Western Electricity Coordinating Council
Modeling and Validation Work Group

Generic Solar Photovoltaic System Dynamic Simulation Model Specification

Prepared by
WECC Renewable Energy Modeling Task Force

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1. Purpose and Scope

This document is intended to serve as a specification for generic solar photovoltaic (PV) system positive-sequence dynamic models to be implemented by software developers and approved by the WECC MVWG for use in bulk system dynamic simulations in accordance with NERC MOD standards. Two specific dynamic models are included in the scope of this document. The first, a Central Station PV System model, is intended to capture the most important dynamic characteristics of large scale (> 10 MW) PV systems with a central Point of Interconnection (POI) at the transmission level. The second, a Distributed PV System model, is intended to represent an aggregation of smaller, distribution-connected systems that comprise a portion of a composite load that might be modeled at a transmission load bus.

2. General Model Requirements

The following general requirements shall apply to both models. These general requirements are consistent with those applied to the generic wind turbine models developed by the WECC REMTF, and define the intended use and limitations of the models:

- The models shall be non-proprietary and accessible to transmission planners and grid operators without the need for non-disclosure agreements.

- The models shall provide a reasonably good representation of dynamic electrical performance of solar photovoltaic power plants at the point of interconnection with the bulk electric system, and not necessarily within the solar PV power plant itself.

- The models shall be suitable for studying system response to electrical disturbances, not solar irradiance transients (i.e., available solar power is assumed constant through the duration of the simulation). Electrical disturbances of interest are primarily balanced transmission grid faults (external to the solar PV power plant), typically 3 - 9 cycles in duration, and other major disturbances such as loss of generation or large blocks of load.

- Systems integrators, inverter manufacturers and model users (with guidance from the integrators and manufacturers) shall be able to represent differences among specific inverter and/or plant controller responses by selecting appropriate model parameters and feature flags.

- Simulations performed using these models typically cover a 20-30 second time frame, with integration time steps in the range of 1 to 10 milliseconds.

- The models shall be valid for analyzing electrical phenomena in the frequency range of zero to approximately 10 Hz.

- The models shall incorporate protection functions that trip the associated generation represented by the model, or shall include the means for external modules to be connected to the model to accomplish such generator tripping.

- The models shall be initialized from a solved power flow case with minimal user intervention required in the initialization process.

- Power level of interest is primarily 100% of rated power. However, performance shall be valid, within a reasonable tolerance, for the variables of interest (current, active power, reactive power and power factor) within a range of 25% to 100% of rated power.

- The models shall perform accurately for systems with a Short Circuit Ratio (SCR) of two and higher at the POI.

- External reactive compensation and control equipment (i.e., beyond the capability of the PV inverters) shall be modeled separately with existing WECC-approved models.

3. Central Station PV System Model (REGC_A, REEC_B, REPC_A)

3.1 Key Modeling Assumptions

Central station PV plants, which are constructed in a similar manner to utility-scale wind plants, are typically transmission-connected, and come under FERC jurisdiction. They are subject to the same NERC and WECC reliability requirements as wind and other central station generation. These reliability requirements are reflected in technical capabilities such as dynamic active and reactive power control and fault ride through.

As a result of investigations and discussions to date in the WECC REMTF, a key simplifying assumption which shall be incorporated in the Central Station PV System model is that the dynamics related to the DC side of the inverter (PV array dynamics, inverter DC link and voltage regulator) shall be ignored. Consultations with several inverter manufacturers have identified that the time constants associated with these dynamics may, in some cases, be too short to ensure reliable numerical stability for the simulation time steps used in many bulk system dynamics cases. This assumption will be reevaluated once the model is validated against field test data.

The overall model structure is shown in Figure 1, below, and consists of a “generator” model (REGC_A) to provide current injections into the network solution, an electrical control model (REEC_B) for local active and reactive power control, and an optional plant controller model (REPC_A) to allow for plant-level active and reactive power control.

