Modeling, Simulation, and Applications of Distributed Battery Energy Storage Systems in Power Systems

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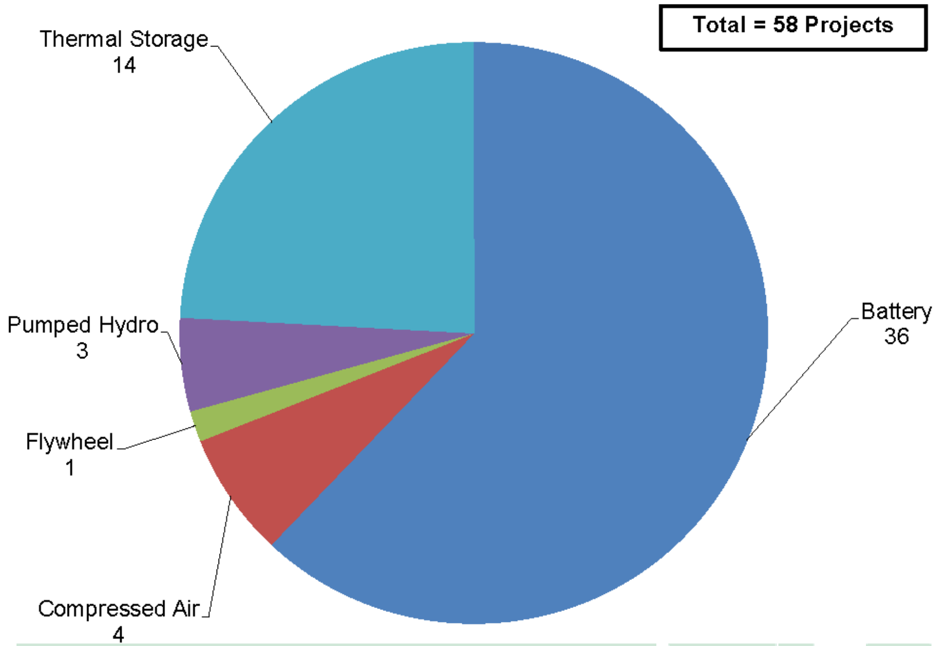
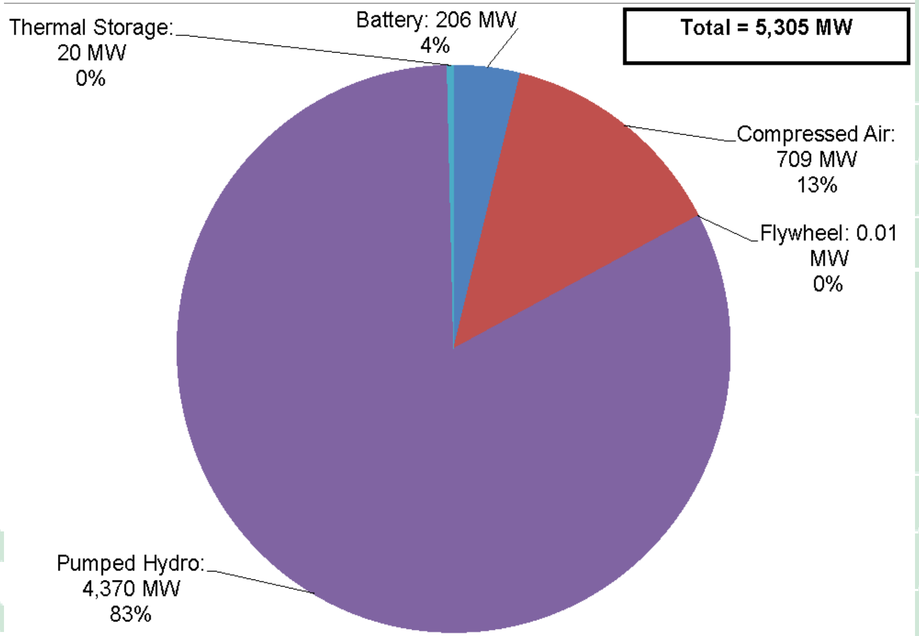
Energy Storage Projects and Capacity in US (from DOE Database as of August 2012)

