# Utility-Scale Vanadium Redox Flow Battery for Distribution Grid Support: System Dynamics and Efficiencies

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Beyond Lithium Ion XII, Poster No. 2

## 1 Abstract


- **Collaboration between National Renewable Energy Laboratory (NREL) and Sumitomo Electric USA**
- **Largest field deployed Vanadium Redox Flow Battery (VRFB) in the United States (2MW/8MWh)**
- **Fully characterized the dynamic losses and efficiency**
- **VRFB system efficiency is a nonlinear function of the active power and state of charge of the system.**
- **Dynamic efficiency is impacted by three loss vectors:**
  1. **Chemically induced losses**
  2. **Parasitic loads associated with operating the auxiliary equipment**
  3. **Losses associated with the Power Conditioning Systems (PCS)**
- **Several use cases analyzed accounting for the dynamic efficiencies**



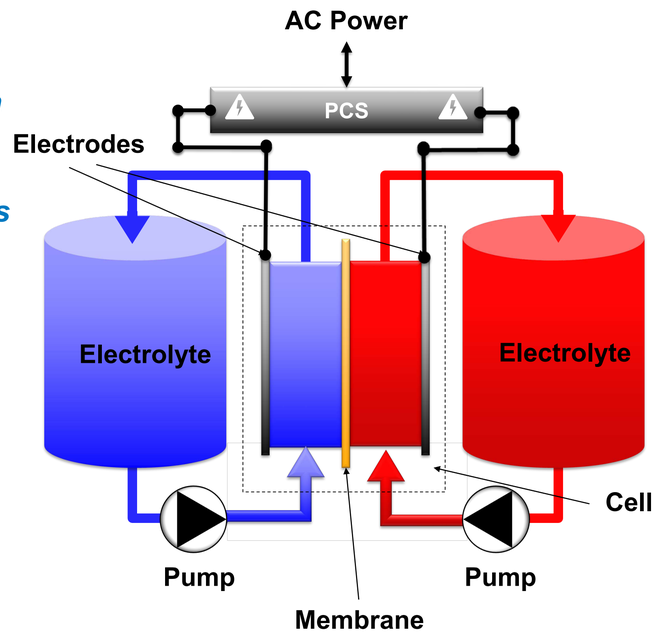
## 2 Vanadium Redox Flow Battery Operation

*Pumps force fluid electrolyte through the system into the VRFB cell.*

*Within the cell, charge concentrations on either side of the membrane produce and electric potential which drives the DC circuit.*

*Discharging:*
- *DC current is passed to PCS which produces AC power.*

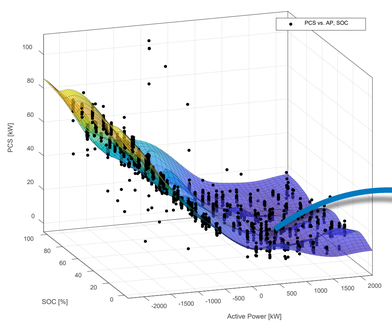
*Charging:*
- *AC power feeds the PCS which applies a voltage across the VRFB cell.*