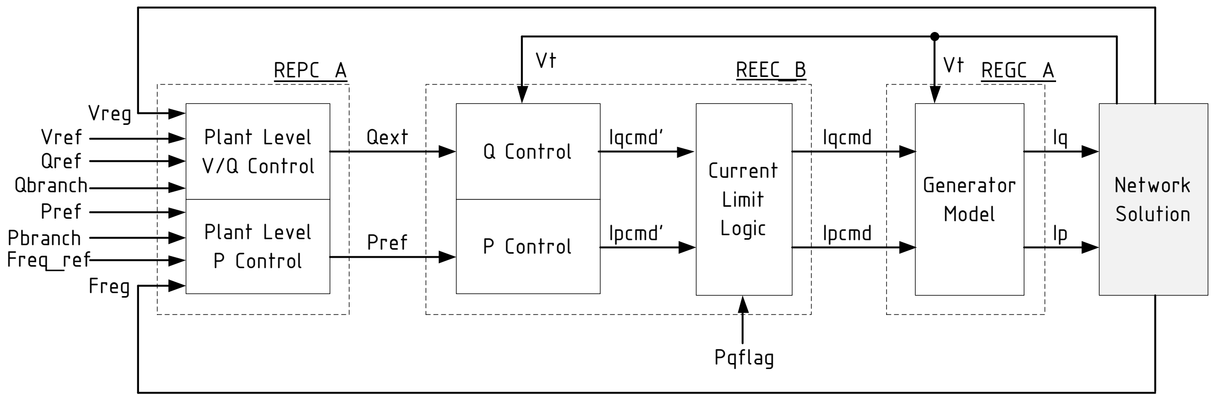

Figure 1. Overall Model Structure for Central Station PV System

3.2 Subsystem Models

3.2.1 Current Injection (included in REGC_A model)

The model shall incorporate a high bandwidth current regulator that injects real and reactive components of inverter current into the external network during the network solution in response to real and reactive current commands. Current injection shall include the following capabilities:

- User settable reactive current management during high voltage events at the generator (inverter) terminal bus
- Active current management during low voltage events to approximate the response of the inverter PLL controls during voltage dips
- Power logic during low voltage events to allow for a controlled response of active current during and immediately following voltage dips

The current injection model is identical to that which the WECC REMTF is proposing to utilize for the Type 3 and Type 4 generic wind turbine models.

3.2.2 Local Active Power Control (included in REEC_B model)

The active power control subsystem shall provide the active current command to the current injection model. The active current command shall be subject to current limiting, with user-selectable priority between active and reactive current. The active current command shall be derived from a reference active power and the inverter terminal voltage determined in the network solution. The reference active power shall be the initial active power from the solved power flow case; or, in the case where a plant controller model (REPC_A) is included, from the plant controller.

3.2.3 Local Reactive Power Control (included in REEC_B model)

The reactive power control subsystem shall provide the reactive current command to the current injection model. The reactive current command shall be subject to current limiting, with user-selectable priority between active and reactive current. The following reactive power control modes shall be accommodated:

- Constant power factor, based on the inverter power factor in the solved power flow case
- Constant reactive power, based either on the inverter absolute reactive power in the solved power flow case or, in the case where a plant controller model (REPC_A) is included, from the plant controller.

The option to process the reactive power command via a cascaded set of PI regulators for local reactive power and terminal voltage control (refer to Figure 3), or to bypass these regulators and directly derive a reactive current command from the inverter terminal voltage, shall be provided. In addition, a supplementary, fast-acting reactive current response to abnormally high or low terminal voltages (again, refer to Figure 3) shall be provided.

3.2.4 Protective Functions (included in REGC_A or other library model)

The model shall incorporate either of the following:

a) A set of six or more definite time voltage and frequency protective elements used to trip the generation represented by the model. Each element shall have an independent user-settable pickup and time delay.

b) The ability to trip the generation represented by the model via external models providing the same functionality. Examples of such external models include the LHFRT and LHVRT models currently available in PSLF, and the FRQDCA/FRQTPA and VTGDCA/VTGTPA models currently available in PSS®E.

3.2.5 Plant Level Active and Reactive Power Control (included in REPC_A model)

The plant controller model (REPC_A) is an optional model used when plant-level control of active and/or reactive power is desired. The model shall incorporate the following:

- Closed loop voltage regulation at a user-designated bus. The voltage feedback signal shall have provisions line drop compensation, voltage droop response and a user-settable deadband on the voltage error signal.
- Closed loop reactive power regulation on a user-designated branch with a user-settable deadband on the reactive power error signal.
- A plant-level governor response signal derived from frequency deviation at a user-designated bus. The frequency droop response shall be applied to active

power flow on a user user-designated branch. Frequency droop control shall be capable of being activated in both over and under frequency conditions. The frequency deviation applied to the droop gain shall be subject to a user-settable deadband.

The plant controller model is identical to that which the WECC REMTF is proposing to utilize for the Type 3 and Type 4 generic wind turbine models.

