White Paper on Modeling Hybrid Power Plant of Renewable Energy and Battery Energy Storage System

WECC REMWG

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1 Introduction

Hybrid power plants are becoming increasingly popular due to cost savings, flexibility, and higher energy production by sharing land, infrastructure, and maintenance services. Hybrid power plants, or hybrid resources, are defined as [1]:

> **Hybrid Power Plant (Hybrid Resource):** A generating resource that is comprised of multiple generation technologies that are controlled by a single entity and operated as a single resource behind a single point of interconnection (POI).

There are many types of hybrid power plants, some including combined heat and power with solar PV and possibly energy storage; however, the most predominant type of hybrid power plant observed in interconnection queues across WECC is the combination of renewable energy (solar PV or wind) and battery energy storage technologies. This white paper thus focuses on modeling hybrid power plant of renewable energy and battery energy storage. However, the modeling principle and approach apply to other types of hybrid power plants as well.

Hybrid plants can be classified as either of the following:

- **AC-Coupled Hybrid Plants:** An ac-coupled hybrid power plant couples each form of generation after it has been converted through a power electronics interface from dc to ac. For example, a BESS system will be coupled with a wind or solar PV facility on the ac-side of the inverters' interfaces, often at the medium voltage bus on the low-side of the main power transformer for the plant. The conversion from dc to ac occurs at each solar inverter or wind turbine, as with other inverter-based generating resources. Figure 1 shows a simple illustration of an ac-coupled hybrid power plant where a BESS is coupled with a solar PV or wind power plant on the ac side.
- **DC-Coupled Hybrid Plants:** A dc-coupled hybrid power plant couples both sources on the dc side of each inverter, prior to its conversion to ac. Each individual dc-ac inverter has a BESS and generating resource coupled at the dc bus, which is then simultaneously converted to ac for the combined BESS and generating component. Figure 2 shows a simple illustration of a dc-coupled hybrid power plant, where the energy storage component is coupled to each individual inverter on the dc side.

