Overview of Combined Cycle Modeling

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Agenda

- Terminology
- Combined Cycle Trains, Configurations, Units
- Data Requirements
  - Transition Matrix
- Settlement Points
  - Logical Resource Node
- Combined Cycle Conceptual Description
- Combined Cycle Implementation
- Combined Cycle DAM Make Whole Concepts

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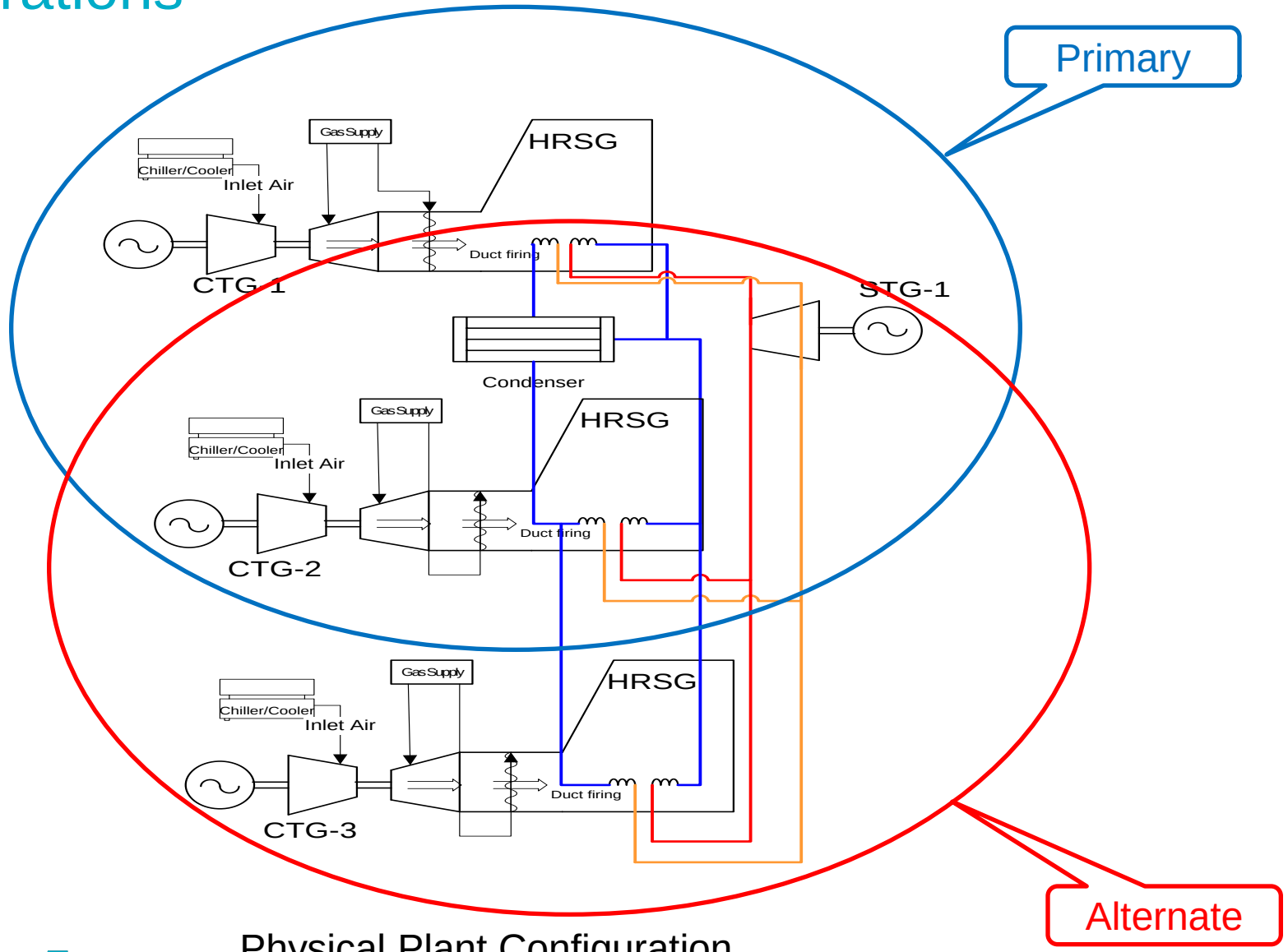
Relevant Combined Cycle Terminology

