Configuration-Based Combined Cycle Model

March 18, 2011

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About This Document

This document describes functional requirements and detailed models of configuration based Combined-Cycle group model.

Change Summary

Document Revision	Transmittal #	Date	Comments
0.1		June 15, 2010	Initial Draft [YYX]
0.2		March 20, 2011	Updated based on discussions with MISO.[YYX]

1 Introduction

A Combined Cycle (CC) Group consists of one or more Combustion turbines (CT), where each CT has a heat recovery steam generator (HRSG) and the steam produced in the HRSGs is used to drive a steam turbine (ST). Each CT and ST unit has an electrical generator. A typical CCP configuration contains 1 – 4 CTs and one ST only. The configuration used to illustrate model details has 3 CT – 1 ST configuration as presented in Figure 1.1.

A CC Group may operate in a number of different configurations (modes) based on the various combinations of the CTs and ST being on-line at any given time. As an illustration, some of the possible configurations for the CC Group used in this document are presented in Figure 1.2. The CC Group operating characteristics differ from one configuration to another and in addition, each transition from one mode of operation to another has its own operational limits and transition costs. Some of transitions are not even allowed (prohibited due to physical or operational constraints).

As a result, modeling of CC Group represents a challenge for the MIP based unit commitment and scheduling applications in the Market Management Systems (MMS). The results (unit commitment decisions and dispatch instructions) have to be not only operationally feasible but also should represent an optimal solution in terms of minimizing the overall objective (cost) function.

Traditionally, there are several different models used to address flexible configurations and operation of CC Groups in both EMS and MMS (e.g. aggregate CCG representation, physical unit-based models, etc). In addition, they also differ in how detailed is modeling of the CT-ST characteristics and corresponding relationships (e.g. ST MW output has been sometimes modeled as a function of total MW output from CT units; in other cases the steam-to-MW relationship is used for ST unit, and consequently, the steam produced in HRSG has to be modeled, etc).

The goal here is to describe in more details only a configuration based CC Group model that has been already used in some MMS (for example, ERCOT) and it may be a good starting point for the MMS applications in other RTO/ISO projects.

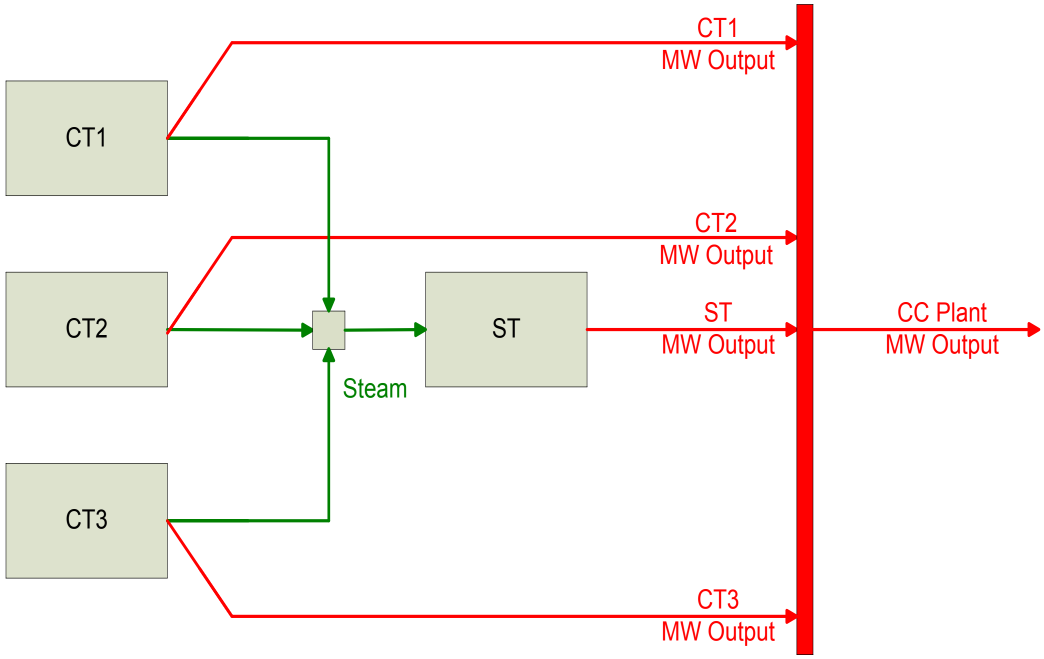

Figure 1.1 Combined Cycle Group (CCG) – An Example

2 Functional Requirements

2.1 Configurations

A CC group can be operated with various eligible configurations of CTs and STs.