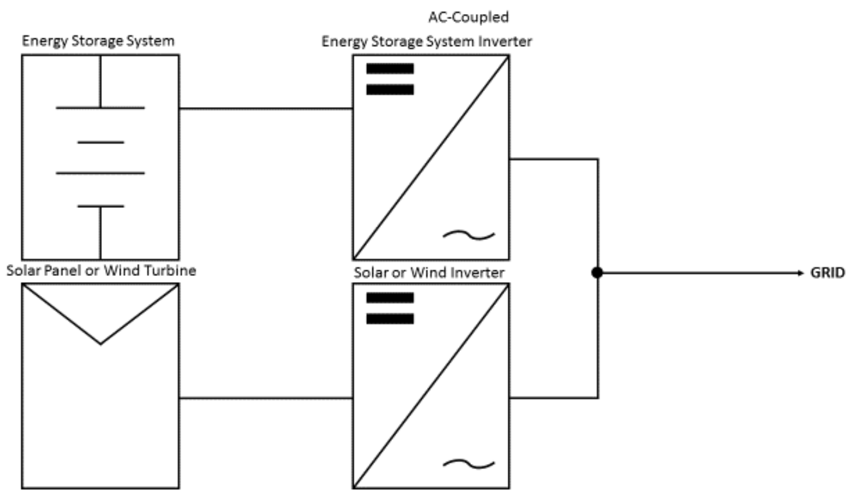


Figure 1: Simple Illustration of AC-Coupled Hybrid Plant

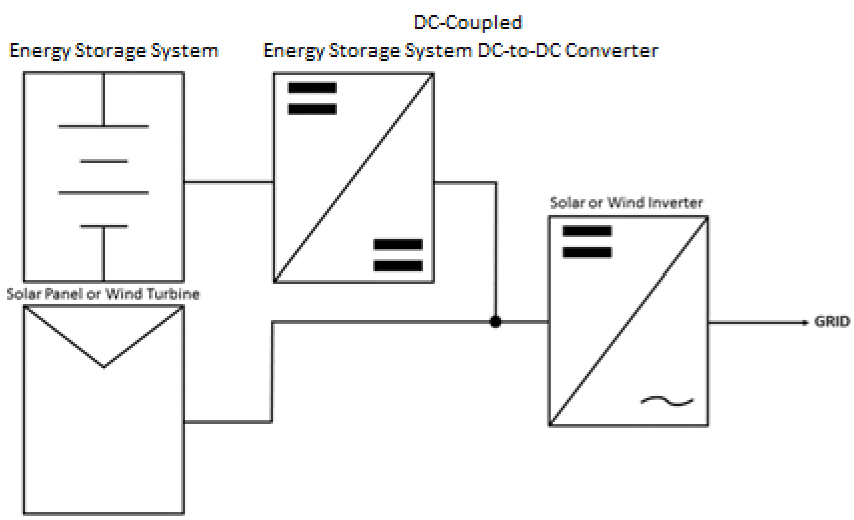


Figure 2: Simple Illustration of DC-Coupled Hybrid Plant

The white paper was developed in coordination with NERC Inverter-Based Resource Performance Task Force (IRPTF). While the NERC guideline being developed by IRPTF covers more broadly the modeling, studying and performance of both stand-alone BESS and hybrid power plants, this white paper goes into depth on modeling the hybrid power plant.

2 Current Modeling Guideline by MVS

The Solar PV Power Plant Modeling and Validation Guideline by Model Validation Subcommittee includes discussion on the modeling of hybrid solar PV and battery plants. The recommendation is summarized below.

2.1 Power Flow Representation

Each hybrid solar PV and BESS power plant with aggregated capacity ≥ 20 MVA and connected to 60 kV and above is modeled explicitly in the power flow model. The power flow representation includes:

- An explicit representation of the interconnection transmission line, if one exists.
- An explicit representation of all substation transformers.
- An equivalent representation of the collector systems.
- An equivalent representation of inverter pad-mounted transformers with a scaled MVA rating except when the pad-mounted transformers are integrated with the inverters.
- One or multiple equivalent representation of generators scaled to match the total capacity of the plant.
- An explicit representation of all plant level reactive compensation devices either as shunts (fixed or switchable) or as generators (FACTs devices), if applicable.

For modeling guideline regarding the substation transformers, collector systems, inverter pad-mounted transformers and reactive devices, please refer to Solar Photovoltaic Power Plant Modeling and Validation Guideline. This white paper focuses on the equivalent generator representation.

If the solar PV and battery storage each has its own set of inverters, i.e. ac coupled (Figure 1), the solar PV and battery storage should both be modeled explicitly by separate equivalent generators, equivalent pad-mounted transformers and equivalent collectors. The turbine type of the solar PV generator is set to 31, 32 or 33[1]. The turbine type of the battery generator is set to 42. The reactive capability requirement applies to the entirety of the solar PV and battery storage generators. The solar PV and battery storage individually may not have capability to meet the requirement alone.

If the solar PV and battery storage are dc-coupled (Figure 2), one equivalent generator will represent the inverters for both solar PV and battery storage. The turbine type of the generator is set to 33 if the storage does not charge from the grid and 42 if the storage charges from the grid. A negative Pmin of the equivalent generator represents the maximum charging power if the battery storage charges from the grid.

[1] Turbine type 32 for photovoltaic (fixed), 33 for photovoltaic (tracking), 31 for photovoltaic (mixed or unknown solar tracking)

Table 1: Equivalent Generator Representation in Power Flow

AC-coupled hybrid	DC-coupled hybrid
Separate generators for solar and BESS	One generator
BESS generator: turbine type = 42, pmin < 0	If BESS could charge from the grid, pmin < 0, turbine type=42
Solar generator: turbine type = 31, 32 or 33	If BESS never charges from the grid, pmin = 0, turbine type = 33

2.2 Dynamic Representation

If the solar PV and battery storage are ac-coupled (Figure 1), the solar PV and battery storage are modeled explicitly by separate equivalent generators, equivalent pad-mounted transformers and equivalent collector systems in the power flow. Each generator has its set of regc and reec models. It is recommended that repc_b is used as the master plant controller to coordinate electrical controls between the solar PV and battery storage.