- **Generation Resource (GR)**
  - A generator capable of providing energy or Ancillary Service to the ERCOT System and is registered with ERCOT as a Generation Resource. The term “Generation Resource” used by itself in these Protocols does not include a Non-Modeled Generator.
- **Combined Cycle Train (CCT)**
  - The combinations of gas turbines and steam turbines in an electric generation plant that employs more than one thermodynamic cycle. For example, a Combined Cycle Train refers to the combination of gas turbine generators (operating on the Brayton Cycle) with turbine exhaust waste heat boilers and steam turbine generators (operating on the Rankine Cycle) for the production of electric power. In the ERCOT market, Combined Cycle Trains are each registered as a plant that can operate as a Generation Resource in one or more Combined Cycle Generation Resource configurations.
- **Combined Cycle Generation Resource (CCGR or CC configuration)** – *type of Generation Resource*
  - A specified configuration of physical Generation Resources (Gas and Steam Turbines), with a distinct set of operating parameters and physical constraints, in a Combined Cycle Train registered with ERCOT.
- **Combined Cycle Physical Units - CCU**
  - Physical units that make up the CCP train. The physical units are used for Network Power Flow and Security Analysis

Example Combined Cycle Train & Operating Configurations

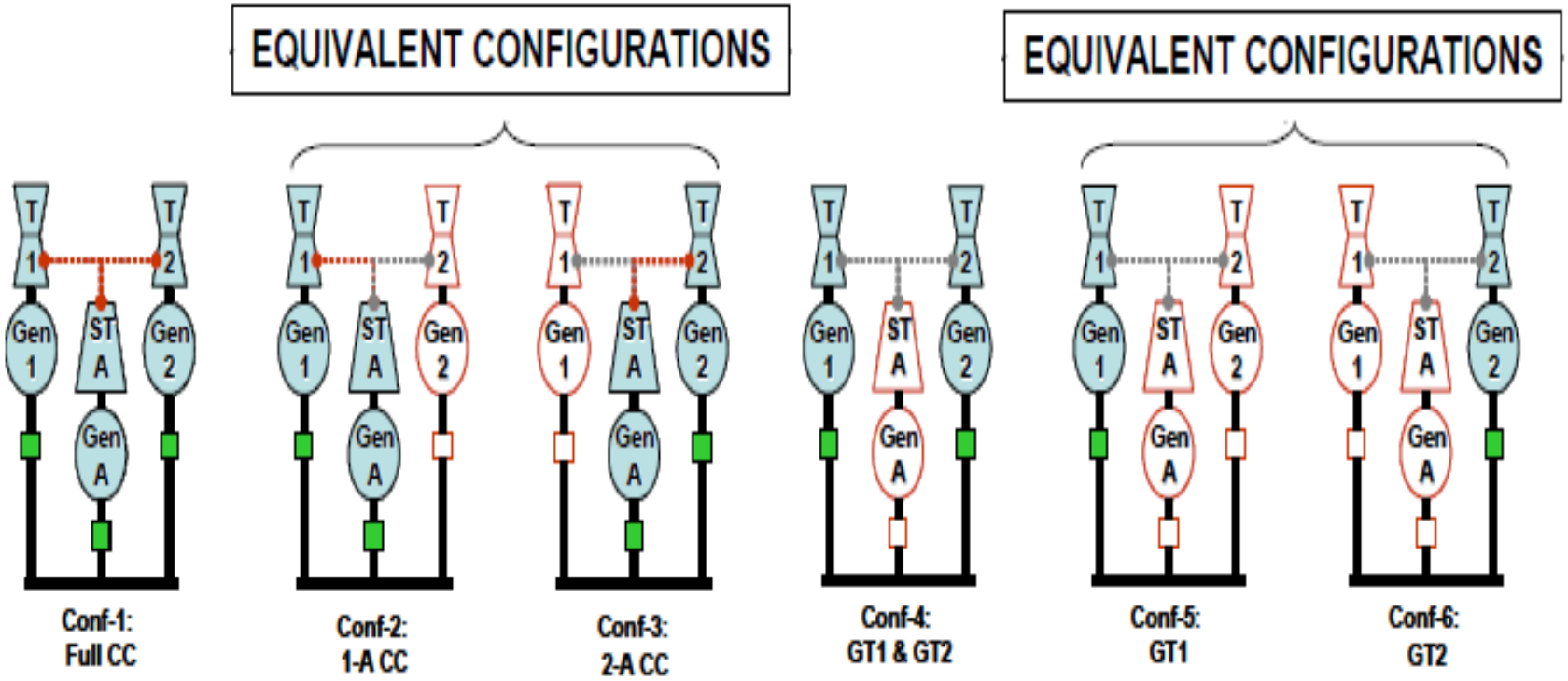
2 X 1

2 X 1



Physical Plant Configuration

Combined Cycle Configurations



Data to Model Combined Cycle Trains

- Combined Cycle Train (CCT)
  - Combined Cycle Units – CCU (individual CTs and STs)
  - Combined Cycle Generation Resources - CCGR (configurations 1x0, 2x0,1x1, etc.)
- Resource Parameters for CCUs
  - e.g. High/Low Limits, Reactive Capability Curves
- Resource Parameters for CCGRs (configurations)
  - e.g. High/Low Limits, Ramp Rates, MinOnTime,MinOffTime,Temperature Dependent Start Time, etc.
- Define the mapping between Physical and CCGRs
- For each CCGR :
  - Map individual CCUs as being either Primary or Alternate
- Define Transition Matrix of registered configurations (CCGR)

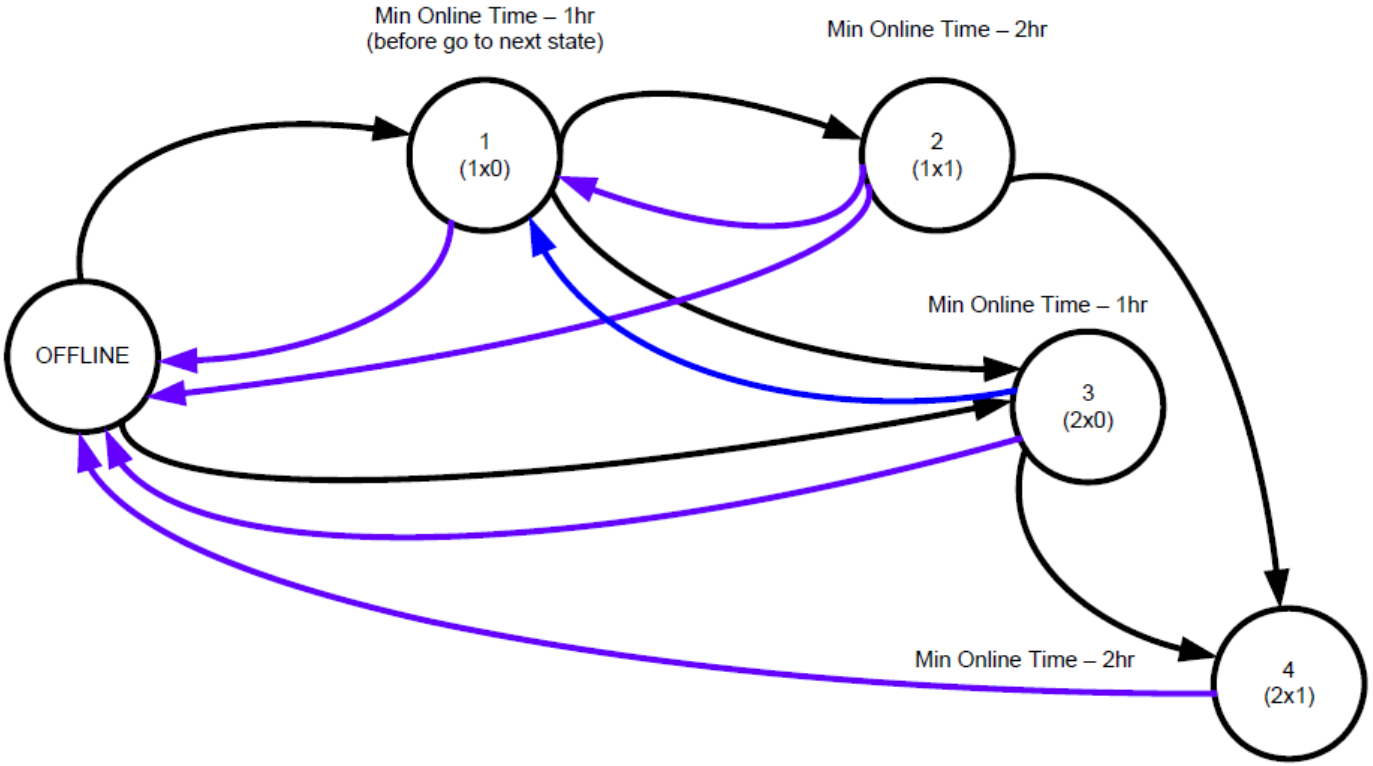
Data to Model Combined Cycle Trains

Unique Issues

- Train must contain one or more configurations
  - Offline is a required (default) configuration
  - Every configuration must have a **To** and a **From** configuration (no orphaned configurations)

