Converting REEC_B to REEC_A/D for Solar PV Generators

WECC REMTF

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Background—Retirement of REEC_B Model

As renewable penetration increased within the Western Interconnection, the WECC Modeling and Validation Work Group (MVWG) developed generic models for the inverter-based generators. The general model structures include the renewable-energy generator/converter (REGC) modules as the interface with the grid, the renewable-energy electrical controls (REEC) modules for the electrical controls of the individual units, and the renewable-energy plant controller (REPC) modules for the plant-level controls. The REGC and REPC models are common among many types of inverter-based generators. The selection of type of REEC model can vary among wind, solar PV, and energy storage plants. Originally, in 2014, the REEC_A model was developed for use for wind turbine generators, and, although it could (and had) been used to model PV inverters, some people within WECC requested and supported the development of the REEC_B model, a simplified version of REEC_A, for modeling solar PV. In 2015, the REEC_C model was developed for energy storage. As such, most people started using REEC_B for modeling solar PV.

Several disturbance events of large-scale solar PV generation loss occurred since 2017. Investigation of these events revealed that many solar PV plants used momentary cessation as a means of ride-through for abnormal voltage conditions. Momentary cessation is when no current is put into the grid by the inverters during low- or high-voltage conditions outside the continuous operating ranges. Such momentary cessation behaviors cannot be modeled using the REEC_B model approved for solar PV inverters. In 2018, the WECC MVWG modified the approval of REEC models to—

- REEC_A for wind, and solar PV, if using momentary cessation
- REEC_B for solar PV not using momentary cessation

However, such distinction between the REEC_A and REEC_B models for solar PV inverters may be neglected or cause confusion. The REEC_B model, simplified from the REEC_A model, does not have much more benefit or modeling capability than the REEC_A model. Therefore, the WECC MVWG approved the retirement of the REEC_B model in April 2019. Future submission of the REEC_B model is no longer accepted and the current REEC_B models in the WECC master dynamic file will be converted to REEC_A or REEC_D models. The recently approved REEC_D model has better modeling capability than REEC_A. Converting from REEC_B to REEC_D is straight-forward and mathematically accurate. Thus, this whitepaper is being revised to include guidelines of converting REEC_B to REEC_D.

Conversion of the REEC_B model to the REEC_A or REEC_D model includes the following:

1. For inverters using momentary cessation, the conversion to REEC_A or REEC_D should include properly accounting for momentary cessation setting. The REEC_A model has limitations on

modeling momentary cessation.[1] REEC_D,[2] recently approved by MVS, is fully capable of modeling momentary cessation. The REEC_B model should be replaced with REEC_D if any of the followings is true. Otherwise, the REEC_B model may be replaced by either REEC_A or REEC_D.

- It requires more than four breaking points to define the voltage-dependent limit for active current or reactive current.
- The momentary cessation voltage thresholds are different from the voltages *vdip* and *vup* at which the inverter closed-loop controls freeze.
- There is a recovery delay for the reactive current when the voltage returns to normal.

2. For inverters not using momentary cessation, the conversion could be done by adding parameters required by the REEC_A or RECC_D model. Converting to REEC_D is more straight-forward and preferred.

Converting REEC_B to REEC_A without Momentary Cessation

REEC_B model was a simplified version of REEC_A. A comparison between the model structures of REEC_A (Figure 1) and RECC_B (Figure 2) shows the following differences when modeling a solar PV plant:

1. The switch in the Kqv reactive current injection arm in REEC_A, but not in REEC_B.
2. VDL blocks in REEC_A, but not in REEC_B.
3. There are a few other parameters in REEC_A, that are not in REEC_B—thld2, vref1, pflag.

[1] https://www.nerc.com/comm/PC/NERCModelingNotifications/Modeling_Notification_-_Modeling_Momentary_Cessation_-_2018-02-27.pdf

[2] https://www.wecc.org/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/Pourbeik%20-%20Memo%20RES%20Modeling%20Updates_August%202020.pdf&action=default&DefaultItemOpen=1

Figure 1: REEC_A Model

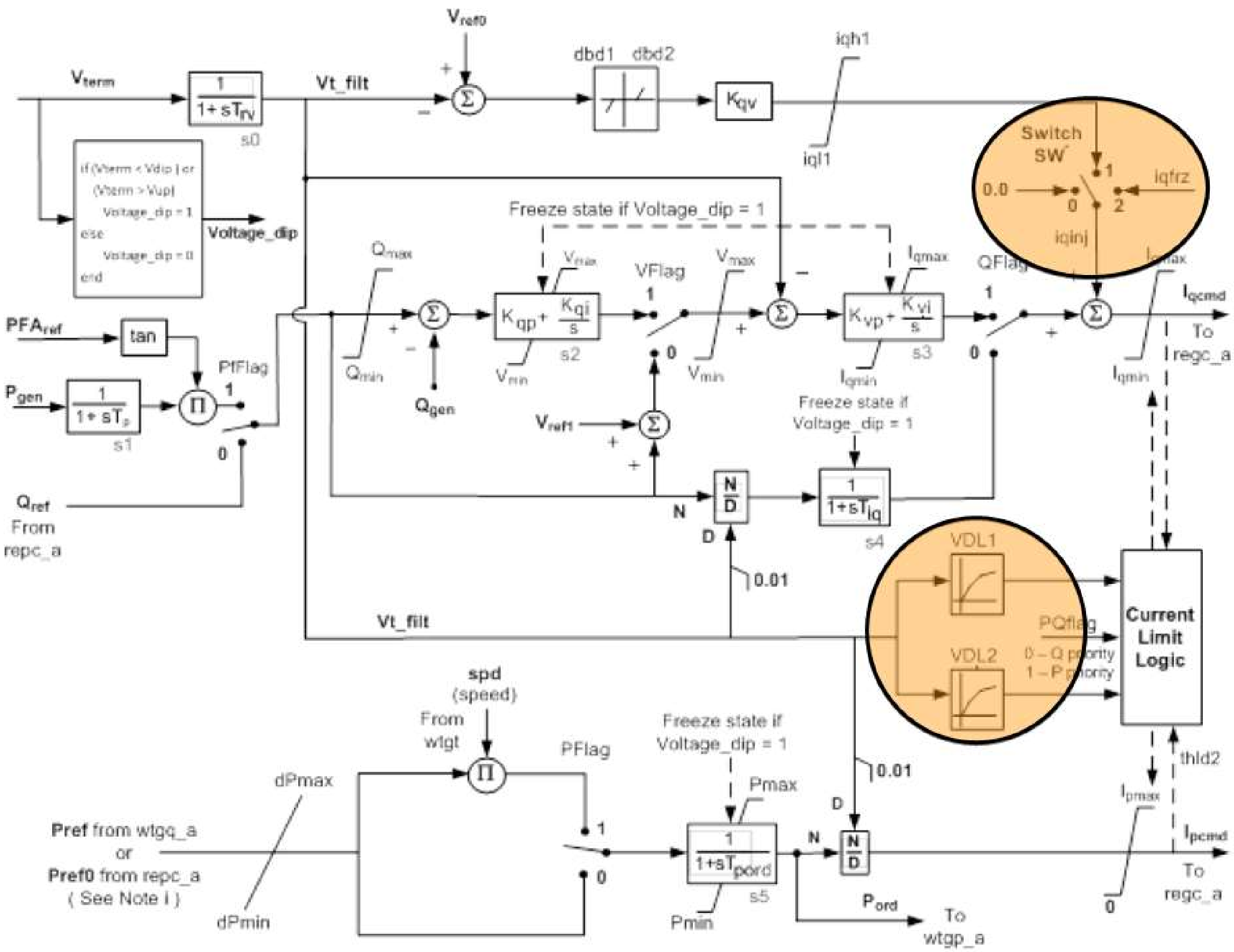
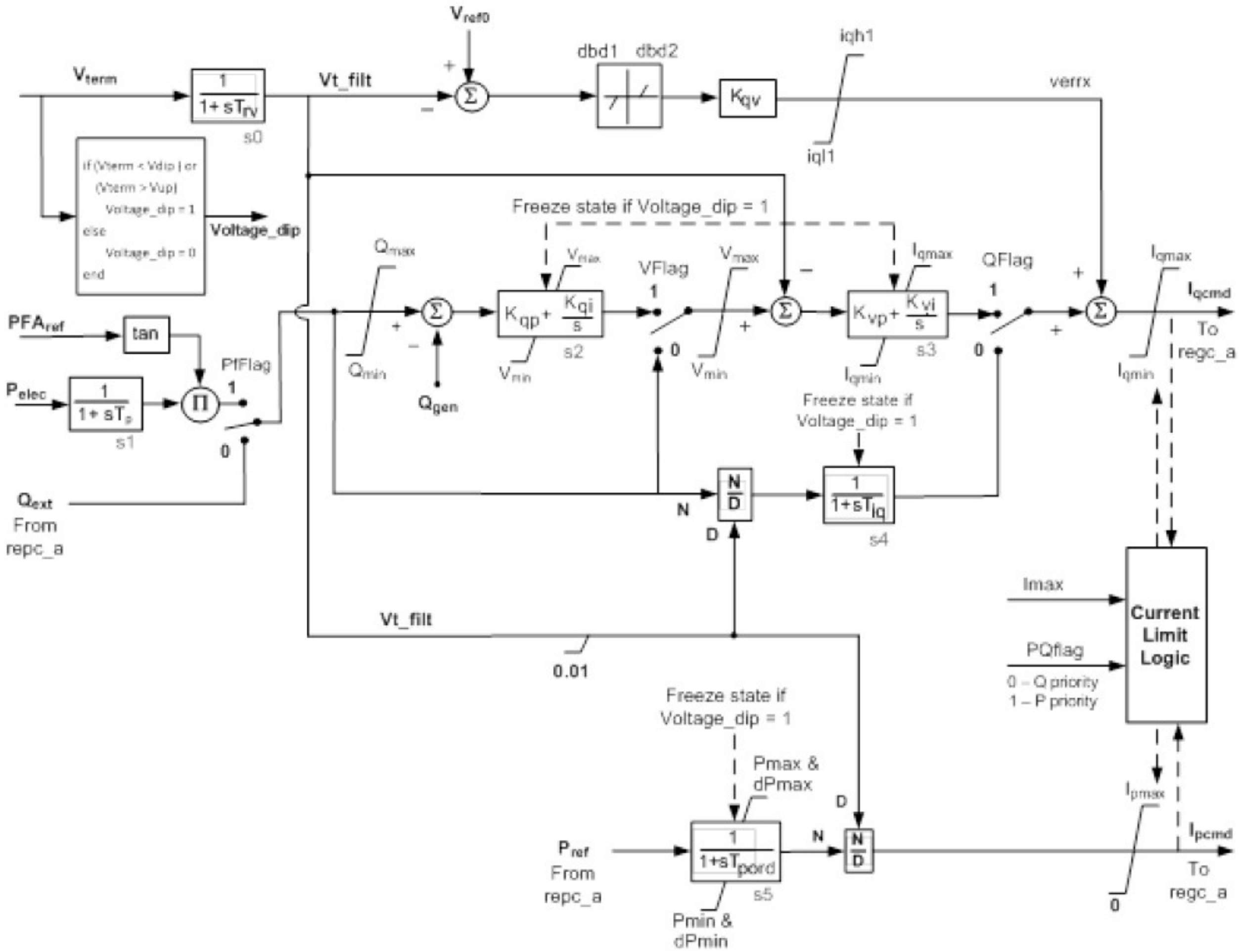


