POWER ENGINEERS, INC.

4100 INTERNATIONAL PLAZA
SUITE 320
FORT WORTH, TX 76109 USA

PHONE 817-882-1900
FAX 817-882-1999

MEMORANDUM

DATE: August 24, 2020

TO: Curtis Sanden

C: Ignacio Sanchez (SCE)
Nagy Abed (SCE)
Saurabh Shah (POWER)
Aaron Findley (POWER)
Stephen Mead (POWER)
Jamie Maciag (POWER)

FROM: Dustin Schutz

SUBJECT: 163500 SCE Inverter Modelling, Rev. 1

MESSAGE

Curtis,

As part of SCE's work to prepare for steadily increasing amounts of inverter-based generation, SCE has hired POWER to perform an evaluation of current industry best-practices regarding the modelling of inverter-based generation and how these practices compare to the built-in models provided by CAPE. POWER has also investigated how the various parameters of CAPE's inverter-based generation model affect short circuit contributions to the bulk power system. These discussions and recommended default values to use when modelling SCE's inverter-based resources are found below.

While validating data in the SCE Bulk Power CAPE model, POWER observed that a number of older wind turbines are Type I or Type II induction machines. These can be modelled as synchronous generators, and do not require use of current limiting modelling options. Unless readily available, negative-sequence impedance can be assumed equal to positive-sequence impedance. Zero-sequence impedance can be set to maximum since Type I and Type II wind turbines are typically ungrounded. Most of the newer wind farms in SCE's system are comprised of double-fed asynchronous turbines (Type III) or fully-converted turbines (Type IV). Photovoltaic solar panels, which inherently require a complete DC to AC conversion, are also best modelled as Type IV machines. SCE also has a small number of solar-thermal generation facilities in its system; since these facilities fundamentally operate by using heat to drive induction generators, they can be modelled as conventional synchronous generation.

The Electric Power Research Institute (EPRI) has developed phasor domain models of Type III and Type IV wind turbines (WT). These models have been validated with electro-magnetic transient (EMT) simulations using EMT-type models. The WT models consist of controlled current sources with the converter controls addressed with an iterative solution (nonlinear behavior). The impacts of control modes such as reactive power or voltage control are now included. The two major short circuit analysis programs used in the United States, Aspen Oneliner and CAPE, have both baselined their Type IV generator models against these EPRI models in 2019. Aspen has also implemented the EPRI model for its Type III generators, while CAPE continues development work to convert its basic Type III model to follow EPRI modelling. In addition to following EPRI developments, both companies have also been following reports produced by PSRC's C24 working group.

An alternative to the EPRI models is to model an inverter-based generator as a voltage-controlled current source. In both Aspen and CAPE, this is defined with a table of output currents and angles at given voltages. If this fault current data is available from the inverter manufacturer, the voltage-controlled current source accurately reproduces inverter fault currents. However, utilities often do not have the detailed inverter information required to model these inverters. Additionally, each control mode requires its own unique table, which imposes extra work on the utility for model maintenance if facilities change modes in the future. In that case, using the EPRI models is a more flexible and accurate approach.

Table of Type III and IV WT Models in CAPE and Aspen

Software	Generator Model	Strengths	Weaknesses
CAPE	Basic Type III with set current limit (EPRI Type III in development)	Simple to model.	Provides inaccurate negative & zero sequence currents for inverters. Slows down SC computation as more are added to model. Crowbars can only be applied to all Type III machines at once in SC preferences, which also turns off all Type IV machines.
	EPRI Type IV model	Current limited model that produces correct sequence currents for inverters. Computation time changeable via iteration variables.	Solution convergence not always possible for close-in faults, regardless of how many iterations are selected.

Aspen (V15)	EPRI Type III	Has detailed input parameters for accurate modelling.	Each generator can only be modelled as either current-controlled or crowbar-limited at one time. Likely doesn’t work from a flat start.
	EPRI Type IV model	Current limited model that produces correct sequence currents for inverters.	Solution convergence not always possible for close-in faults, regardless of how many iterations are selected. Fault Ride Through mode assumed unless otherwise specified.

