California ISO

Business Requirements Specification

Generator Contingency and RAS Modeling (GCARM)

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Revision History

Date	Version	Description
3/16/2018	1.0	Create Document.
12/4/2018	1.1	• **Section 5.1 (Manage Operations Planning):** ○ GCARM-BRQ1010: ▪ Removed support to Partial injection change. ○ GCARM-BRQ1020: ▪ Removed support to Partial injection change. ○ GCARM-BRQ1030: ▪ Added "business process only" next to EMMS. ○ GCARM-BRQ1040: ▪ Marked EMMS impact as "business process only" and added IFM, RTM, CRR in the impacted systems. ○ GCARM-BRQ1055: ▪ Added to mark each contingency as published to RTCA only, Market only, or both. ▪ Added implementation note for using different naming convention for GCARM contingencies and full RTCA contingencies. ○ GCARM-BRQ1057: ▪ Added to safeguard duplicate contingencies from going to same application. ▪ Added implementation note for using different naming convention for GCARM contingencies and full RTCA contingencies. ○ GCARM-BRQ1065:

Date	Version	Description
		▪ Added for OMS to be able to consume modified contingency List payload. ○ GCARM-BRQ1070: ▪ Marked EMMS impact as "business process only". ○ GCARM-BRQ1120: ▪ Added IFM, RTM to impacted system to access FR on physical resource level. ○ GCARM-BRQ1150: ▪ Removed Integration from Potential Application(s) Impacted column and replaced EMMS with VSA. • **Section 5.2 (Manage Entity & Resource Maintenance Updates):** ○ GCARM-BRQ2010: ▪ Deleted. ○ GCARM-BRQ2020: ▪ Deleted. ○ GCARM-BRQ2030: ▪ Deleted. ○ GCARM-BRQ2040: ▪ Deleted. • **Section 5.3 (Manage DAM, RTM):** ○ GCARM-BRQ3010: ▪ Removed "static" from requirement body. ▪ Removed EMMS from impacted applications. ○ GCARM-BRQ3020: ▪ Removed MF from impacted applications. ▪ Removed Integration from Potential Application(s) Impacted column. ▪ Changed IFM, RTM consumption of MF FR on market resources to EMMS physical resources. ○ GCARM-BRQ3025: ▪ Added requirement for topology processor to identify lost injection from switch positions. ○ GCARM-BRQ3030: ▪ Marked this as business process only: "GCARM constraints subject to the current price correction timeline". ○ GCARM-BRQ3043: ▪ Added for using Pmax derates for GDFs calculations. ○ GCARM-BRQ3047: ▪ Added for reporting GDFs for each FR resource. ○ GCARM-BRQ3050: ▪ Added clarification notes. ▪ Removed support to Partial injection change.

Date	Version	Description
		▪ Replaced “same BAA” with “entire market”. o GCARM-BRQ3070: ▪ Removed IFM/RTM from impacted applications. ▪ Added GFF to EDR. o GCARM-BRQ3072: ▪ Added for market to store GFF in save cases. o GCARM-BRQ3074: ▪ Added for MPP to consume GFF. o GCARM-BRQ3075: ▪ Added for GFF reporting. o GCARM-BRQ3080: ▪ Added for GFF reporting. o GCARM-BRQ3085: ▪ Added for GFF reporting. • **Section 5.4 (Manage RT Operations – Transmission & Electric System):** o GCARM-BRQ4005: ▪ Removed “static” from requirement body. • **Section 5.5 (Manage CRR):** o GCARM-BRQ5010: ▪ Removed Integration from Potential Application(s) Impacted column. o GCARM-BRQ5020: ▪ Removed Integration from Potential Application(s) Impacted column. ▪ Removed “(business process only)”. ▪ Modified to let CRR consume physical resources from EMMS. o GCARM-BRQ5060: ▪ Clarified to add IFM as source of original DA unit commitment data. ▪ Added clarification notes that GCARM constraints are treated similar to other constraints. o GCARM-BRQ5063 ▪ Added for CRR to consume MF market to physical resource mapping and distribution factors. o GCARM-BRQ5066 ▪ Added for CRR to consume resource availability from WebOMS. o GCARM-BRQ5068 ▪ Added for CRR to calculate physical resource registered Pmax and availability status. o **Appendix-3 (CRR Formulation for GCARM - GDF):**

Date	Version	Description
		▪ Updated GDF formulation to model outages, use of FR flag on physical resources and model non-ISO footprint as interties.

Disclaimer

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1 Introduction

1.1 Purpose

The purpose of this document is to capture and record a description of what the Users and Business Stakeholders of the project wish to obtain by providing high-level business requirements. This document establishes the basis for the agreement between the initiators and implementers of the project. The information in this document serves as input to determining the scope of projects and to all Business Process Modeling and System Requirements Specifications efforts.

Generator Contingency and RAS Modelling Overview:

The ISO approximately represents constraint impacted by generator contingencies and Remedial Action Scheme (RAS) operation outside the market through manual intervention or in the market using static nomograms which are not optimal.

ISO therefore intends to enhance the Security Constrained Economic Dispatch (SCED) to:

1) Model generation/load loss in the dispatch
2) Model transmission loss along with subsequent generation/load loss due to RAS operation in the dispatch
3) Model transmission reconfiguration due to RAS operation in the dispatch

The generator contingency and remedial action scheme modeling proposal for the day-ahead and real-time markets reserves transmission capacity to account for the change in flows caused by the loss of generation/load. When generation/load is lost, the system has an immediate response whereby all frequency response enabled resources on the system automatically increase their output to compensate for the load and supply imbalance. The loss of the generator/load and the system response to the loss of the generator/load creates dramatically different flows on the system in the post-contingency state. The purpose of this initiative is to ensure that if the contingency were to happen, the resulting flows would not be greater than the emergency ratings on any transmission elements in the system. The proposal seeks to reserve enough transmission capacity in the right places to ensure that no transmission element would be loaded above its emergency rating if the contingency were to occur.

The functionality in this proposal does not reserve generation capacity.