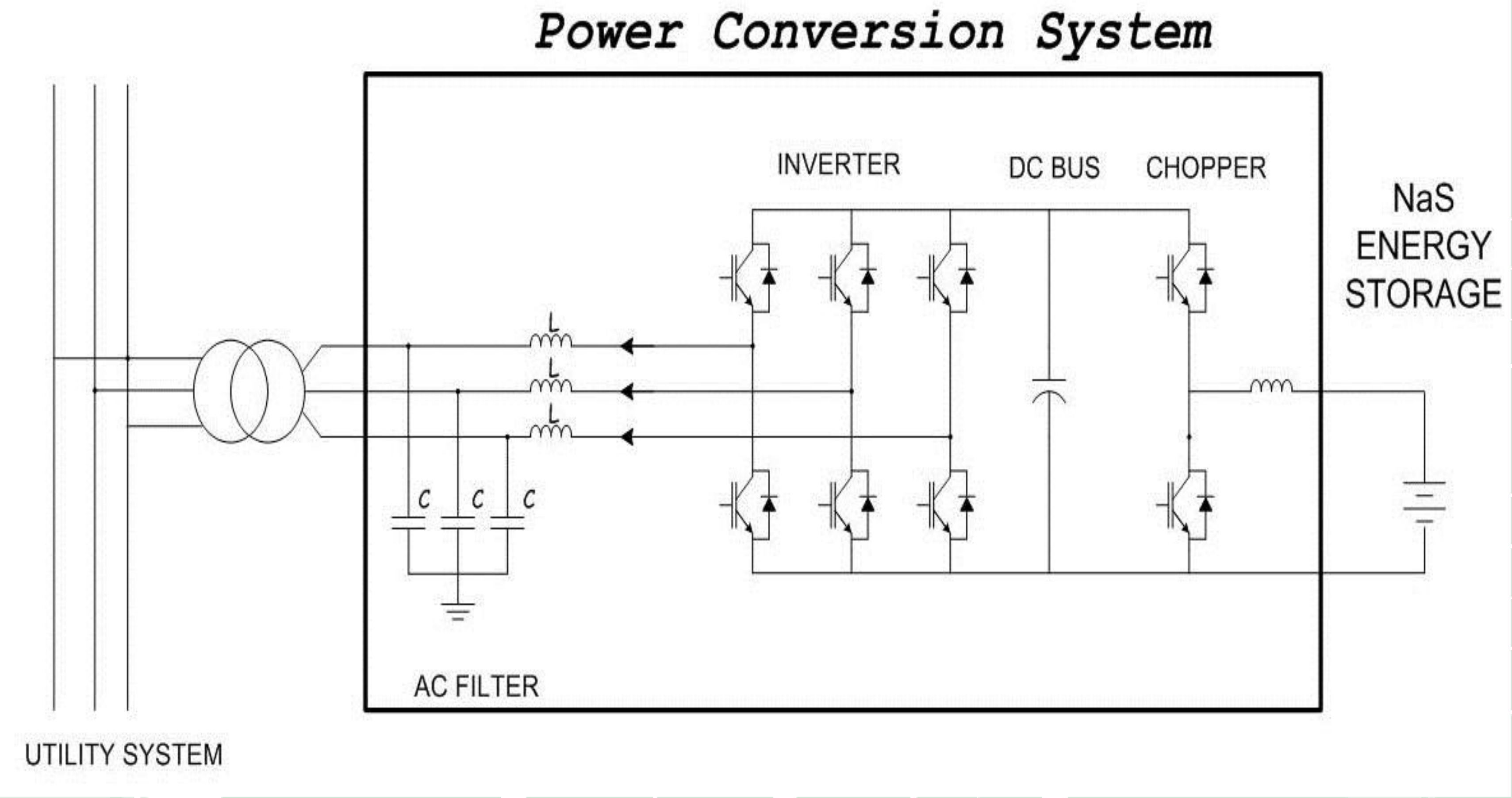




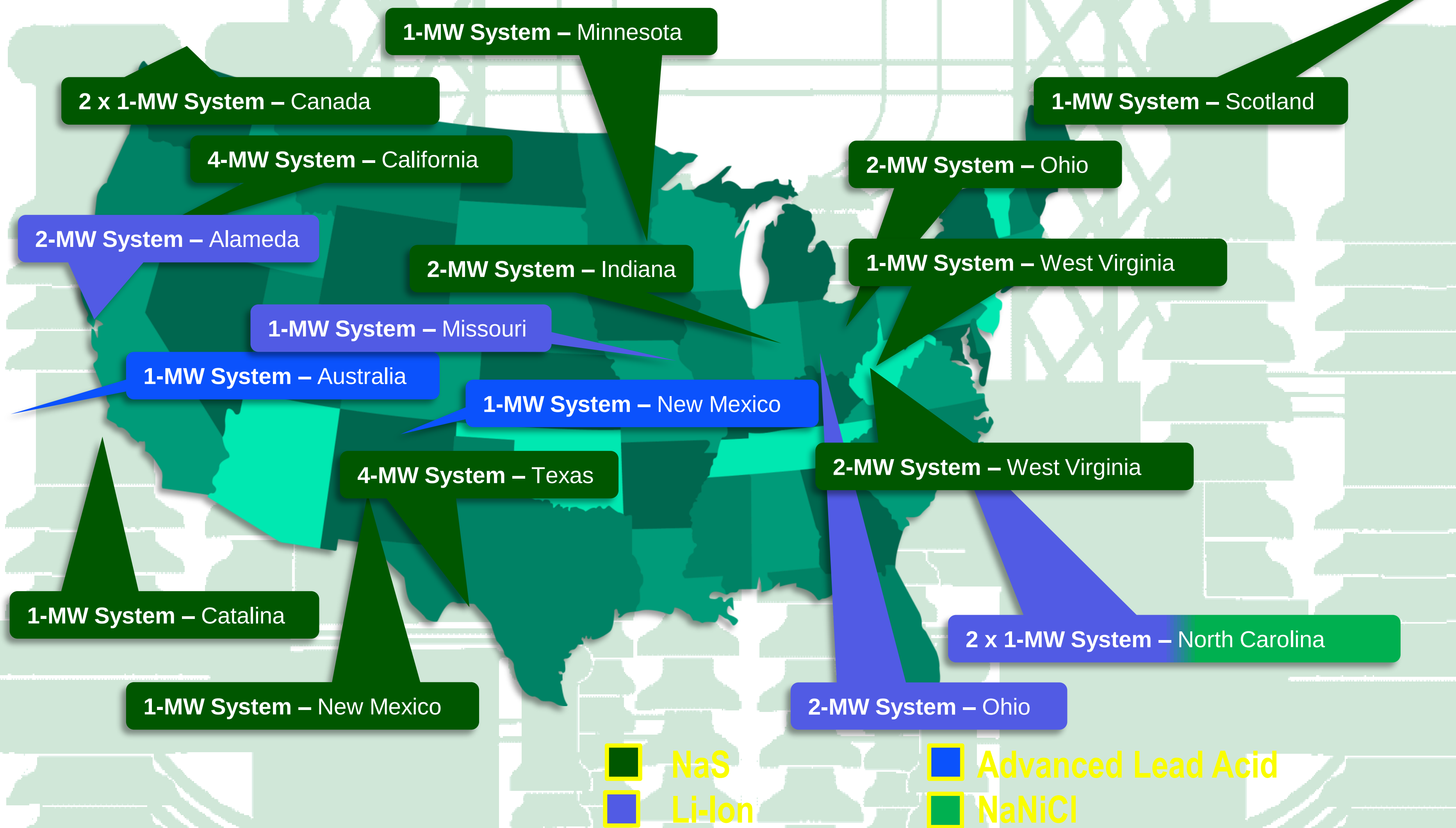
Major Applications of Battery Energy Storage System (BESS)

Generation Applications	Transmission and Distribution Applications	End-User Applications
• Provide renewable sources governor response and system frequency regulation. (Renewable generation typically lacks governor response and frequency regulation capability.) • Balance energy needs such as peaking shaving/valley filling. (Renewable generation non-controllable variability increases balance energy needs.) • Provide short-term and quick start reserves. • Provide renewable energy production shifting, smoothing and leveling.	• Increase transmission capacity factor for renewable sources. • Relieve transmission congestion and relax transmission reliability limits. • Defer transmission, distribution or transformer upgrades, capital expenditure due to congestion, or peak load growth. • Provide voltage and VAR support and reliability enhancement to manage the fluctuations of renewable energy production. • Support islanding system operation and/or serve loads in isolated areas.	• Store renewable generation production. • Provide time-shifting, load-following and load-leveling of demand to avoid peak prices. • Provide reliability enhancement to avoid power interruptions. • Allow utility control for targeted reliability enhancement. • Provide renewable generation and load demand response management. • Provide load specific voltage support. • Provide emergency power.