Figure 2: REEC_B Model



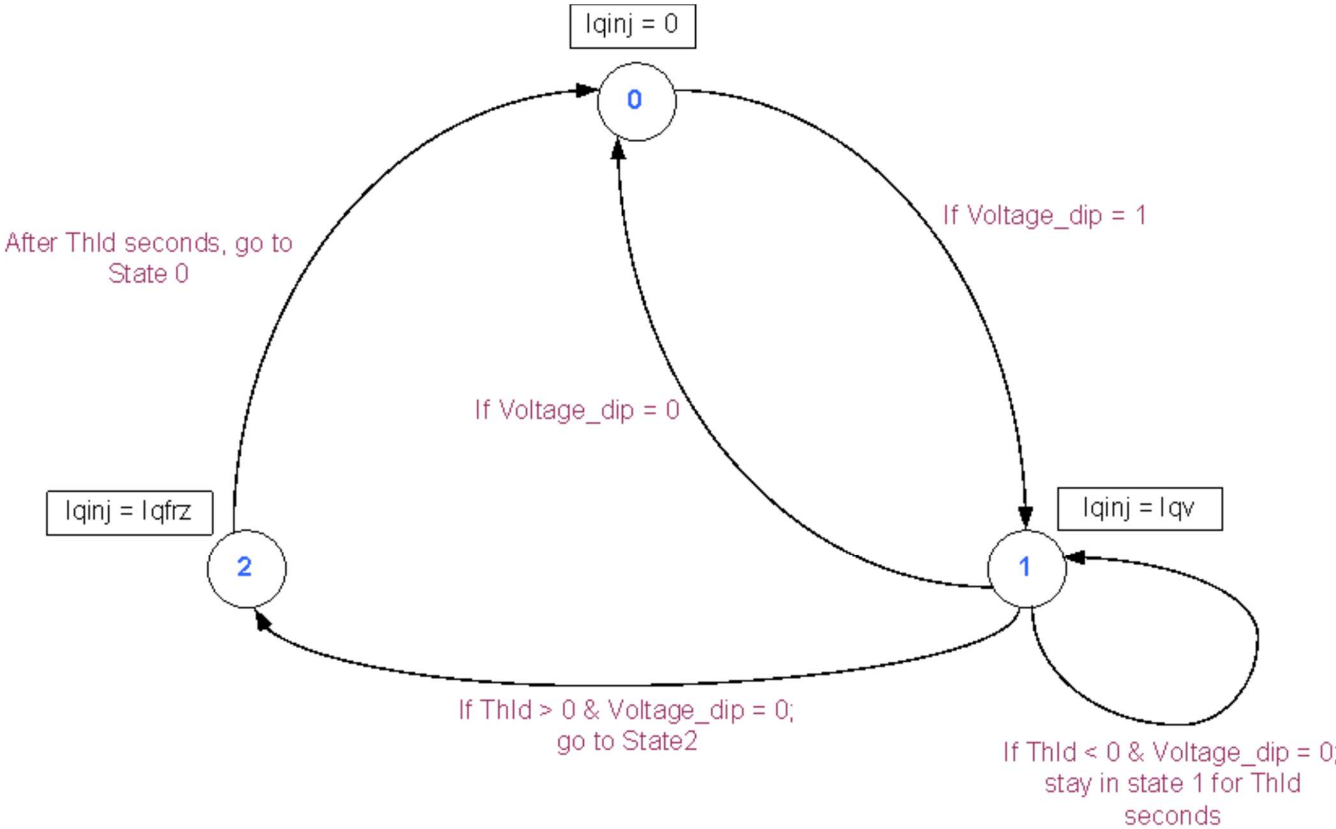
Parameters for Kqv reactive current injection

The reactive current injection switch in REEC_A controls the current injection as described below:

- Under normal operating conditions, *voltage_dip* = 0 and SW = 0.
- When *voltage_dip* changes to 1, SW is set to 1 to enable current injection.
- When *voltage_dip* changes from 1 to 0, depending upon the value of *thld*, one of the following actions takes place:
  - If *thld* = 0, SW is reset to 0 immediately and there is no more current injection from the arm.
  - If *thld* > 0, SW is set to 2 for *thld* seconds. During this *thld* seconds, the current injection is set to *iqfrz*. After *thld* seconds, SW is reset to 0; there is no more current injection from the arm.
  - If *thld* < 0, SW is held at 1 for |*thld*| seconds and the Kqv control continues during this period. After |*thld*| seconds, *SW* is reset to 0; there is no more current injection from the arm.