2 Intellectual Property Ownership

- Intellectual property covers a broad array of information and materials, including written works, computer programs, software, business manuals, processes, symbols, logos, and other work products. Determining ownership of intellectual property is very important in preserving rights of the California ISO and helps to avoid intellectual property infringement issues. In considering the business requirements or service requirements to be performed, the business owner of the project must determine intellectual property Ownership.

2.1 Guidelines

- Intellectual property ownership must be considered by all applicable stakeholders before the services are performed. The level of analysis is two-fold. One, the business owner must determine if the intellectual property necessary to perform the services is owned by the California ISO or whether it must be obtained from a third party. Once it has been determined that the California ISO has secured the proper intellectual property rights to perform the services (i.e., the intellectual property is owned by the California ISO or we have licensed it from a third party), then the second step in the analysis is to consider whether new intellectual property will be created as a result of the business requirements or service requirements to be performed and how that intellectual property will be owned and protected by the California ISO. In order to assist the business owner in the analysis previously described, referRefer to the California Intellectual Property Policy available at http://www.caiso.com/rules/Pages/LegalPoliciesNotices/Default.aspx, which provides a brief tutorial on what Intellectual Property is and how the California ISO can go about protecting its intellectual property. Please contact the Legal Department if you have any questions regarding intellectual property.

2.2 Checklist

Yes,

-
- Intellectual ownership of included business requirements is retained by California ISO.
- The California ISO assumes the ownership of:
  - Design of GCARM;
  - Related Business Practice Manual;
  - Software codes to implement the GCARM.

3 Details of Business Need/Problem

3.1 Description

Currently, the ISO approximately represents constraint impacted by generator contingencies and RAS operation:

- Outside the market through manual intervention, or
- In the market using static nomograms

Both of which are not optimal.

The scope of this project is:

- Enhance the Security Constrained Economic Dispatch (SCED) to:
  - Model generation/load loss in the dispatch.
  - Model transmission loss along with subsequent generation/load loss due to RAS operation in the dispatch.
  - Model transmission reconfiguration due to RAS operation in the dispatch.
- Update the congestion component of LMP so that it considers the cost of positioning the system to account for generator contingencies and RAS operations.
- Enhance DAM, RTM and EIM:
  - Support generator contingencies.
  - An “N-1” preventive constraint enables the market to model and price the immediate impact of RAS operation on the transmission system.
  - Economic dispatch that will respect all emergency limits after loss of a generating unit or after RAS operation without the need of out of market intervention.

Note: The scope does not focus on system response and state after the loss of a generating unit and subsequent deployment of contingency reserves.

The proposed changes result in an update to the congestion component of the Locational Marginal Price (LMP) so that it considers the cost of positioning the system to account for generator contingencies and RAS operations. A RAS-connected generator will potentially receive higher energy prices than generators that are not connected to a RAS at the same bus because a RAS-connected generator does not contribute to binding emergency limits. While under certain scenarios the generator may receive a higher price for its energy, the constraint allows the dispatch to potentially use less expensive generation reducing overall production cost.

4 Business Impacts

4.1 Business Practice Manual (BPM)

BPM	Description of Impact(s)
Managing Full Network Model	Possible Impact
Congestion Revenue Rights	~~Yes~~ GDF calculation derivations for purposes of implementing the GCARM functionality in the CRR process.
Market Operations	~~Yes~~ Preventive constraint modeling and pricing and GDF calculations derivations for purposes of implementing the GCARM functionality.
Energy Imbalance Market (EIM)	~~Yes,~~ Clarify that the constraints are supported for EIM BAAs.

5 Business Requirements

The sections below describe the Business Processes and the associated Business Requirements involved in the project. These may represent high level functional, non-functional, reporting, and/or infrastructure requirements. These business requirements directly relate to the high level scope items determined for the project.

5.1 Business Process: Manage Operations Planning

5.1.1 Business Requirements

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
GCARM-BRQ1010	OES shall define new GCARM type of preventive contingency by defining any contingency and RAS combinations that include any injection change. For example: - Full injection (generation/load) loss contingency (full outage) ~~- Partial injection (generation/load) change (percentage of injection change or amount of injection change or injection go-to level (to simulate partial derate of Gen/Load due to, for example, outage of physical resources in a market aggregation)~~ - Transmission loss along with subsequent generation/load loss or transmission reconfiguration due to a RAS arming. **Notes:** • There will be no CMRI/OASIS system impact, as the new contingency type will not be published. • Actual generation loss is the lower of base-case injection or the loss percentage times Pmax.	Core	- EMMS
GCARM-BRQ1020	RAS arming shall support: List of CB/switch operations (to simulate full outages of injection change or transmission reconfiguration).	Core	- EMMS

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	~~• Partial injection (generation/load) change (percentage of injection change or amount of injection change or injection go-to level (to simulate partial derate of Gen/Load due to, for example, outage of physical resources in a market aggregation).~~		
GCARM-BRQ1030	EIM entities shall be capable of creating and submitting their GCARM type of contingencies within their EIM Areas. **Note:** Currently, EIM entities send a list of contingencies by email to ISO and ISO users enter them into EMMS.	Core	- EMMS (business process only)
GCARM-BRQ1040	RAS definition of GCARM preventive contingency type shall support all types of resources that are modeled in the market. This shall specifically include, but not limited to: - Non-MSG - MSG (plant-level only) - Pump Storage - NGR - Aggregate - Pumps - Loads	Core	- EMMS (business process only) - IFM - RTM - CRR
GCARM-BRQ1055	EMMS shall have safeguarding or validation mechanism that alert the users when duplicate contingencies are sent to same application (RTCA, or Market Application). **Implementation Note:** Users can use different naming conventions for GCARM contingencies and full RTCA contingencies.	Core	- EMMS
GCARM-BRQ1057	EMMS users shall have the capability to mark each contingency as one of these options: • Only published to RTCA • Only Published to Market • Published to both Market as well as RTCA	Core	- EMMS - IFM - RTM - RTCA