- Configurations may contain alternate units
- Registered transition parameters will be honored

Combined Cycle Train – transition matrix



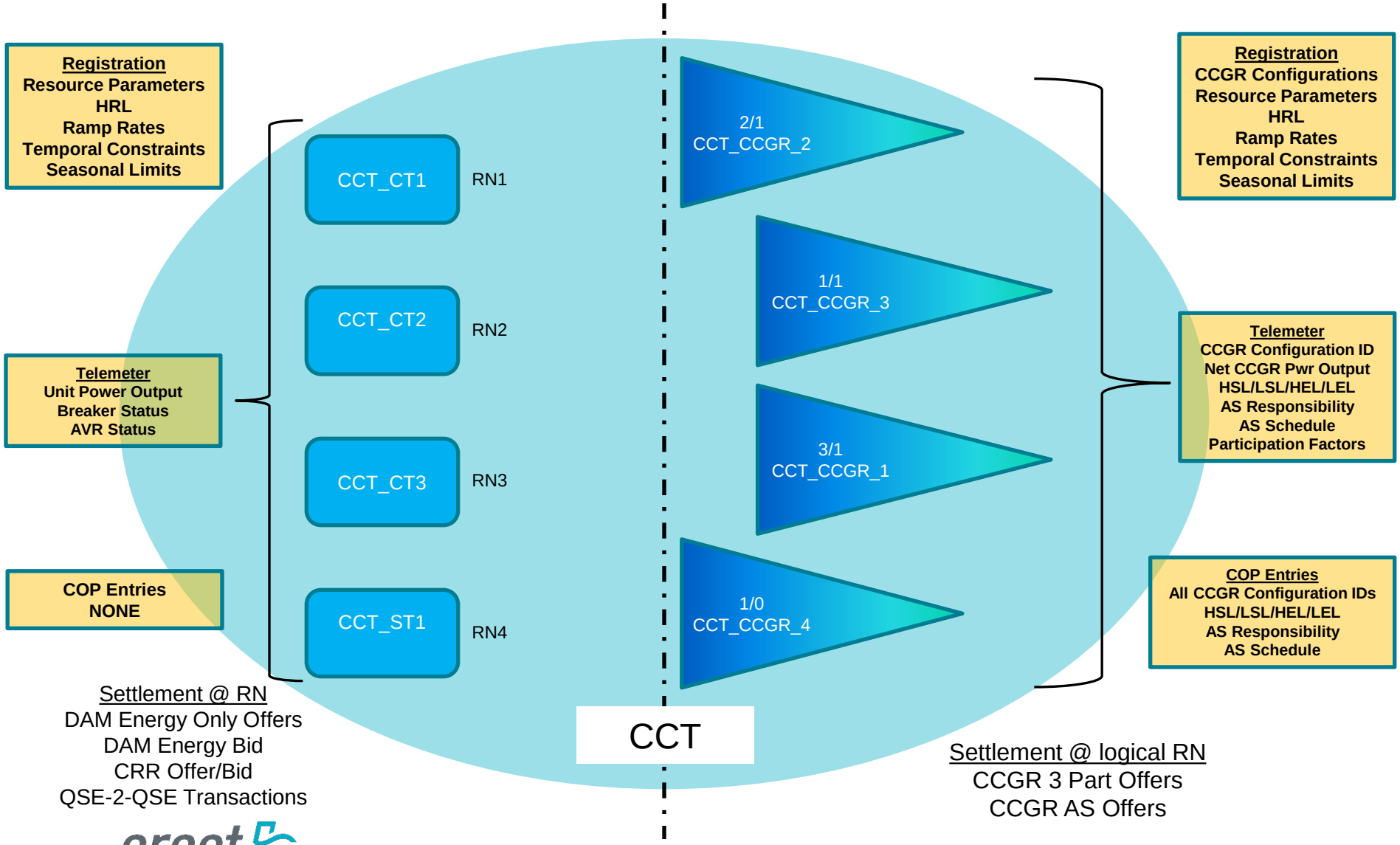
From \ To	Offline	ABC_CC1_1	ABC_CC1_2	ABC_CC1_3	ABC_CC1_4
Offline		X		X	
ABC_CC1_1	X		X	X	
ABC_CC1_2	X	X			X
ABC_CC1_3	X	X			X
ABC_CC1_4	X				