The state transition is shown in Figure 3.

Figure 3: REEC_A Reactive Current Injection State Transition Diagram



The REEC_B model always have current injection logic on.

When converting REEC_B to REEC_A, set ***thld* = 0** and ***iqfrz* = 0** in the REEC_A model. The conversion is not strictly equivalent between the REEC_A and REEC_B, as the REEC_A will check for voltage_dip = 1 to activate the reactive current injection, which is a better representation of the actual inverter controls. In case the REEC_B model does not use voltage_dip logic at all, i.e., vdip and vup parameters are set so that voltage_dip is never activated, a thorough review is required to check the condition under which the kqv current injection is applied in the actual inverters before converting the model.

Note that another possible conversion is to use the REEC_C model and set Pmin = 0; SOCini = 0.5; SOCmax = 1; SOCmin = 0, and T = 99999. This will disable the storage element, then all other parameters convert one to one. The VDL parameters can be set as described in the next section.

Parameters for VDL Blocks

VDL blocks (i.e., VDL1 and VDL2) in REEC_A define the voltage-dependent current limits for active current and reactive current, respectively. They are piecewise linear curves defined to four break points. **<u>The VDL blocks can be used to model inverter momentary cessation by limiting currents to 0 under/above the low/high momentary cessation voltage threshold.</u>** When converting REEC_B to REEC_A, the following VLD parameters provide the same response as the original REEC_B model.

Table 1: Converted VDL Parameters in REEC_A

VDL1		VDL2	
(vq1, iq1)	(-1.0, *imax**)	*(vp1, ip1)*	(-1.0, *imax*)
(vq2, iq2)	(2.0, *imax*)	*(vp2, ip2)*	(2.0, *imax*)
(vq3, iq3)	(0,0)	*(vp3, ip3)*	(0,0)
(vq4, iq4)	(0,0)	*(vp4, ip4)*	(0,0)

Other Parameters for REEC_A

When converting to REEC_A model, the following parameters need to be added:

thld2 = 0—after *voltage_dip* returns to 0, the active current command is held at the last value for *thld2* seconds.

vref1 = 0—user-defined reference on the inner-loop voltage control.

pflag = 0—power reference is P instead of P multiplied by speed.

Case Studies

Several cases are presented below by changing the parameters in the original REEC_B model to compare the performance of the conversion. The REEC_B model parameters selected in the case studies are for demonstration and do not represent any actual plant.

Example 1

Nearly identical responses between REEC_B model and converted REEC_A model

Under a deep fault that activates voltage_dip logic in both the REEC_B and the converted REEC_A model, the two models produce nearly identical responses.

The original REEC_B parameters and converted REEC_A parameters are shown in Table 2.

Table 2: REEC_B Converted to REEC_A—Example 1

	Original REEC_B	Converted REEC_A
vdip	0.5	0.5
vup	1.1	1.1
trv	0.01	0.01
dbd1	-0.1	-0.1
dbd2	0.1	0.1
kqv	2	2
iqh1	1	1
iql1	-1	-1
vref0	1	1
iqfrz		0

thld		0
thld2		0
tp	0.01	0.01
qmax	0.6	0.6
qmin	-0.6	-0.6
vmax	1.2	1.2
vmin	0.8	0.8
kqp	1	1
kqi	1	1
kvp	1	1
kvi	1	1
vref1		0
tiq	0.01	0.01
dpmax	1	1
dpmin	-1	-1
pmax	1	1
pmin	0	0
imax	1	1
tpord	0.01	0.01
pfflag	0	0
vflag	1	1
qflag	1	1
pflag		0
pqflag	0	0
vq1		-1.0
iq1		1.0
vq2		2.0
iq2		1.0
vq3		0.0
iq3		0.0
vq4		0.0
iq4		0.0
vp1		-1.0
ip1		1.0
vp2		2.0
ip2		1.0
vp3		0.0
ip3		0.0
vp4		0.0
ip4		0.0

A four-cycle, three-phase-to-ground bolted fault is applied at the point of interconnection to the transmission grid. The converted model produced a response identical to the original model. The inverter response is shown in Figures 4, 5, and 6. Note that the plots of the REEC_B model and the REEC_A model completely overlap.