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	Implementation Note: Users can use different naming conventions for GCARM contingencies and full RTCA contingencies.		
GCARM-BRQ1060	EMMS shall include GCARM type contingency flag as part of the contingency payload that is publishedbroadcasted to downstream systems.	Core	- EMMS - IFM - RTM - RTCA - CRR - Integration
GCARM-BRQ1065	OMS shall be able to consume the modified contingency list due to addition of : • GCARM contingency type	Core	- OMS - Integration
GCARM-BRQ1070	A new Frequency Response (FR) flag (Y/N) attribute shall be added to network model data for all generating resources. It shall follow network model submission lead timeline. This flag (physical resource level) shall be "Y" for all generating resources that satisfy all these conditions: - Generating resource has frequency response governor. - The frequency response governor is activated.	Core	- EMMS (business process only) - RIMS - Integration
GCARM-BRQ1080	For resources that are within ISO or EIM footprint, each resource's owner shall be responsible of submitting the FR flag (physical resource level) to ISO.	Core	- Business process only
GCARM-BRQ1090	For resources that are neither within ISO nor EIM footprint but are within ISO RC footprint, each resource's BA shall be responsible of submitting the FR flag (physical resource level) to ISO.	Core	- Business process only

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
GCARM-BRQ1100	For resources that are neither within ISO nor EIM nor RC footprint but are participating in neighboring RCs, ISO shall request the FR flag (physical resource level) from the neighboring RC.	Core	- Business process only
GCARM-BRQ1110	For resources that are neither within ISO nor EIM nor RC footprint and are not participating in neighboring RCs, ISO shall request the FR flag (physical resource level) from WECC.	Core	- Business process only
GCARM-BRQ1120	EMMS shall make the FR flag (physical resource level) accessible to downstream systems **Notes:** - RTCA ~~and~~, VSA, IFM/RTM need FR flag (physical resource level) for the entire western interconnection.	Core	- EMMS - MF - RTCA - VSA - IFM - RTM - Integration
GCARM-BRQ1130	~~VSA~~System shall consume and use FR flag (physical resource level) from EMMS for all resources in the network model (western interconnection footprints).	Core	- VSA - EMMS - Integration
GCARM-BRQ1140	~~VSA~~System shall broadcast FR flag (physical resource level) for all resources in the network model (western interconnection footprints) to DSA.	Core	- VSA - Integration
GCARM-BRQ1150	~~DSA~~System shall consume FR flag (physical resource level) from ~~EMMS~~VSA for all resources in the network model (western interconnection footprints).	Core	- DSA ~~- Integration~~

GCARM-BRQ1160	~~DSA~~System shall set and use Base Load (BL) flag as follows:
	• If FR flag "Yes" Then
	  ○ Set BL flag = "No"
	• Else
	  ○ Set BL flag = "Yes"
		Core	- DSA

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	Note: BL flag is the logical complement of FR flag.		

5.2 Business Process: Manage Entity & Resource Maintenance Updates

5.2.1 Business Requirements

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
~~GCARM-BRQ2010~~	~~At regular model update time, MF shall fetch FR flag from EMMS for all physical resources.~~None	~~Core~~	~~- MF~~ ~~- EMMS~~ ~~- Integration~~
~~GCARM-BRQ2020~~	~~At regular model update time, MF shall set FR flag on market resources (ISO and EIM resources) using FR flag on corresponding mapped physical resources, according to the following rules:~~ ~~- If the FR flag is set to 'Y' for all physical resources that are mapped to a market resource, Then~~ ~~o MF shall set FR flag to 'Y' on that market resource~~ ~~- Else~~ ~~o MF shall set FR flag to 'N' on that market resource~~	~~Core~~	~~- MF~~
~~GCARM-BRQ2030~~	~~MF FR flag (market resources level) shall apply to both ISO and EIM market~~	~~Core~~	~~MF~~
~~GCARM-BRQ2040~~	~~At regular model update time, MF shall make the FR flag (market resources level) accessible to downstream systems~~ ~~**Notes:**~~ ~~- CRR and IFM/RTM need FR flag (market resources level) that applies to ISO and EIM markets.~~	~~Core~~	~~- MF~~ ~~- IFM~~ ~~- RTM~~ ~~- CRR~~ ~~- Integration~~

5.3 Business Process: Manage Day-Ahead Market; Manage Real-Time Hourly Market

5.3.1 Business Requirements

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
GCARM-BRQ3010	~~IFM/RTM~~System shall consume GCARM contingency and~~ static~~ RAS definition (including GCARM type contingency flag) as part of the modified contingency payload that is published by EMMS.	Core	- IFM - RTM ~~- EMMS~~ - Integration
GCARM-BRQ3020	~~IFM/RTM~~System shall consume FR flag (~~market~~physical resource level) from ~~MF~~EMMS for ISO and EIM resources.	Core	- IFM - RTM ~~- MF~~ - Integration
GCARM-BRQ3025	System shall identify the lost injections from the switch position settings in the GCARM contingency definition via the topology processor. **Note:** UCON switches may not be part of this definition, but generation/load may be disconnected because of other switches being open.	Core	- IFM - RTM
GCARM-BRQ3030	~~IFM/RTM~~System (for ISO and EIM markets) shall model and price immediate impact of preventive contingencies of GCARM type using RAS definition by adding a new "N-1" preventive constraint in SCED that simulates enforcing emergency limits of transmission system if the GCARM contingency occurred. (i.e. pre-dispatch resources such that transmission lines will not overload its	Core	- IFM - RTM

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	emergency ratings if a generator event or RAS event were to occur). **Notes:** • Refer to Appendix-2 for IFM/RTM model formulation. • SCED, which is the core component of the ISO market, determines a dispatch that produces feasible flows considering transmission constraints in the base case as well as in the contingency cases. That is, SCED produces a single dispatch that will be feasible for the base case and for all contingencies without any re-dispatch. • Similar to other constraints, the new GCARM constraints shall be published to downstream system. • Similar to other constraints, all GCARM constraints shall be included in market save cases. • Similar to other constraints, GCARM constraints shall be subject to the CRR Settlement Rule, following the existing calculation methodology, and the EIM Virtual Congestion Uplift, following the existing calculation.		
GCARM-BRQ3040	~~IFM/RTM~~System (for ISO and EIM markets) shall update calculation of its GDF to account for preventive contingencies of type GCARM. These GDFs shall simulate the system response to injection change (generation/load loss or RAS scheme operations). **Note:** - Refer to Appendix-2 for IFM/RTM model formulation - GDF is the vehicle that distributes the injection change due to a GCARM	Core	- IFM - RTM

