Optimal Sizing and Placement of Energy Storage in a Power System

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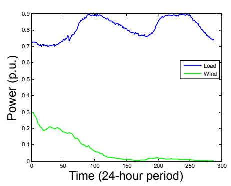
Objectives

1) To determine the optimal locations and capacity of energy storage devices in a power system by using a 2-stage Stochastic optimization approach
2) Determine the optimal number of storage devices by implementing mixed-integer programming
3) Employ a scenario reduction technique to make the Stochastic optimization problem more computationally feasible

Two-Stage Stochastic Optimization

➔ Use Stochastic Optimization to represent different states of the power system
➔ Each scenario in the optimization is a 24-hour period of load/wind
➔ Optimize each scenario simultaneously

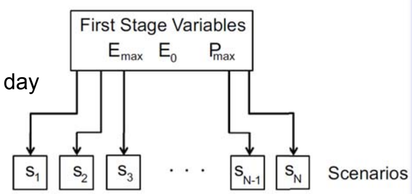
Example of a single scenario:



➔ Perform Economic Dispatch on a 5-minute scale

Variables common to each scenario:

E_{max} : Storage Capacity
P_{max} : Power converter rating
E_0 : Initial stored energy at the beginning of the day (must be equal to energy at the end of the day)



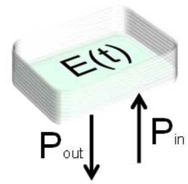
Variables specific to each scenario:

P_{Gi} (s,t): Generation value at bus **i** time **t** for scenario **s**
E_i (s,t): Energy level for storage at bus **i** at time **t** for scenario **s**
Pin_i (s,t): Power into storage at bus **i** at time **t** for scenario **s**
$Pout_i$ (s,t): Power out of storage at bus **i** at time **t** for scenario **s**

Mixed-Integer Programming:

➔ Introduce binary variables $binE_i \in [0,1]$ at each bus that are 0 if there is no storage at that bus and 1 if there is storage at that bus
➔ Introducing a capital cost to place a storage at a bus will minimize the number of total storage devices in the system while still reducing overall system cost

Steady-State Storage Device Model



$E(t+T) = E(t) + \alpha*T*Pin(t) - T*Pout(t)/\alpha$
$0 \le Pin(t) \le Pin^{max}$
$0 \le Pout(t) \le Pout^{max}$
$Emin \le E(t+T) \le Emax$

α = efficiency
T = time scale

Objective Function and Constraints

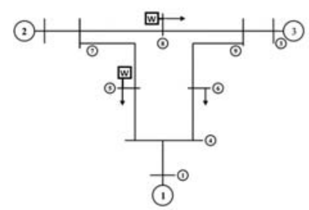
$$\sum_{i=1}^{N} \underbrace{a_i P^2_{Gi} + b_i P_{Gi}}_{\text{Generation}} + \underbrace{c_i P_{max,i} + d_i E_{max,i}}_{\text{Capacity and Power Converter Rating}} + \underbrace{e_i b_i}_{\text{Capital Cost of Storage}}$$

$binE_i \in [0,1]$

$0 \le E_{max,i} \le 10000*binE_i$
$0 \le P_{max,i} \le 10000*binE_i$

➔ If there is no storage at bus *i*, then binE = 0 and Emax and Pmax are forced to 0

Simulation Results



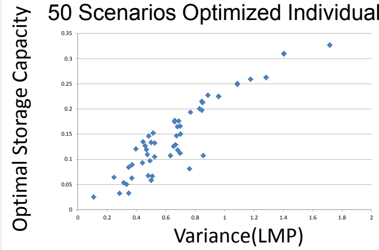
9-bus system with 3 generators, 2 wind generators, 3 loads

50 Scenarios : 3*288*50 + 9*3 = **43,227 Variables**

➔ **How do we perform Scenario Reduction?**

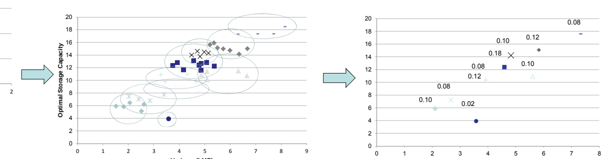
Notice that optimal capacity at a bus (without system congestion) is correlated with the variance in Locational Marginal Price (LMP) at that bus

50 Scenarios Optimized Individually



➔Group similar scenarios together, weight the probability of each scenario by the number of scenarios in that cluster

➔Reduce the number of scenarios while preserving their diversity



Each new scenario is weighted by how many scenarios were clustered into that scenario
➔ 50 scenarios reduced down to 10
➔ Stochastic Optimization with 50 scenarios produces very similar results as stochastic optimization with 10 scenarios. Accuracy increases as the number of clusters increases.