UNIVERSITY of HOUSTON

UH RPG Lab

Grid Operational Models

- Security-Constrained Unit Commitment (SCUC)
- PTDF-based *vs* B-theta based Models
- *N*-1 Constraints
- Optimal Power Flow (OPF)
- AC-based *vs* DC-based Models

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SCUC Model

Notation

Indices:

t	Time period.
n	Bus.
k	Branch.
g	Generator.

Sets:

T	Set of time intervals.
G	Set of generators.
$G(n)$	Set of generators at bus n.
$K(n-)$	Set of lines with bus n as receiving bus.
$K(n+)$	Set of lines with bus n as sending bus.

Variables:

u_{gt}	Commitment status for generator g in period t.
v_{gt}	Startup variable, 1 if generator g is turned on in period t; 0 otherwise.
r_{gt}	Reserve from generator g in period t.
θ_{kt}	Angle difference across line k in period t.

Parameters:

P_g^{max}	Maximum capacity of generator g.
P_g^{min}	Minimum capacity of generator g.
R_g^{SU}	Startup ramping limit in an hour for unit g.
R_g^{SD}	Shutdown ramping limit in an hour for unit g.
R_g^{hr}	Regular ramping limit in an hour for unit g.
R_g^{10}	Outage ramping limit in 10 minutes for unit g.
P_k^{max}	Maximum capacity of branch k.
UT_g	Minimum up time for generator g.
DT_g	Minimum down time for generator g.
c_g^{SU}	Startup cost for generator g.
c_g^{NL}	No load cost for generator g.
d_{nt}	Load at node n in period t.
x_k	Reactance of line k.
nT	Number of time periods.
nb	Number of buses.

- One-hour temporal resolution is assumed. For multi-hour resolutions, it may still work with updated parameters and inclusion of interval length Δt param.
- Grid initial condition-related restrictions not considered here.

Note: this model uses a system-level largest-generation-contingency reserve condition.

SCUC Model 1

Objective function

$$min \quad \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g,t$$

$$P_{gt} + r_{gt} \le P_g^{max} u_{gt} \quad \forall g,t$$

$$0 \le r_{gt} \le R_g^{10} u_{gt} \quad \forall g,t$$

$$\sum_{m\in G} r_{mt} \ge P_{gt} + r_{gt} \quad \forall g,t$$

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} u_{g,t-1} + R_g^{SU} v_{gt} \quad \forall g,t$$

$$P_{g,t-1} - P_{gt} \le R_g^{hr} u_{gt} + R_g^{SD}(v_{gt} - u_{gt} + u_{g,t-1}) \quad \forall g,t$$

$$\sum_{w=t+1}^{t+DT_g} v_{gw} \le 1 - u_{gt} \quad \forall g, t \le nT - DT_g$$

$$\sum_{w=t-UT_g+1}^{t} v_{gw} \le u_{gt} \quad \forall g, t \ge UT_g$$

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$v_{gt} \in \{0,1\} \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

SCUC Model 2

Objective function

$$min \quad \sum_{g \in G} \sum_{t \in T} (c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \leq P_{gt} \quad \forall g, t$$

$$P_{gt} + r_{gt} \leq P_g^{max} u_{gt} \quad \forall g, t$$

$$0 \leq r_{gt} \leq R_g^{10} u_{gt} \quad \forall g, t$$

$$\sum_{m \in G} r_{mt} \geq P_{gt} + r_{gt} \quad \forall g, t$$

$$P_{kt} = \theta_{kt} / x_k \quad \forall k, t$$

$$-P_k^{max} \leq P_{kt} \leq P_k^{max} \quad \forall k, t$$

$$\sum_{g \in G(n)} P_{gt} + \sum_{k \in K(n-)} P_{kt} - \sum_{k \in K(n+)} P_{kt} = d_{nt} \quad \forall n, t$$

$$P_{gt} - P_{g,t-1} \leq R_g^{hr} u_{g,t-1} + R_g^{SU} v_{gt} \quad \forall g, t$$

$$P_{g,t-1} - P_{gt} \leq R_g^{hr} u_{gt} + R_g^{SD} (v_{gt} - u_{gt} + u_{g,t-1}) \quad \forall g, t$$

Assume minimum up/down time limit is just 1 hour; this indicates there is no minimum up/down time limit constraints.

