

Energy Storage System Model Development for Grid-Tied Renewable Applications

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Introduction

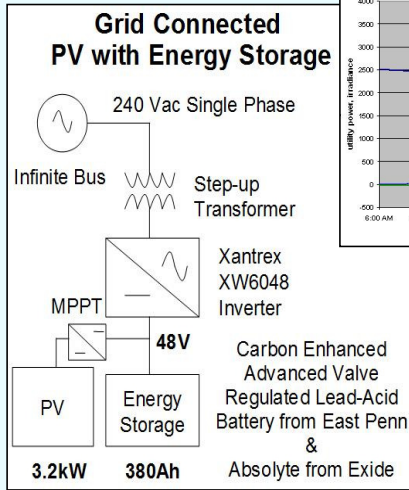


Figure 2 – Grid-Tied PV and Energy Storage System

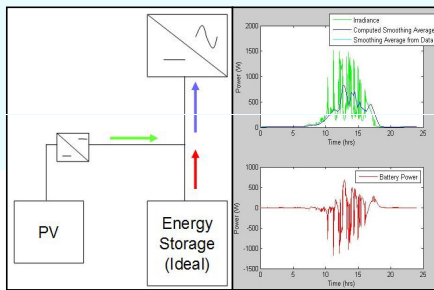


Figure 3 – Power Output for the Three Elements in the System over a Day

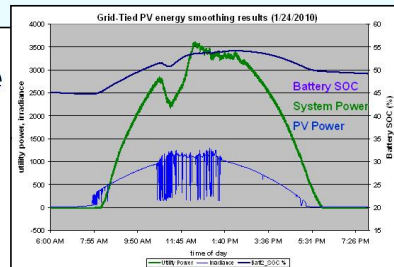


Figure 1 – Irradiance and Smoothing Algorithm Output over a Day

Background
Intermittent power which is put onto the grid must be rate limited to allow for slow reacting generators to respond to fluctuations

This is done through the use of energy storage

The Problem
Current systems control the load put onto the battery indirectly

Un-optimal charging and discharging of the battery causes a decrease in:

- round trip efficiency
- battery utilization
- battery lifetime

Our Plan

Model the system including a detailed electrical battery model
Verify the model matches the collected data
Design control based on battery electrochemistry knowledge
Verify improvements, first in simulation, then on actual system

Inverter Model

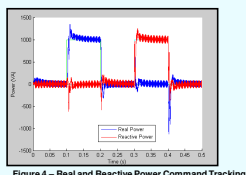


Figure 4 – Real and Reactive Power Command Tracking

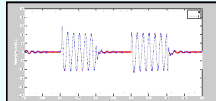


Figure 5 – AC Side Current and Voltage

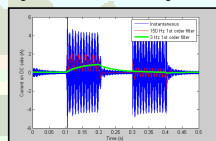


Figure 6 – DC Side Current

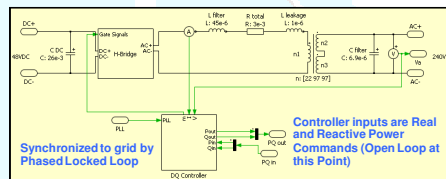


Figure 7 – Model of Xantrex XW6048 Inverter

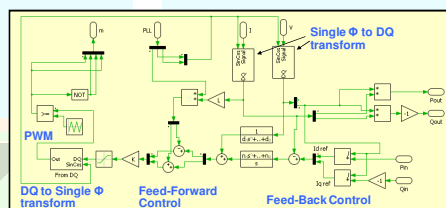


Figure 8 – Inverter Controller in Synchronous Reference Frame

Battery Model

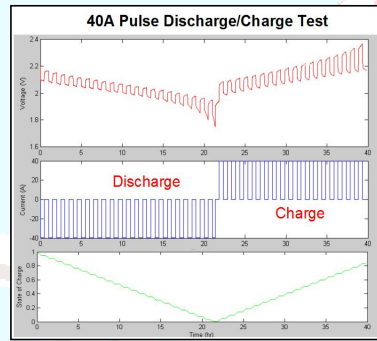


Figure 9 – Battery Voltage, Current, and State of Charge for Characterization Test

Characteristics Modeled
Open Circuit Voltage
Polarization Effect
Electric Resistance

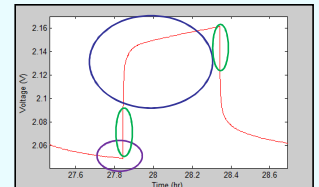


Figure 10 – Indication of the Battery Non-Idealities Modeled

Curves were fit to the equation
 $V = V_{oc} + I \cdot R_{series} + I \cdot (e^{-R_1 C_1 t} + e^{-R_2 C_2 t})$

Each parameter value in the equation was found as a function of state of charge and incorporated into a model

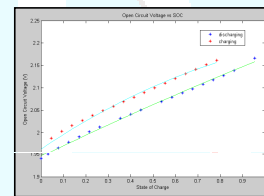


Figure 12 – Open Circuit Voltage vs. State of Charge

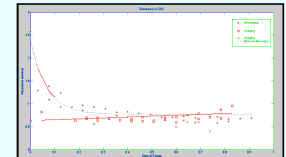


Figure 11 – Electric Resistance vs. State of Charge

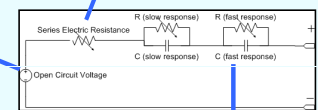


Figure 13 – Battery Model



Figure 14 – Carbon Enhanced Advanced Lead Acid Battery from East Penn (48V Module)

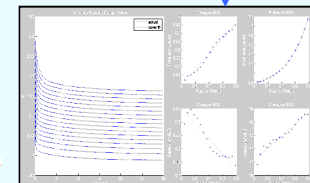


Figure 15 – Polarization Parameter Coefficients vs. State of Charge

Results

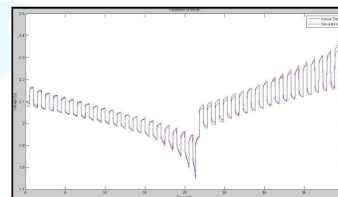


Figure 16 – Comparison of Measured Data and Simulated Data for 40A Test

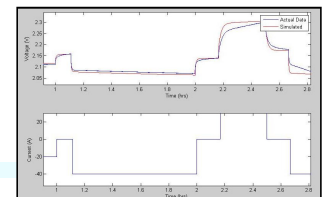


Figure 17 – Comparison of Measured Data and Simulated Data for Arbitrary Profile

$$RMS_Error = \frac{\sum (Actual - Simulated)^2}{\# Samples}$$

$$Energy_returned = \frac{Energy_Out}{Energy_In}$$

Profile	RMS Error	% of 2V	Energy returned: from Data	Energy returned: from Model	% Error
40A	7.6 mV	0.38 %	91.63 %	91.41 %	0.22 %
60 A	26.0 mV	1.3 %	84.99 %	85.82 %	0.83 %
Arbitrary	12.1 mV	0.61 %	55.32 %	55.63 %	0.31 %

Figure 18 – Table Summarizing the Accuracy of the Battery Model

Future Work

Complete and verify battery model and model of entire system
Optimize System Configuration
Optimize Control of system