Design and Simulation of a DC Electric Vehicle Charging Station Connected to a MVDC Infrastructure

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Objectives of Research

- ✓ Investigate operation, interaction, and system integration of power electronic conversion devices, battery energy storage systems, and DC power systems.
- ✓ Evaluate operation of common DC bus electric vehicle charging station (EVCS) employing level 2 DC fast chargers powered via MVDC grid.
- ✓ Benchmark applicability of bidirectional DC-DC converter as an interface between medium and low voltage networks within next generation DC power systems.

Installed Electric Vehicle Charging Station
(C. S. CCJ Digital. (2011). Eaton Research Facility Adds EV Charging Stations)

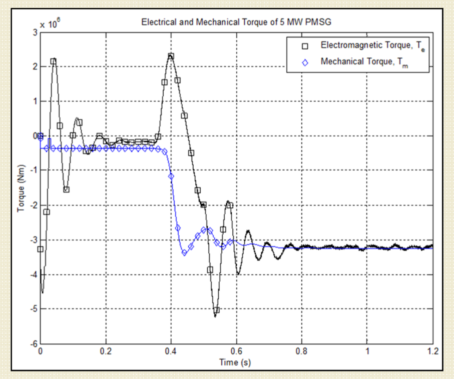
Renewable Generation Modeling

MVDC Wind Turbine System

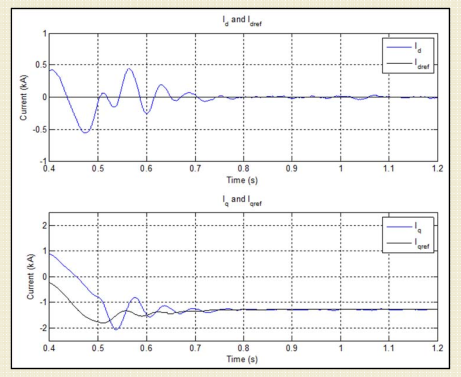
- ✓ Experimentally Validated Aerodynamic Model
- ✓ Permanent Magnet Synchronous Generator
- ✓ Back-to-Back Neutral Point Clamped Converter Interface

$$V_d = R_s i_d + L_s \frac{di_d}{dt} - \omega_r L_s i_q \qquad T_{em} = \frac{3}{2}\frac{P}{2}\left(\lambda_m i_q + \left(L_{ds} - L_{qs}\right) i_d i_q\right)$$

$$V_q = R_s i_q + L_s \frac{di_q}{dt} + \omega_r L_s i_d + \omega_r L_m \qquad T_e - T_m - F\omega_r = J\frac{d\omega_r}{dt}$$