$$v_{g,t+1} \leq 1 - u_{gt} \quad \forall g, t \leq nT - 1$$

$$v_{gt} \leq u_{gt} \quad \forall g, t$$

$$v_{gt} \geq u_{gt} - u_{g,t-1} \quad \forall g, t$$

$$v_{gt} \in \{0,1\} \quad \forall g, t$$

$$u_{gt} \in \{0,1\} \quad \forall g, t$$

SCUC Model 3

Objective function

$$min \quad \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g,t$$

$$P_{gt} + r_{gt} \le P_g^{max} u_{gt} \quad \forall g,t$$

$$0 \le r_{gt} \le R_g^{10} u_{gt} \quad \forall g,t$$

$$\sum_{m\in G} r_{mt} \ge P_{gt} + r_{gt} \quad \forall g,t$$

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} \quad \forall g,t$$

$$P_{gt} - P_{g,t-1} \ge -R_g^{hr} \quad \forall g,t$$

$$v_{g,t+1} \le 1 - u_{gt} \quad \forall g, t \le nT - 1$$

$$v_{gt} \le u_{gt} \quad \forall g,t$$

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$v_{gt} \in \{0,1\} \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \ge P_g^{min}$ that allows feasible startup and shutdown.

SCUC Model 3.2

Objective function

$$min \quad \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g,t$$

$$P_{gt} + r_{gt} \le P_g^{max} u_{gt} \quad \forall g,t$$

$$0 \le r_{gt} \le R_g^{10} u_{gt} \quad \forall g,t$$

$$\sum_{m\in G} r_{mt} \ge P_{gt} + r_{gt} \quad \forall g,t$$

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} \quad \forall g,t$$

$$P_{gt} - P_{g,t-1} \ge -R_g^{hr} \quad \forall g,t$$

This model requires a non-zero positive value of each c_g^{SU}. (valid only at optimality)

~~$v_{g,t+1} \le 1 - u_{gt} \quad \forall g,t \le nT - 1$~~

~~$v_{gt} \le u_{gt} \quad \forall g,t$~~

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$v_{gt} \in \{0,1\} \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \ge P_g^{min}$ that allows feasible startup and shutdown.

SCUC Model 3.3

Objective function

$$min \quad \sum_{g\in G} \sum_{t\in T} (c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g, t$$

$$P_{gt} + r_{gt} \le P_g^{max} u_{gt} \quad \forall g, t$$

$$0 \le r_{gt} \le R_g^{10} u_{gt} \quad \forall g, t$$

$$\sum_{m\in G} r_{mt} \ge P_{gt} + r_{gt} \quad \forall g, t$$

$$P_{kt} = \theta_{kt}/x_k \quad \forall k, t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k, t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n, t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} \quad \forall g, t$$

$$P_{gt} - P_{g,t-1} \ge -R_g^{hr} \quad \forall g, t$$

This model requires a non-zero positive value of each c_g^{SU}. (valid only at optimality)

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g, t$$

$$0 \le v_{gt} \le 1 \quad \forall g, t$$

$$u_{gt} \in \{0,1\} \quad \forall g, t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \ge P_g^{min}$ that allows feasible startup and shutdown.

SCUC Model 4

Objective function

$$min \quad \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g,t$$

$$P_{gt} \le P_g^{max} u_{gt} \quad \forall g,t$$

No reserve is modeled here

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} \quad \forall g,t$$

$$P_{gt} - P_{g,t-1} \ge -R_g^{hr} \quad \forall g,t$$

$$v_{g,t+1} \le 1 - u_{gt} \quad \forall g, t \le nT-1$$

$$v_{gt} \le u_{gt} \quad \forall g,t$$

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$v_{gt} \in \{0,1\} \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \ge P_g^{min}$ that allows feasible startup and shutdown.

SCUC Model 4.2

Objective function

$$\min \quad \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

$$P_g^{min} u_{gt} \leq P_{gt} \quad \forall g,t$$

$$P_{gt} \leq P_g^{max} u_{gt} \quad \forall g,t$$

This model requires a non-zero positive value of each c_g^{SU}. (valid only at optimality)

No reserve is modeled here

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \leq P_{kt} \leq P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \leq R_g^{hr} \quad \forall g,t$$

$$P_{gt} - P_{g,t-1} \geq -R_g^{hr} \quad \forall g,t$$

$$v_{gt} \geq u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$v_{gt} \in \{0,1\} \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \geq P_g^{min}$ that allows feasible startup and shutdown.