3.3 Model Block Diagrams

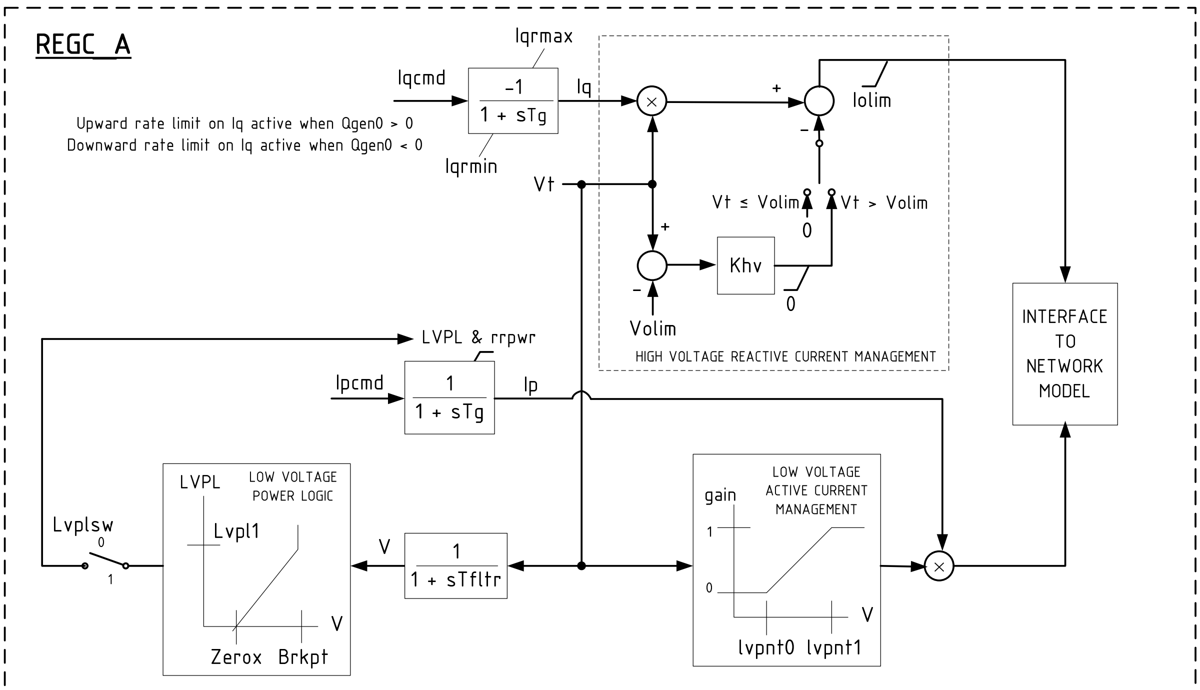

Figure 2. REGC_A Model Block Diagram

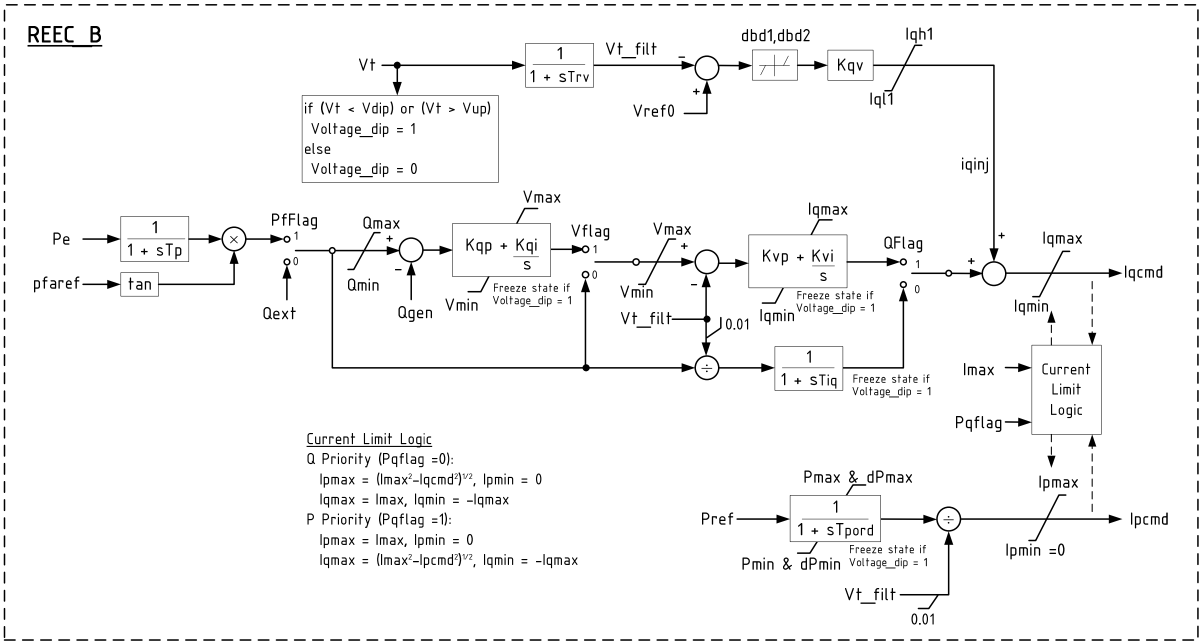

Figure 3. REEC_B Model Block Diagram

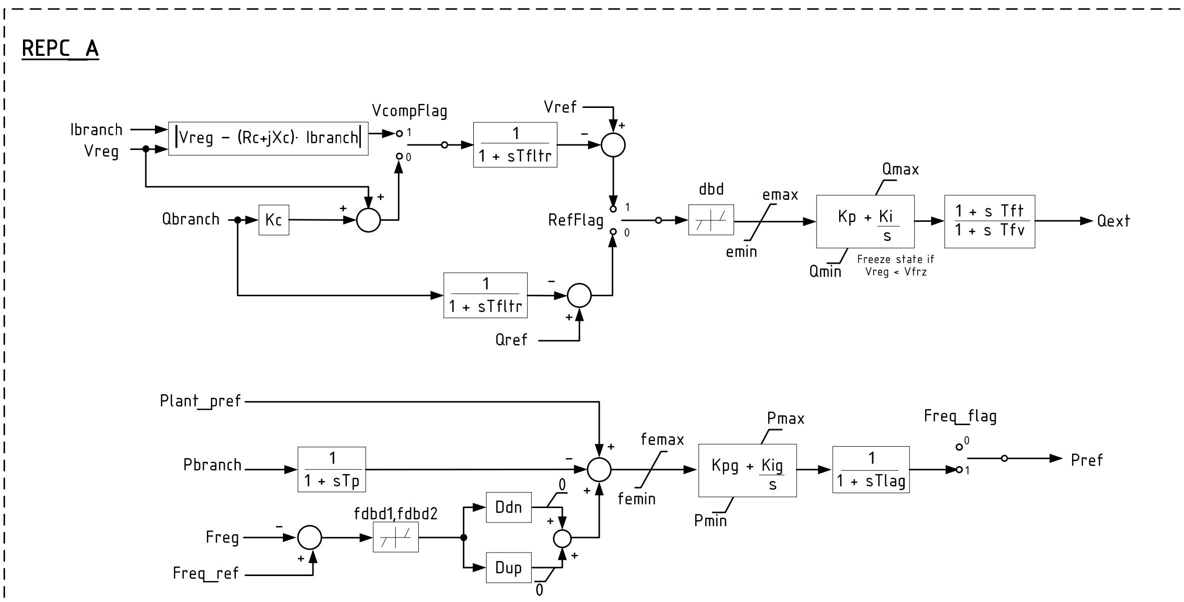

Figure 4. REPC_A Model Block Diagram

3.4 Active and Reactive Control Options

Tables 1 and 2, below, describe the models needed and the proper flag and/or input parameter settings for various active and reactive power control functionality.

Functionality	Models Needed	Freq_flag	Ddn	Dup
No governor response	REGC_A + REEC_B	0	N/A	N/A
Governor response with down regulation, only	REGC_A + REEC_B + REPC_A	1	> 0	0
Governor response with up and down regulation	REGC_A + REEC_B + REPC_A	1	> 0	> 0

Table 1. Active Power Control Options

Functionality	Models Needed	PfFlag	Vflag	Qflag	RefFlag
Constant local pf control	REGC_A + REEC_B	1	N/A	0	N/A
Constant local Q control	REGC_A + REEC_B	0	N/A	0	N/A
Local V control	REGC_A + REEC_B	0	0	1	N/A
Local coordinated V/Q control	REGC_A + REEC_B	0	1	1	N/A
Plant level Q control	REGC_A + REEC_B + REPC_A	0	N/A	0	0
Plant level V control	REGC_A + REEC_B + REPC_A	0	N/A	0	1