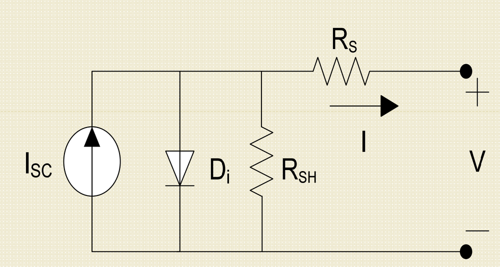


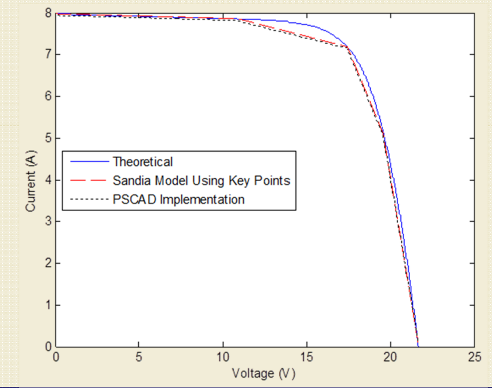
Generator Characteristics



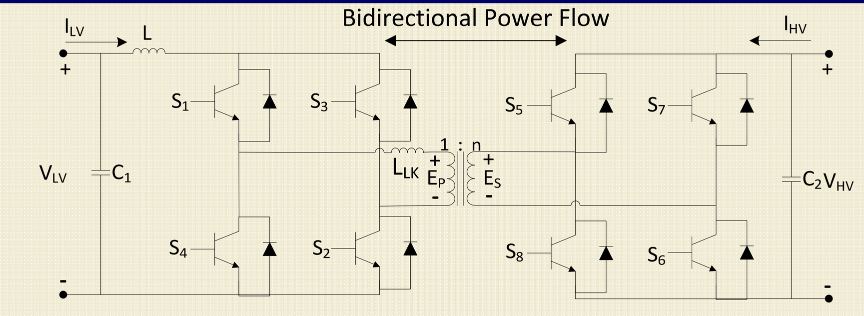
Controller Responses

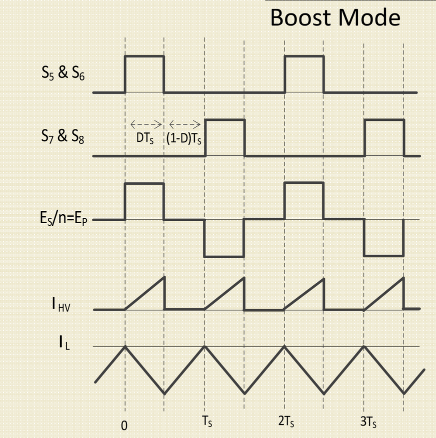
LVDC Photovoltaic System



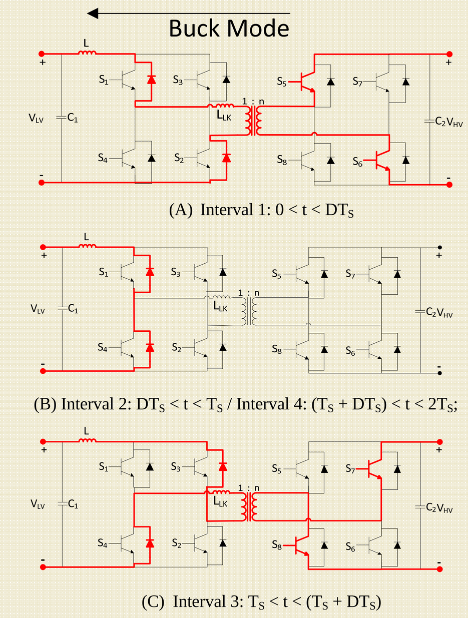


Bidirectional DC-DC Converter

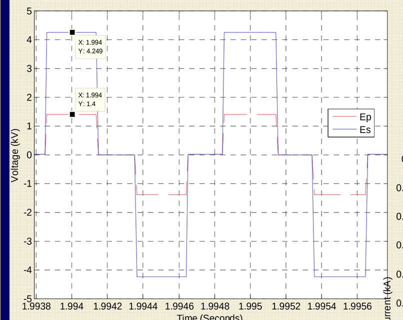




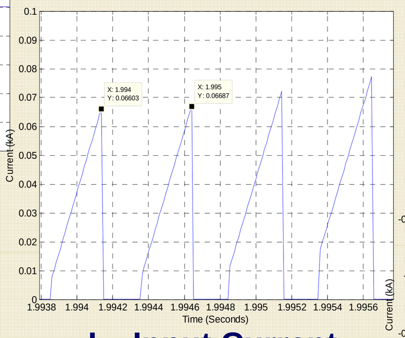
Operating Waveforms



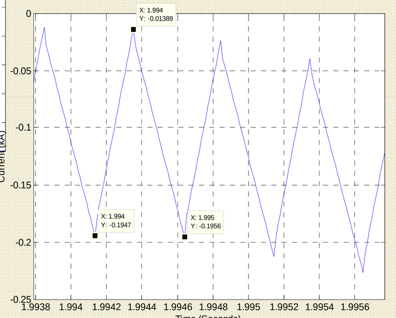
Current Paths



Transformer Voltage



I_{HV} Input Current



I_L Inductor Current

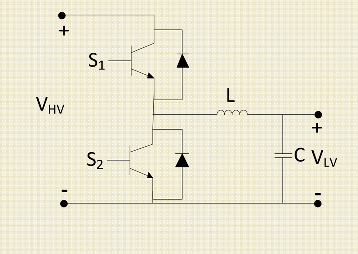
Battery & Battery Charger Modeling

Level 3 DC Fast Charger

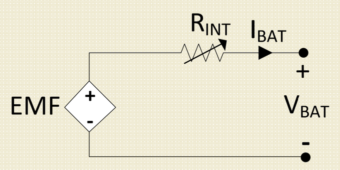
- ✓ Simulated using synchronous buck converter
- ✓ Charges at approximately 50 kW for 15 minutes

EV Battery

- ✓ Simulated using dynamic linear battery model
- ✓ Dynamics of battery governed by equations below
- ✓ 22 Ah battery pulse charged for approximately 0.55 seconds



