PVToolbox Simulation Output Compared with Monitored Data from PV Hybrid Test Bench

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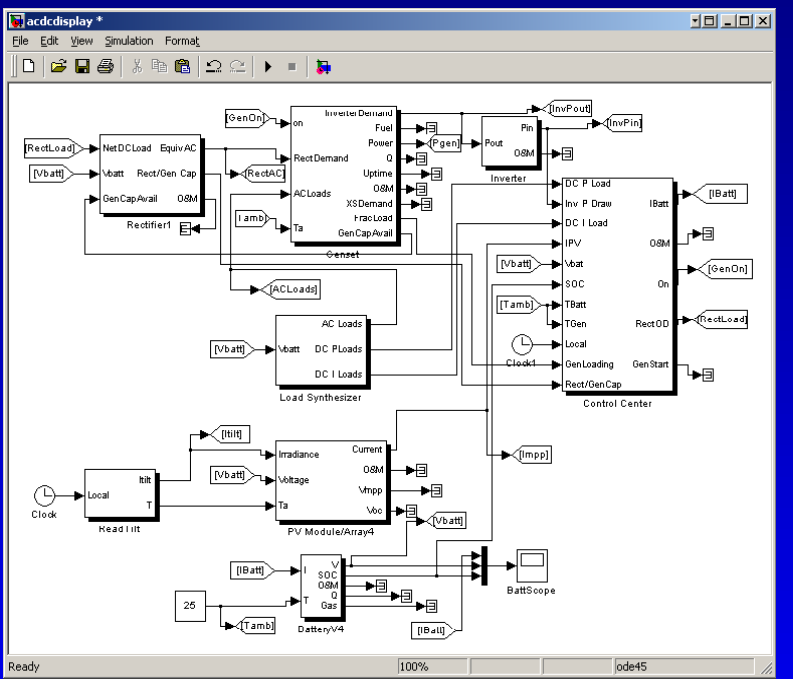
Two tools for investigating PV Hybrid Systems

- PVToolbox simulation tool
  - Flexible set of component models in Matlab/Simulink environment
- Hybrid system test bench at CETC-Varennes
  - 7.5 kW diesel genset
  - Configurable array (1.2 kWp)
  - 24 V, 600 Ah AGM battery
  - 3 kW inverter/ charger
  - Temperature control
  - Monitoring and dispatch control



Simulation vs real world tests

PVToolbox

- Vast range of possible configurations can be simulated (quickly)
- Operating conditions can be run over and over again
- Can provide information not available from test bench