At this time, POWER suggests utilizing CAPE’s available option for current-limited Type III machines, which is a simple phasor solution with a fixed current limit and a fixed impedance for currents below that limit. A Type III generator in CAPE should be filled out like a synchronous generator, apart from defining a current limit after selecting Type III. If the current limit of the converter is not known, a value of 2.5 pu on the machine base may be used (higher end of the typical range, this will vary with converter design). If the positive-sequence impedance of the turbine is not known, a value of 0.2 pu on the machine base may be used (typical value for synchronous generator; equates to 5 pu fault contribution). Similar to Type I and Type II, negative-sequence impedance may be set equal to the positive-sequence value and zero-sequence impedance should be set to the maximum. Note that turbine transformers need to be modeled separately from the generator for Type III machines, unlike Type IV (see below). When CAPE releases its new implementation of the Type III model, POWER recommends that SCE convert all Type III machines to that option. According to Siemens, a Type III model with enhanced positive-sequence controls is tentatively planned for release on December 31, 2020. Optional negative-sequence controls will be added at a later date (CAPE’s existing Type III model contributes negative-sequence current for unbalanced faults, but it is not controlled). CAPE’s EPRI Type III model may require additional manufacturer information on the control schemes implemented on each turbine.

Note that the Current Limited Machine Parameters (located in SC preferences) need to be set to Both_On in order to include all Type III and Type IV machines in the short-circuit solution. Both_Off will take all Type III and Type IV machines out of service. Type_3_Crowbar will crowbar all Type III machines at once and take all Type IV machines out of service. The crowbar action of a Type III machine applies a short to the rotor, effectively bypassing it and preventing damage at high currents. While crowbarred, the machine will behave as an induction machine (similar to Type I and Type II machines) and use the generator impedance without considering the entered current limit.

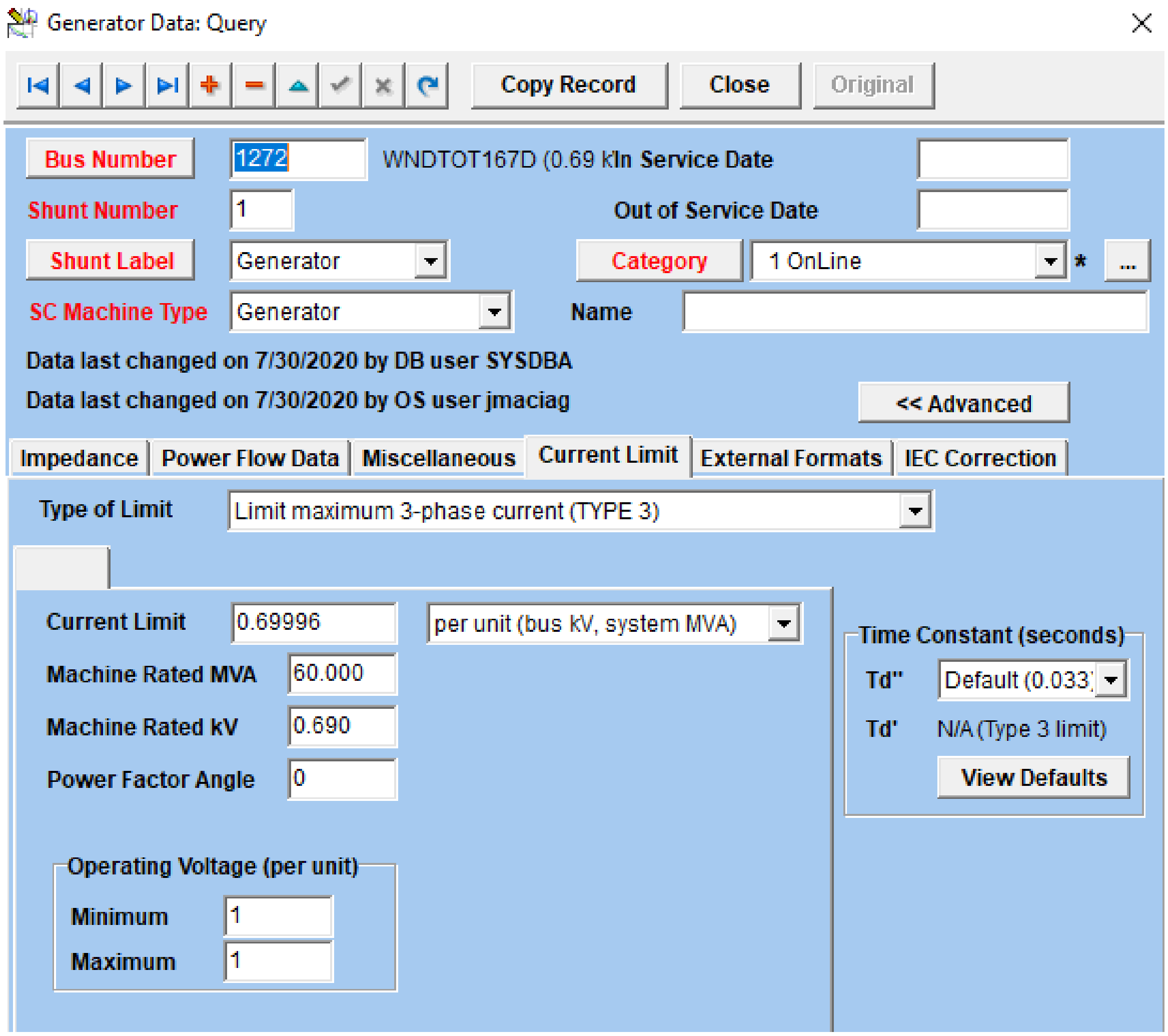
The table of CAPE parameters used in implementing the EPRI Type IV model follows. Note that only Type IV WTs and solar sites should use the EPRI Type IV model while Type III WTs should continue to use the Type III option in CAPE (see above). The recommended Type IV values below are provided to aid in consistent inverter-based generation (IBG) modelling in the SCE Bulk Power model. Values denoted with ** indicate that these fields are installation dependent, such as rated MVA, and will vary from site to site. Values denoted as N/A do not require any entry given SCE’s default IBG modelling, as these values are not used with the other options or control modes that SCE utilizes.