Plant level Q control + local coordinated V/Q control	REGC_A + REEC_B + REPC_A	0	1	1	0
Plant level V control + local coordinated V/Q control	REGC_A + REEC_B + REPC_A	0	1	1	1

Table 2. Reactive Power Control Options

3.5 Model Input Parameters, Internal Variables and Output Channels

REGC_A Input Parameters		
Name	**Description**	**Typical Values**
Tfltr	Terminal voltage filter (for LVPL) time constant (s)	0.01 to 0.02
Lvpl1	LVPL gain breakpoint (pu current on mbase / pu voltage)	1.1 to 1.3
Zerox	LVPL zero crossing (pu voltage)	0.4
Brkpt	LVPL breakpoint (pu voltage)	0.9
Lvplsw	Enable (1) or disable (0) low voltage power logic	-
rrpwr	Active current up-ramp rate limit on voltage recovery (pu/s)	10.0
Tg	Inverter current regulator lag time constant (s)	0.02
Volim	Voltage limit for high voltage clamp logic (pu)	1.2
Iolim	Current limit for high voltage clamp logic (pu on mbase)	-1.0 to -1.5
Khv	High voltage clamp logic acceleration factor	0.7
lvpnt0	Low voltage active current management breakpoint (pu)	0.4
lvpnt1	Low voltage active current management breakpoint (pu)	0.8
Iqrmax	Maximum rate-of-change of reactive current (pu/s)	999.9
Iqrmin	Minimum rate-of-change of reactive current (pu/s)	-999.9