For the purpose of this document only a limited number of configurations (4) are presented just as an illustration and an assumption taken in this example is that all the CTs have similar characteristics and therefore the configuration named “1CT” may in reality be any one of the three physical CT units within the CCP operating in a simple/single cycle. Similarly, the “2CT” configuration may be CT1+CT2, CT1+CT3 or CT2+CT3, and so on, as illustrated in the Table 1.1 below. This table presents a mapping between physical units and eligible configurations.

Table 1.1 CC Group Configurations

		ALLOWED CC Group CONFIGURATIONS									
		1 CT			2 CTs			2CTs+ST			3CTs+ST
PHYSICAL UNITS	CT1	X			X	X		X	X		X
	CT2		X		X		X	X		X	X
	CT3			X		X	X		X	X	X
	ST							X	X	X	X

It is important to mention that in this approach each CC group configuration is treated as a separate “logical” or pseudo generating unit. Only one of them may be on-line at any given time. Each configuration must have all the operating parameters, limits, energy offer curves, ancillary services (AS) offers, minimum and maximum up/down times, ramp rates, etc like any other “normal” generating unit. Please refer to CC Group Modeling sections for details.

2.2 Transition Matrix

The transition between different CC group configurations is illustrated in Figure 1.2 below and may also be represented in the form of so called transition matrix (Table 1.2). Only allowed transitions are specified and provided as an integral part of input data by market participants / CC group owners.

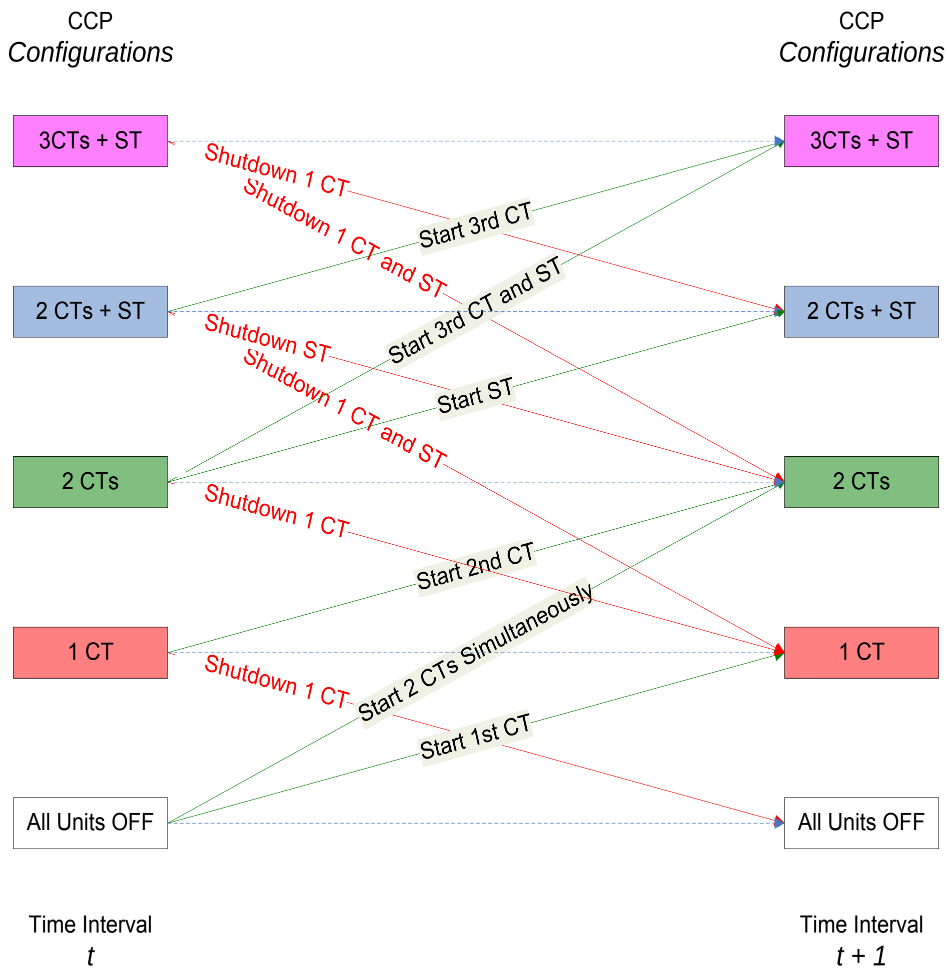

Figure 1.2 Transitions between CC group Configurations

Transition matrix reflects operational rules for the CC group. Observing table 1.2, one of the rules can be interpreted is: at least 2 CTs must be on-line for the ST unit to be started. The optimal solution must always follow transitions that are feasible from the operational point of view.