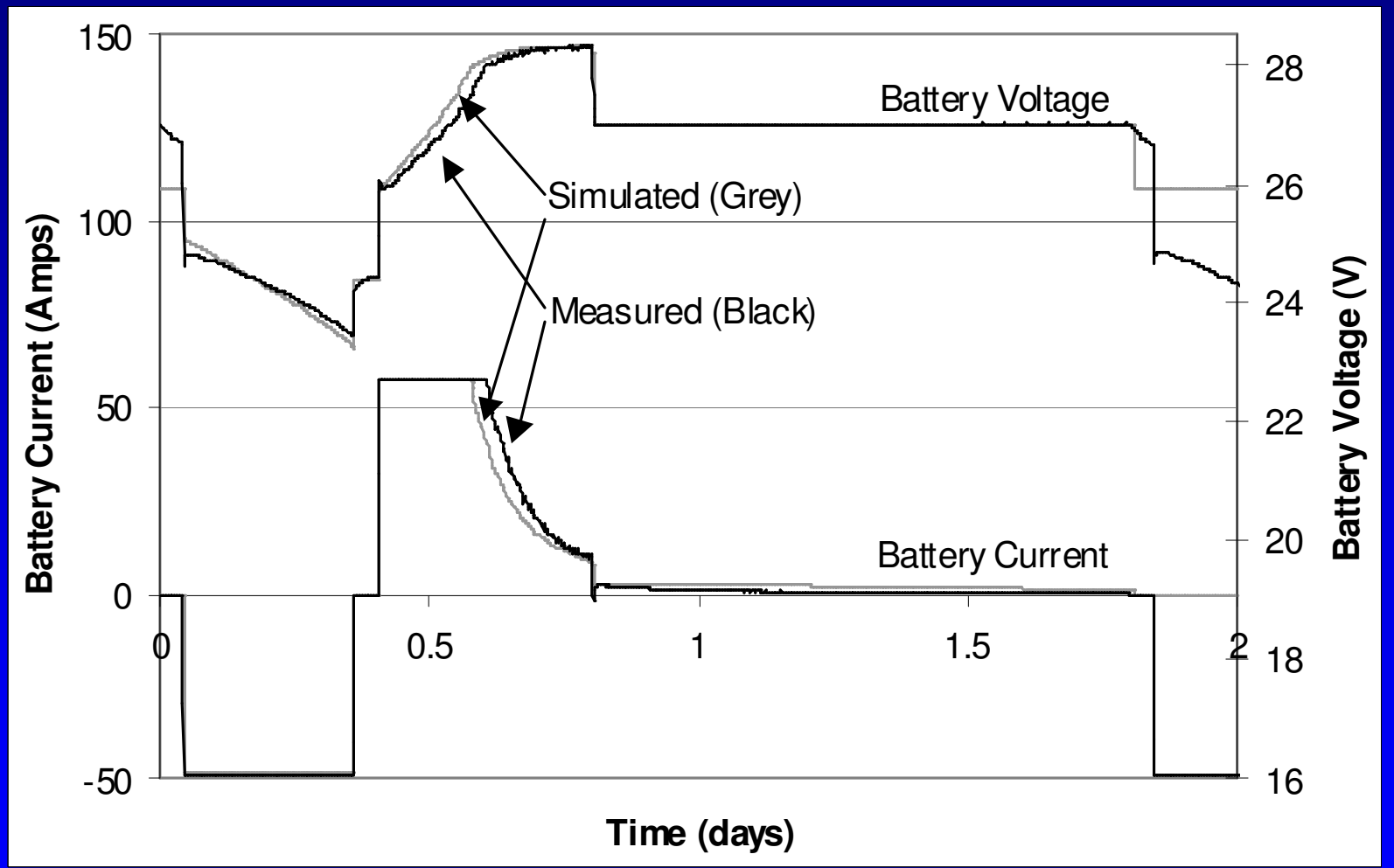
Test Bench

- Real world problems show up
- Complex battery behaviour is accounted for

Role of PVToolbox and test bench

- Use simulation for general understanding
- Use test bench to test particular hypotheses
- Use test bench to determine where simulation can and cannot be trusted
  - Does PVToolbox model major energy flows within 10%?