SCUC Model 4.3

Objective function

$$\min \sum_{g\in G}\sum_{t\in T}(c_g P_{gt} + c_g^{NL} u_{gt} + c_g^{SU} v_{gt})$$

Constraints

This model requires a non-zero positive value of each c_g^{SU}. (valid only at optimality)

$$P_g^{min} u_{gt} \le P_{gt} \quad \forall g,t$$

$$P_{gt} \le P_g^{max} u_{gt} \quad \forall g,t$$

No reserve is modeled here

$$P_{kt} = \theta_{kt}/x_k \quad \forall k,t$$

$$-P_k^{max} \le P_{kt} \le P_k^{max} \quad \forall k,t$$

$$\sum_{g\in G(n)} P_{gt} + \sum_{k\in K(n-)} P_{kt} - \sum_{k\in K(n+)} P_{kt} = d_{nt} \quad \forall n,t$$

$$P_{gt} - P_{g,t-1} \le R_g^{hr} \quad \forall g,t$$

$$P_{gt} - P_{g,t-1} \ge -R_g^{hr} \quad \forall g,t$$

$$v_{gt} \ge u_{gt} - u_{g,t-1} \quad \forall g,t$$

$$0 \le v_{gt} \le 1 \quad \forall g,t$$

$$u_{gt} \in \{0,1\} \quad \forall g,t$$

Assume normal/startup/shutdown ramping rates are the same, and $R_g^{hr} \ge P_g^{min}$ that allows feasible startup and shutdown.

PTDF-based SCUC Models

- All previous SCUC models are based on *B-theta* power flow models.
- These models can be modified to PTDF-based SCUC models, by replacing the line flow equation:
  - from $P_{kt} = \theta_{kt}/x_k$,
  - to $P_{kt} = \sum_n PTDF_{k,n} \cdot P_{n,t}^{NetPowerInjection}$ (cold-start).
- When using PTDF-based SCUC models, we can include the line flow equations for a subset of critical lines we need to monitor, rather than including such equations for all lines.
  - It also eliminates the need to defining variables θ_{kt}.
  - It is typically much more computationally efficient, especially when only a small subset of lines need to be monitored, and also especially *N*-1 contingency constraints are included.

PTDF: Power Transfer Distribution Factor.

N-1 Reliability Constraints

- The previous models do not explicitly include any *N*-1 constraints.
- *N*-1 constraints can be attached as additional constraints to all previous SCUC models.
- For details regarding N-1 constraints, please refer to paper:
  - Arun Venkatesh Ramesh, Xingpeng Li and Kory W. Hedman, "An Accelerated-Decomposition Approach for Security-Constrained Unit Commitment with Corrective Network Reconfiguration," *IEEE Transactions on Power Systems*, vol. 37, no. 2, pp. 887-900, Mar. 2022.
    - Equations (16)-(22) are for the *N*-1 constraints.
    - Paper: https://rpglab.github.io/papers/ArunRamesh-AccDecompSCUC_CNR/
      - Or, https://ieeexplore.ieee.org/document/9492752
    - Open-source codes: https://rpglab.github.io/resources/ABD_N-1_SCUC_CNR_AMPL/

Post-contingency 10-minute ramping restriction on generation and modeling of contingencies:

$$P_{g,t} - P_{g,c,t} \leq R_g^{10} u_{g,t}, \forall g, c \in C, t \quad (16)$$

$$P_{g,c,t} - P_{g,t} \leq R_g^{10} u_{g,t}, \forall g, c \in C, t \quad (17)$$

$$P_g^{min} u_{g,t} \leq P_{g,c,t}, \forall g, c \in C, t \quad (18)$$

$$P_{g,c,t} \leq P_g^{max} u_{g,t}, \forall g, c \in C, t \quad (19)$$

Post-contingency modeling of power flow:

$$P_{k,c,t} - b_k(\theta_{n,c,t} - \theta_{m,c,t}) = 0, \forall k, c \in C, t \quad (20)$$

$$-P_k^{emax} \leq P_{k,c,t} \leq P_k^{emax}, \forall k, c \in C, t \quad (21)$$

$$\sum_{g \in g(n)} P_{g,c,t} + \sum_{k \in \delta^+(n)} P_{k,c,t} - \sum_{k \in \delta^-(n)} P_{k,c,t} = d_{n,t}, \forall n, c \in C, t \quad (22)$$