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	contingency across the system so that the amount of power flowing on transmission elements can be determined after the injection change.		
GCARM-BRQ3043	For each GCARM contingency, when calculating GDFs, system shall use resource availability with respect to Pmax derates (but ignoring capacity reservation for AS).	Core	- IFM - RTM
GCARM-BRQ3047	For each GCARM contingency, system shall report all GDFs for FR resources.	Core	- IFM - RTM
GCARM-BRQ3050	IFMSystem shall treat any virtual supply/demand schedules at generator/load nodes where the generator/load is part of a GCARM contingency definition the same as the physical generation/load at these nodes: if • If the generator/load is outaged, the virtual supply/demand schedules shall vanish in the post-contingency state and they shall be distributed to the online frequency-responsive generators in the same BAAentire market using the same generation/load loss distribution factors used for the physical generation/load; Notes:if the generator/load is partially outaged, the virtual • Contingency constraint will be enforced regardless of amount of supply/demand schedules shall be reduced bid-in at the location o Zero MW of virtual/physical supply bids will simply lead to a zero MW pick-up by the rest of the post-system and no impact on constraints	Core	- IFM

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	• In DAM, generator contingency state withnode is charged for the same partial outage percentage and that generation/load loss shall be distributed using the same generation/load loss distribution factorscongestion it causes: applies to both virtual and physical.		
GCARM-BRQ3060	IFM/RTMSystem LMPM's DCPA calculation shall be updated to incorporate the use of calculated GFF in evaluating the competitiveness of the preventive constraint.	Core	- IFM - RTM
GCARM-BRQ3070	System shall be updated to account for new: • New contingency type structure (for addition of GCARM contingency type flag). • GFF	Core	- EDR - IFM - RTM
GCARM-BRQ3072	System shall be updated to store GFFs in market save cases.	Core	- IFM - RTM
GCARM-BRQ3074	System shall consume and store the following: • GFFs (that are broadcasted by the market).	Core	- MPP - Integration
GCARM-BRQ3075	Similar to reporting shift factors in csv files, system shall report GFFs between generator contingency node(s)/Anode(s) and transmission constraints for all market types and all time intervals. **Note:** • For non-generator-contingency node(s)/Anode(s), GFFs will be same as shift factors, and need not be reported twice.	Core	- IFM - RTM - MPP - Integration
GCARM-BRQ3080	The csv file reports shall have identifiers to distinguish between shift factors and GFFs for	Core	- IFM

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	same node/Anode - transmission constraints records.		- RTM - MPP - Integration
GCARM-BRQ3085	Except as stated in GCARM-BRQ3075 and GCARM-BRQ3080, GFF reporting shall follow same rules as current shift factor reporting.	Core	- IFM - RTM - MPP - Integration

5.4 Business Process: Manage Real Time Operations – Transmission & Electric System

5.4.1 Business Requirements

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
GCARM-BRQ4005	RTCA shall consume GCARM contingency and ~~static~~ RAS definition (including GCARM type contingency flag) as part of the modified contingency payload that is published by EMMS.	Core	- EMMS - RTCA - Integration
GCARM-BRQ4010	RTCA shall consume FR flag (physical resource level) from EMMS for all resources in the network model (western interconnection footprints).	Core	- RTCA - EMMS - Integration
GCARM-BRQ4020	RTCA shall use the resource FR flag (physical resource level) instead of the 0/1field that is currently being entered by RTCA user.	Core	- RTCA

5.5 Business Process: Manage Congestion Revenue Rights

5.5.1 Business Requirements

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
GCARM-BRQ5010	CRR shall consume the list of contingencies of GCARM type (including the GCARM type contingency flag) along with their RAS definition as needed for the development of the monthly and annual CRR model.	Core	- CRR (business process only) - EMMS ~~- Integration~~
GCARM-BRQ5020	CRR shall consume FR flag (~~market~~physical resource level) from ~~MF~~EMMS for ISO and EIM resources.	Core	- CRR ~~(business process only)~~ - ~~MF~~EMMS - Integration
GCARM-BRQ5030	CRR auction and allocation processes (monthly as well as annual) shall be updated to recognize mechanics of the new DAM preventive constraints to maintain revenue adequacy.	Core	- CRR
GCARM-BRQ5040	• CRR shall model preventive contingencies of GCARM type in monthly as well as annual CRR auction and allocation similar to how this contingency type is modeled in DA market. • CRR auction and allocation markets shall limit CRR flows on transmission elements to respect expected post-contingency power flows resulting from the potential loss of generation/load/RAS arming (due to GCARM contingencies) in the system.	Core	- CRR
GCARM-BRQ5050	CRR shall model preventive contingencies of GCARM type by adding a new “N-1” preventive constraint in SFT that simulates enforcing emergency limits of transmission system if the GCARM contingency occurred. **Notes:**	Core	- CRR

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	• Refer to Appendix-3 for CRR model formulation.		
GCARM-BRQ5060	CRR shall consume corrected DA historical unit commitment data for previous year from PCA.	Core	- CRR - PCAIFM - Integration
GCARM-BRQ5063	CRR shall consume market to physical resource mapping and distribution factors from MF.	Core	- CRR - MF
GCARM-BRQ5066	CRR shall consume physical resource availability from WebOMS.	Core	- CRR - WebOMS - Integration
GCARM-BRQ5068	For all physical resources that are mapped to market resources and for each time period (t) within H, system shall calculate Pmax ($\bar{G}_{i,j,t}$) and availability status ($a_{i,j,t}$) of the physical resource *j* follows: $\bar{G}_{i,j,t} = \bar{G}_{i,t} * DF_{i,j}$ $a_{i,j,t} = A_{i,j,t} / \bar{G}_{i,j,t}$ Where, H is the set of hours in the season (or month) in the time period of interest (e.g. peak or off-peak), i is the market resource index; j is the physical unit index;	Core	- CRR