Table of CAPE Type IV Parameters and Recommended Values for SCE Use

Parameter Name	**Function**	**Discussion**	**Recommended Value Based on Existing SCE Installations**
Turbine Type	Turbine type	Only FC (Type IV Full Converter) is allowed for Type IV at present.	FC
Number of Turbines	Scales the "1 Turbine" ratings	Enter one or more turbines that CAPE will combine in parallel and model as a single shunt. This value will scale the S, P & Q values for a single turbine.	**
1 Turbine S (Base MVA)	Apparent power rating	Enter the apparent power rating for a single inverter or turbine. This value will be scaled by the Number of Turbines parameter.	**
1 Turbine P (Prefault MW)	Prefault real power	Enter the desired prefault real power for a single turbine. This determines prefault voltage and current. Use the actual MW per turbine if possible. A value of 0 here with a non-zero PF will result in no machine contribution.	**
1 Turbine Q (Prefault MVAR)	Prefault reactive power	Enter the desired prefault reactive power for a single turbine. This determines prefault voltage and current. This value can be left at 0, as CAPE will calculate it iteratively from PF (or V) and P while in PF or V mode.	0
V (kV line-line)	Voltage rating	Enter the line-line voltage of the generator bus. If the LV-MV transformer is modelled separately (R = 0 and X = 0) this should be the LV bus voltage otherwise (R > 0 and X > 0) it should be the MV bus.	**
Control Mode	Control mode of the plant	Q – Constant reactive power mode PF – Constant power factor mode V – Constant voltage mode FRT – Fault ride through mode Set this to the operating mode of the plant. New plants (post mid-2019) use V mode per the latest SCE interconnection agreement, while earlier plants use PF mode.	PF or V
FRT Slope (dI/dV pu)	Fault ride-through slope	Enter the slope when FRT mode is selected. Typical value is 2 pu.	2 pu
FRT DeadBand Vpu	Fault ride-through voltage deadband	Enter the min and max voltage deadband when FRT mode is selected. Typical values are 0.9 and 1.1 pu.	Min: 0.9 pu Max: 1.1 pu