Figure 4: Inverter Terminal Voltage—Example 1

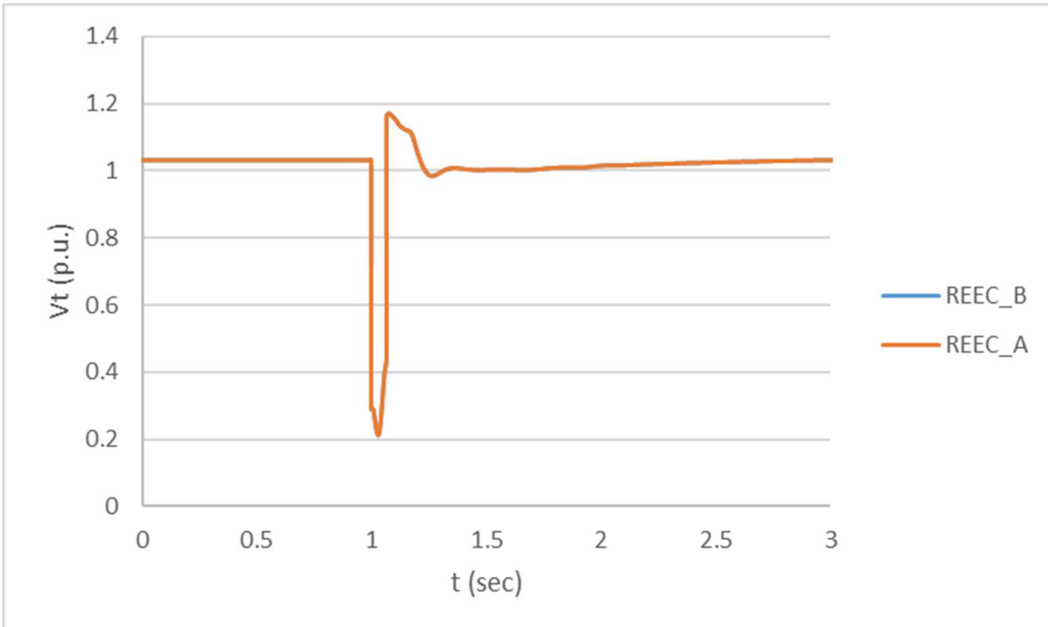


Figure 5: Inverter Active Power Output—Example 1

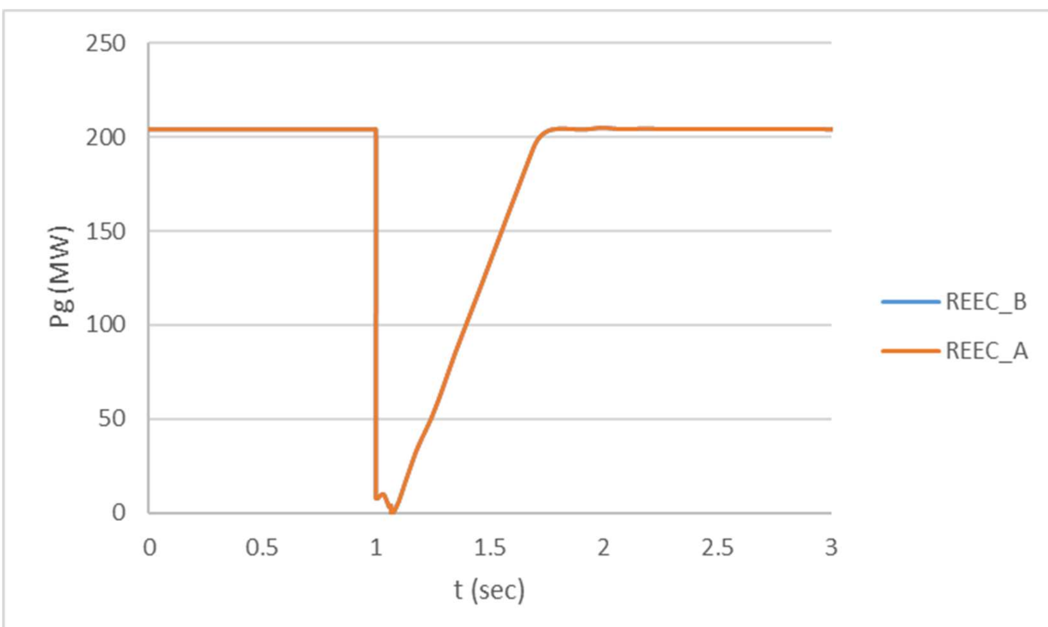
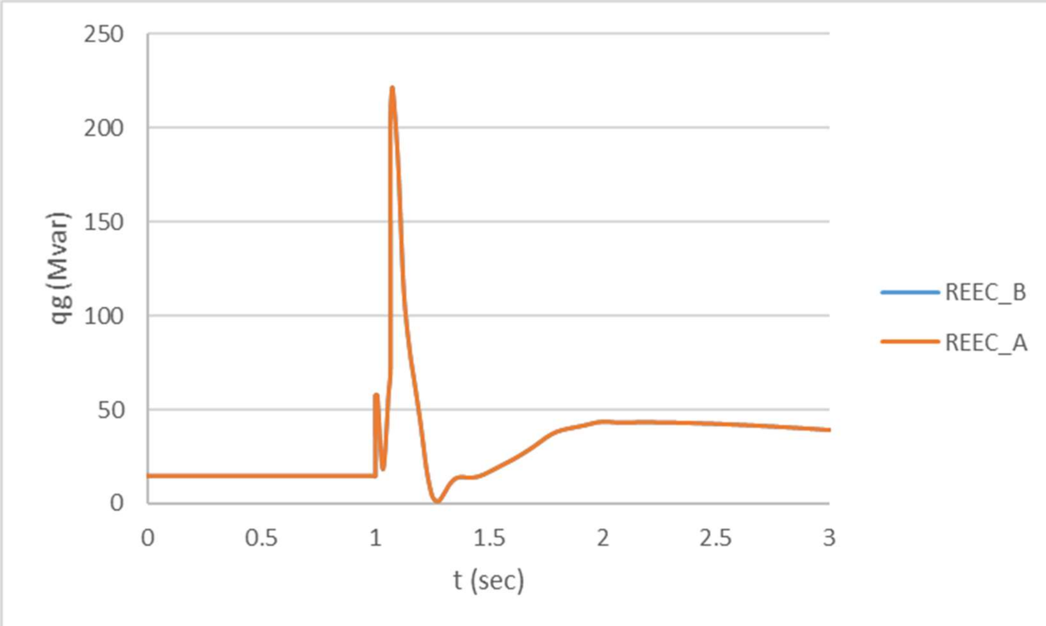


Figure 6: Inverter Reactive Power Output—Example 1



Example 2

Reasonably close responses between REEC_B model and converted REEC_A model

Under a disturbance that would not activate voltage_dip logic in the converted REEC_A model, there might be noticeable but acceptable differences between the REEC_B and the converted REEC_A responses.

To demonstrate the influence of the Kqv reactive current injection arm under normal voltage conditions (voltage_dip is 0, meaning no Kqv path in REEC_A model), a four-cycle, three-phase-to-ground fault with a fault impedance (to make the transient voltage in range between vdip and vup) is applied at the point of interconnection to the transmission grid. The deadband parameters in the original REEC_B model are modified from Table 2 to those in Table 3 to amplify the Kqv path influence. The inverter response is shown in Figures 7, 8, 9, and 10. There is only a small difference in the reactive power outputs, which are caused by the different reactive current commands within normal voltage range.

Table 3: REEC_B Converted to REEC_A—Example 2

	Original REEC_B	Converted REEC_A
vdip	0.5	0.5
vup	1.1	1.1
trv	0.01	0.01
dbd1	-0.05	-0.05
dbd2	0.05	0.05

kqv	2	2
iqh1	1	1
iql1	-1	-1
vref0	1	1
iqfrz		0
thld		0
thld2		0
tp	0.01	0.01
qmax	0.6	0.6
qmin	-0.6	-0.6
vmax	1.2	1.2
vmin	0.8	0.8
kqp	1	1
kqi	1	1
kvp	1	1
kvi	1	1
vref1		0
tiq	0.01	0.01
dpmax	1	1
dpmin	-1	-1
pmax	1	1
pmin	0	0
imax	1	1
tpord	0.01	0.01
pfflag	0	0
vflag	1	1
qflag	1	1
pflag		0
pqflag	0	0
vq1		-1.0
iq1		1.0
vq2		2.0
iq2		1.0
vq3		0.0
iq3		0.0
vq4		0.0
iq4		0.0
vp1		-1.0
ip1		1.0
vp2		2.0
ip2		1.0