Table 1.2 Transition Matrix

TRANSITION		TO CONFIGURATION				
		All OFF	1 CT	2 CTs	2CTs+ST	3CTs+ST
FRO	All OFF		↑ UP	↑ UP		

	1 CT	↓ DN		↑ UP		
	2 CTs		↓ DN		↑ UP	↑ UP
	2 CTs + ST		↓ DN	↓ DN		
	3 CTs + ST			↓ DN	↓ DN	

2.3 Configuration Transition Costs

Each CC configuration has its own data for start-up (SU) costs. Normally, the total SU cost for a given configuration will be calculated as a sum of the SU costs of the physical units included in the CC configuration. As an illustration, SU cost for the 2CT+ST configuration will be equivalent to: 2 x [CT unit SU cost] + [ST unit SU cost], etc.

It is assumed that SU costs will be provided as separate parameters for the cold, intermediate and hot start, along with the corresponding values for the time off-line that define the warmth state of a unit.

Any transition between different CC configurations in fact represents either unit SU(s) or shut-down (SD) (s). As an example, transition from “All Units OFF” to 2CTs configuration represents start of 2 CT units simultaneously, as presented in Figure 1.2.

Based on that, the transition costs to be used in the optimization model for the “up” transitions (i.e. those that are characterized by starting additional units, as marked in Table 1.2) will be calculated as:

SU cost of TO-Configuration - SU cost of FROM –Configuration.

Here the cold, intermediate or hot SU costs are to be used based on the warmth state of the configuration (i.e. time off-line before the transition takes place).

To be noted, warmth state of a configuration is considered based on the time off-line of a configuration and time thresholds for hot-to-intermediate and hot-to-cold status change. For example, configuration A with 2CT/1ST is transferred to configuration B with 1CT/1ST. After 5 hours, configuration B is changed to configuration A again. When calculating the SU costs, the cooling time of configuration A should be 5.

Costs for shutdown transitions are considered as zero.