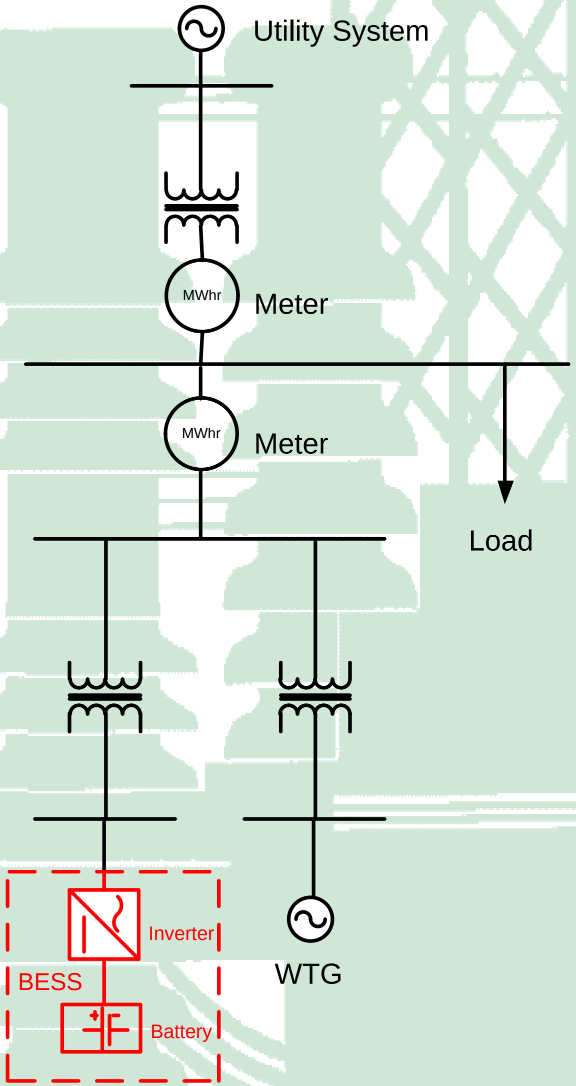
Schematic Diagram of a Typical BESS

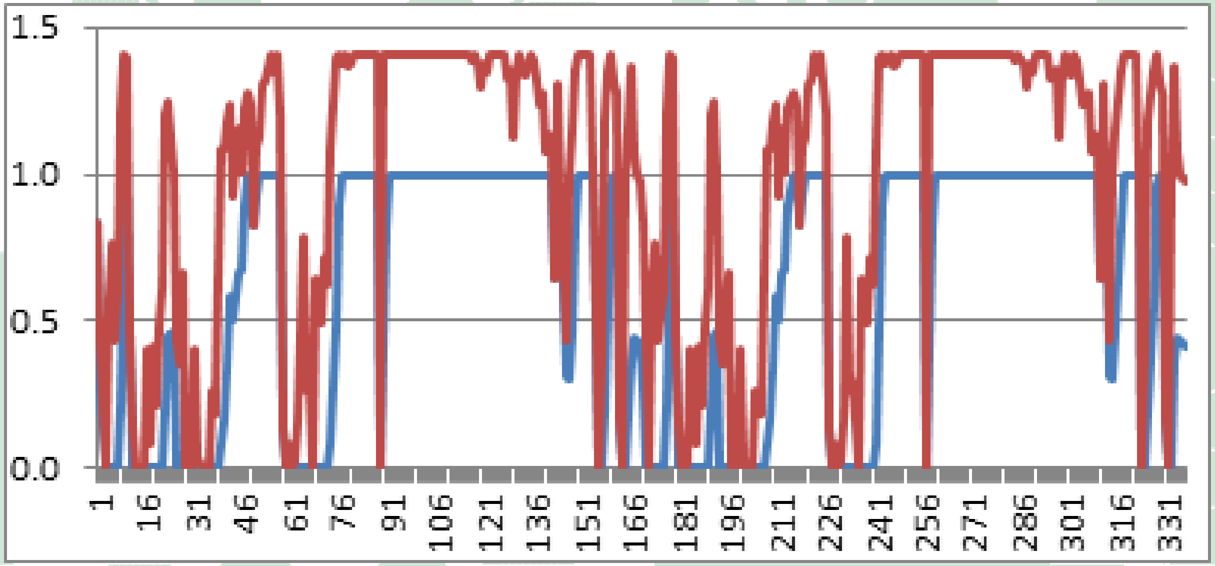


S&C Delivered BESS Projects



BESS with Renewable Energy Application





Case Study Results

Case	Cost of Energy from Utility	Cost of Energy from WTG and/or BESS	Total Payment from Load	Savings for Load due to WTG and/or BESS	WTG Energy Curtailment (MWHr)	Cost of WTG Energy Curtailment	Discharging MWHr from BESS	Revenue from BESS
Energy from Utility only	$3,504,000	$0	$3,504,000	$0	0	$0	0	$0
Energy from Utility and WTG	$1,555,824	$1,461,132	$3,016,956	$487,044	1,315	$394,359	0	$0
Energy from Utility and WTG plus BESS	$1,297,149	$1,655,138	$2,952,287	$551,713	674	$202,153	647	$194,006

For example, when the WTG production is such that the BESS operates with 100% Depth of Discharge (DOD) per day, the revenue from the BESS would be:

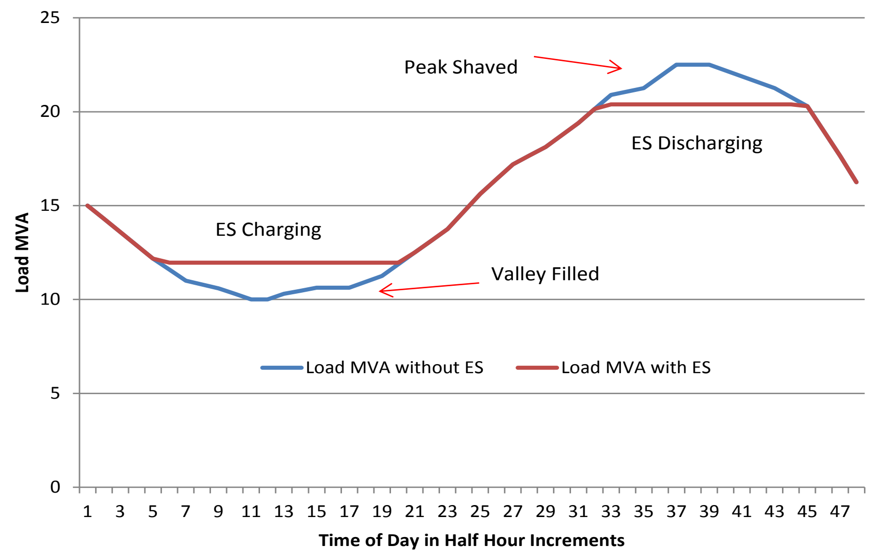
Revenue from BESS = 6 MWh × $300 × 365 (days) = $657,000/year