Controlled battery discharge/recharge cycle

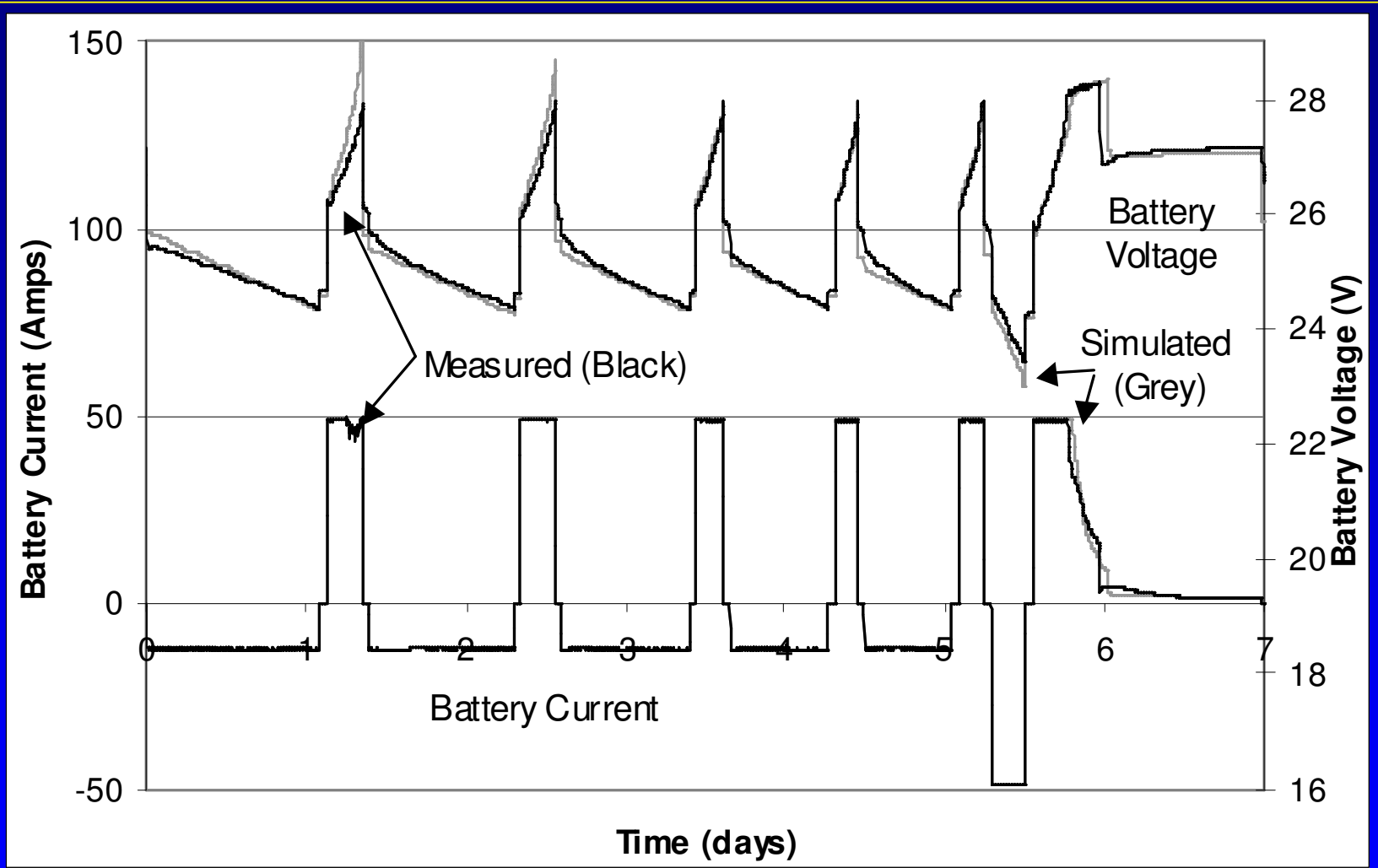


Controlled battery discharge/recharge cycle

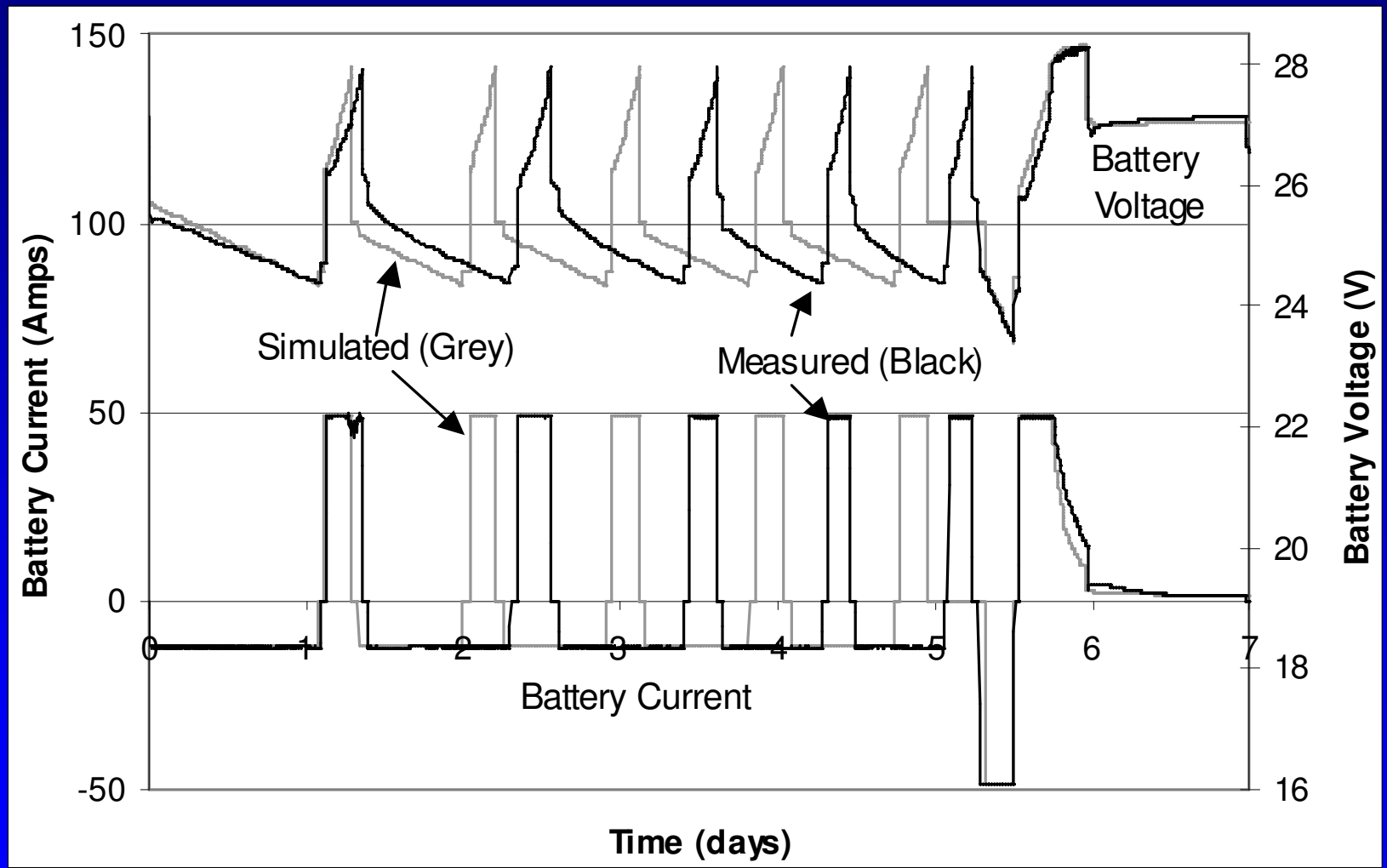
- Absorb charge is very good test of battery model, and PVToolbox does not do too badly
- Cheated:
  - Did not end discharge at 23.4 V (voltage setpoint)
  - Absorb did not last same elapsed time
  - Errors can accumulate so that events diverge– although on average behaviour will be accurately simulated

	Test bench	Simulation	Error
Coulombic Efficiency	92.9%	93.7%	0.9%
Round-trip (Energy) Efficiency	83.0%	83.3%	0.4%

Battery cycling without absorb charging (cheat)



