WECC White Paper on Converting REEC_B to REEC_A for Solar PV Generators

WECC REMTF

June 13, 2019

155 North 400 West, Suite 200

Salt Lake City, Utah 84103-1114

Developed as WECC-xxxx

Background - Retirement of REEC_B Model

As the renewable penetration increased within the Western Interconnection, the WECC Modeling and Validation Work Group developed the generic models to model 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 different 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 by some) been used to model PV inverters, some within WECC requested and supported the development of the REEC_B model, a simplified version of REEC_A, for modeling solar PV. Later (in 2015) the REEC_C model was developed for energy storage. As such, the majority of folks started using REEC_B for modeling solar PV.

Several disturbance events of large-scale solar PV generation loss occurred since 2017. Through investigation of these events, it was revealed that many current solar PV plant used momentary cessation as a means of ride-thought abnormal voltage conditions. Momentary cessation is when no current is injected 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 REEC_A model, does not have much benefit or additional modeling capability from REEC_A model. Therefore, the WECC MVWG approved the retirement of 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 models. Conversion of REEC_B model to REEC_A model includes

1) For inverters using momentary cessation, the conversion to REEC_A should include properly accounting for momentary cessation setting. The REEC_A model has limitation on modeling momentary cessation[1]. A new model, REEC_D[2], being developed will have the full capability of modeling momentary cessation.
2) For inverters not using momentary cessation, the conversion could be done by adding parameters required by the REEC_A model.

[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/Memo%20RES%20Modeling%20Updates-%20Pourbeik.pdf&action=default&DefaultItemOpen=1

The section below address the second scenario – converting REEC_B to REEC_A without momentary cessation.

Converting REEC_B Model to REEC_A Model without Momentary Cessation

REEC_B model was a simplified version of REEC_A. Comparing the model structures between REEC_A (Figure 1) and RECC_B (Figure 2), the differences for modeling a solar PV plant are:

