Near Optimal Fuel Scheduling for Enhanced Real Time Dispatch (RTD) with Diverse Generation Technologies

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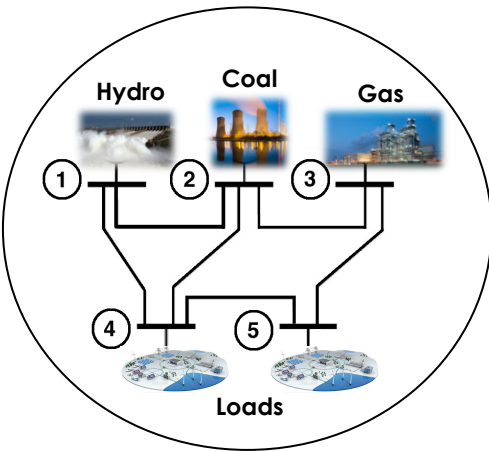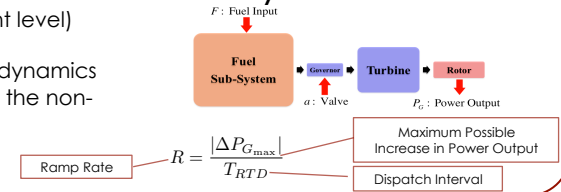**Electrical & Computer ENGINEERING**

Motivation

- High Wind Penetration: Large intra-hour variations
- Operating Conditions: Unexpected changes
- Significant reserves required for large intra-hour wind variations
- Example CAISO-23rd Feb 2012
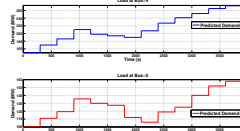- Dynamic Efficiency: Two-fold objective Plant vs. System
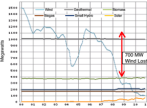
Non-Linear Energy Conversion Dynamics

- Objective: Minimize net fuel input (system/plant level)
- Generator Composition: Three sub-systems
- Fuel Subsystem: Non-linear energy conversion dynamics
- Design Local Controls: Predictable response of the non-linear power plants
- Non-linearity: Varying operating conditions
- Revisit scalar ramp-rates

F : Fuel Input

Fuel Sub-System → Governor → Turbine → Rotor

a : Valve P_G : Power Output

Ramp Rate $R = \dfrac{|\Delta P_{G_{max}}|}{T_{RTD}}$

Maximum Possible Increase in Power Output

Dispatch Interval

Intra-hour Variations

Hydro   Coal   Gas

1   2   3

4   5

Loads

Enhanced Real Time Dispatch

System Efficiency: Proposed RTD[1]

$$\min J = \sum_{K=0}^{12} \left(F^T [KT_{RTD}]\, RF\, [KT_{RTD}] \right)$$

s.t.

$$P_G [(K+1)T_{RTD}] = P_G [KT_{RTD}] + K_P T_{RTD} \omega_G \\ - D_P(\hat{P}_L [(K+1)T_{RTD}] - \hat{P}_L [KT_{RTD}])$$

Fuel Minimization : System Efficiency

Network Constraints

Conventional Economic Dispatch

$$\min_{P_{G_1}, P_{G_2}, P_{G_3}} \sum_{i=1}^{3} \left(a_i P_{Gi}^2 + b_i P_{Gi} + c_i \right)$$

subject to

$$\sum_{i=1}^{3} P_{Gi} = \hat{D}[kT]$$

$$|P_{Gi}[(k+1)T] - P_{Gi}[kT]| < R_i \quad \forall i = 1,2,3$$

$$P_{Gi}^{min} \le P_{Gi}[kT] \le P_{Gi}^{max} \quad \forall i = 1,2,3$$

Net Cost of Producing Power

Generation equals Demand

Scalar Ramp Constraints

Scalar Ramp Constraints

Intra-Hour Schedule
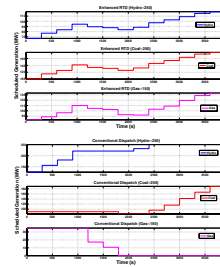
Comparative Analysis

- Smoother Generation Schedule
- Distributed Ramping Effort
- Hard-limits encountered less often
- Network Constraints: Electrical distance between load and generators
- Energy conversion: Critical metric for system-wide efficiency in terms of fuel

- Excessive ramping of cheapest and expensive generator
- Lack of network constraints
- Hard-limits encountered more often
- Significant wear and tear
- Quadratic cost curves: Energy conversion dynamics ignored

Observations

- Smooth schedule: Hard-limits avoidable
- Frequency imperfect at scheduling

Future Work

- Market Design for Load Following
- Incentivize GSE: Improved control design for predictable response rate

(1) Nipun Popli, Marija Ilić, "Multi Input Multi Output Tracking of Power Imbalances in Wind Penetrated Electric Power Grids", TECHON, SRC September 2013

(2) Nipun Popli, Marija Ilić, "A Possible Framework for Dynamic Generation Scheduling in Large-Scale Power Systems", Working Paper

Intra-Hour Load Following

Local Dynamics[2]

- **Hydro Power Plant**: Season based parameterization of surge-tank and tunnel flow dynamics
- **Coal Power Plant**: Non-linear feedback linearization of mill boiler dynamics. Results in time-varying system
- **Gas Power Plant**: Dynamics of fuel injection and governor valve

Plant Efficiency for Load Following

- RTD Generation Schedule: Local set-point trajectory pre-determined
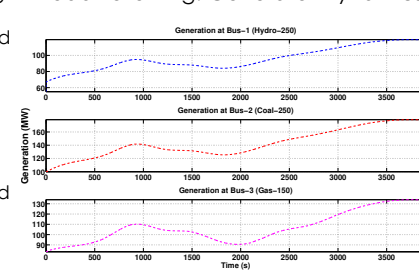- LQR Gain 'G' to perfectly follow intra-hour load

$$\min J_i = \int_0^\infty \left((x_i - x_i^{ref})^T Q_i (x_i - x_i^{ref}) + F_i^T R_i F_i \right)$$

s.t.

$$\dot{x}_i = A_i x_i + B_i F_i - W_i D$$

- Net Fuel Input: System Efficient and Plant Efficient

$$F_i(t) = \hat{F}_i^{ref}(t) - G_i\left(x_i(t) - \hat{x}_i^{ref}(t)\right)$$

System Efficient Fuel Schedule

Plant Efficient Real-time Fuel Input

Load Following: Generator Dynamics

Local Frequencies

Net Fuel Inputs