Synchronous Buck Converter



Linear Battery

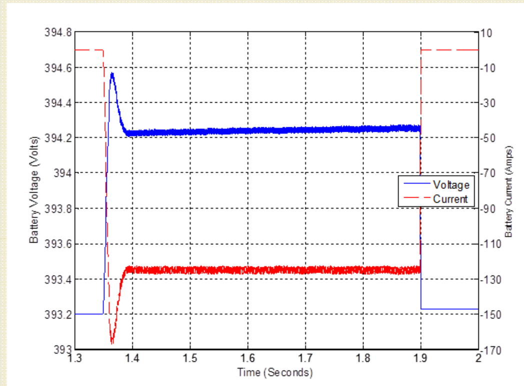
$$Q_e = -\int_0^t I_{bat}(\tau)d\tau$$

$$\mathrm{SOC} = \frac{Q_e}{C_{max}}$$

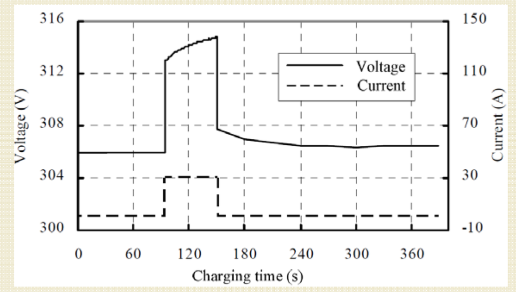
$$R_{int} = R_{min} + (K_R \mathrm{SOC})$$

$$\mathrm{EMF} = V_{min} + (K_V \mathrm{SOC})$$

Linear Battery Equations



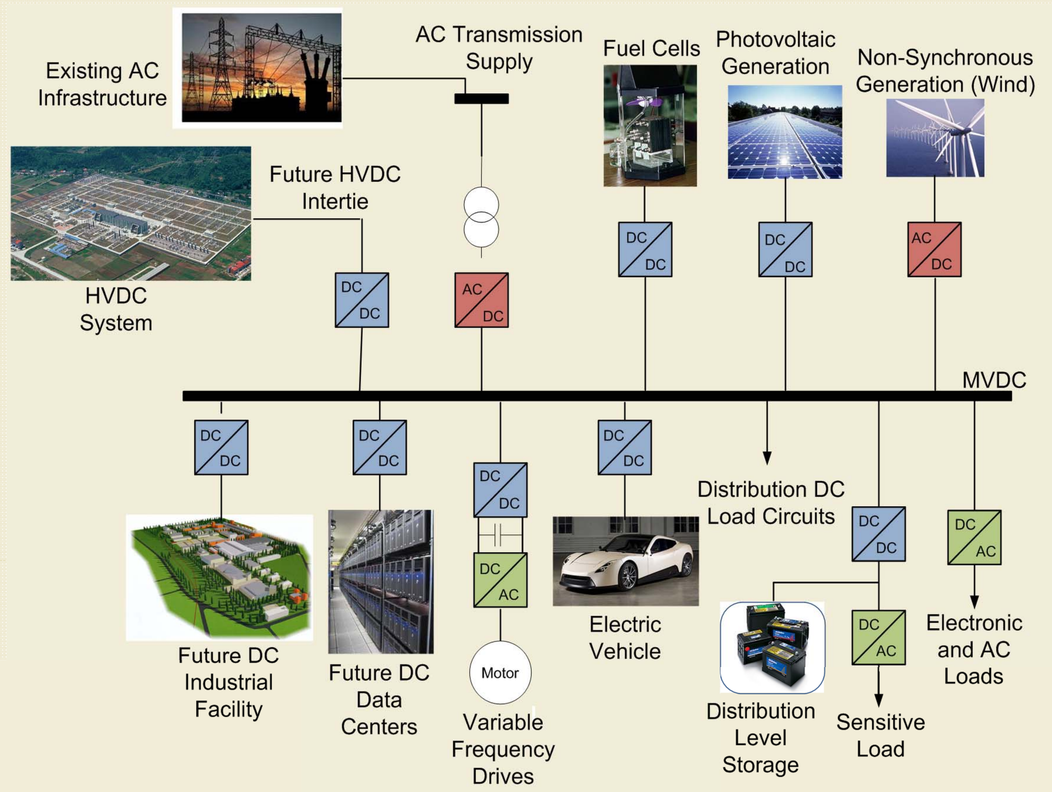
Pulsed Charge (Battery 2)