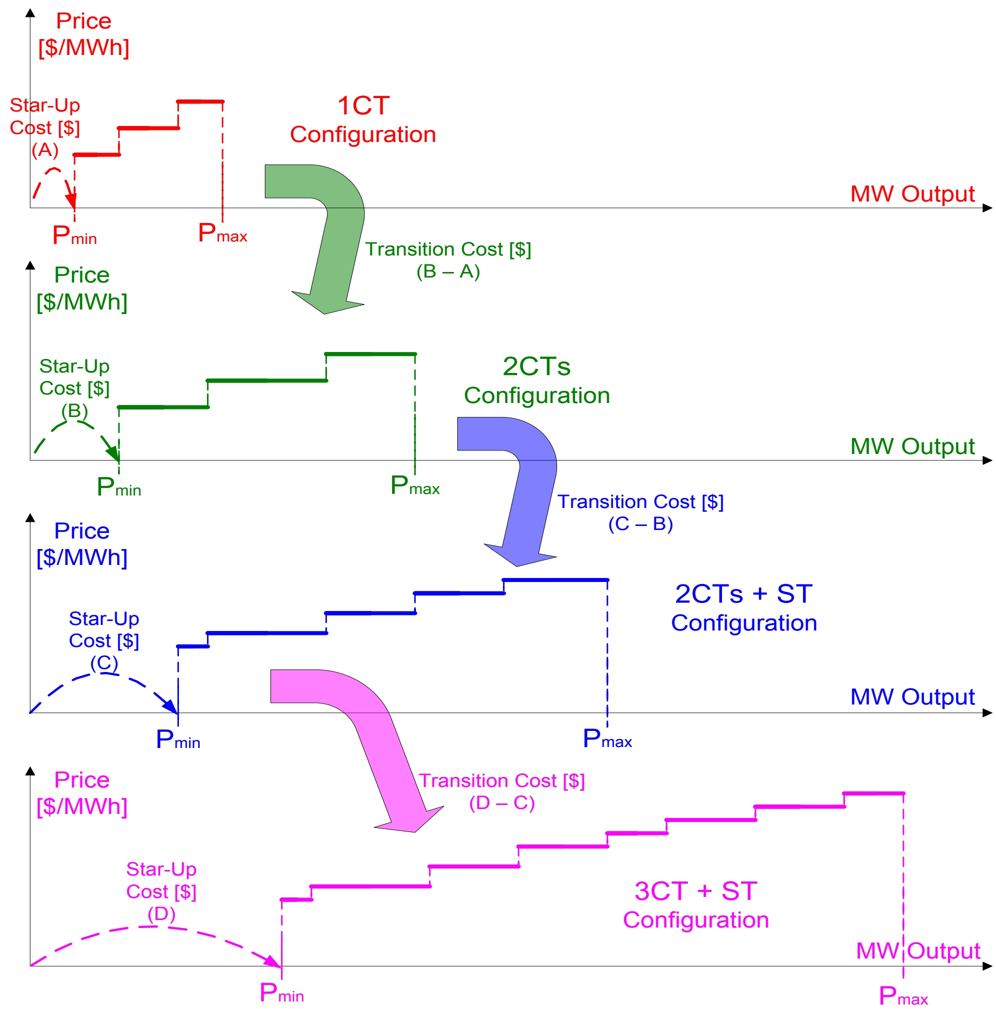

Figure 1.3 Configuration-based Price Curve and Transition Costs

3 CC Group Modeling

Based on the functional requirements described above, the CC Group will be modeled with configuration as basic components.

3.1 Configuration Model in MCE

3.1.1 Configuration Selection

For a CC group at an interval, only one configuration can be selected for energy and online reserves.

3.1.2 Dispatch Range

For an online CC configuration, it shall be dispatched within the specified dispatch range. During emergency, emergency limits shall be used.

3.1.3 Energy Offer

The following input data will be provided for each pre-defined CC configuration registered with the ISO/RTO for use by the MMS application(s):

- Energy Offer – Price Curve [$/MWh]

  This curve represents a cost of operating a CCP at given MW output (above its minimum economic MW limit). It is defined separately for each CC Configuration as a piece-wise monotonically increasing curve with up to pre-defined max number of segments (e.g. default of 10), as illustrated in figure 1.3.

- Minimum Load Cost [$/MWh]

  This represents a cost of a CC configuration operating at the minimum economic (operating) limit [MW] defined separately for each CC configuration. Minimum and maximum economic limits are considered to be time dependent, i.e. they may be provided on a study interval basis.

3.1.4 Minimum and Maximum Up/Down Time

As mentioned before, each CC configuration may have its own up/down times defined separately. This input data will be used to ensure that once on-line, any configuration should stay on-line for at least the minimum up time. Similarly, the maximum time up may be enforced by including adequate constraints into the mathematical model.

To satisfy minimum down time requirement, a CC configuration needs to be offline for at least the down time limit before it’s started up again.

3.1.5 Transition Matrix and Transition Costs

CC configuration transfer following given transition matrix.

Transition costs are calculated based on the difference between SU costs of “To Configuration” and “From Configuration”. Warmth state of “To Configuration” is considered in SU cost model.

3.1.6 Dispatch Ramping Model

For an online configuration, the dispatch between intervals shall not exceed the specific dispatch ramp rate.

3.1.7 Max Startup Limits

For a configuration in a CC group, the total start-up events shall be no higher than the specific max startup limits.

3.1.8 Max Energy Limits

For a configuration in a CC group, the total energy production shall be within the given max energy limit.

3.1.9 AS Models

Energy and AS are dispatched in a co-optimization fashion.

3.1.9.1AS Dispatch Range

Just like a “normal” generator, with AS product capacity, each configuration may eligible to provide one or multiple AS services.

Each AS product shall be cleared within given limits. Total amount of energy and AS products shall be dispatched within a specific range.

3.1.9.2AS Offer

Similar to an energy offer, the price curve will be modeled for AS Offer for each CC Configuration separately.

3.1.9.3 AS Clearing Model

For online reserves, the model is the same as that of normal units.

For offline reserve, for example, non-spinning reserve, as offline configurations are more than one, the following specific rules shall be followed for Non-spinning reserve dispatch:

- No more than one offline configuration can be selected for non-spinning reserve;
- The offline configuration should be transferable from previous interval's online configuration;
- The offline configuration should already meet min down time requirement;
- Max non-spinning reserve amount is: *Capacity of offline* configuration *for non-spinning reserve - Capacity of current selected online* configuration at the same interval.

3.2 Power Augmentation Modeling

Power augmentation is the ability of a CC plant to operate at a higher output rating than that of the typical base operating configurations. General power augmentation methods are combustion turbine inlet air cooling (CTIAC), duct firing, and so on. With any power augmentation methods, the efficiency of the CC plant is lower, but it allows the plant have a better load following capability.

Power augmentation can be modeled by extending the capacity of corresponding base configurations. For example, for a configuration with ecomax as 100MW and an offer curve with two segments, considering the increased output from power augmentation, the configuration may submit an offer with ecomax as 120MW and an offer curve with additional segment and higher offer price to represent the cost in the augmentation mode.