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

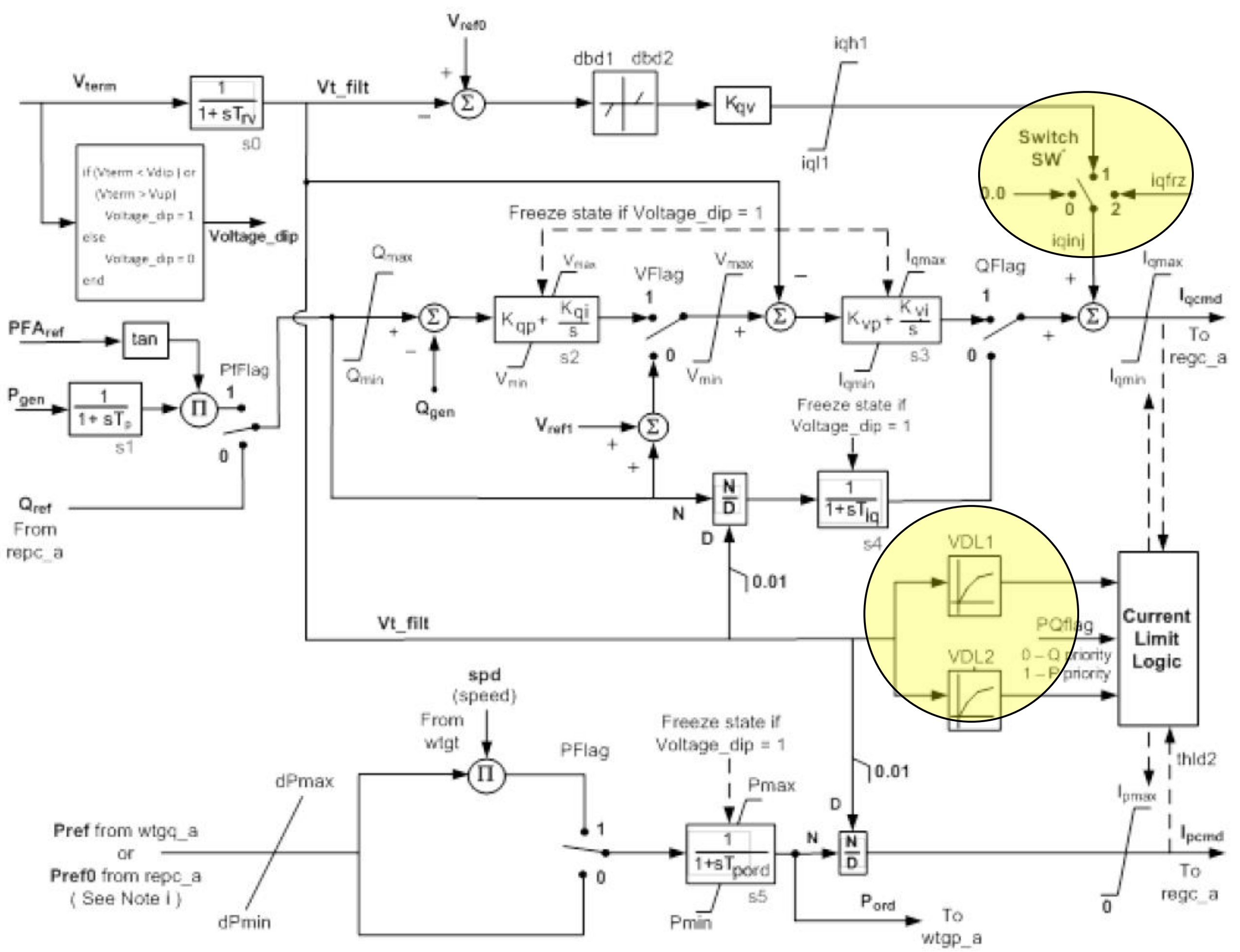

Figure 1: REEC_A Model

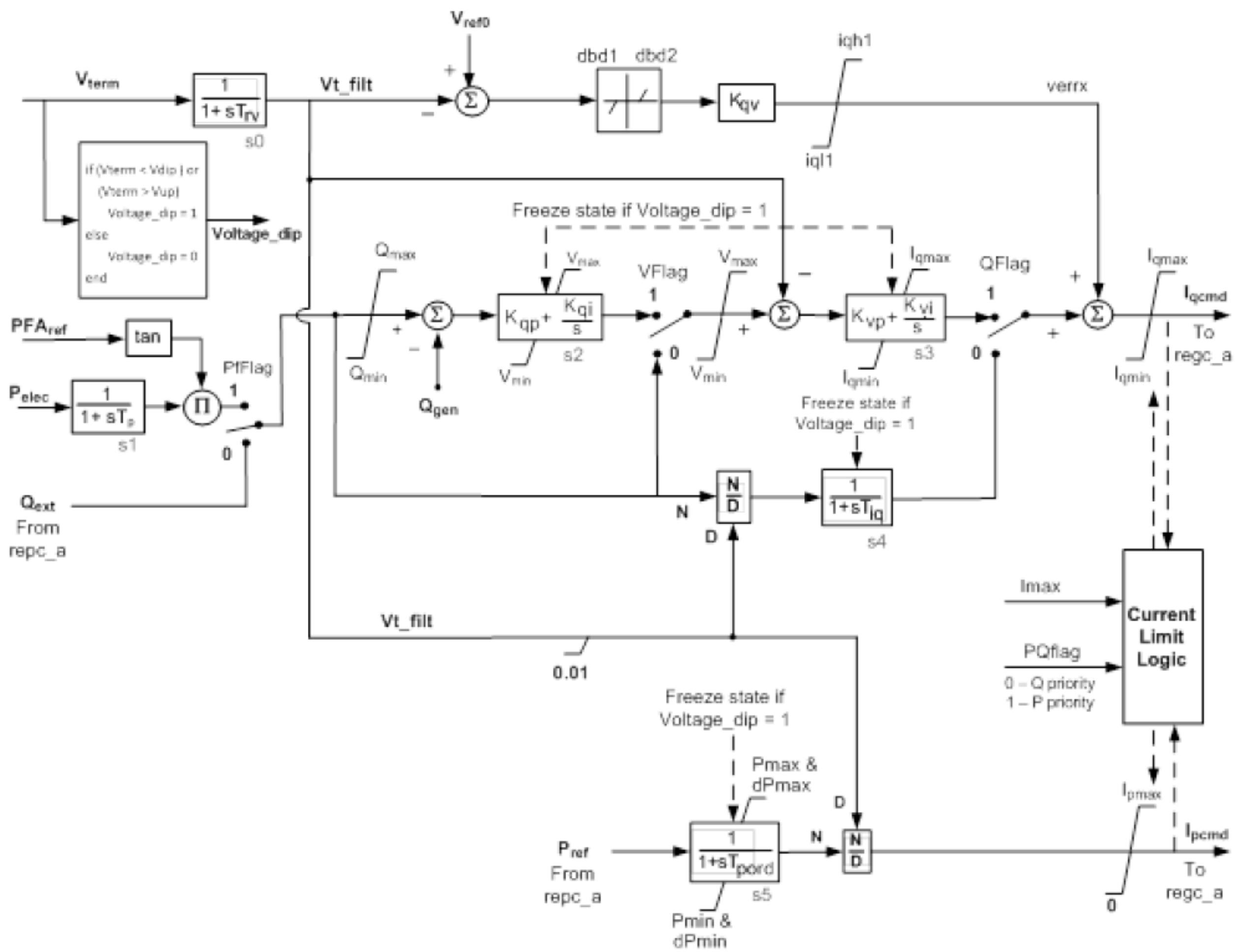

Figure 2: REEC_B Model

<u>Parameters for Kqv reactive current injection</u>

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 three 