Example Pulsed Charge
(Zheng et. al. - Dynamic Model for Characteristics of Li-ion Battery on Electric Vehicle)

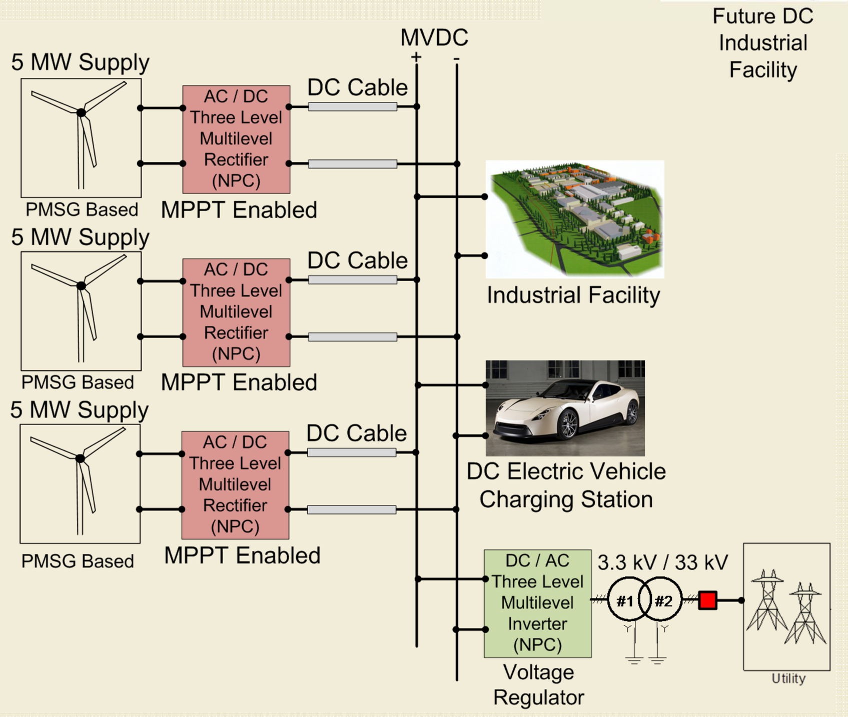
Medium Voltage DC Concept and Modeled Systems

- ✓ The emerging applications of DC resources and supply establish the potential for a paradigm shift in the future development of transmission and distribution systems toward a larger overall DC infrastructure.
- ✓ The medium-voltage DC (MVDC) concept is ultimately a collection platform designed to help integrate renewables, serve emerging DC-based and constant-power loads, interconnect energy storage, and address future needs in the general area of electric power conversion.