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	t is the time period (hour) index within H; $a_{i,j,t}$ is the availability status of physical unit j of resource i in time period t; (=available MW/registered Pmax) $\bar{G}_{i,j,t}$ is the registered maximum capacity of physical unit j of market resource i in time period t. $\bar{G}_{i,t}$ is the registered maximum capacity of market resource i in time period t. $DF_{i,t}$ is the distribution factor of Physical resource j out of market resource i. $A_{i,j,t}$ is the available MW Capacity of physical unit j of market resource i in time period t. **Notes:** • Refer to Appendix-3 for CRR GDF formulation		
GCARM-BRQ5070	• CRR shall update calculation of its GDF to account for preventive contingencies of type GCARM based on committed capacity and utilizing historical monthly and seasonal average. • CRR GDF shall be calculated: ○ Per GCARM Type contingency, ○ Per resource ○ Per month	Core	- CRR

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	○ Per TOU **Notes:** • Refer to Appendix-3 for CRR GDF formulation • CRR market runs for two TOU periods: Peak and Off-Peak.		
GCARM-BRQ5080	For CRR annual allocation and auction process, CRR shall use previous year's seasonal average GDF. **Note:** Refer to Appendix-3 for CRR GDF formulation	Core	- CRR
GCARM-BRQ5090	For CRR monthly allocation and auction process, CRR shall use previous year's monthly average GDF. **Note:** Refer to Appendix-3 for CRR GDF formulation	Core	- CRR
GCARM-BRQ5110	For monthly CRR allocation and auction markets, CRR shall enforce GCARM contingencies~~,~~ that are expected to be enforced in DAM, in the appropriate month and TOU. **Note:** The decision of which contingencies to protect will be made through existing outage planning process that occurs during CRR market set-up.	Core	- CRR
GCARM-BRQ5120	For annual CRR allocation and auction markets, CRR shall enforce GCARM contingencies~~,~~ that are expected to be enforced in DAM, in the appropriate season and TOU, as of the time that the annual CRR FNM is released.	Core	- CRR (Business process only)

ID#	Business Feature	Requirement Type	Potential Application(s) Impacted
	Notes: • The decision of which contingencies to protect will be made through existing outage planning process that occurs during CRR market set-up. • If OES team finds a scenario requiring the enforcement of GCARM contingencies in a given month or season per the annual process, it will communicate this with the CRR team. The CRR team will follow its rules for deciding whether it is necessary to model the contingency in the CRR market.		
GCARM-BRQ5130	CRR shall support partial-month GCARM type of preventive contingencies.	Core	- CRR (Business process only)

6 Appendix-1: Acronym Definition

Acronym	Definition
~~AGR~~	~~Aggregate Generating Resource~~
~~API~~	~~Application Program Interface~~
~~B2B~~	~~Business-to-Business~~
~~BA~~	~~Business Analyst~~
BA	Balancing Authority
BAA	Balancing Authority Area
BL	Base Load
~~BOG~~	~~Board Of Governors~~
BPM	Business Process Manual
BRS	Business Requirement Specifications
~~BSAP~~	~~Base Schedule Aggregation Portal~~
CAISO	California Independent System Operator
CB	Circuit Breaker
~~CIP~~	~~Critical Infrastructure Protection~~
CMRI	Customer Market Results Interface
~~CONFIG~~	~~Configuration~~
CRR	Congestion Revenue Right
DA	Day-Ahead
DAM	Day-Ahead Market
~~DB~~	~~Data Base~~

Acronym	Definition
DCPA	Dynamic Competitive Path Assessment
~~DDS~~	~~Design & Development Specifications~~
~~DI~~	~~Develop Infrastructure~~
~~DM~~	~~Develop Markets~~
~~DMM~~	~~Department of Market Monitoring~~
DSA	Disturbance Stability Analysis
~~ED~~	~~Exceptional Dispatch~~
EDR	Enterprise Data Repository
EIM	Energy Imbalance Market
~~EMM~~	~~Enterprise Modeling Management~~
EMMS	Enterprise Modeling Management System
~~ESP~~	~~Electronic Security Perimeter~~
~~e-Terra~~	~~Settlements Application System~~
~~FERC~~	~~Federal Energy Regulatory Commission~~
FNM	Full Network Model
~~FMM~~	~~Fifteen Minute Market~~
~~FODD~~	~~FERC Outgoing Data Depository~~
FR	Frequency Response
GCARM	Generator Contingency and RAS Modelling
GDF	Generation Distribution Factor
GFF	Generation Flow Factor

Acronym	Definition
~~GIP~~	~~Generator Interconnection Procedure~~
~~GRDT~~	~~Generator Resource Data Template~~
~~GUI~~	~~Graphical User Interface~~
~~IC~~	~~Injection Change~~
~~ICCP~~	~~Inter Control Center Protocol~~
ID	Identification
IFM	Integrated Forward market
~~IOOC~~	~~Integrated Optimal Outage Coordination~~
~~IS~~	~~Information Security~~
ISO	California Independent System Operator
~~IT~~	~~Information Technology~~
~~ITPD~~	~~Information Technology Product Development~~
~~ITPM~~	~~Information Technology Product Management~~
LMP	Local Marginal Price
LMPM	Local Market Power Mitigation
LPF	Loss Penalty Factor
~~MCI~~	~~Model & Contract Implementation~~
~~MED~~	~~Manual Economic Dispatch~~
MF	Master File
~~MHC~~	~~Manage Human Capabilities~~
~~MMG~~	~~Manage Markets & Grid~~

