California ISO

Evaluation of Generator Reactive Capability

White Paper

October 4, 2019

Foreword

This white paper is developed by the CAISO in coordination with Participating TOs to ensure a consistent methodology is applied to evaluate a generator's reactive capability in the generator interconnection studies.

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1. Introduction

This white paper focuses on methodology to evaluate reactive capability of non-synchronous generators and establishes a common approach for the CAISO and all Participating TOs to evaluate the reactive capability of newly interconnecting generators in the interconnection studies. The actual operational capability shall be verified when the generator achieves commercial operation and will not be addressed here.

FERC Order 827 requires all newly interconnecting non-synchronous generators[1], including wind generators, to provide dynamic reactive power within the range of 0.95 leading to 0.95 lagging at the high-side of the generator substation unless the transmission provider has established a different power factor range that applies to all non-synchronous generators in the transmission provider's control area on a comparable basis. These new non-synchronous generators are required to maintain a composite power delivery at continuous rated power output.

Non-synchronous generators may meet the dynamic reactive power requirement by utilizing a combination of the inherent dynamic reactive power capability of the inverter, dynamic reactive power devices (e.g., Static VAR Compensators), and static reactive power devices (e.g., capacitors) to make up for losses.

The requirement is applicable to:

- An existing non-synchronous generating facility making upgrades to its generating units after September 21, 2016
- Non-synchronous generating facilities submitting a written request to conduct a re-study under Section 6.4 of Appendix U of the CAISO tariff on or after September 21, 2016
- An interconnection customer that posts the Interconnection Financial Security for a non-synchronous generating facility pursuant to Appendix DD of the CAISO tariff section 11.2.2 on or after September 21, 2016
- An interconnection customer that submits an interconnection request for a non-synchronous generating facility under the Fast Track process on or after September 21, 2016

The guidelines presented in this paper are to ensure that all PTOs generally use consistent principles when evaluating the reactive capabilities of new generators. PTOs may procedurally deviate in the application but the following general principles should be followed:

1. If a generator can meet the power factor requirement under normal conditions but is deficient under abnormal conditions[2], the IC can mitigate the deficiency by adding more reactive resources, changing the project's interconnection parameters to reduce VAR requirements, or use an automated control scheme to de-rate the real power output of the generator to meet the reactive power requirement.

[1] The requirements did not change for synchronous generators. A synchronous generator is required to maintain a composite power delivery at continuous rated power output at the terminals of the Electric Generating Unit at a power factor within the range of 0.95 leading to 0.90 lagging. Such requirement can be verified from the generator capability curve directly.

[2] Abnormal conditions here refer to steady state post contingency voltage limits as applicable to PTO and captured in the ISO planning standards.

2. Generators that are capable of providing more reactive support than required are modeled in the studies providing only the required amount, if technically feasible.

2. Methodology

2.1. Model Generator Reactive Capability

The power flow model submitted by the interconnection customer shall include all VAR devices in the generating plant. In addition, the interconnection customer shall provide reactive capability curve(s) for the generating units. If multiple capability curves are provided, the interconnection customer shall specify the intended operating conditions to determine the capability. For example, the IC submits reactive capability curves at 25°C and 50°C, and specifies 40°C as the operating temperature. If the CAISO and Participating TOs agree with 40°C operating temperature, the IC will provide the capability curve at the agreed upon operating temperature. The CAISO and Participating TOs will review and validate the submission. In case agreement can't be reached, the most conservative capability will be assumed in the evaluation (e.g. capability at 50°C).

For new synchronous generators, the reactive capability curve is modeled by "qtab" table in GE PSLF and the QTAB flag in the "gens" table is set to 1.

For non-synchronous generators,

- ***During the Interconnection Request validation*** : Refer to the two approaches proposed in Section 2.3
- ***During the interconnection studies***, studies will assume that the generator will operate its reactive capability up to the requirement and model the reactive requirement in the "gens" table:
  - Control mode=2: voltage at regulated bus is held constant within Q limits of generator specified by pf input parameter
  - If regulating high side bus of the GSU: Power factor = higher numerical value of 0.95 and the generator power factor. Typically the generator power factor is less than or equal to 0.95 in order to meet the power factor requirement at the high side of the step-up transformer. In case, there is dynamic reactive devices other than generator itself, the generator power factor may be higher than 0.95.
  - If regulating the generator terminal bus: Power factor = generator power factor to meet the power factor requirement at the high side of the step-up transformer.
  - The reactive capability in "qtab" table is for information and the QTAB flag in the "gens" table is set to 0.

The control mode 2 approach has one limitation when the generator is dispatched at much lower than its PMAX and there are shunt capacitors at the plant. Unless manual adjustment is made to turn off the shunt capacitor, the reactive supply from the plant is over-estimated. This is typically not an issue in the generation interconnection studies since generators in the study area are dispatched close to PMAX. However, attention is needed to switch out shunt capacitors in the study area when testing congestion management by scaling down generation.

