation and dissemination
- First three years for prototype development
  - Three generations at one year for each
- Last two years for field testing
  - Cal Poly sustainable agriculture project
    - Cal Poly Organic Farm
  - Establishing contacts overseas
SuPER Prototype Development – First Year Progress Report

- Summer 2005: White Paper documented
- Fall 2005: 1 NSF and at least 6 foundation proposals submitted; no awards
- Winter 2006: Cal Poly SuPER project lab established in 20-101; initial simulation model completed – 1 senior project
- Spring 2006: BUS 454 four person senior project team develops business/marketing plans
- Summer 2006: initial Phase 0 prototype system implemented - 1 thesis and 3 senior projects
Weekly Seminar Meeting in Power Senior Project Room (20-101)
SuPER Project Laboratory
SUPER prototype cart with solar panel, battery, instrumentation and control subsystems

Members present in photo: (left to right) Eran Tal, Eric Phillips, Gustavo Vasquez, Alexander Gee, Jennifer Cao, Sam Muehleck, Dr. Jim Harris, Dr. Taufik, Tyler Sheffield, Dr. Ali Shaban; Members missing: Dr. Ahmad Nafisi, Robert Johnson
Eran Tal working with prototype SuPER System – June 2006
SuPER Prototype Development – Second Year Progress Report

- Fall 2006: integrated pyranometer for local insolation measurements (G,T)
- Winter 2007: added loads (LED, cooler), initiate motor/ultracapacitor study
- Spring 2007: SuPER system simulation model and Phase 0 prototype system completed – 1 thesis and 6 senior projects
- Summer 2007: dc-dc converter development; proposal prepared for Solar America Initiative (SAI) / Solar Energy Technologies Program (SETP) University Photovoltaic Process and Product Development Support (not awarded)
Tyler Sheffield with SuPER prototype – April 2007
SuPER Prototype Development – Third Year Progress Report

- Fall 2007: continue dc-dc converter development; review of NEC standards; initiation of plan for field testing at Cal Poly Organic Farm
- Winter 2008: Completion of safety/NEC review of SuPER prototype; completion of field testing study and analysis of electrical power requirements for Cal Poly Organic Farm; initiated port of laptop status/control software to FPGA/uClinux environment – 2 senior projects
- Spring 2008: planned integration of dc-dc converter into prototype, and complete port of laptop S/W to FPGA – 1 thesis and 2 senior projects
Figure 2.1 Photo of SuPER Cart Prototype including Loads
**Notes:**
1) All loads and load probes are represented as one in this diagram.
2) All probes are connected to the USB 6009 via an op amp gain circuit, omitted from this block diagram.
3) The combiner box, which doesn't appear in the block diagram, junctions all the power lines.

*Stage: Integrate all individual system components to one unit on the cart*
Figure 2.3 SuPER Power Flow Diagram
Figure 2.5 Status System Interface Block Diagram
Figure 3.2 SuPER Status and Control Interface Diagram
SuPER Simulation Model

- MATLAB/Simulink implementation
  - SimPowerSystems package used
    - DC-DC converter
    - Loads: LEDs, cooler, LEDs, laptop, DC motor, TV
    - Loss model
  - C-MEX S-functions: C rather than .m files
    - PV S-function block
    - Control S-function block
    - Switch control S-function block
    - Battery S-function block
    - Loads: cooler, laptop, dc motor
Figure 4.2 Simulink Model Map
SuPER Simulation Model

- Separate simulations to develop model
  - DC-DC converter: PSpice and Simulink
  - DC motor with ultracapacitor
  - Cooler
  - Laptop
  - PWM duty cycle
  - LEDs
SuPER Simulation Model

- Prototype system measurements to verify simulation
  - Pyranometer data for local insolation
  - DC motor simulation
  - Battery SOC estimation
  - Cooler operation
  - Laptop battery characteristics
  - LED operation scenarios
Application of Simulation

- Results with typical insolation
- Peak versus average power
  - Peak power of motor load (230W demand) met with battery/ultracapacitor
  - Average daily load of at least 700 Wh can be supported by 150 W PV module source with 98 Ah battery/ultracapacitor storage
- Results validated with prototype system measurements
Application of Simulation
Preliminary Conclusions

• SOC of battery important system parameter
  – Peak power source during insolation
  – Total power source during non-insolation times

• Load demand is important
  • Schedule of loading of system

• Load factor is important
  • average power / peak power

• Dispatching of power to loads must be included in system design
Plans for field testing at Cal Poly Organic Farm

Cal Poly Organic Farm

- Festival Circle
- Packing Shed
- Straw Bale House
- Pond
- Greenhouse
- Storage Shed
@ 6:05PM: Circulation fan, blower fan, air pump, pond pump, computer + monitor on
# Conclusion

<table>
<thead>
<tr>
<th>#</th>
<th>Building / Area</th>
<th>Total Power Per Day (AC)</th>
<th>Total Power Per Day (DC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Packing Shed</td>
<td>4,712.4 Wh</td>
<td>633.5 Wh</td>
</tr>
<tr>
<td>2</td>
<td>Straw Bale House</td>
<td>806.4 Wh</td>
<td>317.8 Wh</td>
</tr>
<tr>
<td>3</td>
<td>Storage Shed</td>
<td>13.33 Wh</td>
<td>0.96 Wh</td>
</tr>
<tr>
<td>4</td>
<td>Greenhouse</td>
<td>13,837 Wh</td>
<td>12,200 Wh</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>19,369.13 Wh</strong></td>
<td><strong>13,152.26 Wh</strong></td>
</tr>
</tbody>
</table>
Conclusions

• Cal Poly SuPER project low tech, small science
• Project fits into Cal Poly’s mission
  – Education
  – Talloires Declaration
• Systems approach to development
  – Digital/computer controlled
    • Simulation model
    • Consideration of loads, load factor, utilization
• DC power distribution to loads
  – Efficiency based upon power electronics
  – New market for DC household appliances
  – LED lighting
Future Efforts: Cal Poly Resources for SuPER Project

• Development laboratory established
  – Power Senior Project Lab (20-101)
  – Also use Power Electronics Lab (20-104)
• Field testing site at Cal Poly
  – Cal Poly Organic Farm: part of Sustainable Agriculture Research Center (SARC)
• Faculty team identified: Jim Harris (CPE and EE), Ali Shaban (EE), Jim Widmann (ME), Dan Waldorf (IE), Neal MacDougall (AGBus/econ), Norm Borin (Marketing), Doug Cerf (Accounting)
• Industrial consultant identified: Jim Medeiros, CEO, Seven Pinnacles Development (SLO)
Cal Poly SuPER Project website URL:

http://www.ee.calpoly.edu/~jharris/research/super_project/super_table_of_contents.htm

Acknowledgement: Sam Vigil, Professor of Environmental Engineering at Cal Poly and member of ASES for suggesting that we present this work at Solar 2008.

Additional Material:
Photos of first year progress
Photos of second year progress
Solar insolation: simulation and measured
Second DC motor simulation data
Photos of SuPER Lab and field test site
Estimate of SuPER prototype cost to date
Future efforts: prototype, simulation, system analysis
Details of cost estimate