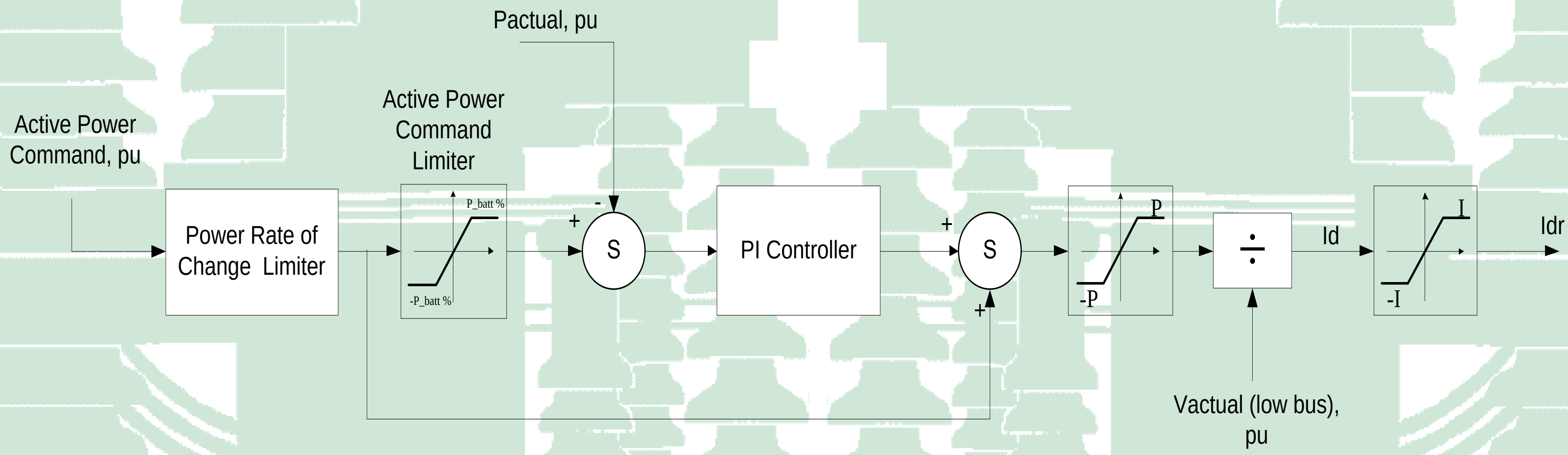
When operating with 90% DOD per day, the revenue from the BESS would be:

Revenue from BESS = 90% × 6 MWh × $300 × 365 (days) = $591,300/year

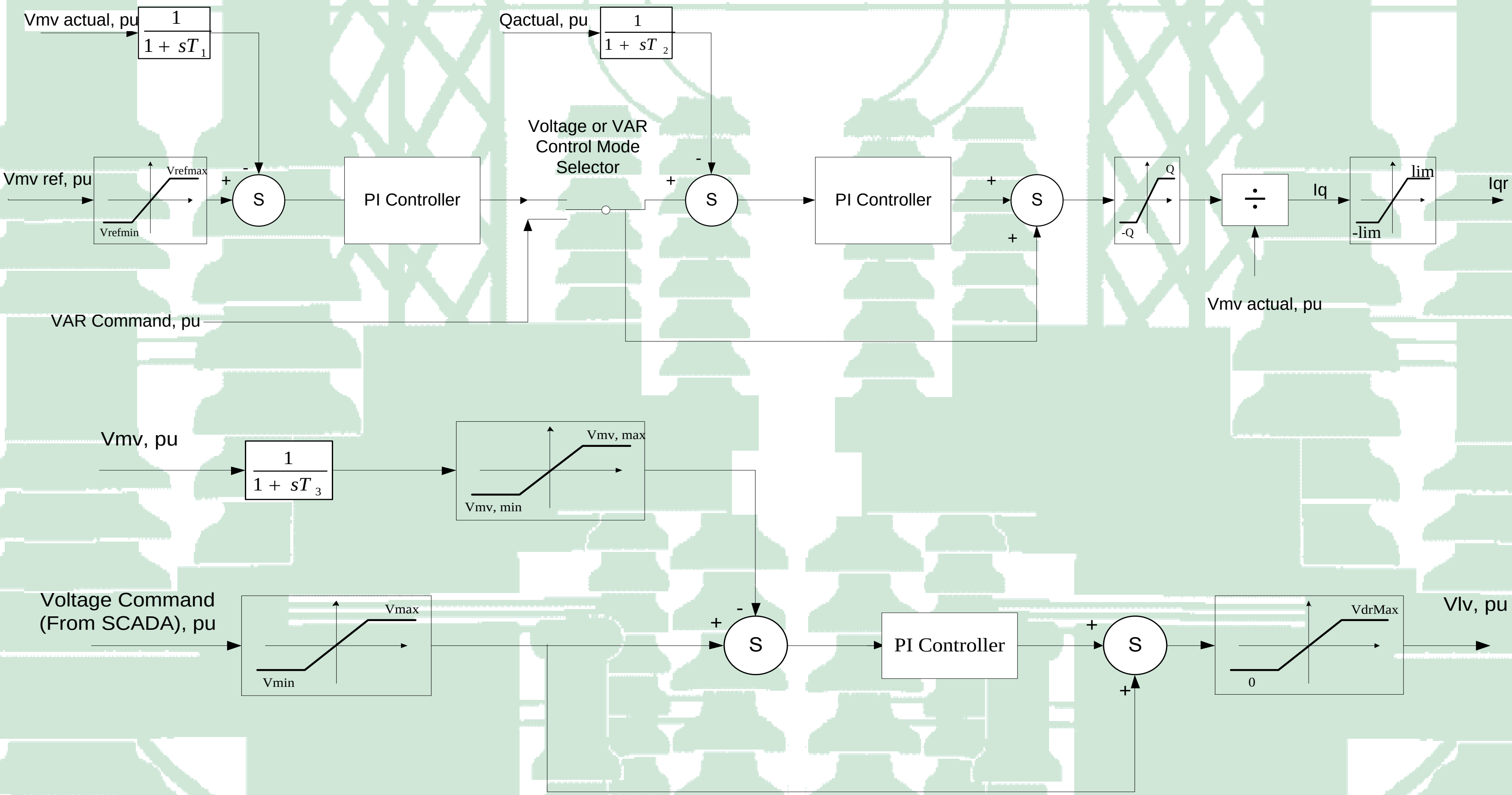
Depth of Discharge (DOD)	Battery Designed Life (Cycles)	Battery Designed Life (Equivalent Years)	Revenue from BESS	Total Revenue from BESS for Life Cycle
100%	2,500	7	$657,000	$4,613,764
90%	4,500	13	$591,300	$7,474,298