REGC_A Internal Variables	
Name	**Description**
Vt	Raw terminal voltage (pu, from network solution)
V	Filtered terminal voltage (pu)
LVPL	Active current limit from LVPL logic (pu on mbase)
Iqcmd	Desired reactive current (pu on mbase)
Ipcmd	Desired active current (pu on mbase)
Iq	Actual reactive current (pu on mbase)
REGC_A Output Channels	
Name	**Description**
Vt	Terminal voltage (pu)
Pgen	Electrical power (MW)
Qgen	Reactive Power (MVAR)
Ipcmd	Active current command (pu on mbase)
Iqcmd	Reactive current command (pu on mbase)
Ip	Active terminal current (pu on mbase)
Iq	Reactive terminal current (pu on mbase)

Table 3. REGC_A Input Parameters, Internal Variable and Output Channels

REEC_B Input Parameters		
Name	**Description**	**Typical Values**
PFflag	Constant Q (0) or PF (1) local control	-
Vflag	Local Q (0) or voltage control (1)	-
Qflag	Bypass (0) or engage (1) inner voltage regulator loop	-
Pqflag	Priority to reactive current (0) or active current (1)	-
Trv	Terminal bus voltage filter time constant (s)	0.01 to 0.02
Vdip	Low voltage condition trigger voltage (pu)	0.0 to 0.9
Vup	High voltage condition trigger voltage (pu)	1.1 to 1.3
Vref0	Reference voltage for reactive current injection (pu)	0.95 to 1.05
dbd1	Overvoltage deadband for reactive current injection (pu)	-0.1 to 0.0
dbd2	Undervoltage deadband for reactive current injection (pu)	0.0 to 0.1
Kqv	Reactive current injection gain (pu/pu)	0.0 to 10.0
Iqhl	Maximum reactive current injection (pu on mbase)	1.0 to 1.1
Iqll	Minimum reactive current injection (pu on mbase)	-1.1 to -1.0
Tp	Active power filter time constant (s)	0.01 to 0.02
Qmax	Maximum reactive power when Vflag = 1 (pu on mbase)	-
Qmin	Minimum reactive power when Vflag = 1 (pu on mbase)	-
Kqp	Local Q regulator proportional gain (pu/pu)	-
Kqi	Local Q regulator integral gain (pu/pu-s)	-
Vmax	Maximum voltage at inverter terminal bus (pu)	1.05 to 1.15
Vmin	Minimum voltage at inverter terminal bus (pu)	0.85 to 0.95
Kvp	Local voltage regulator proportional gain (pu/pu)	-

Kvi	Local voltage regulator integral gain (pu/pu-s)	-
Tiq	Reactive current regulator lag time constant (s)	0.01 to 0.02
Tpord	Inverter power order lag time constant (s)	-
Pmax	Maximum active power (pu on mbase)	1.0
Pmin	Minimum active power (pu on mbase)	0.0
dPmax	Active power up-ramp limit (pu/s on mbase)	-
dPmin	Active power down-ramp limit (pu/s on mbase)	-
Imax	Maximum apparent current (pu on mbase)	1.0 to 1.3

REEC_B Internal Variables	
Name	**Description**
Vt	Raw terminal voltage (pu, from network solution)
Vt_filt	Filtered terminal voltage (pu)
Voltage_dip	Low/high voltage ride-though condition (0 = normal, VRT = 1)
Pe	Inverter active power (pu on mbase)
Pref	Inverter active power reference (pu on mbase, from power flow solution or from plant controller model)
Pfaref	Inverter initial power factor angle (from power flow solution)
Qgen	Inverter reactive power (pu on mbase)
Qext	Inverter reactive power reference (pu on mbase, from power flow solution or from plant controller model)
Iqinj	Supplementary reactive current injection during VRT event (pu on mbase)
Ipmax	Maximum dynamic active current (pu on mbase)
Ipmin	Minimum active current (0)
Iqmax	Maximum dynamic reactive current (pu on mbase)
Iqmin	Minimum dynamic reactive current (pu on mbase, = -iqmax)
Ipcmd	Desired active current (pu on mbase)
Iqcmd	Desired reactive current (pu on mbase)

REEC_B Output Channels	
Name	**Description**
Pref	Reference active power (pu on mbase)
Qext	Reference reactive power (pu on mbase)
Vt_filt	Filtered terminal voltage (pu)
Iqinj	Reactive current from VRT logic (pu on mbase)
Ipcmd	Active current command (pu on mbase)
Iqcmd	Reactive current command (pu on mbase)

Table 4. REEC_B Input Parameters, Internal Variable and Output Channels

REPC_A Input Parameters		
Name	**Description**	**Typical Values**
RefFlag	Plant level reactive power (0) or voltage control (1)	-
VcompFlag	Reactive droop (0) or line drop compensation (1)	-
Freq_flag	Governor response disable (0) or enable (1)	0