Upward transition

Downward Transition

CC configuration internally marked with SHUTDN flag = 'Y' in MMS

Combined Cycle Train Treatment in ERCOT Systems



Settlement @ RN
DAM Energy Only Offers
DAM Energy Bid
CRR Offer/Bid
QSE-2-QSE Transactions

Settlement @ logical RN
CCGR 3 Part Offers
CCGR AS Offers

Settlement Points (Hubs, Load Zones, Resource Nodes)

≈ 630 Settlement Points

- 6 Hubs (345 KV)
- 9 Load Zones
- 5 DC Tie
- ≈ 540 Resource Nodes
- ≈ 70 Logical Resource Nodes

≈ 70 Combined Cycle Trains

- ≈ 287 Combined Cycle Configurations (CCGR)

	ACTIVITIES					
Settlement Point Type	3PO	AS Offer	DAM Energy Only Offers	DAM Energy Bid	CRR Offers and Bids	QSE to QSE Transaction
Resource Node for Non-Combined Cycle Generators	Yes	Yes	Yes	Yes	Yes	Yes
Logical Resource Node for Combined Cycle Trains	Yes	Yes	No	No	No	No

Combined Cycle Train Logical and Physical Resource Nodes

Logical Resource Nodes

- Defined for each Combined Cycle Train (CCT) & mapped to All CCGRs (Configuration) within the CCT
- Abstract in network model, i.e., not mapped to any Electrical Bus
- Resource specific submissions (3PO & AS offer) for the CCGRs are optimized and settled at the logical Resource Node for the CCT
- Used in NCUC and SCED

Physical Resource Nodes

- Defined for each generation unit in a CCT
- Mapped to an EB (Electrical Bus) in the Network model
- Could be Settlement Point for
  - CRR offer
  - DAM Energy only offer/bid,
  - PTP Obligation bids, and
  - QSE to QSE trades
- Used in Power Flow and Contingency Analysis

Combine Cycle Conceptual Description

CCT logical Resource Node (RN)

- May be used only for 3PO and AS Offer Settlement
- Represents each registered CCGR (configuration) as an aggregated representation of the underlying CT and ST elements
- DAM/SASM/SCED/RUC optimization is based on the CCGR representation at the logical RN

Dis-aggregate down to the physical representation

Aggregate up to the CCGR representation

CT1 Associated with RN-CT1

CT2 Associated with RN-CT2

ST1 Associated with RN-ST1

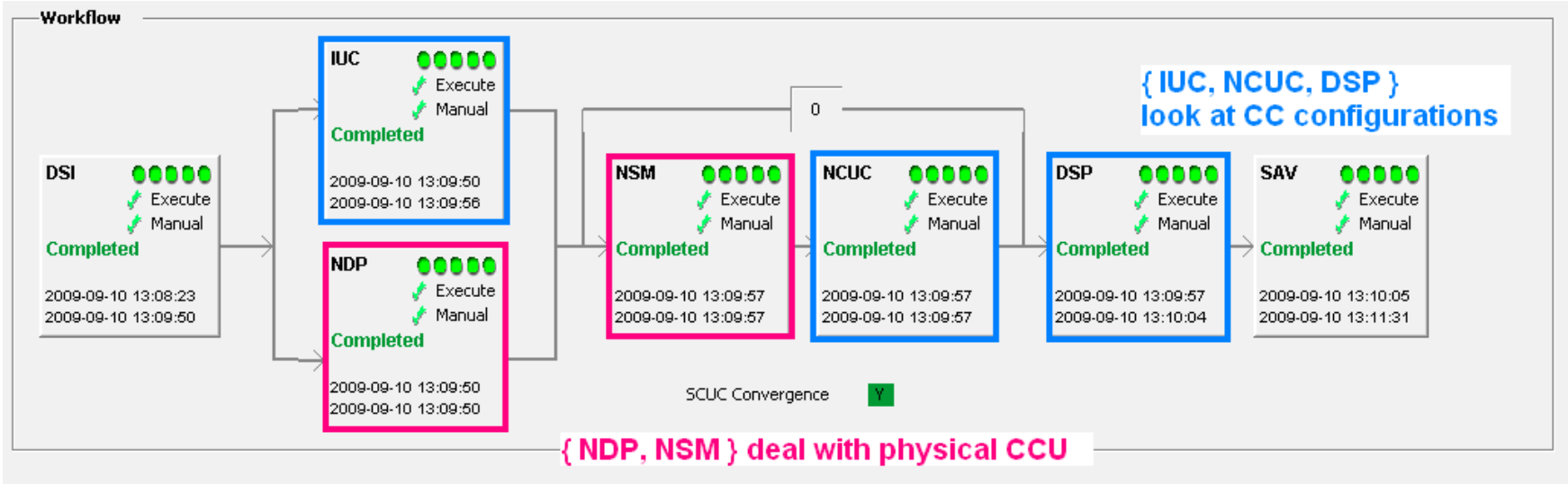
- All Network modeling is at the generation unit level
- Each CT and ST in the CCT must be registered with ERCOT
- RT Telemetry must be provided for each CT and ST in the CCT