System Modeling (Peak-Shaving, Islanding Operation, etc)

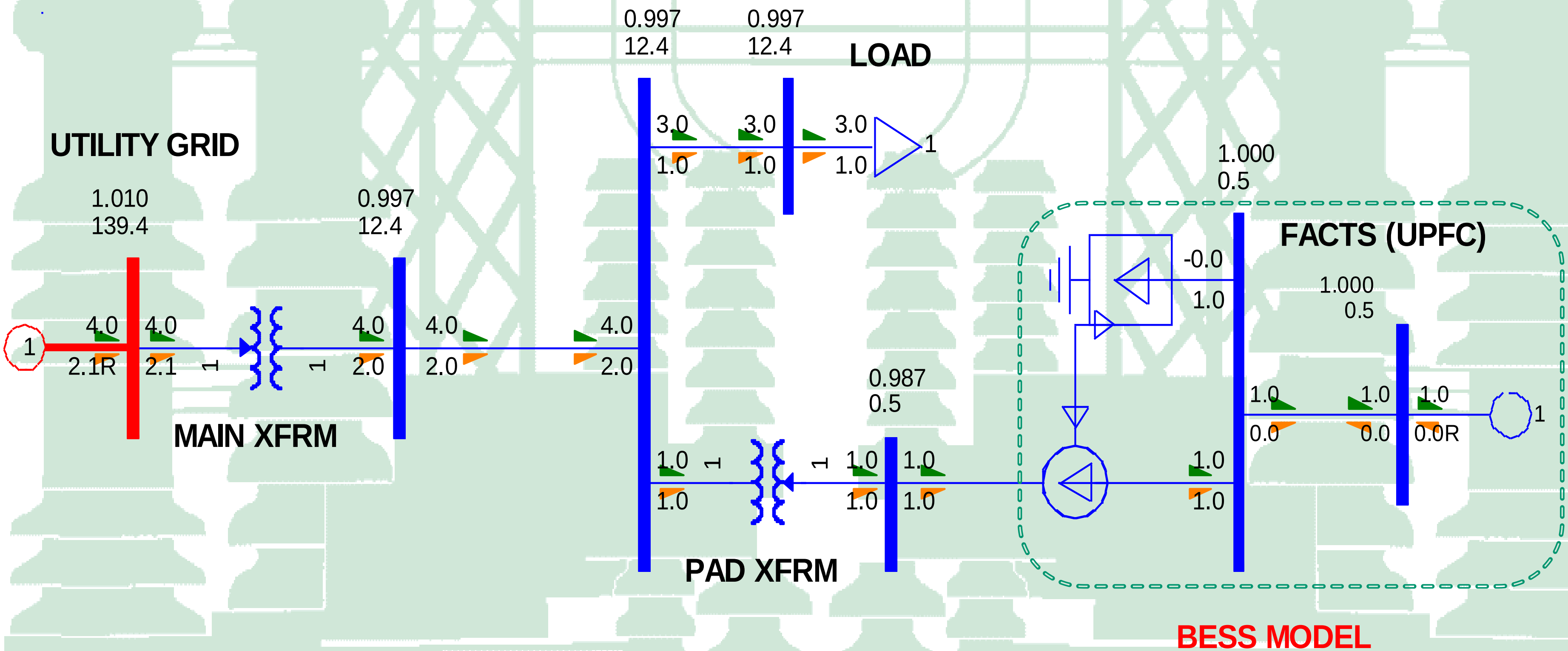