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 *thl*d 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 depicted in Figure 3.

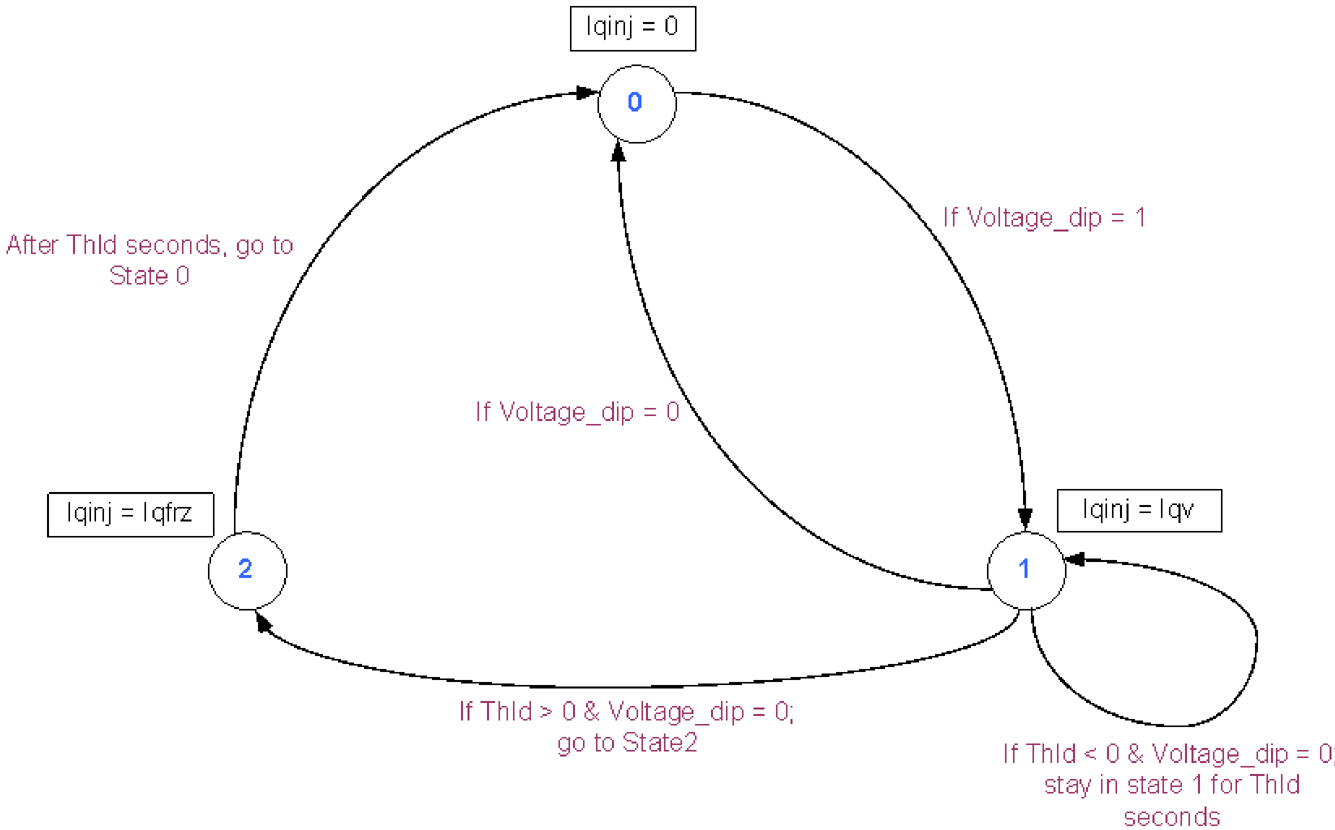

Figure 3: REEC_A Reactive Current Injection State Transition Diagram

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 that the REEC_B model does not use voltage_dip logic at all, i.e. vdip and vup parameters are set in a way that voltage_dip is never activated, a thorough review is required to check the condition under which the kqv current injection is implemented in the actual inverters before converting the model.