Acronym	Definition
MMR	Manage Market & Reliability Data & Modeling
MOS	Manage Operations Support & Settlements
MPMPP	Market Participant Portal
MQRI	Market Quality and Renewable Integration
MQS	Market Quality System
MSG	Multi-Stage Generator
MVQ	Market Validation Quality
MVQA	Market Validation Quality & Analysis
N/A	Not Applicable
NGR	Non-Generating Resource
OASIS	Open Access Same-Time Information System
OES	Operations Engineering Services
OMS	Outage Management System
PCA	Price Correction Application
Pmax	Maximum Generation (Load) MW Level
PMB	Plan & Manage Business
Pmin	Minimum Generation (Load) MW Level (same as ML)
PSTD	Power Systems Technology Development
PSTO	Power Systems Technology Operations
PTO	Participating Transmission Owner
QRB	Quality Review Board

Acronym	Definition
RAS	Remedial Action Scheme
RC	Reliability Coordinator
~~RDT~~	~~Resource Data Template~~
~~RES~~	~~Resource~~
RT	Real-Time
RTCA	Real-Time Contingency Analysis
RTM	Real-Time Market
~~RTN~~	~~Real-Time Market~~
~~RUC~~	~~Residual Unit Commitment~~
~~SADS~~	~~System And Design Specifications~~
~~SBS~~	~~Support Business Services~~
SFT	Simultaneous Feasibility Test
~~SC~~	~~Scheduling Coordinator~~
SCED	Security Constrained Economic Dispatch
~~SCS~~	~~Support Customers & Stakeholders~~
~~SCUC~~	~~Security Constrained Unit Commitment~~
SF	Shift Factor
~~SIBR~~	~~Scheduling Infrastructure Business Rules~~
~~SME~~	~~Subject Matter Expert~~
~~SRS~~	~~System Requirement Specifications~~
~~STUC~~	~~Short-Term Unit Commitment~~

Acronym	Definition
T	Operating Day
~~T-1~~	~~Operating Day minus 1 calendar day~~
TBD	To Be Determined
TOU (tou)	Time Of Use
TTC	Total Transfer Capability
~~UI~~	~~User Interface~~
WebOMS	Web-based Outage Management System
WECC	Western Electricity Coordinating Council

7 Appendix-2: IFM/RTM Formulation for GCARM

7.1 Notation

i	node index
m	transmission constraint index
k	preventive contingency index
g	generation contingency index
o_g	node index for generator outage under generation contingency g
N	total number of nodes
M	total number of transmission constraints
K	total number of preventive contingencies
K_g	total number of generation contingencies
S_{FR}	set of supply resources with frequency response capability
^{k}	superscript denoting preventive post-contingency values
^{g}	superscript denoting generation post-contingency values
$^\sim$	superscript denoting initial values from a power flow solution
$\forall$	for all…
Δ	denotes incremental values
u_i	commitment status of generating resource i (0: offline, 1: online)
G_i	generation schedule at node i
$G_{i,\min}$	minimum generation schedule at node i
$G_{i,\max}$	maximum generation schedule at node i
L_i	load schedule at node i

C_i energy bid from generation at node i

$\boldsymbol{G}$ generation schedule vector

$g(\boldsymbol{G})$ power balance equation

$h_m(\boldsymbol{G})$ power flow for transmission constraint m

F_m power flow limit for transmission constraint m

$Loss$ power system loss

LPF_i loss penalty factor for power injection at node i

$SF_{i,m}$ shift factor of power injection at node i on transmission constraint m

$GDF_{o_g,i}$ generation loss distribution factor of generation contingency g at node i

LMP_i locational marginal price at node i

λ system marginal energy cost (shadow price of power balance constraint)

μ_m shadow price of transmission constraint m

D_{o_g} Derate % of generator outage o_g under generation contingency g. (e.g. 100% for full outage, 0% for no outage)

$\delta_{o_g,i}$ Binary parameter (0 or 1) that identifies the generator node i with generator outage o_g under generation contingency g

7.2 Simplifying Assumptions

To simplify the mathematical formulation solely for the purpose of presentation, the following assumptions are made:

- There is a single interval in the time horizon, thus inter-temporal constraints are ignored.
- There is a single BAA, thus EIM Entities and Energy Transfers are ignored.
- Imports and exports are ignored.
- Unit commitment costs and variables are ignored, thus it is assumed that all generating resources are online and all MSG resources are fixed in a given state.
- Load bids are ignored, thus load is scheduled as a price-taker at the load forecast.
- The energy bids cover the entire generating resource capacity from minimum to maximum.
- There is a single energy bid segment for each generating resource.
- Ancillary services are ignored.

7.3 Mathematical Formulation

The mathematical formulation of the complete preventive contingency optimization problem is as follows:

$$\min \sum_{i=1}^{N} C_i \left(G_i - G_{i,\min}\right) \qquad (a)$$

subject to:

$$g(\boldsymbol{G}) = 0 \qquad (b)$$

$$h_m(\boldsymbol{G}) \le F_m, \qquad m = 1,2,\dots,M \qquad (c)$$

$$h_m^k(\boldsymbol{G}) \le F_m^k, \qquad \begin{cases} m = 1,2,\dots,M \\ k = 1,2,\dots,K \end{cases} \qquad (d)$$

$$G_i^g = G_i + GDF_{o_g,i} \cdot G_{o_g}, \qquad \begin{cases} i = 1,2,\dots,N \\ g = 1,2,\dots,K_g \end{cases} \qquad (e)$$

$$h_m^g(\boldsymbol{G}^g) \le F_m^g, \qquad \begin{cases} m = 1,2,\dots,M \\ g = 1,2,\dots,K_g \end{cases} \qquad (f)$$

$$G_{i,\min} \le G_i \le G_{i,\max}, \qquad i = 1,2,\dots,N \qquad (g)$$

Where:

(a) is the objective function comprised of the bid cost for energy.