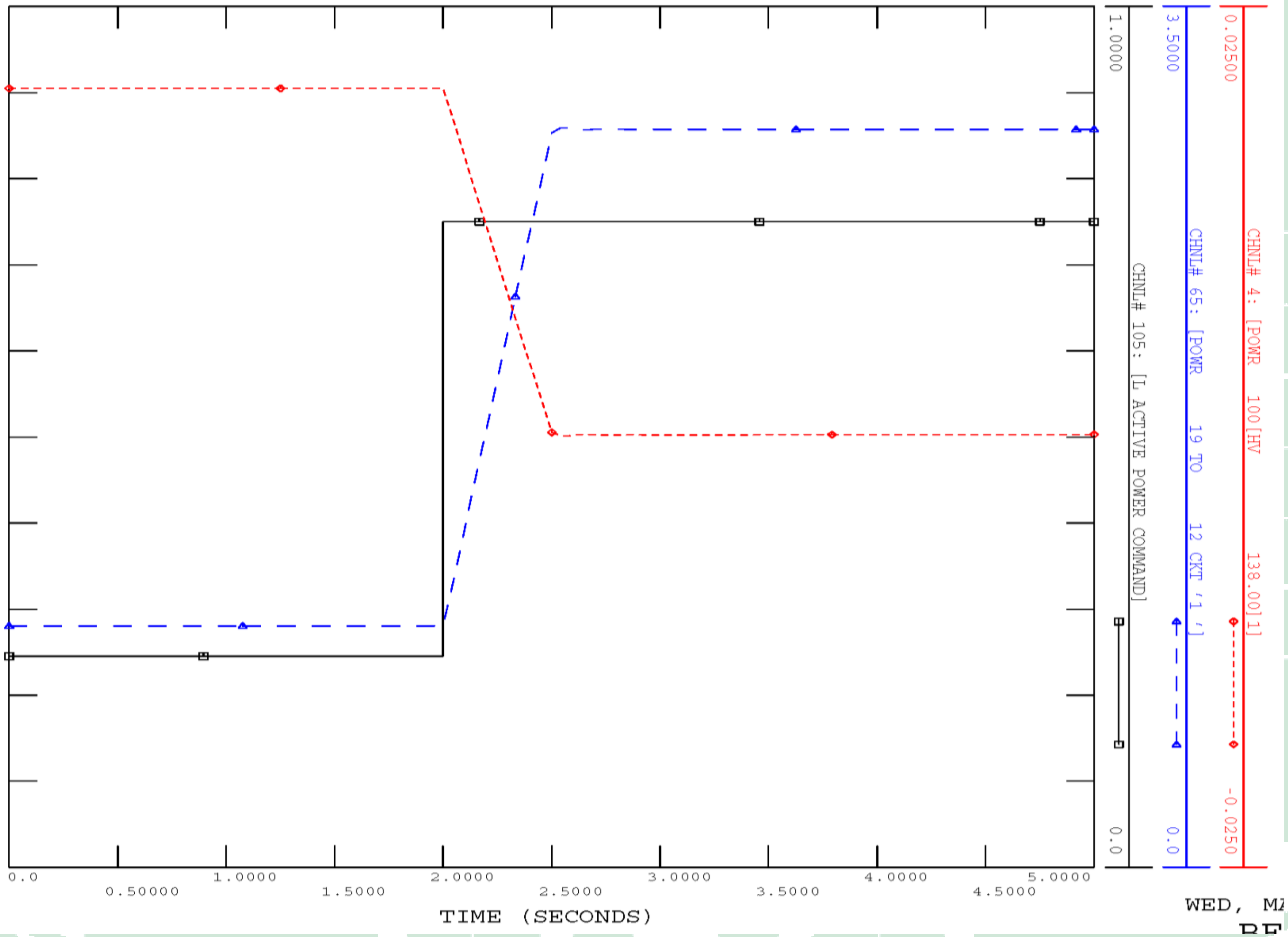
System Modeling (Peak-Shaving, Islanding Operation, etc) (Cont'd)