__**Note:**__ 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 essentially disable the storage element and then all other parameters converter one to one. The VDL parameters can be set as described below.

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 curve defined to four break points. **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.** 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)

* *imax* is the parameter in the REEC_B model

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 purpose and do not represent any actual plant.

Example 1: Nearly identical responses between the REEC_B model and the 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 4-cycle three-phase-to-ground bolted fault is applied at the point of interconnection to the transmission grid. The converted model produced the identical response as the original model. The inverter response is shown in Figure 4, Figure 5 and Figure 6. Note that the plots of REEC_B model and REEC_A model completely overlap.

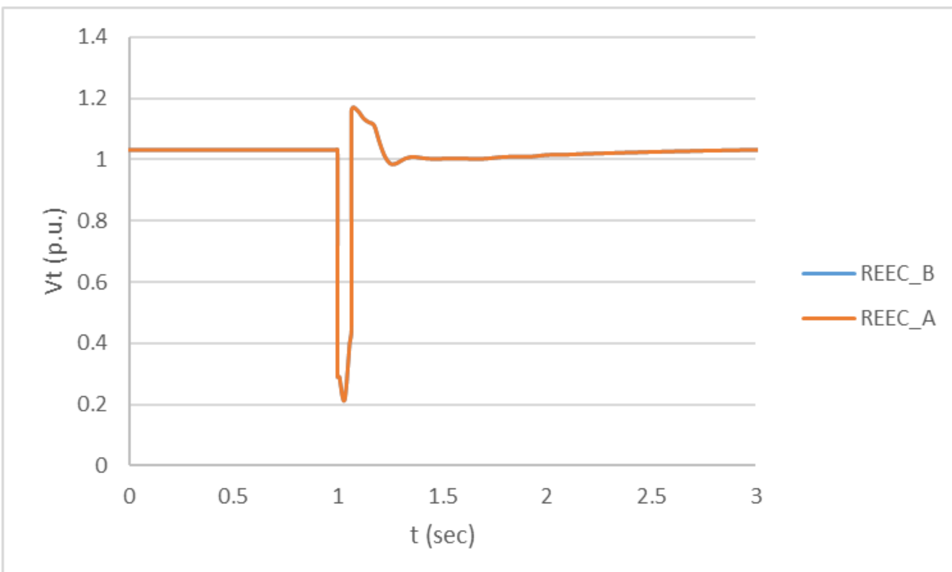

Figure 4: Inverter Terminal Voltage – Example 1

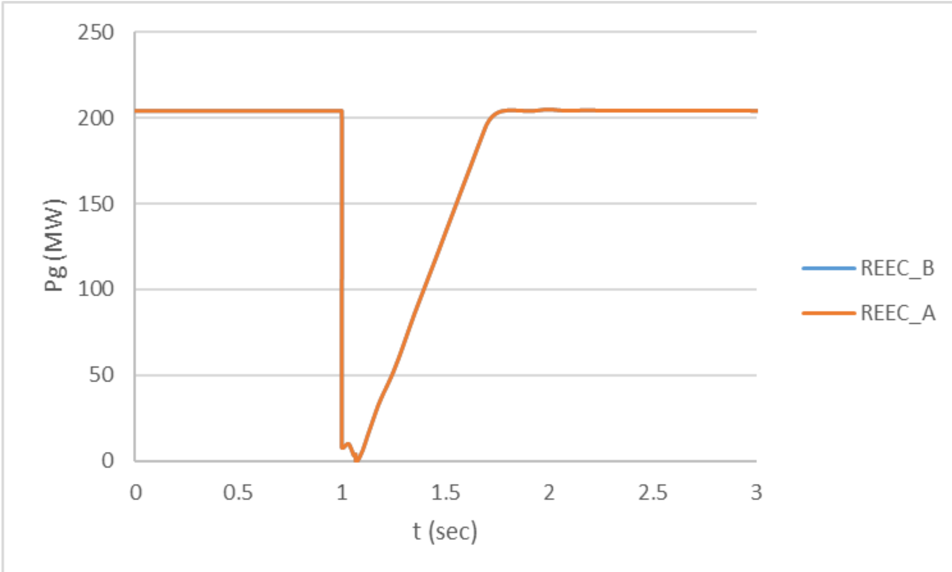

Figure 5: Inverter Active Power Output – Example 1

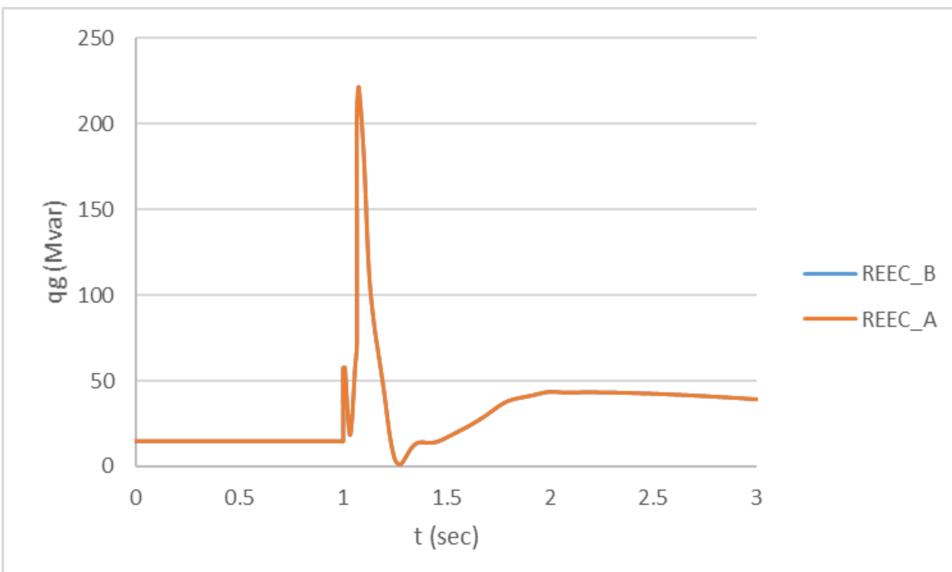

Figure 6: Inverter Reactive Power Output – Example 1

Example 2: Reasonably close responses between the REEC_B model and the 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 difference between the REEC_B and the converted REEC_A responses.

To demonstrate the influence of the Kqv reactive current injection arm under normal voltage condition (voltage_dip is 0, meaning no Kqv path in REEC_A model), a 4-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 these in Table 3 to amplify the Kqv path influence. The inverter response is shown in Figure 7, Figure 8, Figure 9 and Figure 10. There is only small difference in the reactive power outputs which 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