2.2. Base Cases

During the interconnection request validation, the reactive capability may be evaluated with the stand-alone power flow model submitted by the interconnection customer. If the submitted power flow model is not a stand-alone case that can be solved in GE PSLF, the Participating TO may choose to add infinite bus and generator in the power flow model or add the model to one of the Participating TO's GIP reliability assessment base case. If the actual base case is used, the POI bus of the generation project is set to type 0 in the test, which effectively becomes the infinite bus.

During the interconnection studies, the reactive capability is examined in the GIP peak reliability assessment base case, and the charging reliability assessment base case for energy storage project in charging mode.

For material modification evaluation or repower affidavit evaluation, the reactive capability of the generation project is tested in the latest GIP reliability assessment base cases with updated models.

2.3. Evaluate Reactive Capability

Evaluation as part of Interconnection Request Validation

Evaluation of reactive capability is performed during a new/modified IR review and validation. The following approaches are used to conduct this test:

The first approach[3] is to determine PGEN to achieve requested MW injection at POI and test reactive capability through one test procedure. Since PGEN is being adjusted, qtab is used to calculated Qmax and Qmin from PGEN. Generator regulating voltage schedule is set to a low value to force the generator to absorbvars and then set to a high value to force the generator to produce vars.

1. Set POI bus voltage schedule to the normal operating voltage (mid-point of the operating voltage range specified by the applicable operating procedure).
2. Adjust PGEN of the project to achieve requested MW injection at POI.
3. Set PMAX = PGEN.
4. Set control mode to 0 and enable qtab modeling.
5. Set terminal bus voltage schedule to 1.1[4].
6. Determine if overall power factor and dynamic power factor requirements are met.
7. Set terminal bus voltage schedule to 0.9[5].
8. Turn off shunt capacitors, if any.
9. Determine if overall power factor and dynamic power factor requirements are met[6].

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[3] PG&E used second approach for the evaluation

[4] This is a test to draw the full leading reactive capability from the generator. It should not be interpreted as the generator will be regulating voltage to 0.9 p.u or Section 2.3 Step 5 proposed voltage schedule in steady-state. If it is not sufficient to make QGEN = QMIN, the voltage schedule could be adjusted lower.

[5] This is a test to draw the full lagging reactive capability from the generator. It should not be interpreted as the generator will be regulating voltage to 1.1 p.u. or Section 2.3 Step 6 proposed voltage schedule in steady-state. If it is not sufficient to make QGEN = QMAX, the voltage schedule could be adjusted higher.

[6] If there is a shortage at 0.9 or 1.1 pu voltage, but there is no shortage at 0.95 and 1.05 pu (pre contingency high low voltage range), the IC will be requested to provide confirmation that they will de-rate their facility active power output to have sufficient reactive power capability whenever voltages are outside of the continuous normal range. The control scheme to limit

The second approach is to have PGEN pre-determined and fixed in the test. Qmax and Qmin are already obtained for PGEN. The QGEN is set to Qmax and Qmin, respectively, to verify the reactive capability measured at the high-side of the step-up transformer.

1. Set P gen = P required to meet requested MW @ POI
2. Set generator bus type = 1
3. Set Q gen = Q max
4. Set POI bus to swing (type = 0)
5. Set swing bus scheduled voltage to post-contingency minimum voltage using voltage from CAISO Planning Standards.
6. Turn off all shunt devices (Capacitors, Reactors and SVDs)
7. Record P gen, Q gen, P at high side of GSU, and Q at high side of GSU
8. VAR losses = Q at high side of GSU – Q gen
9. If VAR losses < Shunt Capacitor + SVDs, then Dynamic Q = Q gen
10. If VAR losses > Shunt Capacitor + SVDs, then Dynamic Q = Q gen – (VAR losses - Shunt Capacitor – SVD)
11. Dynamic PF = P at high side of GSU / SQRT((P at high side of GSU ^2 + Dynamic Q ^2))
12. Set P gen = P required to meet requested MW @ POI
13. Set generator bus type = 1
14. Set Q gen = Q min
15. Set POI bus to swing (type = 0)
16. Set swing bus scheduled voltage to post-contingency maximum voltage using voltage from CAISO Planning Standards.
17. Turn off all shunt devices (Capacitors, Reactors and SVDs)
18. Record P gen, Q gen, P at high side of GSU, and Q at high side of GSU
19. VAR losses = Q at high side of GSU – Q gen
20. Dynamic Q = Q gen
21. Dynamic PF = P at high side of GSU / SQRT((P at high side of GSU ^2 + Dynamic Q ^2))

If the generation project includes energy storage facilities, and it is expected that the charging scenario is more stressed than the discharging scenario, then an evaluation can be performed for the reactive capability in charging mode as follows:

1. Set PGEN to the max charging power requested by the Interconnection Customer.
2. Set POI bus voltage schedule to 1.1. or appropriate post-contingency high voltage limit[7] as applicable to PTO and specified in the ISO planning standard
3. Determine if overall power factor and dynamic power factor requirements are met.
4. Set POI bus voltage schedule to 0.9. or appropriate post-contingency low voltage limit as applicable to PTO and specified in the ISO planning standard
5. Turn off shunt capacitors, if any.
6. Determine if overall power factor and dynamic power factor requirements are met.