(b) is the power balance constraint in the base case, which can be linearized around the base case power flow solution as follows:

$$g(\boldsymbol{G}) \equiv \sum_{i=1}^{N} (G_i - L_i) - Loss \cong \sum_{i=1}^{N} \frac{\left(G_i - \tilde{G}_i\right)}{LPF_i} = 0$$

(c) is the set of transmission constraints in the base case, which can be linearized around the base case power flow solution as follows:

$$h_m(\boldsymbol{G}) \cong \tilde{h}_m\left(\widetilde{\boldsymbol{G}}\right) + \sum_{i=1}^{N} SF_{i,m} \left(G_i - \tilde{G}_i\right) \le F_m, \qquad m = 1,2,\dots,M$$

(d) is the set of transmission constraints in each preventive contingency case, which can be linearized around the post-contingency case power flow solution as follows:

$$h_m^k(\boldsymbol{G}) \cong \tilde{h}_m^k\left(\widetilde{\boldsymbol{G}}\right) + \sum_{i=1}^{N} SF_{i,m}^k \left(G_i - \tilde{G}_i\right) \le F_m^k, \qquad \begin{cases} m = 1,2,\dots,M \\ k = 1,2,\dots,K \end{cases}$$

where the shift factors reflect the post-contingency network topology and the transmission power flow limits are the applicable emergency limits.

(e) is the generation loss distribution in the generation contingency state, which is assumed lossless and pro rata on the maximum online generation capacity from supply resources with frequency response capability, ignoring associated capacity and ramp rate limits. This value approximates the system response to loss of generation closely to how the system will actually behave. This value is used only to model flows placed on transmission in the contingency case, and is aligned with current operations engineering study practices:

$$GDF_{o_g,i} = \begin{Bmatrix} -(\frac{D_{o_g}}{100}) & i = o_g \\ 0 & i \notin S_{FR} \wedge i \neq o_g \\ \frac{D_{o_g}}{100} \frac{u_i\, G_{i,\max}}{\sum_{\substack{i \in S_{FR} \\ i \neq o_g}} u_i\, G_{i,\max}} & i \in S_{FR} \wedge i \neq o_g \end{Bmatrix}, \begin{cases} i = 1,2,\ldots,N \\ g = 1,2,\ldots,K_g \end{cases}$$

(f) is the set of transmission constraints in each generation contingency case, which can be linearized around the post-contingency case power flow solution as follows:

$$h_m^g(\boldsymbol{G}^g) \cong \tilde{h}_m^g(\widetilde{\boldsymbol{G}}) + \sum_{i=1}^{N} SF_{i,m}^g\,(G_i^g - \tilde{G}_i) = \tilde{h}_m(\widetilde{\boldsymbol{G}}) + \sum_{i=1}^{N} SF_{i,m}^g\,\left(G_i + GDF_{o_g,i}\,G_{o_g} - \tilde{G}_i\right)$$

$$\leq F_m^g, \quad \begin{cases} m = 1,2,\ldots,M \\ g = 1,2,\ldots,K_g \end{cases}$$

where the shift factors reflect the post-contingency network topology, which can be different than the base case if the contingency definition includes a transmission outage, and the transmission power flow limits are the applicable emergency limits.

(g) is the set of the resource capacity constraints in the base case.

7.4 Locational Marginal Prices

The LMPs are as follows:

$$LMP_i = \frac{\lambda}{LPF_i} - \sum_{m=1}^{M} SF_{i,m}\, \mu_m - \sum_{k=1}^{K}\sum_{m=1}^{M} SF_{i,m}^{k}\, \mu_m^{k} - \sum_{g=1}^{K_g}\sum_{m=1}^{M}\left(SF_{i,m}^{g} + \delta_{o_g,i} \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j} \right) \mu_m^{g}, \qquad i = 1,2,\ldots,N$$

Where:

$$\delta_{o_g,i} = \begin{cases} 1 & i = o_g \\ 0 & i \neq o_g \end{cases}, \begin{cases} i = 1,2,\ldots,N \\ g = 1,2,\ldots,K_g \end{cases}$$

Therefore, the marginal congestion contribution from a binding transmission constraint in a generator contingency to the locational marginal price at the node of the generator outage includes the impact of the assumed generation loss distribution.

A generator modeled in a generator contingency receives appropriate compensation taking into account its contribution to total production cost. The transmission constraint shadow prices are zero for constraints that are not binding in the base case or the relevant contingency case.

7.5 Generation Flow Factors (GFFs)

Similar to how a traditional "shift factor" represents the control variable's contribution to a particular constraint ($SF_{i,m}$ and $SF_{i,m}^{k}$), we can summarize a generator's contribution to the generator preventive constraint cost for a particular monitored element as a GFF in order to simplify the LMP calculation in the examples presented in this paper.

The GFF, or contribution to the generator contingency preventive constraint, is:

$$GFF_{i,m}^{g} = SF_{i,m}^{g} + \delta_{o_g,i} \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

The GFF for the all generators that are not the contingency generator ($i \neq o_g$) simplifies to the network topology shift factor because each generator's $\delta_{o_g,i} = 0$:

$$GFF_{i,m}^{g} = SF_{i,m}^{g} + \delta_{o_g,i} \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j} = SF_{i,m}^{g} + (0) \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

$$GFF_{i,m}^{g} = SF_{i,m}^{g} \qquad \forall i \neq o_g$$

The GFF for the generator that is the contingency generator ($i = o_g$) simplifies as follows:

$$GFF_{o_g,m}^{g} = SF_{o_g,m}^{g} + \delta_{o_g,i} \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

$$GFF_{o_g,m}^{g} = SF_{o_g,m}^{g} + (1) \sum_{j=1}^{N} SF_{j,m}^{g}\, GDF_{o_g,j} = SF_{o_g,m}^{g} + SF_{o_g,m}^{g} \cdot GDF_{o_g,o_g} + \sum_{\substack{j=1 \\ j \neq o_g}}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

$$GFF_{o_g,m}^{g} = SF_{o_g,m}^{g} + SF_{o_g,m}^{g} \cdot (-\frac{D_{o_g}}{100}) + \sum_{\substack{j=1 \\ j \neq o_g}}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

$$GFF_{o_g,m}^{g} = SF_{o_g,m}^{g} \cdot (1 - \frac{D_{o_g}}{100}) + \sum_{\substack{j=1 \\ j \neq o_g}}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

For Full Outage (D_{o_g}=100%):

$$GFF_{o_g,m}^{g} = \sum_{\substack{j=1 \\ j \neq o_g}}^{N} SF_{j,m}^{g}\, GDF_{o_g,j}$$

This GFF simplifies the LMP calculation in the examples below. All generators not part of the generator contingency definition ($i \neq o_g$) are charged $GFF_{i,m}^{g}$ (simplified above to the network topology shift factor $SF_{i,m}^{g}$) multiplied by the shadow cost of the generator contingency constraint (μ_m^g).The generator on contingency ($i = o_g$) is charged $GFF_{o_g,m}^{g}$ multiplied by the shadow cost of the generator contingency constraint (μ_m^g). It represents the total impact on the monitored element from all of the locations on the system to where the optimization distributes the lost generation.