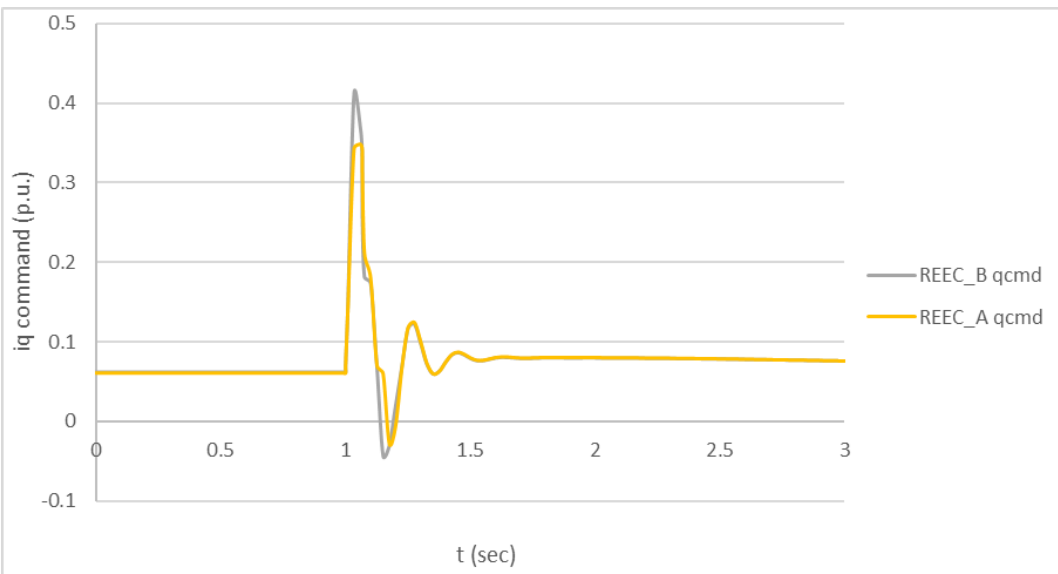

Figure 7: Comparison of Iq Command between REEC_A and REEC_B – Example 2

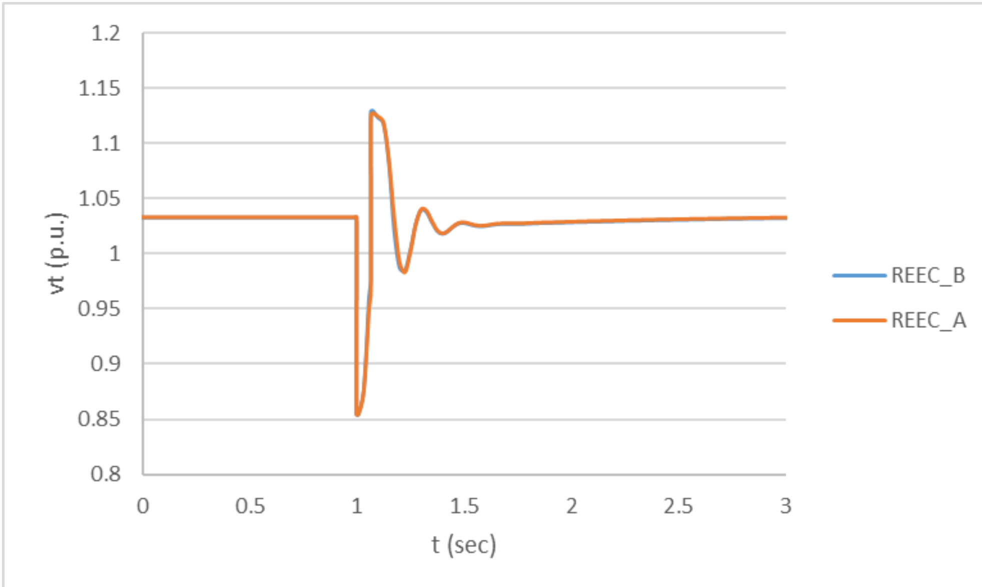

Figure 8: Inverter Terminal Voltage – Example 2

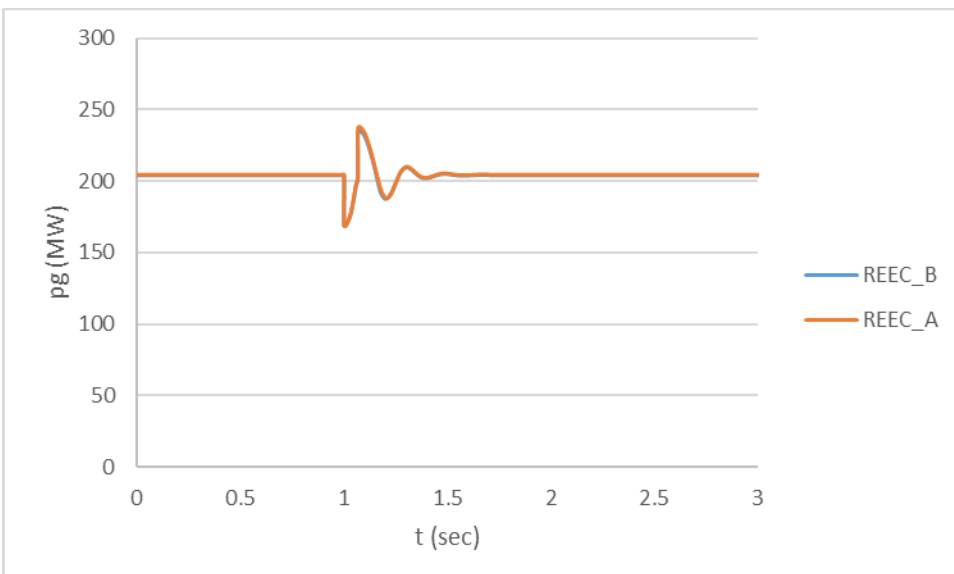

Figure 9: Inverter Active Power Output – Example 2

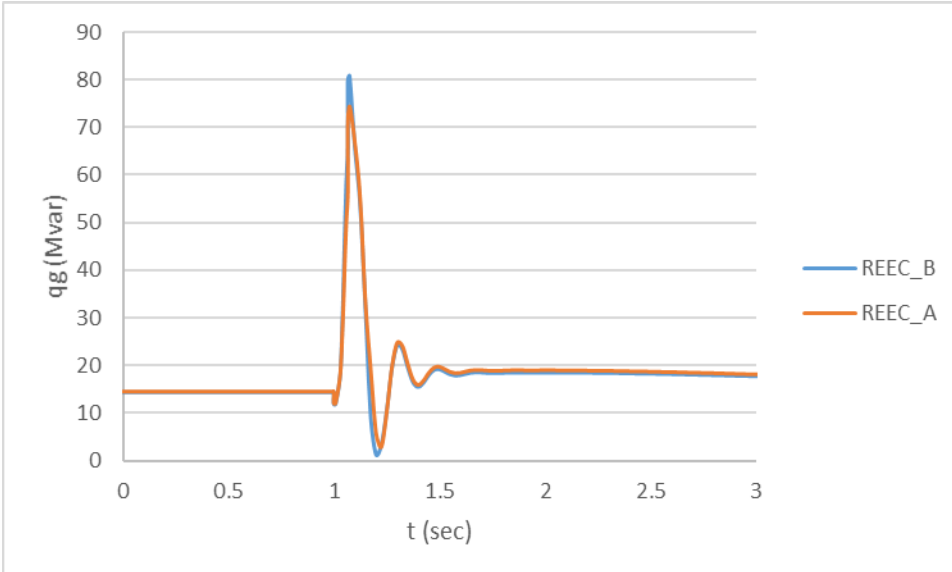

Figure 10: Inverter Reactive Power Output – Example 2

It should be noted that the *vdip*, *vup*, *dbd1* and *dbd2* parameters were intentionally set in the case study for demonstration purpose. 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 such 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 does not produce similar response as 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