Tfltr	Voltage and reactive power filter time constant (s)	0.01 to 0.02
Vbus	Monitored bus number	-
FromBus	Monitored branch "from" bus number	-
ToBus	Monitored branch "to" bus number	-
Ckt	Monitored branch circuit designation	-
Rc	Line drop compensation resistance (pu on mbase)	-
Xc	Line drop compensation reactance (pu on mbase) when VcompFlag = 1	-
Kc	Reactive droop (pu on mbase) when VcompFlag = 0	-
dbd	Reactive power deadband (pu on mbase) when RefFlag = 0; Voltage deadband (pu) when RefFlag = 1	-
emax	Maximum Volt/VAR error (pu)	-
emin	Minimum Volt/VAR error (pu)	-
Kp	Volt/VAR regulator proportional gain (pu/pu)m	-
Kq	Volt/VAR regulator integral gain (pu/pu-s)	-
Qmax	Maximum plant reactive power command (pu on mbase)	-
Qmin	Minimum plant reactive power command (pu on mbase)	-
Vfrz	Voltage for freezing Volt/VAR regulator integrator (pu)	0.0 to 0.9
Tft	Plant controller Q output lead time constant (s)	-
Tfv	Plant controller Q output lag time constant (s)	0.15 to 5.0
fdbd1	Overfrequency deadband for governor response (pu)	0.01
fdbd2	Underfrequency deadband for governor response (pu)	-0.01
Ddn	Down regulation droop (pu power/pu freq on mbase)	20.0 to 33.3
Dup	Up regulation droop (pu power/pu freq on mbase)	0.0
Tp	Active power filter time constant (s)	0.01 to 0.02
femax	Maximum power error in droop regulator (pu on mbase)	-
femin	Minimum power error in droop regulator (pu on mbase)	-
Kpg	Droop regulator proportional gain (pu/pu)	-
Kig	Droop regulator integral gain (pu/pu-s)	-
Pmax	Maximum plant active power command (pu on mbase)	1.0
Pmin	Minimum plant active power command (pu on mbase)	0.0
Tlag	Plant controller P output lag time constant (s)	0.15 to 5.0

REPC_A Internal Variables	
Name	**Description**
Vreg	Regulated bus voltage (pu, from network solution)
Vref	Regulated bus initial voltage (pu, from power flow solution)
Ibranch	Branch current for line drop compensation (pu on mbase)
Qbranch	Branch reactive power flow for plant Q regulation (pu on mbase)
Qref	Regulated branch initial reactive power flow (pu, from power flow solution)
Qext	Reactive power command from plant controller (pu on mbase)
Pbranch	Branch active power flow for plant P regulation (pu on mbase)
Plant_pref	Initial branch active power flow (pu on mbase, from power flow solution)

Freq	Frequency deviation (pu, from network solution)
Freq_ref	Initial frequency deviation (0)
Pref	Active power command from plant controller (pu on mbase)

REPC_A Output Channels	
Name	**Description**
Vreg	Regulated bus voltage (pu)
Vref	Regulated bus reference voltage (pu)
Pbranch	Regulated branch active power flow (MW)
Plant_pref	Regulated branch reference active power flow (MW)
Qbranch	Regulated branch reactive power flow (MVAR)
Qref	Regulated branch reference reactive power flow (MVAR)
Pref	Active power command from plant controller (pu on mbase)
Qext	Reactive power command from plant controller (pu on mbase)

Table 5. REPC_A Input Parameters, Internal Variable and Output Channels

4. Distributed PV System Model (PVD1)

4.1 Key Modeling Assumptions

Unlike central station PV plants, distributed PV systems are connected at the distribution level, and thus are under state jurisdiction. Reliability and interconnection requirements, while varying from state to state, tend to reflect the requirements outlined in IEEE Standard 1547. In contrast with NERC and WECC central station reliability requirements, distributed PV systems at this time normally do not participate in steady state voltage regulation, and tighter bounds on operation for off-nominal voltage and frequency conditions result in significantly different fault ride-through capability.

In the near term, it is anticipated that the PV inverters applied in distributed systems will continue to comply with IEEE 1547, and will operate under constant power factor or constant reactive power modes of operation. The elimination of the closed-loop voltage regulator dynamics, along with the elimination of the DC dynamics (for the same reasons described for the Central Station model), allows for substantial simplification of the model with respect to that of the Central Station. However, unlike a Central Station plant, the terminal voltages seen by the individual inverters within the composite load in the bulk system dynamic model are likely to vary substantially. A different protection model is used to capture the effect of the diverse terminal conditions on the aggregate generation.

Note: The REMTF is currently considering the possibility of integrating this model into the existing WECC complex load model (CMPLDW)[1]. However, the integration of this model into CMPLDW is outside the scope of this document.