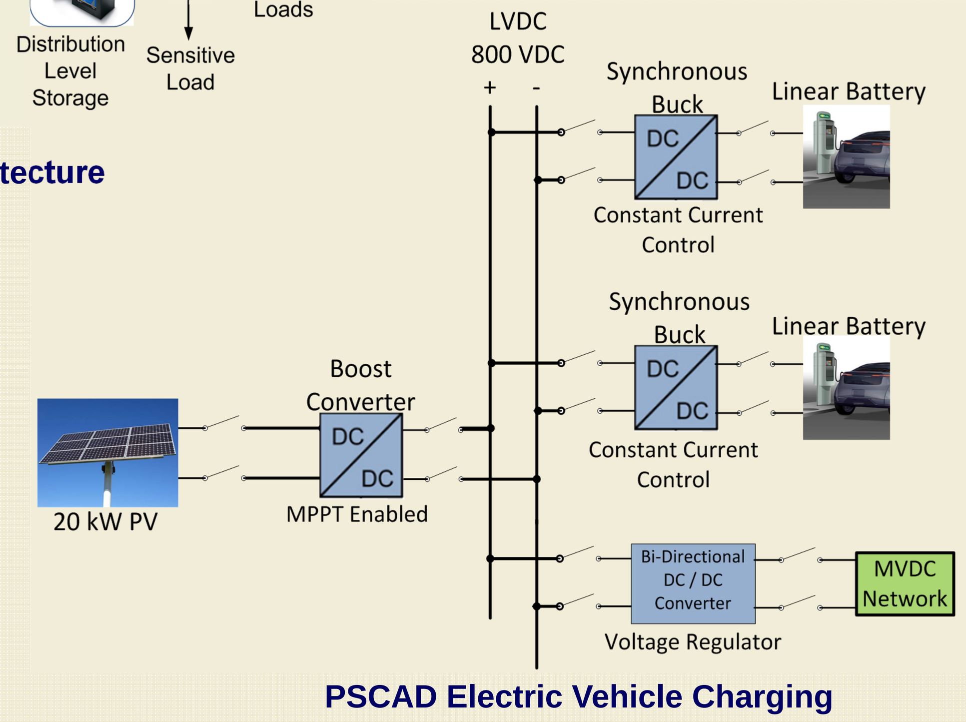


General MVDC Architecture

- ✓ Certain applications require lower operating voltages and would not be able to directly connect to the medium voltage DC architecture. Electric Vehicle charging station infrastructure is such an example.
- ✓ To accommodate lower voltage applications, bidirectional DC/DC converter research is critical. These components will serve as the interface between the medium and low voltage bus bars as depicted in the low voltage DC framework found below.