SCED/OPF Models

- While day-ahead energy scheduling solves SCUC problems, real-time economic dispatch solves OPF problems.
- The paper below presents practical OPF/SCED models:
  - Xingpeng Li and Kory W. Hedman, “Enhanced Energy Management System with Corrective Transmission Switching Strategy— Part I: Methodology,” *IEEE Transactions on Power Systems*, vol. 34, no. 6, pp. 4490-4502, Nov. 2019.
    - Paper: https://rpglab.github.io/papers/XingpengLi-KWH-TPWRS-Part-I/
      - Or, https://ieeexplore.ieee.org/document/8736407
    - Open-source codes: https://rpglab.github.io/resources/GRTOS-Java/

- SCED-M1: hot-start PTDF based SCED model,
- SCED-M2: warm-start PTDF based SCED model,
- SCED-M3: cold-start PTDF based SCED model,
- SCED-M4: hot-start B-θ based SCED model,
- SCED-M5: cold-start B-θ based SCED model.

	Power balance constraints	Network constraints	Shared constraints
SCED-M1	(16)	(31), (34)-(35), (38)-(39)	(17)-(21), (24)-(27), (29)-(30), (33), (37)
SCED-M2		(28), (31)-(32), (34)-(35)	
SCED-M3		(28), (40)-(41)	
SCED M4	(44)-(45)	(38), (42)-(43)	
SCED M5		(28), (42)-(43)	

SCED: Security-Constrained Economic Dispatch.
OPF: Optimal Power Flow.

Practical ISOs’ RT-SCED Models

Table I - Comparison between various U.S. ISOs’ RT-SCED applications

ISO	Execution cycle (minutes)	Type of periods	Only implement the solution of first period	Interval of the first period (minutes)	Look-ahead interval (minutes)	Co-optimize energy and reserve	Model
PJM	5	single	NA	15	15	Yes	LP
MISO	5	single	NA	5	5	Yes	LP
ISO-NE	5	single	NA	15	15	Yes	LP
NYISO	5	multiple	Yes	5	~60	Yes	Unknown
CAISO	5	multiple	Yes	5	Unknown	Yes	Unknown
ERCOT	5	single	NA	5	5	~~No~~	QP

NA denotes “not applicable”, and Unknown means the associated information is not available publicly.

Since Dec. 5, 2025, ERCOT co-optimizes energy and reserve, plus batteries.

- Reference paper:
  - Xingpeng Li and Kory W. Hedman, “Enhanced Energy Management System with Corrective Transmission Switching Strategy— Part II: Results and Discussion,” *IEEE Transactions on Power Systems*, vol. 34, no. 6, pp. 4503-4513, Nov. 2019.
    - Paper: https://rpglab.github.io/papers/XingpengLi-KWH-TPWRS-Part-II/
      - Or, https://ieeexplore.ieee.org/document/8736266
    - Open-source codes: https://rpglab.github.io/resources/GRTOS-Java/

ISO: Independent System Operator.
RT-SCED: Real-Time SCED.

Modeling Fidelity: AC vs DC

- All the previous SCUC/OPF models are based on the simplified linearized line flow equations, referred to as DC power flow-based SCUC/OPF models.

- When using the exact AC line flow equations, then the models become AC-based SCUC/OPF models that are far more complex than previous DC-based SCUC/OPF models.
  - AC-based models require voltage and reactive power variables.
  - There are extensive papers in the literature studying AC-based SCUC/OPF models, especially AC-OPF.
  - While, due to complexity, practically, grid operators mainly use DC-based SCUC/OPF models, which work well for transmission networks especially with a hot-start modeling method.

Open-Source Materials

- ECE6327 Smart Grid Systems:
  - https://rpglab.github.io/resources/ECE6327-SGS/
- ECE6379 Power System Operations and Modeling:
  - https://rpglab.github.io/resources/ECE6379-PSOM/
- Other open-source codes, data, documents:
  - Most of them are related to our published papers.
  - https://rpglab.github.io/resources/
  - https://github.com/rpglab

They are licensed under the terms of the Creative Commons Attribution 4.0 (CC BY 4.0) license.