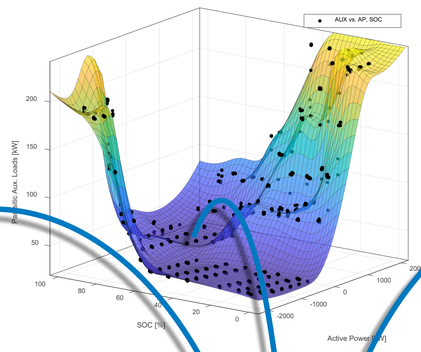

## 3 VRFB System Dynamic Losses

### Three primary sources of losses as VRFB operates

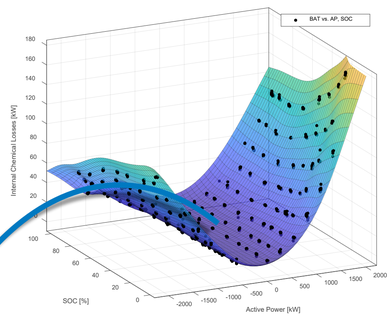
**1 Power Conditioning System Losses**




**2 Parasitic Auxiliary Loads**



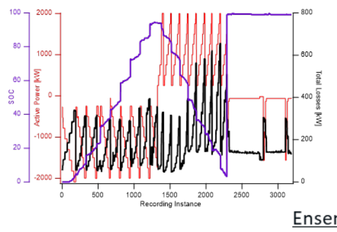

**3 Chemically induced losses**



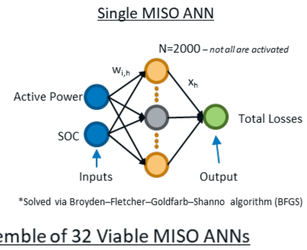

**Non-Parametric Modeling**

Ensemble Artificial Neural Networks

Cleaned Cycled Testing Data

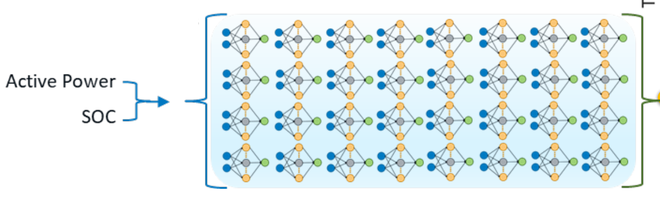



Single MISO ANN



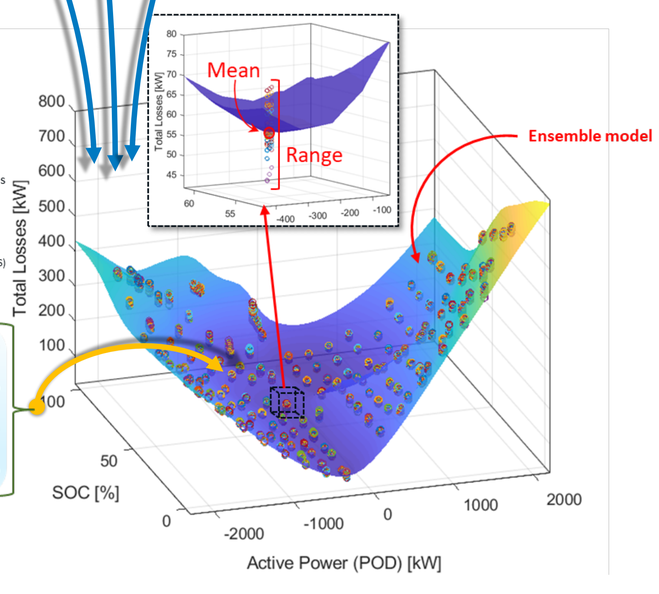

*Solved via Broyden–Fletcher–Goldfarb–Shanno algorithm (BFGS)