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the project's output must be automated. The range can be found in the CAISO Planning Standards: http://www.caiso.com/Documents/ISOPlanningStandards-September62018.pdf.

[7] Refer to Section 2-Voltage Standard of the ISO Planning Standards located at (http://www.caiso.com/Documents/ISOPlanningStandards-September62018.pdf.)

	Discharging Case		Charging Case	
Terminal Voltage Schedule (p.u.)	0.9	1.1	0.9	1.1
PGEN (MW)				
QGEN (Mvar)				
PF at terminal				
Shunt Capacitors/SVDs (MVar)				
Var Losses (MVar)				
P at High Side of GSU (MW)				
Q at High Side of GSU (MVar)				
PF at High Side of GSU				

The evaluation is reported in the IR validation form.

Verification as Part of the Interconnection Studies[8]

During the interconnection studies, such as Phase I, Phase II and System Impact Study, the generator reactive capability will be verified with the peak reliability assessment base case. The generators are modeled with

1. Control mode = 2
2. Power factor = higher numerical value of 0.95 and the generator power factor
3. The regulating bus is set to the high side bus of the GSU

The reactive capability is evaluated in conjunction with determining the gross MW output to achieve requested MW at POI. The generator PGEN is adjusted such that the MW injection to POI equals the requested value. For a project that shares gen-tie with others, the PGEN at the terminal to achieve MW at POI could vary noticeably from the value obtained in the IR validation due to non-linearity of the transmission losses. Given higher losses, the PGEN and PMAX needs to be higher, therefore less reactive capability is available. The power factor associated with control mode 2 shall be set properly to reflect the lower reactive capability.

The reactive losses from the generator terminal to the high side of the main transformer and the active and reactive power flows toward the POI measured at the high side of the main transformer are recorded. Then the reactive capability is demonstrated with the calculation illustrated in the example below.

Project MW Calculation	
No. of Inverters	107
Rated MW	3.9154
Rated MVA	4
Total Rated MW	418.9478
Total Rated MVA	428
Actual individual inverter MW Output to achieve MW at POI	3.87

[8] PG&E performs this evaluation as part of the IR review process.

Total actual MW output to achieve MW at POI	414.18
Total MW flow at High Side of GSU	406.32
Reactive Power Requirement	
(A) 0.95PF at High Side of GSU (MVar)	**132.81**
Transmission Var Losses	
+ Pad-Mount transformer losses (Mvar)	26.87
+ Collector equivalent losses (Mvar)	21.7
+ Main transformer losses (Mvar)	52.86
- Less collect line charging (Mvar)	0.27
(B) Total losses (Mvar)	**101.16**
Static Reactive Power Supply	
(C) Shunt capacitors (Mvar)	**130**
Dynamic Reactive Power Supply	
Generator reactive capability at the actual output (Mvar)	107.88
Other dynamic var devices (Mvar)	0
(D) Total Dynamic Supply (Mvar)	**107.88**
Reactive Capability Evaluation	
Overall reactive power (shortage)/surplus = (C) + (D) – (A) – (B)	0.93
Dynamic reactive power (shortage)/surplus = (D) - (A)	(24.93)

For energy storage charging mode, the evaluation is performed in the IR validation at the requested maximum charging power. It is not re-evaluated during the interconnection studies unless the CAISO or the Participating TOs identify changes that require re-evaluation.

The evaluation is reported in the interconnection study reports and material modification analysis. The report shall include the key evaluation data such as PGEN at which the reactive capability is evaluated, the assumed generator and other devices' reactive capability, the resulting power factor at the high side of the transformer, etc. As such calculation varies slight as the system condition changes, the data is only used to indicate if the requirement is met under the assessed scenario.

3. Implementation Plan

Reactive capability evaluation is included in the interconnection request validation, Phase I and Phase II interconnection studies, system impact study and facilities study, material modification analysis, repower analysis, and etc.

During the study process, a project shall cure deficiency before the next interconnection study based on information provided to the interconnection customer. For example, deficiency identified in Phase I study report shall be cured in Appendix B submission.

Deficiency identified in the Phase II study is discussed at the results meeting. The interconnection customer shall modify the generating or interconnection facilities to cure the deficiency. The modification is reviewed by the CAISO and Participating TO through MMA. The planning groups performs a final check at the synchronization request from the generator owner to ensure that the facilities installed have the capability. However, the generation project may be subject to other tests required by the CAISO and Participating TOs, which is not the intention of this paper and is not covered here.