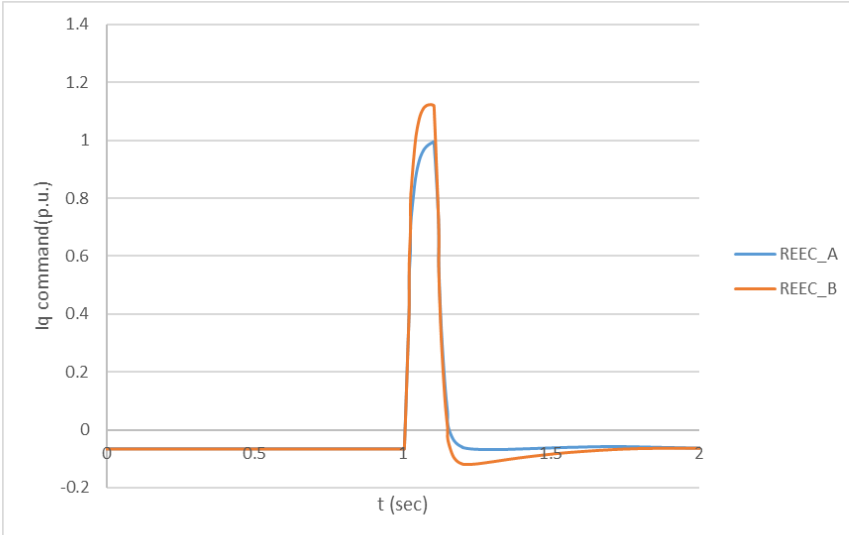

Figure 11: Comparison of Iq Command between REEC_A and REEC_B

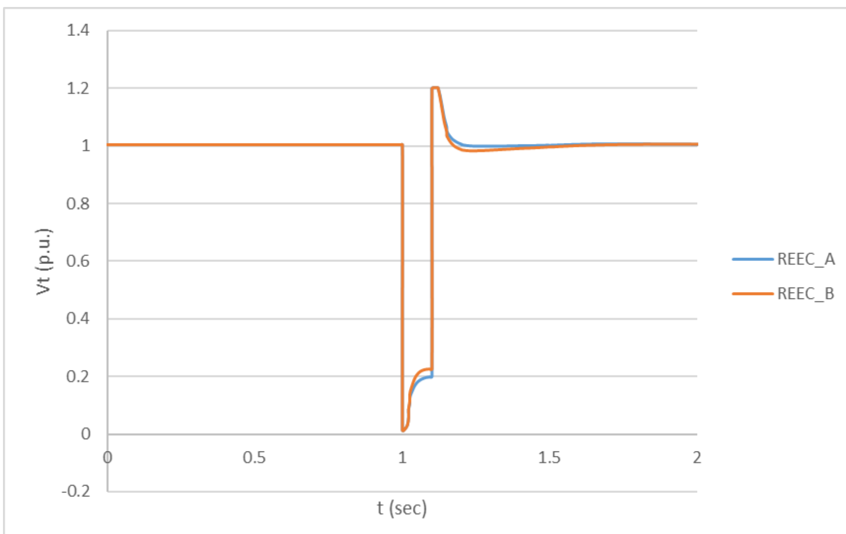

Figure 12: Inverter Terminal Voltage – Example 3

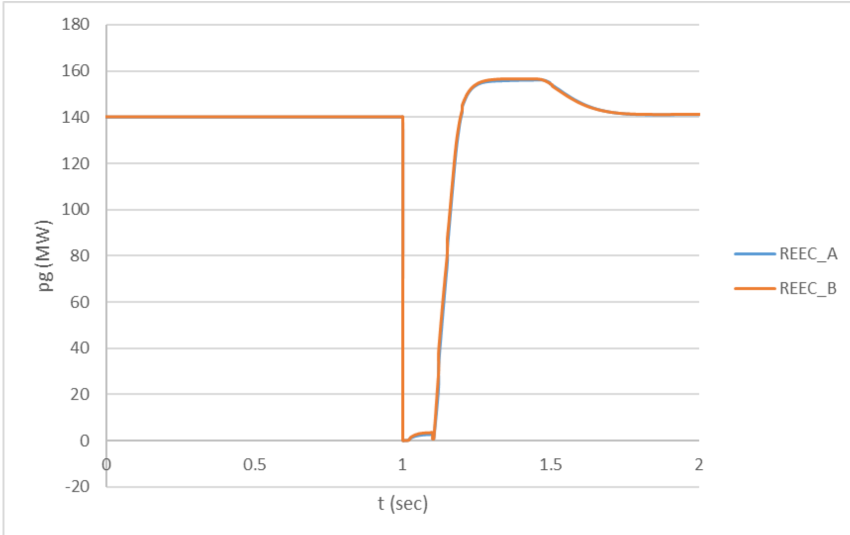

Figure 13: Inverter Active Power Output – Example 3

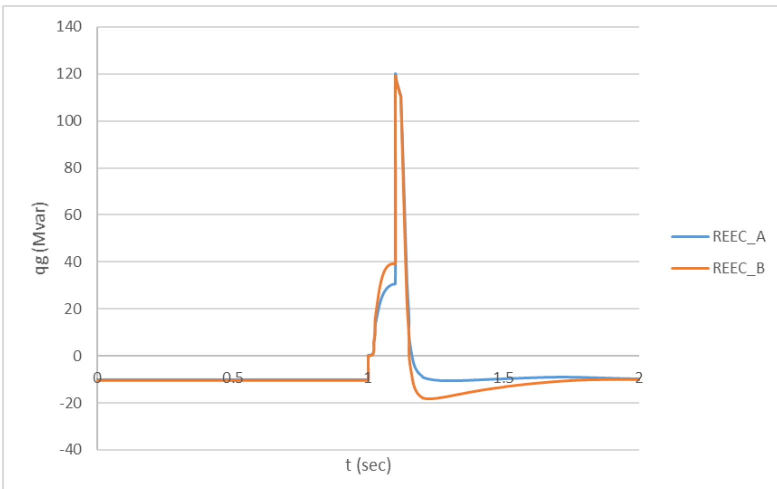

Figure 14: Inverter Reactive Power Output – Example 3

In this example, changing vdip and vup parameters achieves reasonable responses from the converted REEC_A model, as shown in Figure 11 to Figure 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.

Proposed Actions

Conversion from REEC_B to REEC_A could be done systematically without losing any model accuracy or introducing any modeling errors in most of the cases. It is recommended to convert all REEC_B models in the WECC master dynamic file to REEC_A.