vp3		0.0
ip3		0.0
vp4		0.0
ip4		0.0

Figure 7: Comparison of Iq Command between REEC_A and REEC_B—Example 2

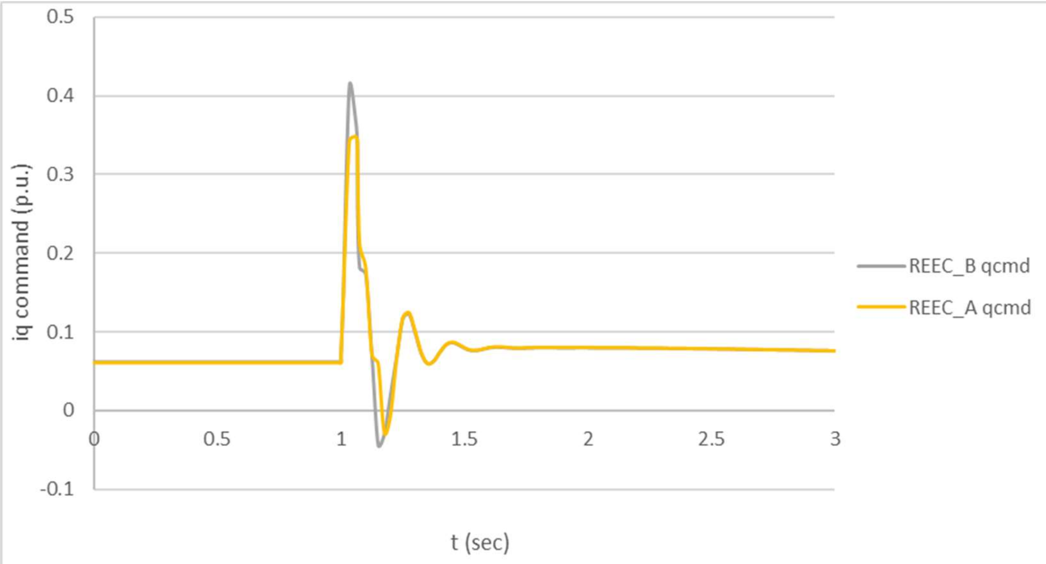


Figure 8: Inverter Terminal Voltage—Example 2

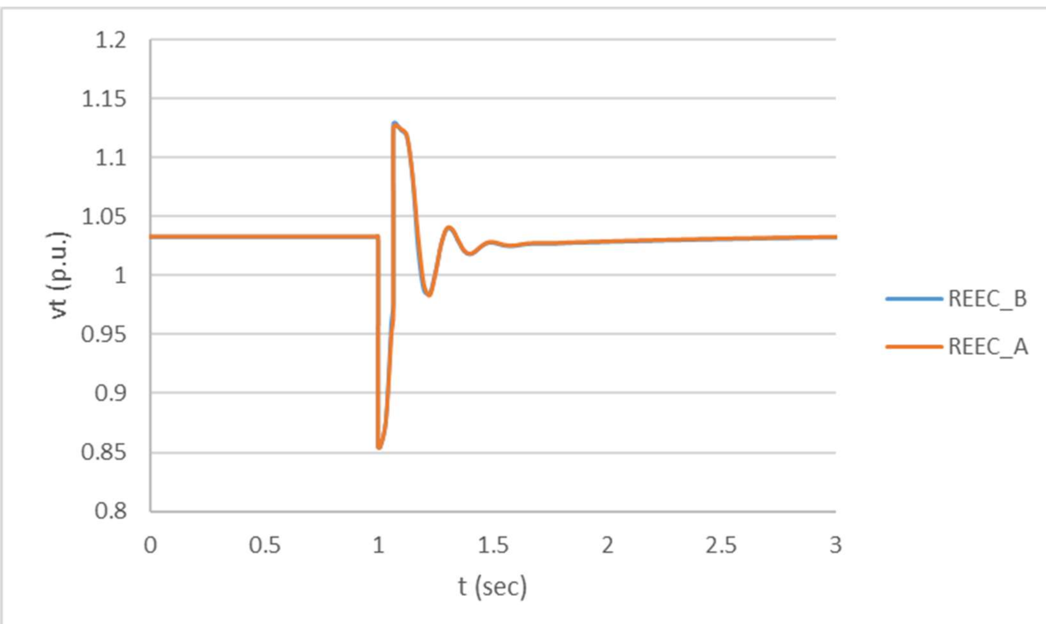


Figure 9: Inverter Active Power Output—Example 2

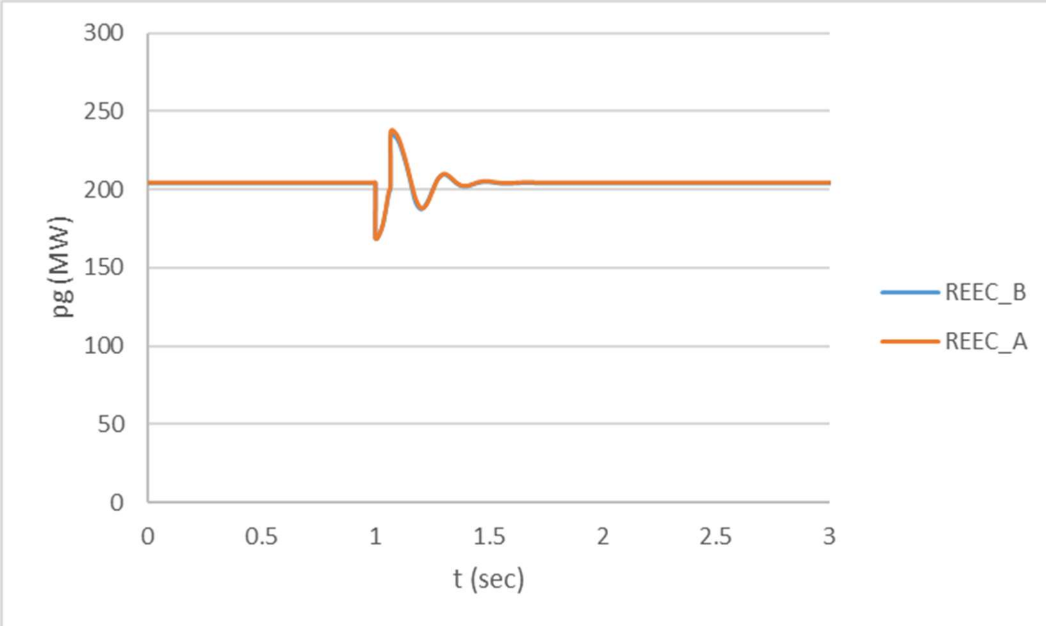
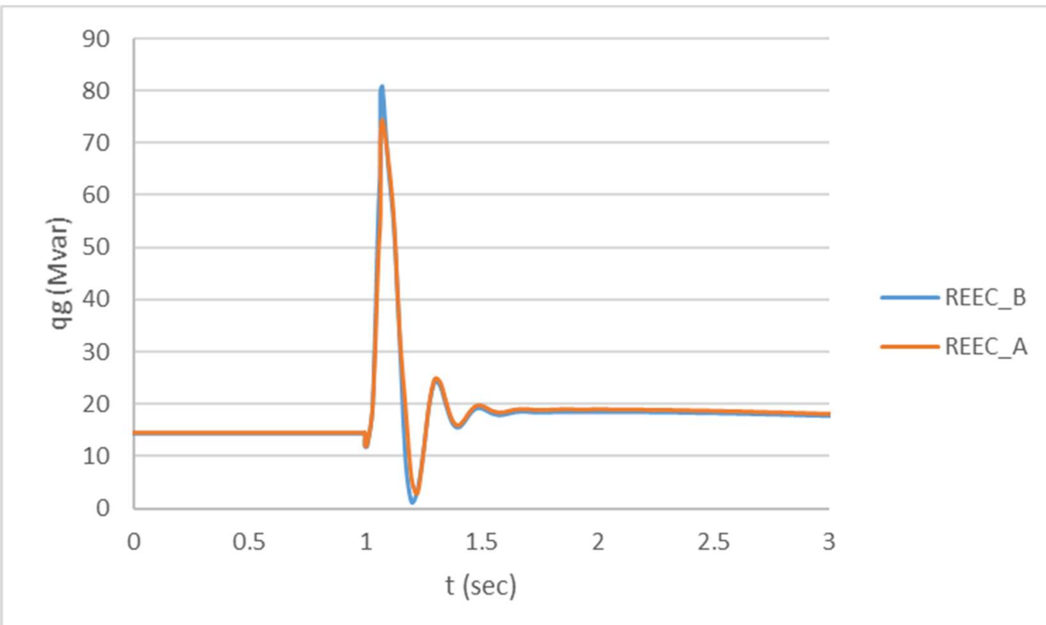


Figure 10: Inverter Reactive Power Output—Example 2



Note that the *vdip*, *vup*, *dbd1* and *dbd2* parameters were intentionally set in the case study for demonstration purposes. Typically, for inverters not using momentary cessation, *vdip* is 0.9 and *vup* is 1.1, and the control deadbands match the voltage dip setup, i.e., *dbd1* = *vdip* – 1 and *dbd2* = *vup* – 1. Under this typical setting, there is no difference between the converted REEC_A and the original REEC_B for all operating conditions.

Example 3

Converting REEC_B model that does not use voltage_dip logic

If the REEC_B model uses Kqv control (i.e., kqv>0), but not the voltage_dip logic, converting to REEC_A model could require re-tuning of the model.

Table 4 shows the conversion, in this case, involves changing vdip and vup parameters between the REEC_B and the REEC_A models. The setup of the REEC_B model relies on Kqv current injection for voltage control. Without modifying vdip and vup in REEC_A to activate Kqv control, the REEC_A produces a different response than the REEC_B model.

