SWITCH 24/7 Model Formulation

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Objective Function in detail

$$\min(PPACapacityCosts + PPAEnergyCosts + CongestionCosts + WholesaleStorageArbitrage)$$

$$\sum_{g} BuildGen_g * PPACapacityCost_g$$

$$\sum_{g,t} (PnodePrice_{g,t} - DeliveryNodePrice_t)(RenewableGeneration_{g,t})$$

$$\sum_{g,t} PPAEnergyPrice_g(RenewableGeneration_{g,t} + StorageDischarge_{g,t} - StorageCharge_{g,t})$$

$$= BuildGen_g * CapacityFactor_{g,t}$$

$$\sum_{g,t} PnodePrice_{g,t}(StorageCharge_{g,t} - StorageDischarge_{g,t})$$

Note on Total Cost of Energy

- Although the objective function minimizes congestion costs (including for generation that exceeds load in a specific hour), the total cost of energy in the summary report does not include this cost term. Instead, it considers DLAP load cost and Pnode revenues, and it also considers the cost of RA

$$\text{Total Cost of Energy} = \begin{array}{c} (Storage)PPACapacityCosts + PPAEnergyCosts + \\ DLAP\ Load\ (Delivered\ Energy)\ Cost + Generator\ Pnode\ Revenue \\ +Storage\ Pnode\ Arbitrage \end{array}$$

Balancing Constraints

Load Balance Constraint:

$$Supply_{z,t} \geq Demand_{z,t}$$

$$\underbrace{RenewableGeneration_{z,t} + GridPower_{z,t} + StorageDischarge_{z,t}}_{Supply_{z,t}} \geq \underbrace{Demand_{z,t} + StorageCharge_{z,t} + LoadShift_{z,t}}_{Demand_{z,t}}$$

Volumetric Renewable Target:

$$\sum_{z,t} RenewableGeneration_{z,t} \geq RenewableTargetPercent * \sum_{z,t} Demand_{z,t}$$

Time-coincident Renewable Target:

$$\sum_{t} GridPower_{z,t} \leq (1 - RenewableTargetPercent) * \sum_{t} Demand_{z,t}$$

Battery Dispatch Constraints

		Hybrid (with battery g and paired generator G)
Charging	$ChargeStorage_{g,t} \leq BuildGen_g * ChargeToDischargeRatio_g$	AND $ChargeStorage_{g,t} \leq RenewableGeneration_{G,t}$ (hybrid storage can only charge from the paired generator)
Discharging	$DischargeStorage_{g,t} \leq BuildGen_g$	AND $DischargeStorage_{g,t} + RenewableGeneration_{G,t} \leq BuildGen_G$ (the combined generation from the hybrid project cannot exceed the nameplate capacity of the paired generator, assuming interconnection is not oversized)
State of Charge (MWh, not %)	$SOC_{g,t} = (SOC_{g,t-1} * (1 - LeakageLoss_g)) + (ChargeStorage_{g,t} * \sqrt{RTE_g}) - (DischargeStorage_{g,t} * \frac{1}{\sqrt{RTE_g}})$ AND $SOC_{g,t} \leq EnergyCapacity_g$ Where RTE is roundtrip efficiency	
Cycle Limit	$\sum_t DischargeStorage_{g,t} * \frac{1}{\sqrt{RTE_g}} \leq MaxCycles_g * EnergyCapacity_g$	

Renewable Percentage Calculations

Accounting for hourly CFE %

- This is difficult when there is energy storage because you would have to track the RECS in and out
- What if you just treat storage as a load-modifying resource, rather than a supply resource?
  - Creates an issue when discharge is greater than load

Time coincident Renewable

- Based on system power

$$1 - \frac{Total\ System\ Power\ [MWh]}{TotalDemand\ [MWh]}$$

Based on time-coincident generation

$$\frac{\sum_t \min_t(TotalGeneration_t, TotalDemand_t)}{\sum_t TotalDemand_t}$$

Where

$$TotalGeneration_t = Generation_t + StorageDispatch_t$$

$$TotalDemand_t = ZoneDemand_t + StorageCharge_t + NetLoadShift_t$$

Annual Renewable % (REC accounting)

- Treat storage as a supply-side asset (discount generation by the storage roundtrip losses)

$$\frac{\sum_t Generation_t + \sum_t StorageDischarge_t - \sum_t StorageCharge_t}{\sum_t ZoneDemand_t}$$

Excess RECs

- Excess Volumetric RECs

$$Excess\ RECs = \sum_{t} (RenewableGeneration_t - (ZoneDemand_t + StorageCharge_t))$$

- Excess time-coincident RECs

$$Excess\ hourly\ RECs = \sum_{t} (RenewableGeneration_t - TimeCoincidentGeneration_t)$$

How to deal with storage

The assumptions		
Energy Demand (MWh)	100	
Renewable Generation (MWh)	20	
Battery Charge (MWh)	10	
Battery Discharge (MWh)	8.5	
Battery Roundtrip Efficiency	85%	

Approach	Calculation	Annual Renewable Energy %
Ignore Storage:	Generation / Demand	20.0%
Storage as Supply:	(Generation + Discharge - Charge) / Demand	18.5%
Storage as Supply and Demand:	(Generation + Discharge) / (Load + Charge)	25.9%
Storage as Demand:	Generation / (Demand + Charge - Discharge)	19.7%

The assumptions		
Energy Demand (MWh)	100	
Renewable Generation (MWh)	100	
Battery Charge (MWh)	100	
Battery Discharge (MWh)	85	
Battery Roundtrip Efficiency	85%	

Approach	Calculation	Annual Renewable Energy %
Ignore Storage:	Generation / Demand	100.0%
Storage as Supply:	(Generation + Discharge - Charge) / Demand	85.0%
Storage as Supply and Demand:	(Generation + Discharge) / (Load + Charge)	92.5%
Storage as Demand:	Generation / (Demand + Charge - Discharge)	87.0%