Control Priority	Control priority for current limits	Select P if the inverter prioritizes real power/current. Select Q if the inverter prioritizes reactive power/current. For V or FRT typically choose Q priority to maintain bus voltage. For Q or PF control choose P priority to maximize real power.	P if PF mode Q if V mode
Desired bus voltage (pu)	Voltage reference	Enter the desired voltage reference. This is used for V control and is the target voltage for fault ride-through. CAPE allows data entry, but parameter has no impact on SC results when in PF mode.	N/A
Desired reactive power generation (pu)	Reactive power reference	Enter the desired reactive power reference when Q mode is selected. A positive value injects lagging current into the network. CAPE allows data entry, but parameter has no impact on SC results when in PF mode.	N/A
Desired Power Factor	Power factor reference	Enter the desired power factor reference when PF mode is selected. A negative PF reflects leading PF and is a negative PF angle between -90 and 0 degrees. A positive PF reflects lagging PF and is a positive PF angle between 0 and 90 degrees.	** if known 1.0 otherwise
Enter Data Using	Base MVA	Select Total MVA of turbines (= XX) if pu values are entered on the aggregate plant base. Choose System Base MVA (= 100) if pu values are entered on the system base.	Total MVA of turbines
I limit (pu)	Total current limit	Enter the total current limit. If unknown assume 1.1 pu.	1.1 pu
Id limit (pu)	Real current limit	Enter the real current limit. If unknown enter 1 pu.	1.0 pu
Iq limit (pu)	Reactive current limit	Enter the reactive current limit. If unknown enter 1 pu.	1.0 pu
LV-MV Transformer R (pu)	LV-MV transformer resistance	Enter the resistance for the LV-MV transformer. Set to 0.01 unknown.	0.01 pu
LV-MV Transformer X (pu)	LV-MV transformer reactance	Enter the reactance for the LV-MV transformer. Set to 0.1 if unknown.	0.1 pu
Filter Admittance G (pu)	Filter conductance	Enter the AC filter conductance of the inverter/turbine. Set to 0 if unknown	0 pu
Filter Admittance B (pu)	Filter susceptance	Enter the AC filter susceptance of the inverter/turbine. Set to 0.01 if unknown	0.01 pu