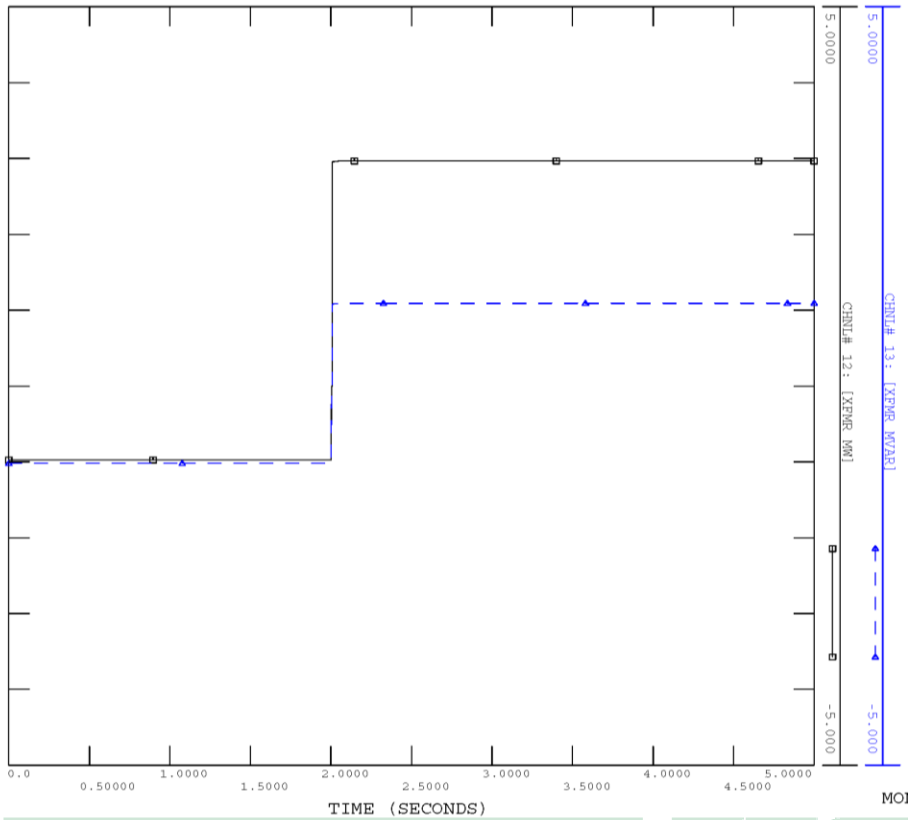
Case Study - System

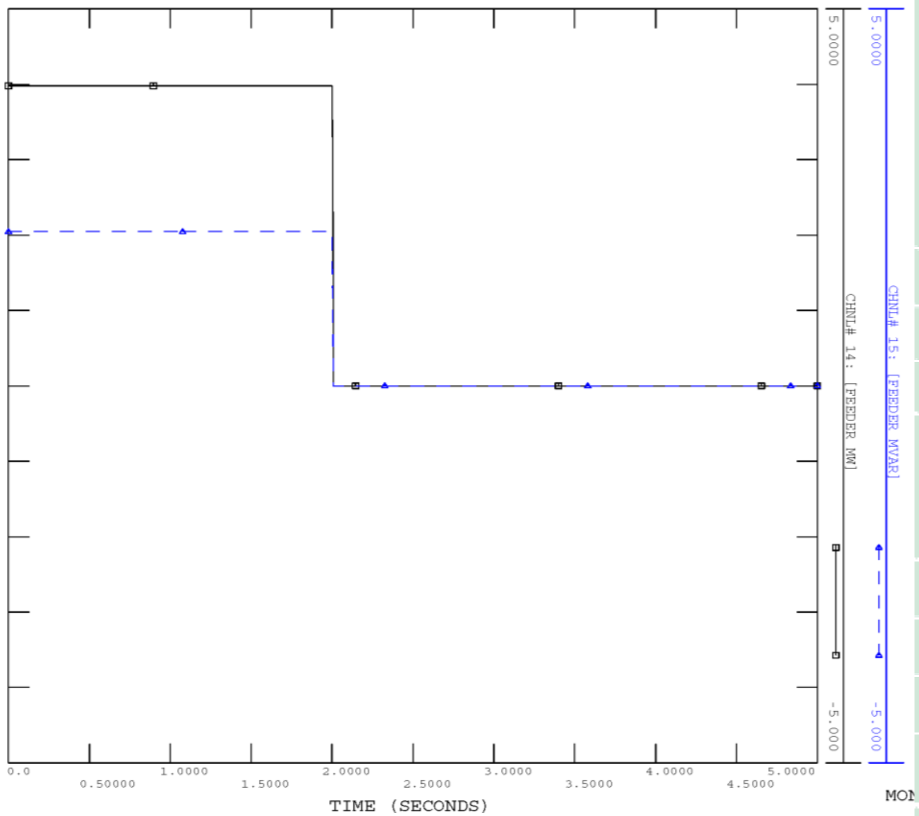


Case Study – Peaking-Saving



Case Study – Islanding Operation





Conclusions

- Typical applications of the BESS include output smoothing and time shifting for intermittent renewable (wind and solar) energy sources, and peak shaving and valley filling for the power grid, and islanding system operations. This paper presented case studies to discuss these types of applications. The paper also included modeling and simulation of the BESS with the widely-used Power System Simulator PSS®E. Simulation results show that the BESS dynamic model responds properly and correctly as expected when operating in peak shaving/valley filling mode and in islanding operation mode in a simplified system. This model can be used for power system studies involving those typical BESS applications.