Combined Cycle implementation

Logical and Physical CCT representation

- Logical CCT configurations are used by DAM, SASM, RUC, SCED, and LFC.
- Market Operation is optimized using 3PO and ASO from CCP configurations

- Physical CCU resources are used in Network Power Flow and Security Analysis within MMS (NSM, OS) and EMS (SE, TCM, OTS, VSA)
- Network analysis considers power injection at Physical Resource Node



DAM statistics

- DAM is voluntary – no must offer rule
- ≈ 70 Combined Cycle Trains
  - ≈ 287 Combined Cycle Configurations (CCGR)

	Average # of Configurations	Average DAM Run Time	Average # of Iterations	Average Mip Gap (%)
July 2016	67	1:30:14	8	0.009%
December 2016	56	1:09:52	7	0.01%

Combined Cycle implementation (cont)

The logical CC configuration and physical CCU resource must be mutually consistent and convertible from one to another

1) Energy Schedule Disaggregation (NCUC to NSM)
   - Use capacity weights (HRL) as distribution factors
   - Energy schedule for CC configuration (from NCUC) is distributed to power output of online CCU

$$PowOut_{CCU,i} = \frac{HRL_{CCU,i}}{\sum_{i \in CCP} HRL_{CCU,i}} \times EnergySch_{CCP}$$

			CC1_1	CC1_2	CC1_3	CC1_4
CC1		MW	1x0	2x0	1x1	2x1
Unit 1	CT	100	x	x	x	x
Unit 2	CT	100	a	x	a	x
Unit 3	CA	100			x	x
		300	100	200	150	300
			1	*3*	*2*	*4*

NCUC dispatches configuration 3 @ 80 MW

Then, NSM will see injections:-
Unit 1 @ 40 MW
Unit 3 @ 40 MW

Combined Cycle implementation (cont)

2) Aggregation of Shift Factor (NSM to NCUC)

- Linearized constraints are passed from NSM to NCUC to optimize energy offer. The aggregated Shift Factors are needed
- In DAM & RUC, NCUC uses capacity (HRL) weighted average of Shift Factors for physical CCU from NSM that are online in that CCP configuration

$$SF_{CCP} = \frac{\sum_{i \in CCP} \left(HRL_{CCU,i} \times SF_{CCU,i} \right)}{\sum_{i \in CCP} \left(HRL_{CCU,i} \right)}$$

- In SCED, aggregated SF is calculated by EMS using telemetry power output weighted average of units that are online in current operating configurations

			CC1_1	CC1_2	CC1_3	CC1_4
CC1		MW	1x0	2x0	1x1	2x1
Unit 1	CT	100	x	x	x	x
Unit 2	CT	100	a	x	a	x
Unit 3	CA	100			x	x
		300	100	200	150	300
			1	*3*	*2*	*4*

There is binding constraint k

SF_Unit 1, k = 0.085
SF_Unit 3, k = 0.077

Then, NSM pass SF for CC1_3 to NCUC = (0.085x100)+(0.077x100)

(100+100)
= 0.081

Combined Cycle implementation (cont)

- 3PO and online reserves can be submitted for each CCGR (configuration) separately.

- CRR offer, DAM Energy only offer/bid, PTP Obligation bids, QSE to QSE trades cannot be submitted at logical Resource Node.

- Offline Non-Spin offer can be submitted only for CCGR that are registered as a startup mode.
  - If multiple Offline Non-Spin offers exist from different CCGR within the same CCT, then the offer from for the CCGR with max HSL capacity is selected as the only valid offer.

Combined Cycle implementation (cont)

Treatment of Primary/Alternate CCU

- Only CT units can be mutually alternate, and only ST units can be mutually alternate, i.e. cannot replace CT with ST unit

- If multiple alternate CCU are specified for a CCP configuration, then the following rules apply sequentially to replace outaged primary CCU

  1) Select alternate CCU with highest voltage level
  2) Select alternate CCU with highest capacity
  3) Select alternate CCU that is first in database, i.e. randomly

- The rules apply only for DAM and RUC processes and do not apply for SCED (i.e. SCED only dispatch telemetry online configuration).