An alternative way is to use additional configurations to model the augmentation mode explicitly. This approach allows to model detailed transition between base configuration and configuration with power augmentation. However, due to additional integer variables and constraints being introduced, it may cause performance degradation.

3.3 Interaction between MCE and Network Model in EMS

For a CC group, EMS network model models individual CT/ST. MCE sees both individual physical units and configurations of CC group. Data interaction between MCE and network model is illustrated in Figure 1.4.

Network provides sensitivities of CTs and ST. Based on sensitivities and telemetry output of physical units, sensitivity of a configuration can be estimated. Following the same method, loss penalty factor of CTs and ST can be used to calculate the factor of a configuration.

CC group’s SE gen value is the total of SE gen MW of CTs/ST.

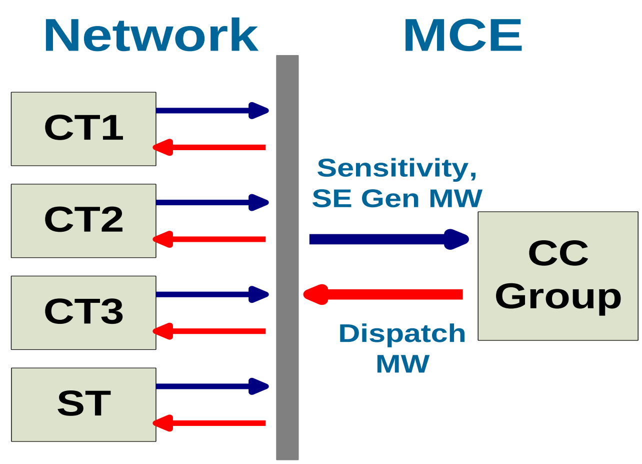

Figure 1.4 Data Conversion between EMS and MCE

For physical unit power injection data, configuration level dispatch MW will be disaggregated based on capacity of individual physical units and steam factor of the ST.

Initial configuration can be determined based on the online status of CT/ST. Minimum value of initial on (off) times of all physical units is considered as the initial on (off) time for the configuration.

4 Performance

For CC group modeling, potential performance issues may be caused by additional integer variables and constraints, where the amount of integer variables and constraints depends on.

- number of CC groups,
- number of CTs in CC group,
- transition matrix density.

  Compared with sparse transition matrix, obviously more solutions needed to be searched over for an optimal one for CC groups with dense transition matrix.

To improve performance, all methods should focus on:

- Reducing candidate configurations
- Pruning transition matrix.

A two-round-solve based method is proposed to improve performance on CC group modeling:

1. 1st round solve with Aggregation CC model to calculate total MW dispatch of the whole CC group. In the aggregation model, the whole CC group is treated as one generator. Please refer to Appendix for proposed rules to construct data for the aggregated unit based on characteristics of physical units.

2. Based on total MW dispatch, reduce configurations and prune transition matrix. For example, as shown in figure 1.5, the configuration set has been reduced to only include configurations with bold frames, and transition paths also have been pruned to a great degree, as indicated in thick lines.

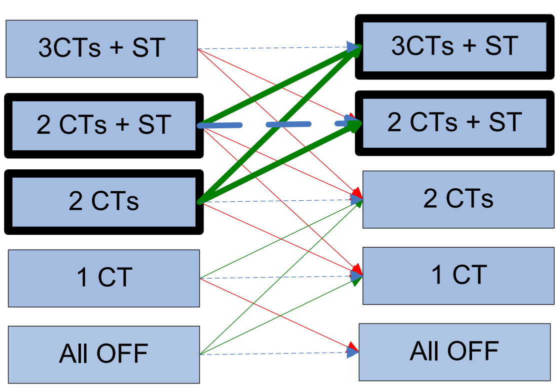

Figure 1.5 Reducing Configurations and Pruning Transition Matrix

3. 2nd round solve with configuration based CC model and based on the reduced configurations and transition matrix.

5 Appendix: Proposed Rules to Construct Aggregated Unit Data

The following rules are proposed to construct data for the aggregated unit based on input data of the physical units within the CC group:

- SU cost takes the average of SU cost of each CTs.
- Ecomin is the minimum value of ecomin of all CTs;
- Ecomax is the sum of ecomax of the CC group;
- Energy offer price curve is Ecomax weighted average of the CC group;
- AS capacity for regulation reserve is within the range of [min regmin, sum regmax] of all units in the CC group;
- AS capacity for other reserve types may be sum of ecomax or emergency Max.
- Minup/down time may use the minimum value of min up/down time of units in the CC group.
- ED ramp rate may use average of ED ramp rates of all units in the group.

These rules are subject to change based on MISO's preference and case analysis results.