Battery cycling without absorb charging

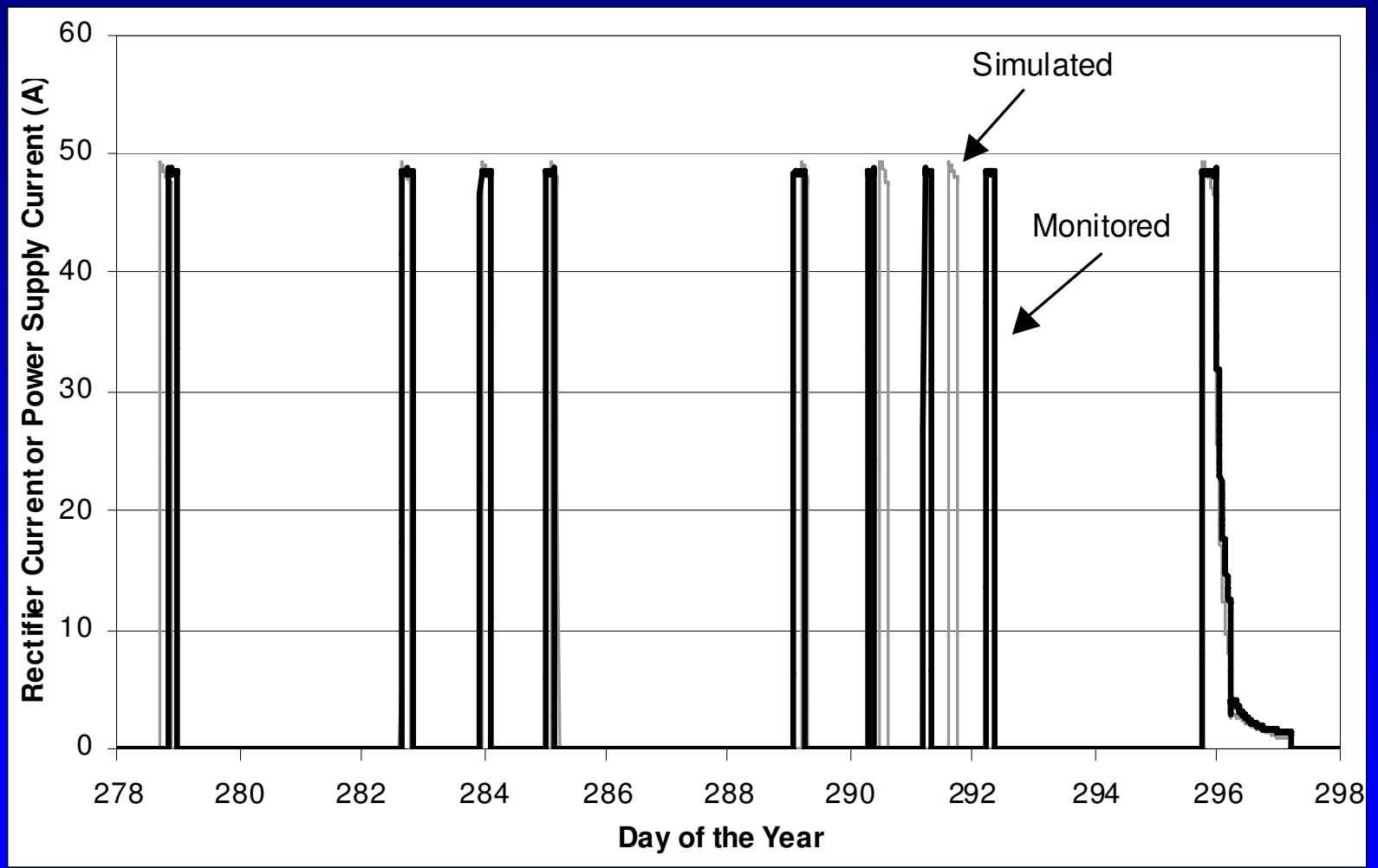


Battery cycling without absorb charging

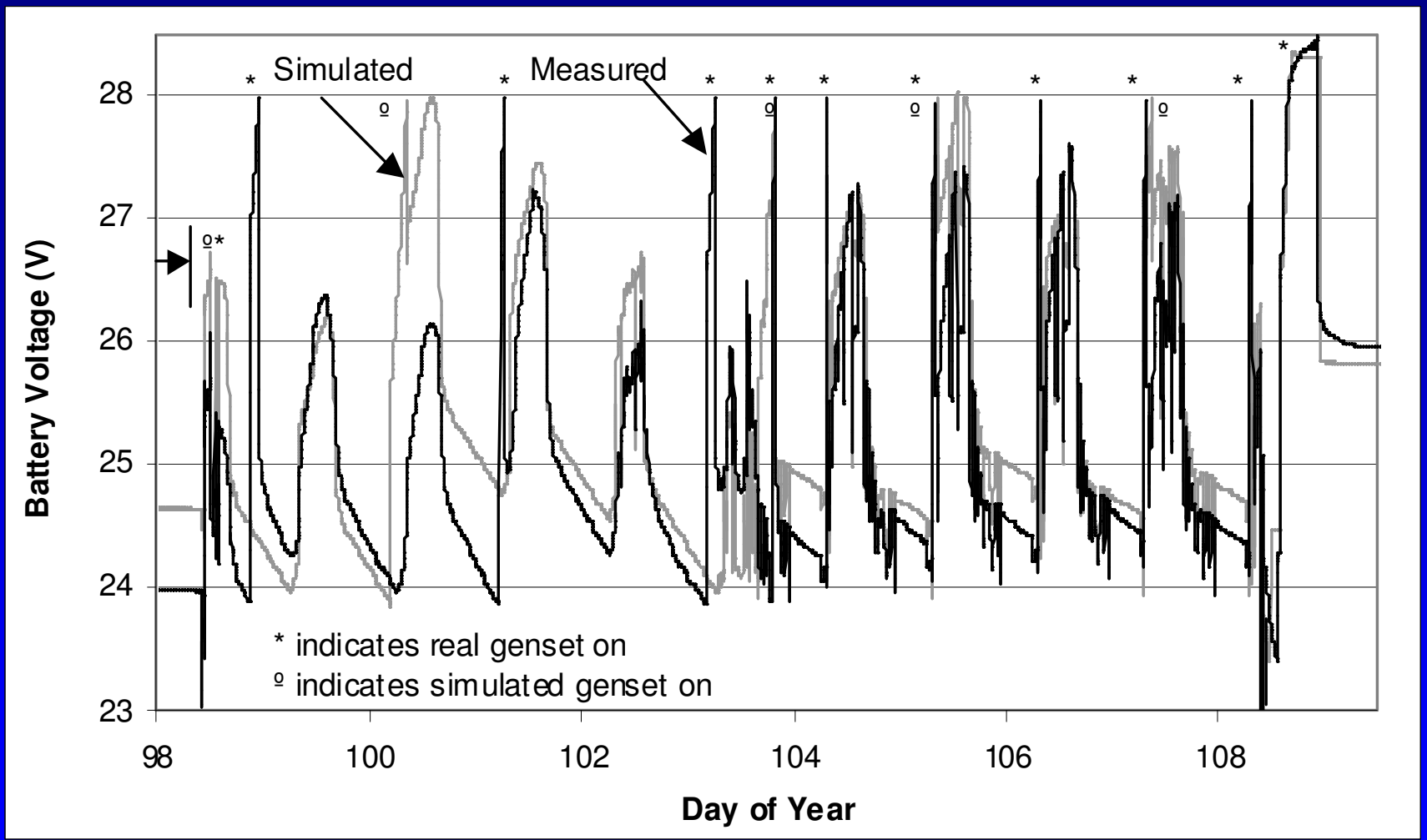
	Monitored	Simulation Error	
		w/ Measured Currents	w/ Voltage Setpoints
Charge in	1483 Ah	na	-8.1%
Charge out	1440 Ah	na	-8.5%
Coulombic Efficiency	97.1%	na	-0.4%
Energy in	39.9 kWh	0.7%	-7.5%
Energy out	35.6 kWh	-0.4%	-8.6%
Energy Efficiency	89.3%	-1.1%	-1.2%