Table 4: REEC_B Converted to REEC_A—Example 3

	Original REEC_B	Converted REEC_A
vdip	-99	0.95
vup	99	1.05
trv	0.02	0.02
dbd1	-0.05	-0.05
dbd2	0.05	0.05
kqv	2	2
iqh1	1.25	1.25
iql1	-1.05	-1.05
vref0	1	1
iqfrz		0
thld		0
thld2		0
tp	0.05	0.05
qmax	1.0	1.0
qmin	-1.0	-1.0
vmax	1.1	1.1
vmin	0.9	0.9
kqp	1	1
kqi	0	0
kvp	1	1
kvi	0	0
vref1		0
tiq	0.3	0.3
dpmax	99	99
dpmin	-99	-99
pmax	1	1
pmin	0	0
imax	1.3	1.3

tpord	0.02	0.02
pfflag	0	0
vflag	1	1
qflag	0	0
pflag		0
pqflag	0	0
vq1		-1.0
iq1		1.3
vq2		2.0
iq2		1.3
vq3		0.0
iq3		0.0
vq4		0.0
iq4		0.0
vp1		-1.0
ip1		1.3
vp2		2.0
ip2		1.3
vp3		0.0
ip3		0.0
vp4		0.0
ip4		0.0

Figure 11: Comparison of iq Command between REEC_A and REEC_B

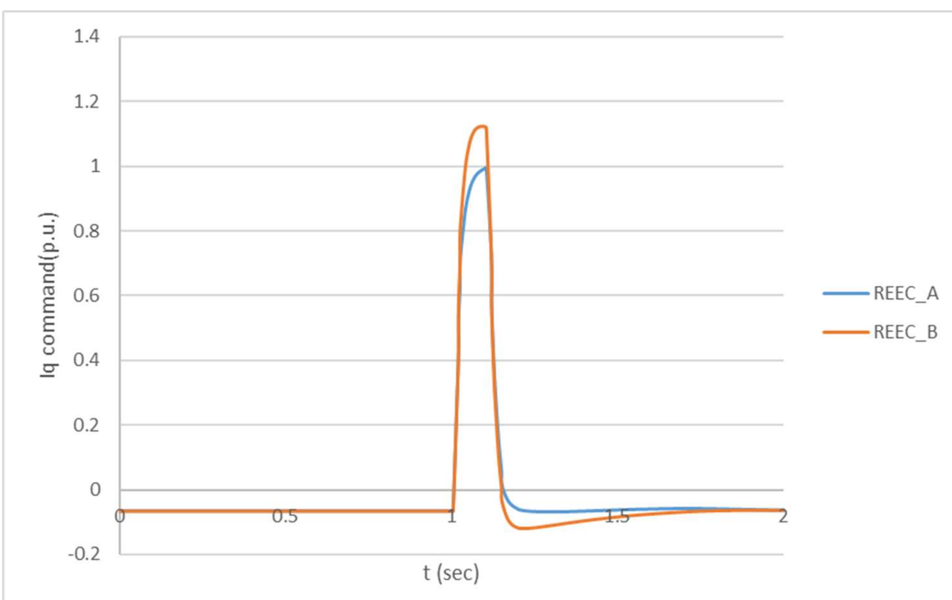


Figure 12: Inverter Terminal Voltage—Example 3

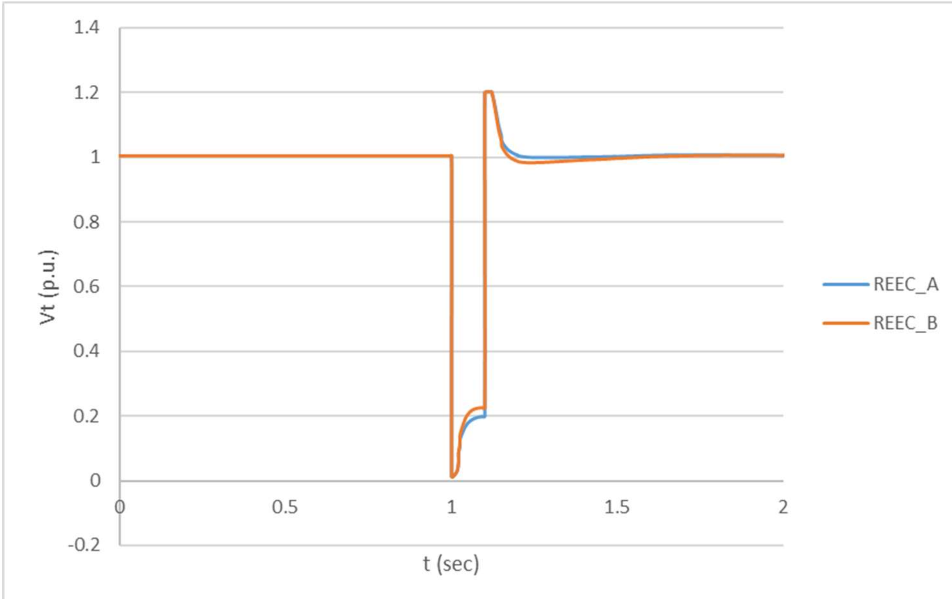


Figure 13: Inverter Active Power Output—Example 3

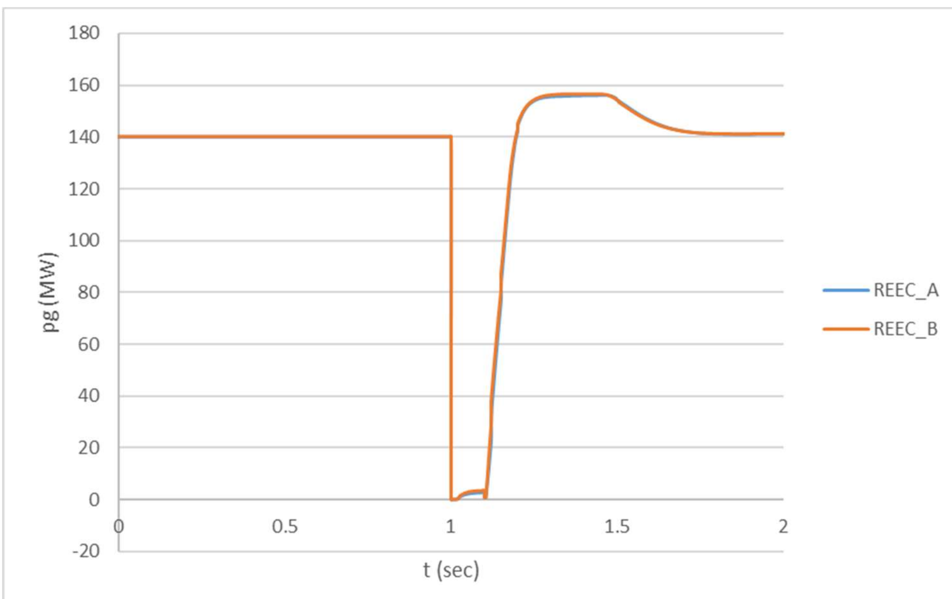
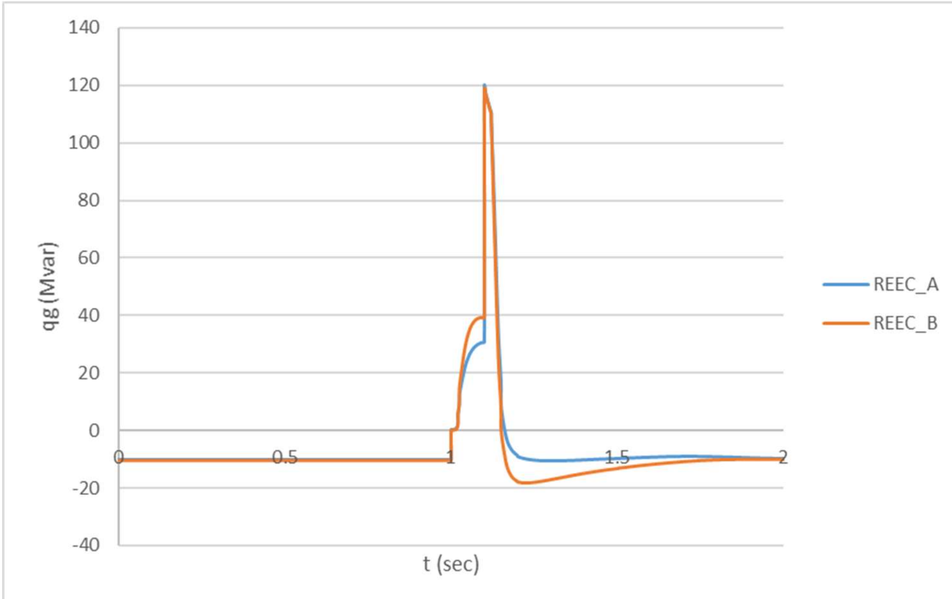


Figure 14: Inverter Reactive Power Output—Example 3



In this example, changing vdip and vup parameters achieves reasonable responses from the converted REEC_A model, as shown in Figures 11 through 14. It may not always be proper to change vdip and vup parameters, as the voltage_dip logic impacts the other control loops as well. A thorough review of the models is recommended. Converting to REEC_D model instead of REEC_A may be more appropriate.