Ensemble of 32 Viable MISO ANNs



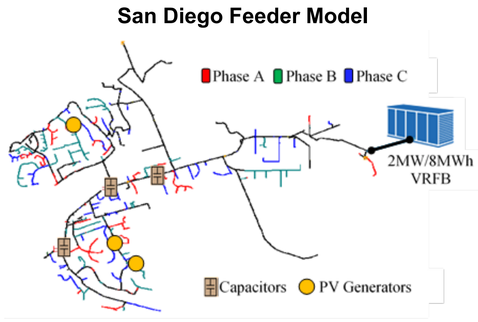

$R^2$ =0.9993, RMSE =2.7

**Total System Losses**

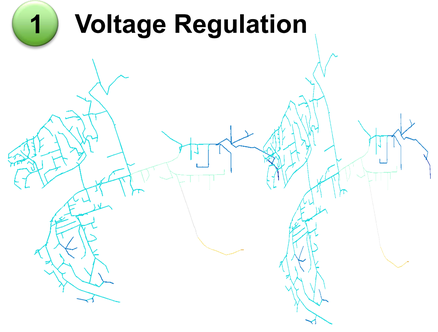



## 4 Utility Feeder and VRFB Use Cases

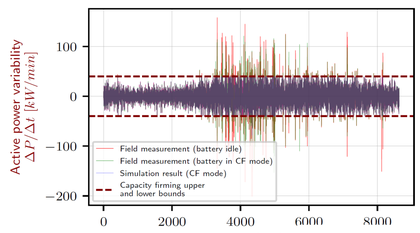
**San Diego Feeder Model**



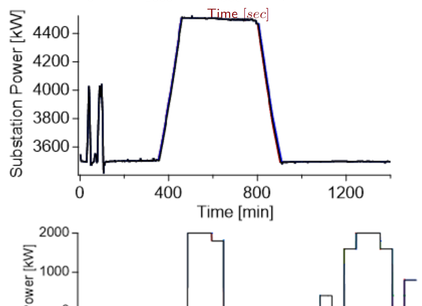

**1 Voltage Regulation**



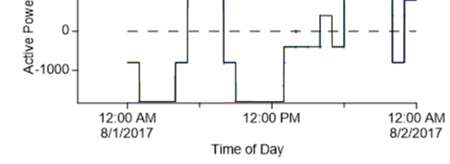
**2 Solar PV Capacity Firming**




**3 Transformer Peak Shaving and Base-loading**



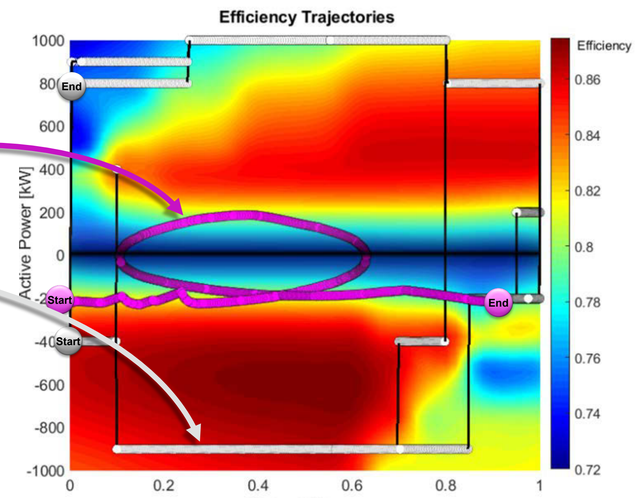

**4 Energy Arbitrage**




## 5 VRFB System Dynamic Efficiency

**Dynamic efficiency trajectory with VRFB operated for:**

1) **Peak Shaving and Base-loading**
   - Max. dynamic efficiency of 82%
2) **Energy Arbitrage**
   - Max. dynamic efficiency of 86%

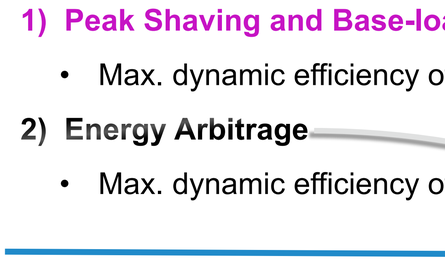



**Efficiency as Function of SOC**

$$\eta_{Chr}^{VRFB} \equiv \frac{|P^{VRFB}|}{|P^{In}|} = \frac{|P^{In}| - (L_{PCS} + L_{Internal} + L_{Parasitic})}{|P^{In}|}$$




$$\eta_{Dis}^{VRFB} \equiv \frac{|P^{Out}|}{|P^{VRFB}|} = \frac{|P^{Out}|}{(L_{PCS} + L_{Internal} + L_{Parasitic}) + |P^{Out}|}$$




**Efficiency as Function of Active Power**

$$\eta^{\mathrm{VRFB}}\left(P_{(p.u.)}\right) = \eta_{\max} - \frac{e^{\alpha\left(P_{(p.u.)} - \mathrm{P}_{\eta_{\max}}(\mathrm{p.u.})\right)}}{1000} - \beta\left(P_{(p.u.)} - \mathrm{P}_{\eta_{\max}}(\mathrm{p.u.})\right)^2$$




| | Discharging | | | Charging | | |
|---|---|---|---|---|---|---|
| SOC | 25% | 50% | 75% | 25% | 50% | 75% |
| $\alpha$ | -22.610 | -22.197 | -19.952 | -18.215 | -17.428 | -18.657 |
| $\beta$ | 32.257 | 27.182 | 30.397 | 16.854 | 15.347 | 36.004 |
| $\eta_{\max}$ | 83.316 | 85.250 | 86.141 | 87.134 | 87.388 | 84.886 |
| $\mathrm{P}_{\eta_{\max}}(\mathrm{p.u.})$ | 0.5068 | 0.5177 | 0.5737 | 0.6302 | 0.6584 | 0.6097 |

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