Within 10%

Hybrid Test #1: Genset stops after certain elapsed time



Hybrid Test #3: Voltage thresholds, variable loads



Hybrid Test #3: Non-ideal battery behaviour

Test bench			Simulation		
Start Time (day)	**Energy (Wh)**	**Time (mins)**	**Start Time (day)**	**Energy (Wh)**	**Time (mins)**
87.68	8593	216	Test bench – 3.1 h	9503	236
91.19	6516	160	Test bench – 2.2 h	8519	210
92.05	6514	158	Test bench + 3.8 h	8497	210
92.83	6193	144	Test bench + 9.4 h	7890*	194
98.86	5843	144	Test bench + 32.4 h	7520*	184
101.21	3914	98			
103.18	4624	114			
Varying load begins					
103.78**	1950	50	103.67**	8897	220
104.29**	1922*	50			
105.29**	1751*	46	Test bench + 4 min**	3816*	94
106.29**	1779*	46			
107.29**	1800*	48	Test bench + 4 min**	3708*	92
108.29**	2141*	56			

* Significant PV current at termination of genset run
** Genset start coincides with high load

Hybrid Test #3: On average, simulation is okay

- Despite divergence of simulation and reality, errors low
  - PV and genset energy flows accurate to within 5% over entire test
  - Energy into and out of battery to within 3%
  - Battery efficiencies to within 1%
  - Simulated solar fraction of 62.1% close to real figure of 64.3%

Areas needing improvement

- Battery model
  - Temperatures other than 25º C
  - Can a single state variable (i.e., state-of-charge) capture complex effects that partial state-of-charge cycling has on plates?
- Division of global irradiance/insolation into beam and diffuse components
  - The diffuse fraction is not solely a function of clearness index
  - No problems here, but could be major source of error in other situations (e.g., northern climates)

Conclusions

- PVToolbox generally accurate within 5 to 8% for major energy flows, when plane-of-array irradiance data is used
- When non-linear control decisions (e.g., dispatch) are based on voltage or current thresholds, errors in battery model will cause divergence of simulation and reality in terms of timing of events
- Complex battery behaviour can not be captured in a single state variable such as state-of-charge