Converting REEC_B to REEC_D without Momentary Cessation

Difference may be introduced between REEC_B and REEC_A response due to Kqv reactive current injection switching logic in REEC_A not in REEC_B. This issue can be resolved by converting REEC_B to REEC_D model instead. Converting from REEC_B to REEC_D is straightforward. All original REEC_B parameters remain unchanged with additional parameters being added. Figure 15 shows the control block diagram for REEC_D model, where the expansion from REEC_B model is shown in red. The parameters to be added to REEC_D model are listed in Table 5.

Figure 15: REEC_D Model

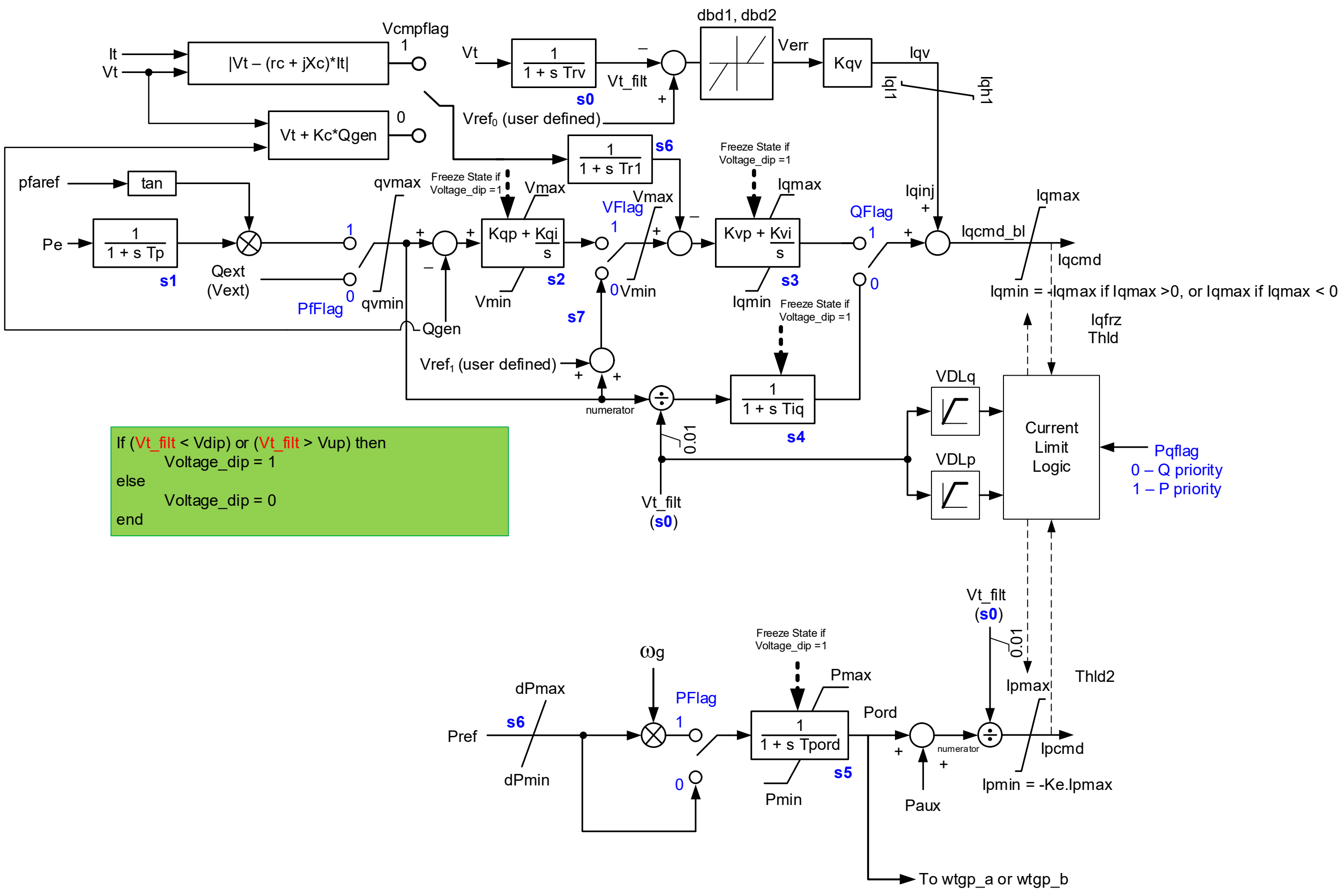


Table 5: Parameters Added When Converting from REEC_B to REEC_D

Parameter Name	Value
rc	0
Xc	0
Tr1	0
Kc	0
Vcmpflag	0
Ke	0
Iqfrz	0
Thld	0
VDLq	(-1.0, *imax*), (2, *imax*), (0,0) …
VDLp	(-1.0, *imax*), (2, *imax*), (0,0) …
vblkl	0
vblkh	2
Tblk_delay	0
iqfrz	0
thld	0

thld2	0
vref1	0
pflag	0

With this conversion, the response should be the same between REEC_B and REEC_D. A simple example 4 verifies that. In example 4, reec_b was renamed to reec_d with the parameters listed in Table 5 inserted.