ECE6327 Smart Grid Systems

Graduate-Level Class

Course Scope and Specific Topics:

- Lectures 1 - 2: Course Introduction and Overview
- Lectures 3 - 4: AC & DC Power Flow, Sensitivity Factor PTDF
- Lectures 5 - 6: DCOPF & SCUC
- Lectures 7 - 8: State Estimation, FDI Cyber-Attack
- Lectures 9 - 10: Demand Side Management, Demand Response
- Lecture 11: Data Center Grid Interconnection
- Lectures 12 - 14: Renewable Energy: overview, wind, solar, biomass, hydro, and geothermal
- Lectures 15 - 16: Renewable Energy Grid Integration
- Lecture 17: Offshore Power
- Lectures 18 - 19: Flexible Transmission: network topology control, FACTS, bus splitting, and DLR
- Lectures 20 - 21: Energy Storage, Battery Degradation, and Electric Vehicle
- Lectures 22 - 23: DER, Microgrid, Energy Management and Sizing, and Power-Hydrogen
- Lecture 24: Advanced Metering Infrastructure & Home Energy Management
- Lecture 25: ERCOT Grid Crisis 2021, Wholesale Power Energy Market, and LMP

- https://rpglab.github.io/resources/ECE6327-SGS/

Shared Contents:

1. Folder "__Lectures" contains all lecture source PowerPoint slides and converted PDF copies.
2. Folder "_Examples_Codes\AMPL_Codes" contains about 40 AMPL programs, including simple tutorial-level examples and codes for DCOPF, SCUC, DSM, SUC, transmission switching, FACTS, energy storage, and microgrid energy management and sizing examples that are used for this class. AMPL tutorial is also provided.
3. Folder "_Examples_Codes\Python_Codes" contains about 40 Python/Pyomo programs, including simple tutorial-level examples and codes for DCOPF, SCUC, DSM, SUC, transmission switching, FACTS, energy storage, and microgrid energy management and sizing examples that are used for this class.
4. Folder "Discussion_Assignment" contains 1 discussion assignment (both word and PDF files).
5. Folder "HW" contains 6 homework assignments (both word and PDF files).
6. Folder "Project" contains the project assignment (both word and PDF files; and data/codes).
7. Syllabus is also provided as a reference.

ECE6379 Power System Operations and Modeling

Graduate-Level Class

Course Scope and Specific Topics:

- Lectures 1: Course Introduction
- Lectures 2-3: Generation & Business environment
- Lectures 4-6: Economic Dispatch/OPF
- Lectures 7-10: Unit Commitment
- Lectures 11-13: AC & DC Power Flow analysis
- Lectures 13-15: Sensitivity Factors
- Lectures 16-18: Security
- Lectures 18-19: State Estimation
- Lecture 20: OPF Revisit
- Lecture 21: SCUC Revisit.
- Lecture 22-24: Energy Markets
- Lecture 25: Fuel-Hydro & Hydro-Thermal Coordination

- https://rpglab.github.io/resources/ECE6379-PSOM/

Shared Contents:

1. Folder "__Lectures" contains all lecture source PowerPoint slides and converted PDF copies. Notes used in the lectures are also included.
2. Folder "_Examples_Codes\AMPL_Codes" contains 30 AMPL programs, including simple tutorial-level example codes, and codes for course-level DCOPF, SCUC and LMP examples that are used for this class. AMPL tutorial is also provided.
3. Folder "_Examples_Codes\Python_Codes" contains 30 Python/Pyomo programs, including simple tutorial-level examples and codes for course-level DCOPF, SCUC and LMP examples that are used for this class.
4. Folder "Discussion_Assignment" contains 1 discussion assignment (both word and PDF files).
5. Folder "HWs" contains 5 homework assignments (both word and PDF files).
6. Folder "Project" contains the project assignment (both word and PDF files; and data/codes).
7. Folder "Quizzes" contains 2 online open-book open-note quizzes (both word and PDF files).
8. Syllabus is also provided as a reference.

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UH RPG Lab