[1] Refer to W.W. Price, "CMPLDWG - Composite Load Model with Photovoltaic Distributed Generation", Final Report, July 20, 2012

4.2 Subsystem Models

4.2.1 Active Power Control

The active power control subsystem shall provide the active current injection to the network solution. The active current command shall be subject to current limiting, with user-selectable priority between active and reactive current. The active current command shall be derived from a reference active power and the inverter terminal voltage determined in the network solution. The reference active power shall be the initial active power from the solved power flow case.

The active power control subsystem shall provide a high frequency droop (governor response) function with user-settable deadband and droop gain.

4.2.2 Reactive Power Control

The reactive power control subsystem shall provide the reactive current command to the network solution. The reactive current command shall be subject to apparent current limiting, with user-selectable priority between active and reactive current. The reactive power control mode shall be limited to constant reactive power. The reference reactive power shall be the sum of the following:

- The initial reactive power from the solved power flow case
- A droop signal derived from voltage deviation at a user-specified bus. The voltage deviation applied to the droop characteristic shall be subject to deadband control and line drop compensation.

4.2.3 Protective Functions

The model shall incorporate functions which reduce generation outside of user-specified deadbands on voltage and frequency in an amount proportional to the voltage or frequency deviation. User-settable flags shall determine whether recovery of generation shall occur when voltage or frequency excursions reverse and return toward the deadband, and in what proportion. The tripping logic shall be as follows:

For low voltage tripping:

```
if( Vt < Vmin )  Vmin = Vt    [Initially, Vmin = Vt or a large value]
if( Vmin < Vt0 ) Vmin = Vt0   [Vmin tracks the lowest voltage during
                                     the simulation but not below Vt0]
if( Vt < Vt0 )
```

```
   Fvl = 0.0                   [All generation is tripped below Vt0]
else if( Vt < Vt1 )
   if( Vt <= Vmin )            [While decreasing between Vt1 and Vto]
      Fvl = (Vmin – Vt0) / (Vt1 – Vt0)
   else                        [While recovering above Vmin, partial
                               reconnection]
      Fvl = ((Vmin – Vt0) + Vrflag * (Vt - Vmin)) / (Vt1 – Vt0)
   endif
else
   if( Vmin >= Vt1 )
      Fvl = 1.0                [If Vt has not gone below Vt1]
   else                        [Vt has been below Vt1 but has recovered]
      Fvl = ((vmin – Vt0) + Vrflag * (Vt1 - vmin)) / (Vt1 – Vt0)
   endif
endif
```

<u>For high voltage tripping</u>:

```
if( Vt > Vmax )  Vmax = Vt    [Initially, Vmax = Vt or 0]
if( Vmax > Vt3 ) Vmax = Vt3

if( Vt > Vt3 )
   Fvh = 0.0
else if( Vt > Vt2 )
   if( Vt >= Vmax )
         Fvh = (Vt3 - Vmax) / (Vt3 – Vt2)
   else
         Fvh = ((Vt3 - Vmax) + Vrflag * (Vmax - Vt)) / (Vt3 – Vt2)
   endif
else
   if( Vmax <= Vt2 )
         Fvh = 1.0
   else
         Fvh = ((Vt3 - Vmax) + Vrflag * (Vmax – Vt2)) / (Vt3 – Vt2)
   endif
endif
```

The logic for the low and high frequency tripping is the same with “V” replaced by “F”. The outputs of this logic are four factors (Fvl, Fvh, Ffl and Ffh) which represent the “untripped” PV generation on a per unit basis. The multiplication of these factors, in the manner shown in Figure 5, results in a reduction in aggregate active and reactive current under the assumption that voltage and frequency tripping events following a disturbance are statistically uncorrelated.