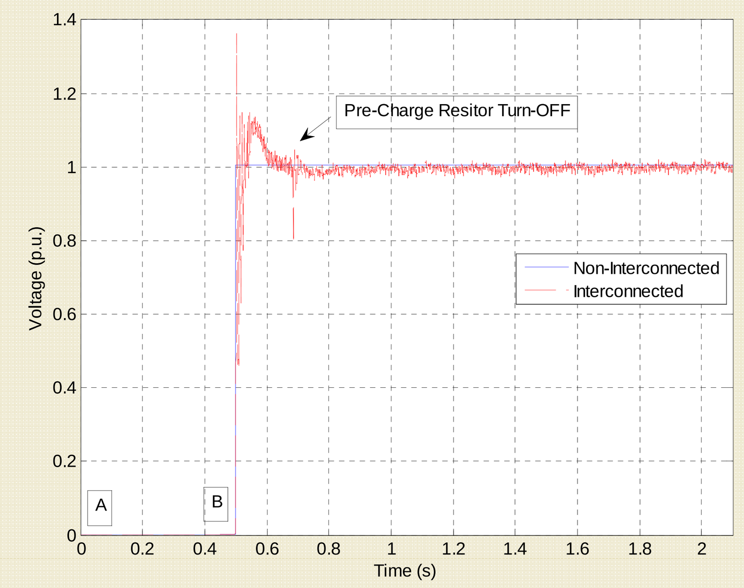


PSCAD MVDC Implementation

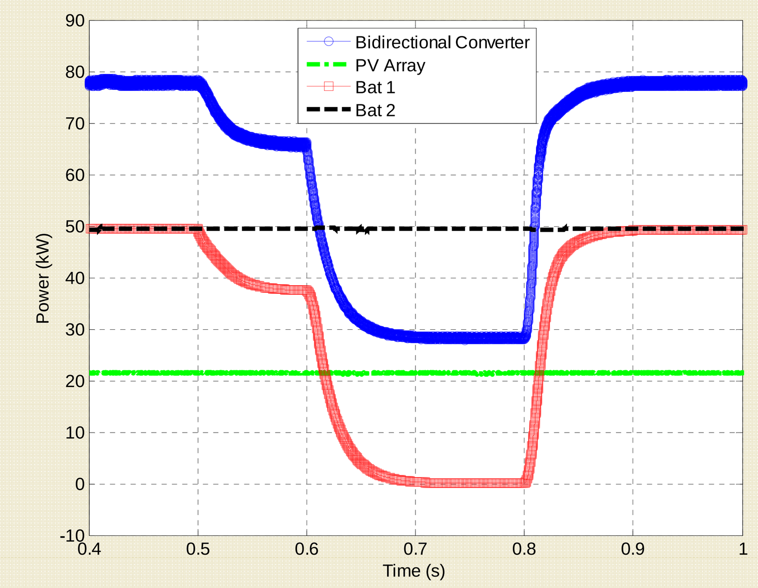


PSCAD Electric Vehicle Charging Station Implementation

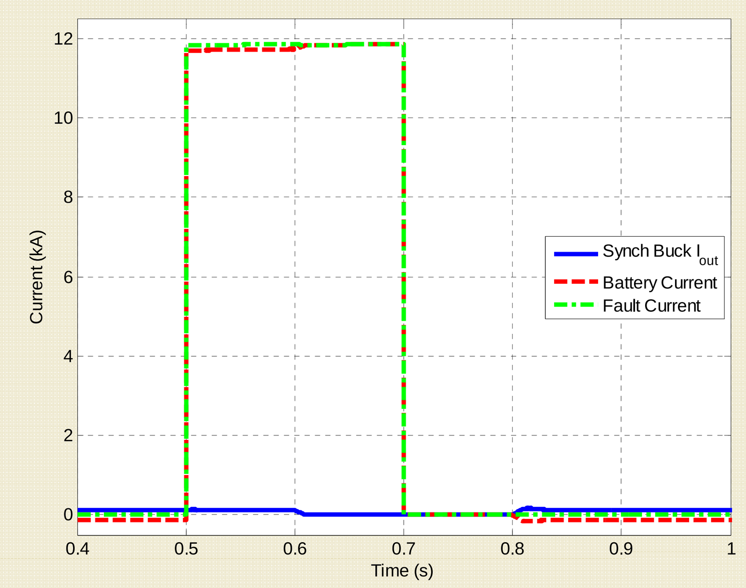
System Operation, Validation, and Transient Behavior



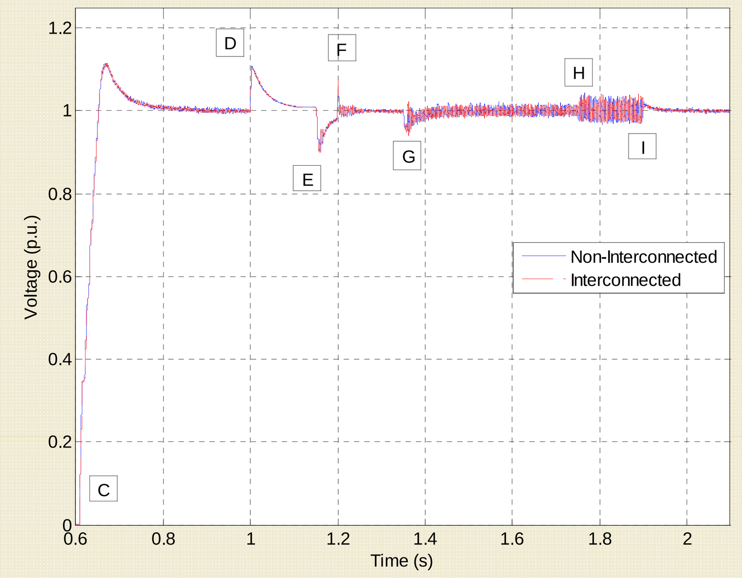
Regulated MVDC Bus Voltage



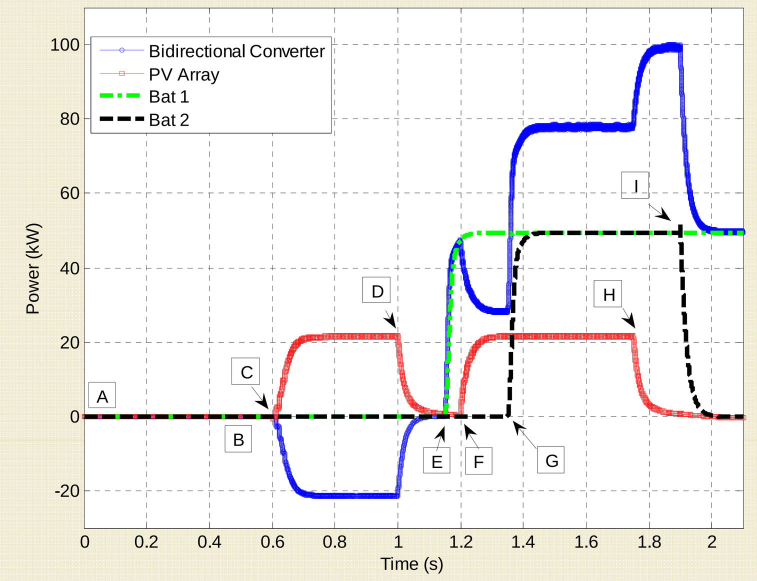
Power Flow During Battery Short Circuit



Battery Short Circuit Fault Current



Regulated LVDC Bus Voltage



Component Supplied and Absorbed Power

Stated	Process
(A) – 0.00 s	Wind turbines begin 'warm-up'
(B) – 0.50 s	MVDC grid connected to EVCS
(C) – 0.61 s	PV array ON
(D) – 1.00 s	PV array OFF
(E) – 1.15 s	EV bat 1 begins charging
(F) – 1.20 s	PV array ON
(G) – 1.35 s	EV bat 2 begins charging
(H) – 1.75 s	PV array OFF
(I) – 1.90 s	EV battery 2 stops charging

System Operating States