Combined Cycle implementation (cont)

- Each CCGR (Configuration) of a CCT is modeled as a separate Resource in the optimization.

- For each time interval
  - Only one CCGR is awarded online reserve/energy
  - Either offline NSRS or Energy/online reserve is awarded not both

- CCGR committed at the end of study period shall be a shutdown capable CCGR of the CCT.

- If a CCGR is already self committed in an hour then RUC will not transition the CCT to another CCGR in the same hour.

CC implementation – Startup Cost

StartUp Cost calculation

- The 3PO are submitted for each CCP configuration. The configuration startup cost represents the sum of startup costs of all physical CCU that are online in that configuration

- Combined Cycle plant offline time is used in determining the warmth state (hot, intermediate and cold status) for the startup cost.

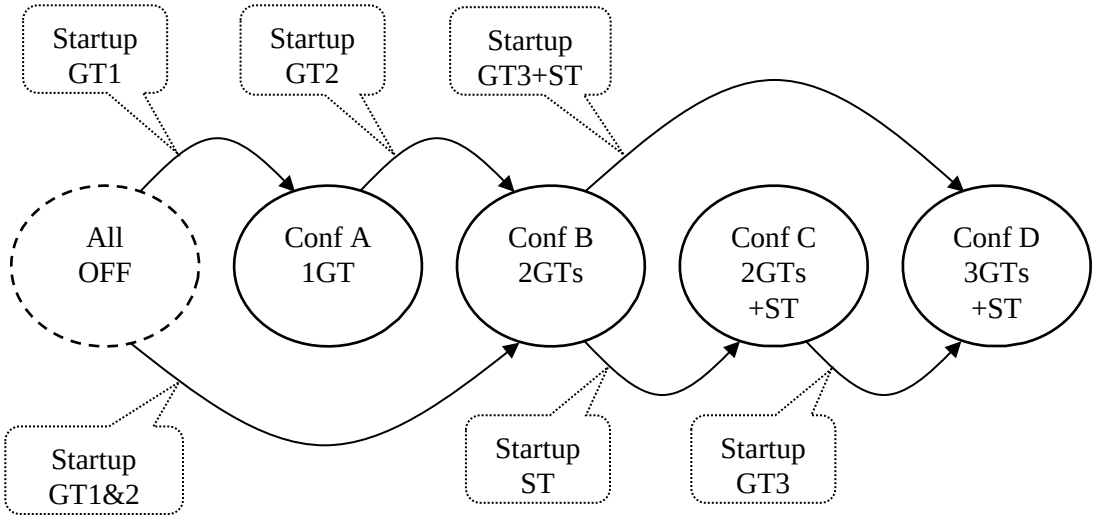
- MMS will provide S&B the warmth state for each start and each transition.

Transition cost [A to B] = max(0, StartUpCost [B] – StartupCost [A])
Note: the warmth state is determine for TO config in transition cost calculation only for the UP transition

The downward transition costs are equal to zero in all cases

CC implementation – Startup Cost (cont)

StartUp Cost example



TRANSITION MATRIX		Transition To Configuration				
		OFF	A	B	C	D
Transition From Configuration	OFF		↑	↑		
	A	↓		↑		
	B	↓	↓		↑	↑
	C	↓	↓	↓		↑
	D	↓	↓	↓	↓	