4.3 Model Block Diagram

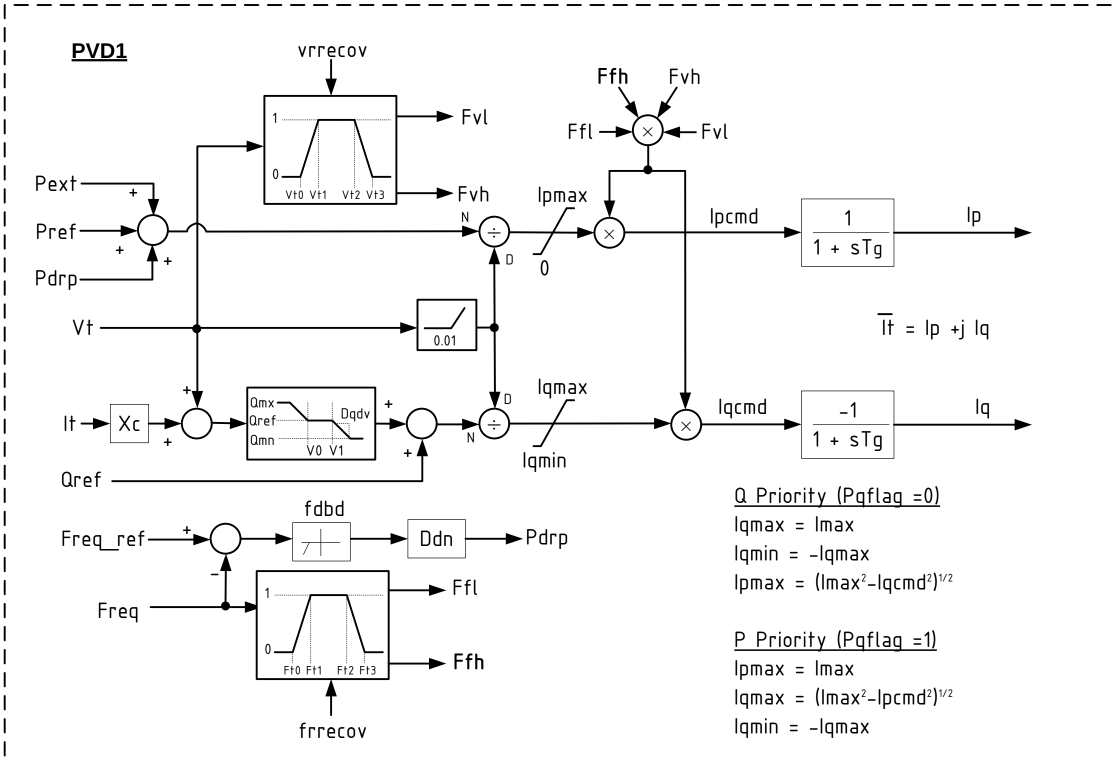

Figure 5. Distributed PV Model Block Diagram

4.4 Model Input Parameters, Internal Variables and Output Channels

PVD1 Input Parameters		
Name	**Description**	**Typical Values**
Pqflag	Priority to reactive current (0) or active current (1)	-
Xc	Line drop compensation reactance (pu on mbase)	0
Qmx	Maximum reactive power command (pu on mbase)	0.328
Qmn	Minimum reactive power command (pu on mbase)	-0.328
V0	Lower limit of deadband for voltage droop response (pu)	-
V1	Upper limit of deadband for voltage droop response (pu)	-
Dqdv	Voltage droop response characteristic	-
fdbd	Overfrequency deadband for governor response (pu deviation)	-
Ddn	Down regulation droop gain (pu on mbase)	-
Imax	Apparent current limit (pu on mbase)	1.0 to 1.3
Vt0	Voltage tripping response curve point 0 (pu)	0.88
Vt1	Voltage tripping response curve point 1 (pu)	0.90
Vt2	Voltage tripping response curve point 2 (pu)	1.1

Vt3	Voltage tripping response curve point 3 (pu)	1.2
Vrflag	Voltage tripping is latching (0) or partially self-resetting (>0 and ≤1)	0
Ft0	Frequency tripping response curve point 0 (Hz)	59.5
Ft1	Frequency tripping response curve point 1 (Hz)	59.7
Ft2	Frequency tripping response curve point 2 (Hz)	60.3
Ft3	Frequency tripping response curve point 3 (Hz)	60.5
Frflag	Frequency tripping is latching (0) or partially self-resetting (>0 and ≤1)	0
Tg	Inverter current lag time constant (s)	0.02
PVD1 Internal Variables		
Name	**Description**	
Vt	Terminal voltage (pu, from network solution)	
It	Terminal current (pu, from network solution)	
Pref	Initial active power (pu on mbase, from power flow solution)	
Pext	Supplemental active power signal (pu on mbase; zero unless written to by external model)	
Pdrp	Governor response (droop) power (pu on mbase)	
Qref	Initial reactive power (pu on mbase, from power flow solution)	
Freq	Terminal frequency deviation (pu, from network solution)	
Freq_ref	Initial terminal frequency deviation (0)	
Fvl	Multiplier on current commands in high voltage condition	
Fvh	Multiplier on current commands in low voltage condition	
Ffl	Multiplier on current commands in high frequency condition	
Ffh	Multiplier on current commands in low frequency condition	
Ipmax	Dynamic active current limit (pu on mbase)	
Iqmax	Dynamic reactive current limit (pu on mbase)	
Iqmin	Dynamic reactive current limit (pu on mbase, = -Iqmax)	
Iqcmd	Desired reactive current (pu on mbase)	
Iqcmd	Desired reactive current (pu on mbase)	
Ip	Active current injection to network solution (pu on mbase)	
Iq	Reactive current injection to network solution (pu on mbase)	
PVD1 Output Channels		
Name	**Description**	
Vt	Terminal voltage (pu)	
Pgen	Electrical power (MW)	
Qgen	Reactive Power (MVAR)	
Ipcmd	Active current command (pu on mbase)	
Iqcmd	Reactive current command (pu on mbase)	
Ip	Active terminal current (pu on mbase)	
Iq	Reactive terminal current (pu on mbase)	

Table 5. PVD1 Input Parameters, Internal Variable and Output Channels