Figure 16: Inverter Terminal Voltage—Example 4

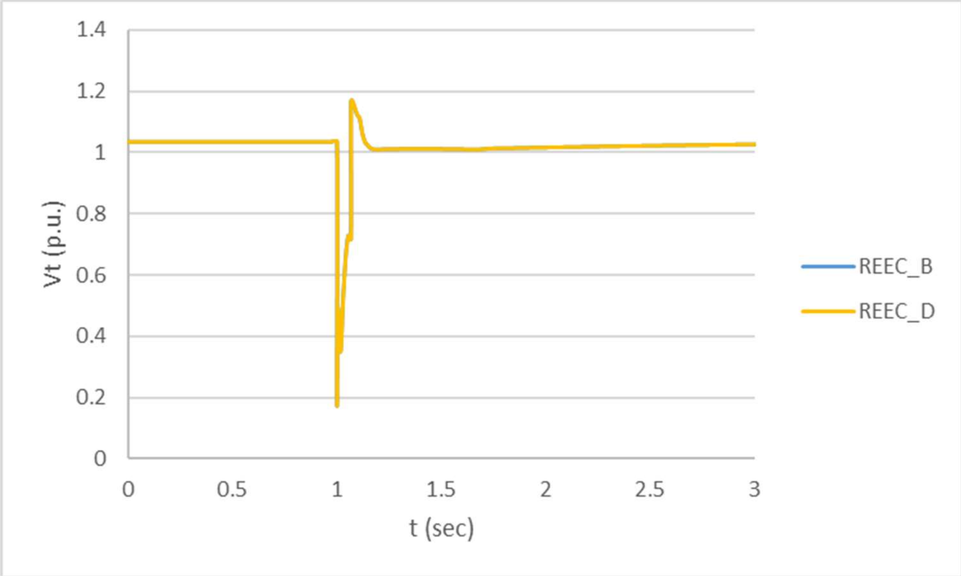


Figure 17: Active Power Output —Example 4

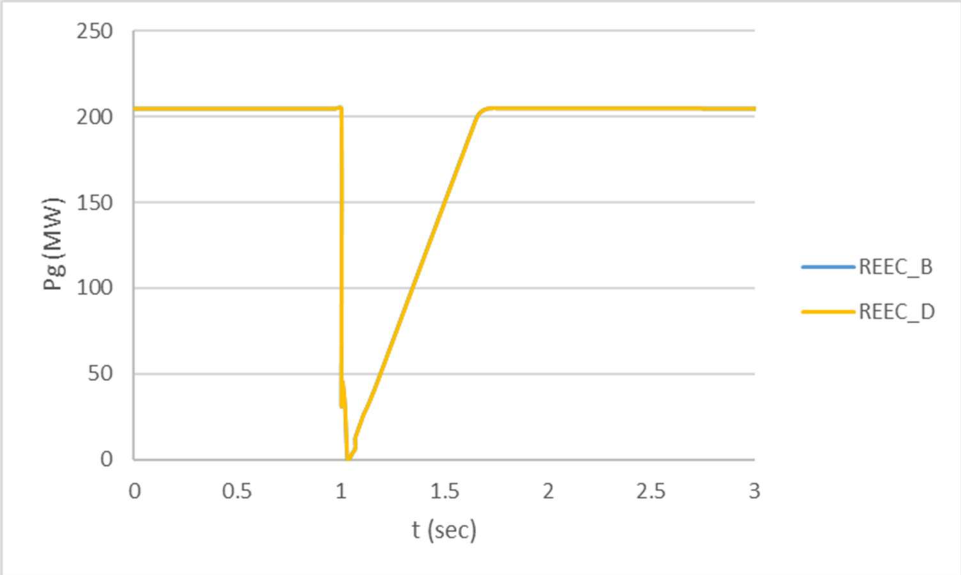
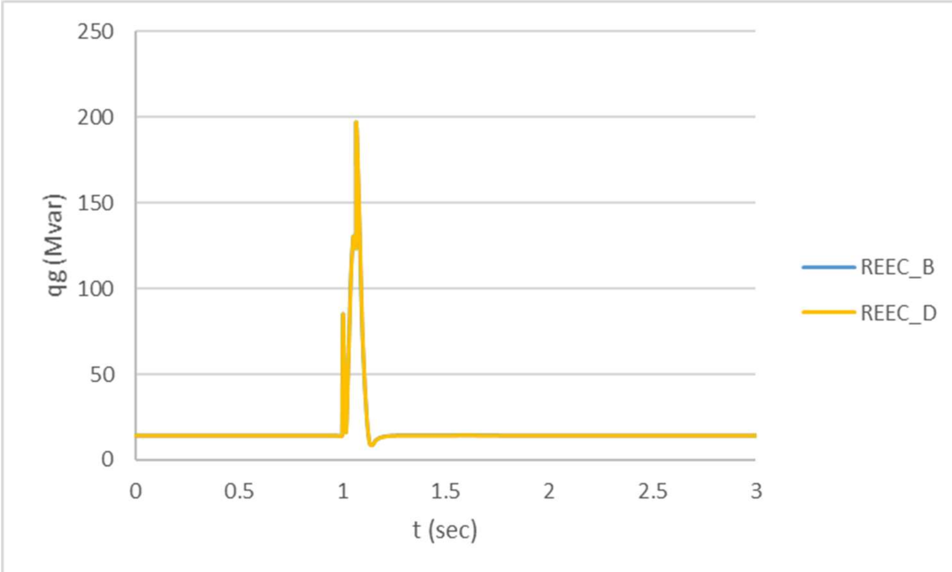


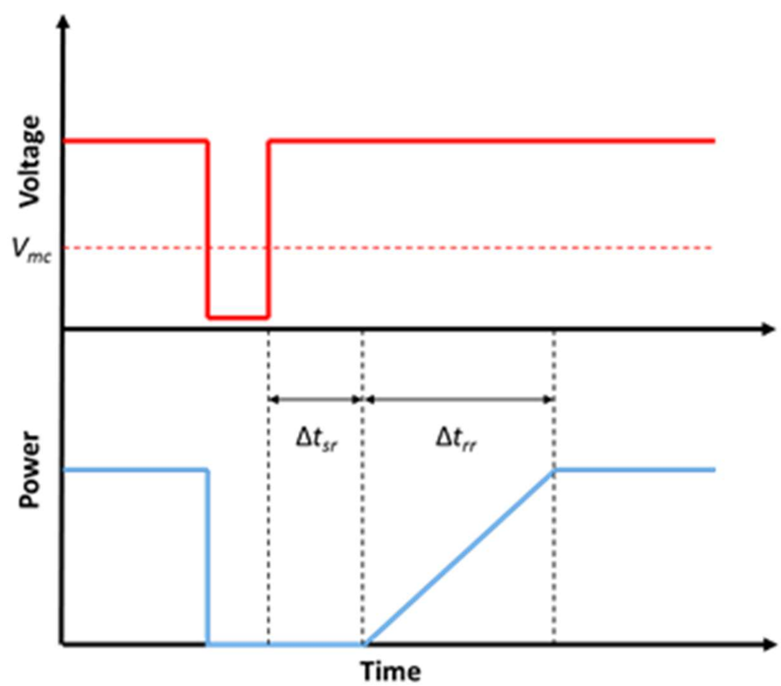
Figure 18: Reactive Power Output —Example 4



Replacing REEC_B to Model Momentary Cessation

For solar PV plants that use momentary cessation, the REEC_B model is not an accurate representation of the inverter controls. The REEC_B model needs to be replaced by REEC_A or REEC_D in order to model momentary cessation. Momentary cessation can be characterized using the response shown in Figure 19.

Figure 19: Illustration of Momentary Cessation



Accurately modeling momentary cessation consists of the following key aspects in addition to the controls without momentary cessation:

- **Momentary Cessation Voltage Threshold:** the low and high voltage thresholds below/above which the inverters go into momentary cessation.
- **Voltage-dependent active and reactive current reduction:** Both active and reactive current limits are reduced to 0 when the voltage is below the low voltage threshold or above the high voltage threshold.
- **Ramp control of active and reactive current:** Active and reactive current ramp rates and limits are modeled in regc_a by rrpwr, iqrmax, and iqrmin. No parameters in reec model are needed.
- **Recovery delay:** The delay in recovery of active current and reactive current

Modeling capability of REEC_A and REEC_D is provided in Table 6.

Table 6: Model Momentary Cessation with REEC_A or REEC_D

	REEC_A	REEC_D
MC low voltage threshold	vdip	vblkl
MC high voltage threshold	vup	vblkh
Voltage-dependent reactive current limit*	VDL1 4 pairs of (iq,vq)	VDLq 10 pairs of (iq, vq)
Voltage-dependent reactive current limit*	VDL2 4 pairs of (ip,vp)	VDLp 10 pairs of (ip, vp)
Active current recovery delay	Thld2	Tblk_delay
Reactive current recovery delay	Not modeled	Tblk_delay

* to model momentary cessation, the first pair of (iq, vq) and (ip, vp) should be (0, MC low voltage threshold) and the last pair of (iq, vq) and (ip, vp) should be (0, MC high voltage threshold)

As seen from Table 6, the REEC_A model has limitations on modeling momentary cessation and should not be used if any of the followings is true.

- It requires more than four breaking points to define the voltage-dependent limit for active current or reactive current.
- The momentary cessation voltage thresholds are different from the voltages vdip and vup at which the inverter closed-loop controls freeze.
- There is a recovery delay for the reactive current when the voltage returns to normal.

The REEC_D model is fully capable of modeling momentary cessation.

Proposed Actions

Conversion from REEC_B to REEC_A or REEC_D could be done systematically without losing any model accuracy or introducing any modeling errors. WECC recommends converting all REEC_B models in the WECC master dynamic file to REEC_A or REEC_D.

Version History

Modified Date	Modified By	Description
June 13, 2019	REMTF	Initial publication
August 28, 2020	REMWG	Add guidelines of converting to REEC_D model