CCT: Start Up and Transition Modeling

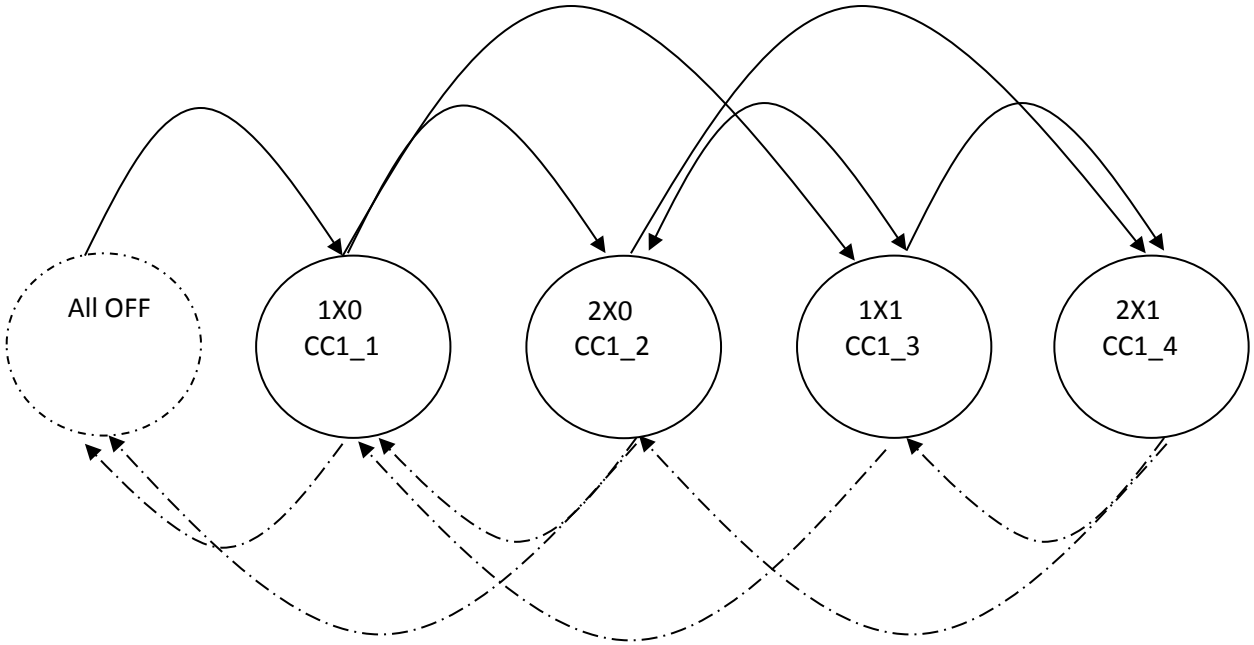
Up Transition

- Number of primary units in To CCGR >= Number of primary units in From CCGR

Down Transition

- Number of primary units in To CCGR < Number of primary units in From CCGR

Transition Matrix		To configuration				
		OFF	1	2	3	4
From configuration	OFF		↑			
	1	↓		↑	↑	
	2	↓	↓		↑	↑
	3		↓	↑		↑
	4			↓	↓	



CCT: Start Up and Transition Modeling

Transition

- Transition cost [1->2] = max(0, StartUpCost [2]– StartupCost [1])
- *Down transition* –> transition costs are considered as *zero* in MMS
- # of startups = # of up transitions for the CCGR.

S&B

- MMS will provide S&B the warmth state for each start and each up transition.
- Settlements calculates transition cost for up & down transition based on the warmth state from MMS

CCT: Start Up and Transition Modeling

Up Transition

- Considers Min On time; Min off time; Max on time; Max Startup #
- Time from “to configuration” was last off > Min off time;
- Time from “to configuration” was last off is used for the up transition warmth state

Startup

- Considers Min On time; Min off time; Max on time; Max Startup #
- Time from “plant” was last off > Min off time;
- Time from “plant” was last off is used to for the start up warmth state

Down Transition

- Considers Max on time only

CCT LMP at Logical Resource Node and Physical Resource Node

- Need settlement price for both Logical Resource Node and physical Resource Node
- LMP at Logical Resource Node (LCCRN) is used to settle resource-specific energy award (3PO)
- LMP at physical Resource Node (PCCRN) is used to settle non-resource-specific award (PTP bid, CRR offer, DAM energy only offer, DAM energy only bid)

PCCRN LMP: $$LMP_{CCU} = \lambda_{sys} \pm \sum_{lines} SP_{line} \cdot SF_{CCU}^{line}$$

LCCRN LMP: $$LMP_{CCT} = \lambda_{sys} \pm \sum_{lines} SP_{line} \cdot SF_{CCT}^{line}$$

DAM: LCCRN LMP represents weighted average of PCCRN LMP. The calculation is performed implicitly through aggregation of SF of physical CCU as capacity (HRL) weighted.

Real-Time: The aggregated SF of operational CC configuration is weighted by telemetry power output of physical CCU of that online configuration.

Combined Cycle Train – Day Ahead Make Whole

The Day Ahead Make Whole Payment

- Compensates an eligible Generation Resource for the portion of its guaranteed operating costs that are greater than the Day Ahead energy and ancillary service revenue.
- The payment for Combined cycle units will be at the train level and is a result of comparing all guaranteed cost for the train to all revenue for the train.
- The inputs used to calculate each hourly interval for a train will correspond to the CCGR that is DAM-Committed for that hour.
- Startup eligibility will be based on Real Time telemetry for the Combined Cycle train.
- If the CC Train is DAM committed in multiple configurations during the day, further compensation may be awarded during the Startup transition process.

Questions

Questions?