CAPE Type III Input Form



CAPE Type IV Input Form

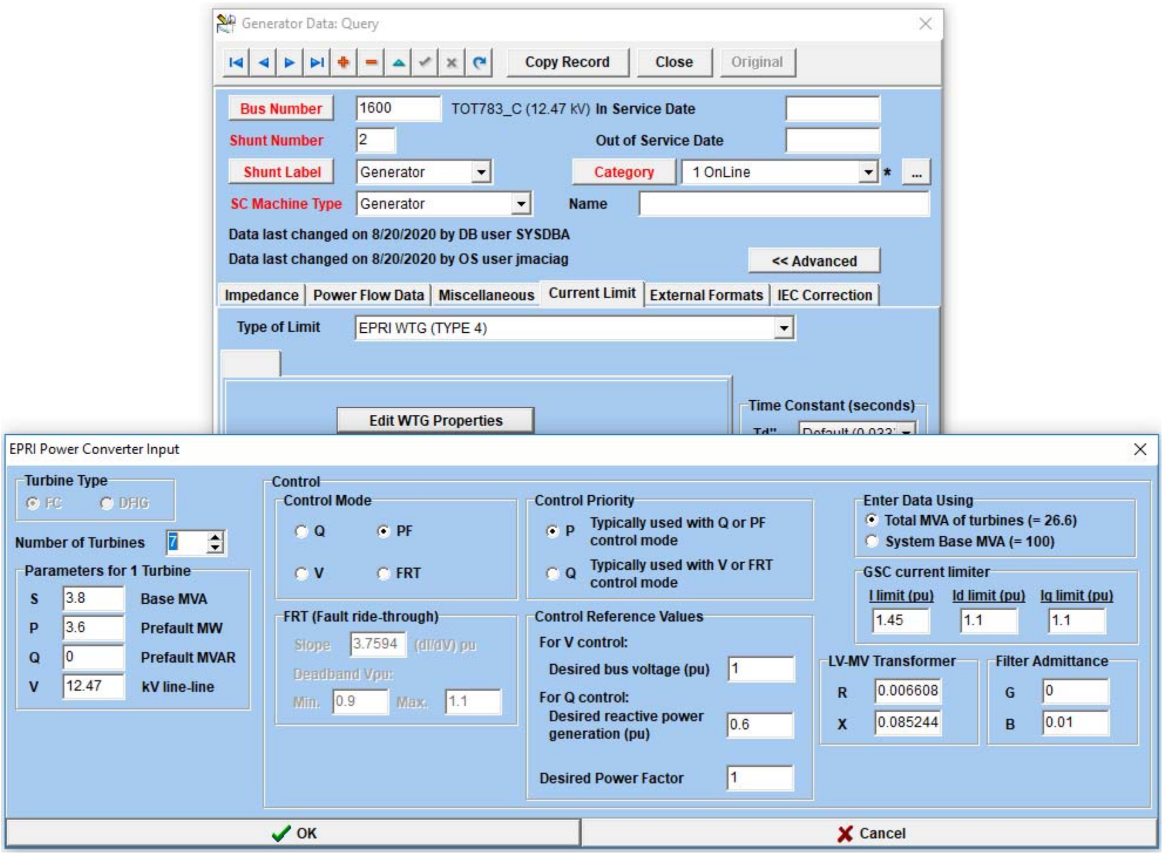


Diagram of individual turbine and transformer

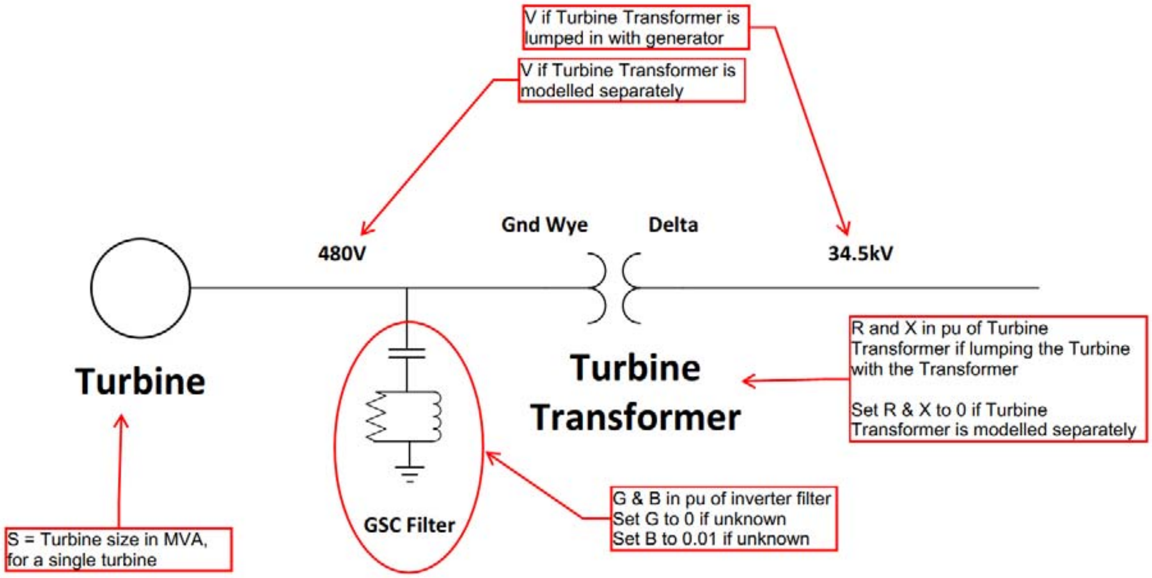
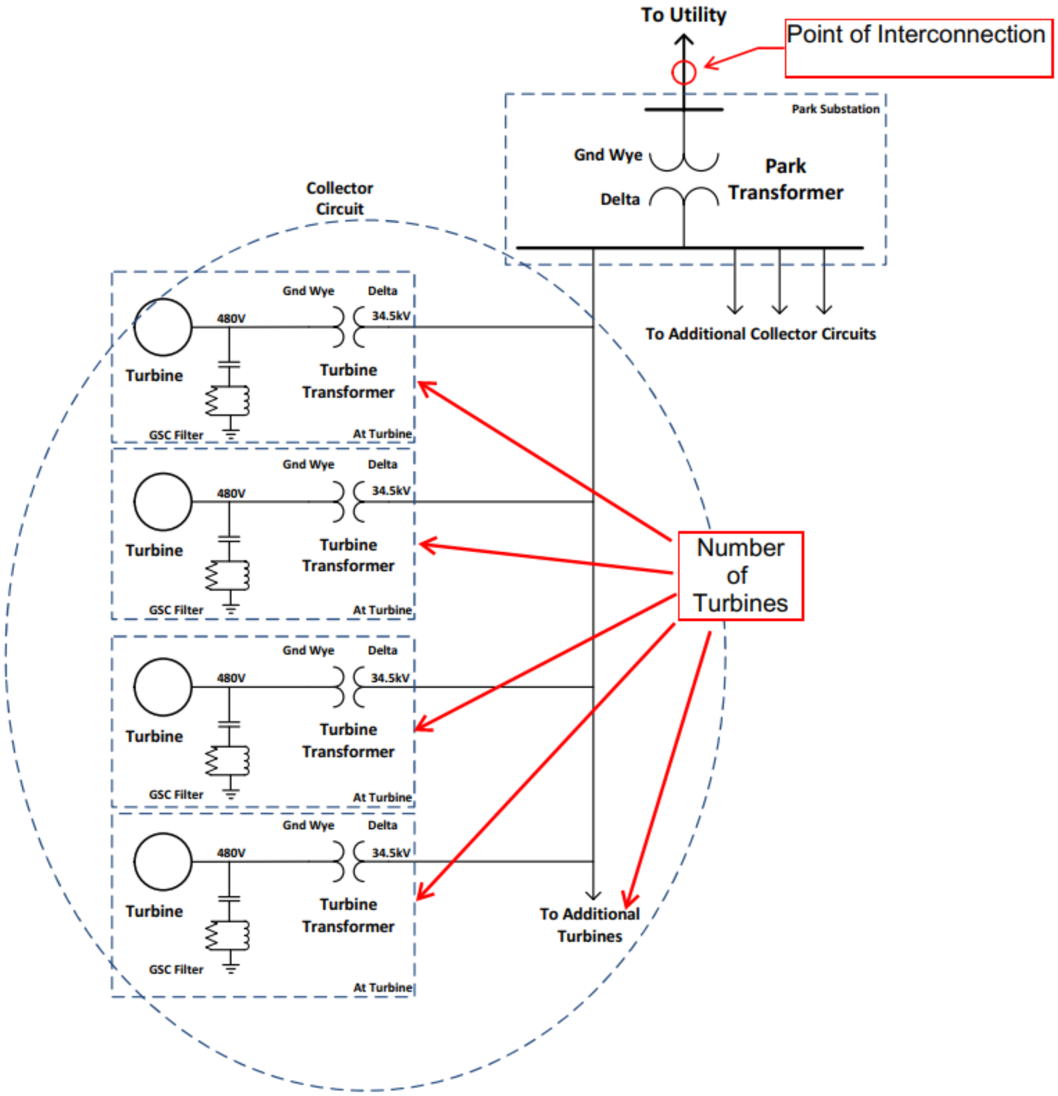


Diagram of wind park



References

"Inverter-Based Generator Models with Controlled Power and Current," presented at the 2019 PSS-CAPE User Group Meeting, Siemens Industry Inc., June 2019.

"Phasor Domain Modeling of Converter Interfaced Wind Turbines for Protection Studies," Evangelos Farantatos, EPRI.

"Technical Bulletin on Modeling Type-4 Wind Plant and Solar Plants," technical bulletin from www.aspeninc.com

"Modification of Commercial Fault Calculation Programs for Wind Turbine Generators" (Technical Report PES-TR78), IEEE Power & Energy Society - Power System Relaying and Control Committee - System Protection Subcommittee, Working Group C24

Sincerely,

Dustin Schutz