8 Appendix-3: CRR Formulation for GCARM

8.1 Preventive Constraint Modeling

During the SFT, transmission constraints will be enforced. For GCARM type contingencies, the transmission constraints that are used in the SFT are the emergency ratings of transmission elements.

Flow Constraints for each constraint, g	$\sum_{i=1}^{N} X_i \cdot GFF_{i,g} \leq hourlyTTC_g$	$GFF_{i,g}$ is the Generator Flow Factor (calculated as the aggregate impact on the constraint from the locations where the injection is distributed) for the i^{th} control variable on the g^{th} GCARM constraint. HourlyTTC_g is the limit for the g^{th} constraint. X_i is the MW quantity of CRRs awarded.

Similar to the GFF calculation used in the DAM and RTM, the CRR market will use a calculated GFF based on the CRR full network model and derived GDFs. Where o_g is the contingency generator (or in this case the contingency generator node):

$$GFF_{i,g} = SF_{i,g} \qquad \forall i \neq o_g$$

$$GFF_{i,g} = SF_{i,g} \cdot (1 - \frac{D_i}{100}) + \sum_{\substack{j=1 \\ j \neq o_g}}^{N} SF_{j,g}\, GDF_{o_g,j} \qquad i = o_g$$

8.2 GDF

~~$$GDF_{o_g,i} = \begin{cases} -\left(\frac{D_{o_g}}{100}\right) & i = o_g \\ 0 & i \notin S_{FR} \wedge i \neq o_g \\ \left(\frac{1}{N}\right)\frac{D_{o_g}}{100} \cdot \sum_{t \in H}\left(\frac{u_{i,t} \cdot G_{i,max,t}}{\sum_{i \in S_{FR}, i \neq o_g}(u_{i,t} \cdot G_{i,max,t})}\right) & i \in S_{FR} \wedge i \neq o_g \end{cases}$$~~

The frequency-responsive contribution of resources outside the market footprint

~~Where,~~

~~*H is the set of hours in the season (or month) in the time period of interest (e.g. peak or off-peak),*~~

~~*N is the number of hours in H*~~

~~*t is the hour within H*~~

~~$u_{i,t}$ *is the unit commitment status in hour t*~~

is represented at system resources at the interties of the market footprint using the shift factors of the frequency-responsive physical units of these resources to those interties:

$$I_{k,t} = \sum_{i \notin MF} \sum_{j} SF_{i,j,k,t} \cdot FR_{i,j} \cdot a_{i,j,t} \cdot \bar{G}_{i,j,t}$$

The lost injection GDFs are derived as the average pro rata distribution to all available frequency-responsive physical units, including system resources at the interties of the market footprint:

$$GDF_{o_g,i} = \begin{cases} -\left(\frac{D_{o_g}}{100}\right), & i = o_g \\ \left(\frac{1}{N}\right)\frac{D_{o_g}}{100} \cdot \sum_{t \in H}\left(\frac{u_{i,t} \cdot \sum_j FR_{i,j} \cdot a_{i,j,t} \cdot \bar{G}_{i,j,t}}{\sum_{i \in MF-K \wedge i \neq o_g}\left(u_{i,t} \cdot \sum_j FR_{i,j} \cdot a_{i,j,t} \cdot \bar{G}_{i,j,t}\right) + \sum_{k \in K} I_{k,t}}\right), & i \in MF-K \wedge i \neq o_g \\ \left(\frac{1}{N}\right)\frac{D_{o_g}}{100} \cdot \sum_{t \in H}\left(\frac{I_{k,t}}{\sum_{i \in MF-K \wedge i \neq o_g}\left(u_{i,t} \cdot \sum_j FR_{i,j} \cdot a_{i,j,t} \cdot \bar{G}_{i,j,t}\right) + \sum_{k \in K} I_{k,t}}\right), & i = k \in K \end{cases}$$

Where,

H is the set of hours in the season (or month) in the time period of interest (e.g. peak or off-peak),

N is the number of hours in H

g is the generation contingency index;

i is the resource index;

o_g is the lost resource index for generation contingency g;

j is the physical unit index;

k is the market footprint intertie index and the system resource index at that intertie;

t is the time period (hour) index within H;

T is the set of time periods in the season (or month) in the time period of interest (e.g. peak or off-peak);

N is the number of time periods in T;

MF is the set of resources within the market footprint;

K is the set of system resources at market footprint interties;

$\wedge$ Logical and.

D_{o_g} is the percentage loss for resource o_g.

$u_{i,t}$ is the unit commitment status of resource i in time period t; (1=committed; 0=decomitted)

$a_{i,j,t}$ is the availability status of physical unit j of resource i in time period t; (=available MW/registered Pmax)

$SF_{i,j,k,t}$ is the shift factor of physical unit j of resource i to the market footprint intertie k in time period t;

$I_{k,t}$ is the import contribution from resources outside the market footprint at intertie k in hour t;

$FR_{i,j}$ is the frequency response flag for physical unit j of resource i (1 for frequency-responsive and 0 otherwise); and

$\bar{G}_{i,j,t}$ is the maximum capacity of physical unit j of resource i in time period t.

It is assumed that the set of frequency-responsive units ~~(S_{FR})~~ and the partial outage percentage (D_{o_g}) are constant over H. In case of unavailability of historical unit commitment status data (e.g. for new resources), the commitment status ($u_{i,t}$) should be 1~~, except for known generator outages that are modeled in H.~~.