If the solar PV and battery storage are dc-coupled (Figure 2), one equivalent generator represents the inverters for both solar PV and battery storage. One set of regc, reec and repc models is needed for the equivalent generator. The electrical control model suitable for the battery storage could always be used for this type of inverters. In case the battery does not charge from the grid, one may choose to use the electrical control model suitable for the solar PV instead of battery storage to represent the inverters with dc-coupled solar PV and battery storage.

Table 2: Equivalent Generator Representation in Dynamic Model

AC-coupled hybrid	DC-coupled hybrid
regc for each generator in the model	
If charging from the grid,	
reec_c or reec_d for BESS reec_a or reec_d for solar	reec_c or reec_d
If not charging from grid	
reec_c or reec_d for BESS reec_a or reec_d for solar	reec_a or reec_c or reec_d
repc_b or repc_c	repc_*

Detailed discussion on regc, reec and repc models can be found in Solar Photovoltaic Power Plant Modeling and Validation Guideline. The same modeling principle applies to other type of hybrid power plant as well.

3 Power Flow Modeling Capability Enhancement

Typically, the ac-coupled hybrid plant has a contractual output limit (plant Pmax) that is lower than the sum of the installed solar PV capacity and BESS capacity. The power plant controller manages both the active power output between the solar PV and the BESS and the reactive power output to maintain the voltage at the high side of the substation transformer within a specified range. The plant could supplement reactive power capability between the solar PV inverter and BESS inverters. For example, the BESS may be operated at full dispatching power without any reactive power capability remaining and the solar PV inverters are relied upon to meet the reactive power capability need. A power plant controller model is needed in the power flow to reflect such controls. The power plant controller model shall

1) Monitor outputs from individual generators represented in the power flow. If the individual outputs cause the plant output outside the plant contractual operating range, produce a warning message.
2) Control reactive power outputs for the individual generators and other controllable var devices in the plant in accordance with the hybrid plant volt/var control mode.

The active power monitor is straight-forward. A plant MW point of measurement (MW-POM) is defined. After the power flow solution is reached, MW injection to the MW-POM is calculated and compared to the defined plant maximum and minimum.

The reactive power control needs to reflect how the plant is operated. In the following sections, first the available modeling capability is summarized. Then recommendation is made to enhance the modeling capability.

3.1 Summary of Current Reactive Power Control Modeling Capability

Currently all the power flow software platforms have multiple options for generator reactive power control:

- Voltage regulation - voltage at the regulated bus is held constant with reactive output within the generator MVar limits Qmin and Qmax.
- Constant Q – generator reactive output is held constant at the specified value.
- Constant Power Factor – generator reactive output is held constant at the value specified by the power factor and active power output.

For voltage regulation, the Qmin and Qmax could be

- specified constants, or
- calculated from the active power output and reactive capability look up table (Q-table), or
- calculated from the active power output and the specified power factor range.

The regulated bus may be the generator terminal or a remote bus. In addition, a line drop compensation may be added to the generator terminal bus, i.e. reactive output is dispatched to regulate $V_t - I_t \times (R_{comp} + jX_{comp})$ to a voltage schedule.

Multiple generators can contribute to the control of voltage at a single bus. Each generator in the group regulating the same bus voltage is assigned a reactive power regulation factor that specifies the proportion of the total reactive power required from the group that is to be delivered by the generator.

Besides generators, there are volt/var controls through switchable static var devices and tap changers of transformers. The regulated buses and the regulated voltage schedules among all controllable devices need to setup carefully in the power flow model to achieve good quality solution. It has been common to observe reactive control hunting in the power flow solution and will be aggravated with increased number of hybrid plants.

Power World has implemented voltage droop control with deadband in the power flow to emulate typical renewable plant volt/var control. A group of generators regulating the same remote bus voltage are assigned to a voltage droop control. Within a specified deadband of the regulated bus voltage, the generators provides zero Mvars (or a specified amount of Mvars). Once the voltage is outside the deadband, a negative slope of Q vs. voltage is followed by all the generators in the group. This eliminates hunting among the generators and is a more realistic presentation of the plant. Details of implementing voltage droop control with deadband is published by Power World at https://www.powerworld.com/files/VoltageDroopControl_Software_Implementation.pdf.

3.2 Modification to existing Generator Mvar Limit specification

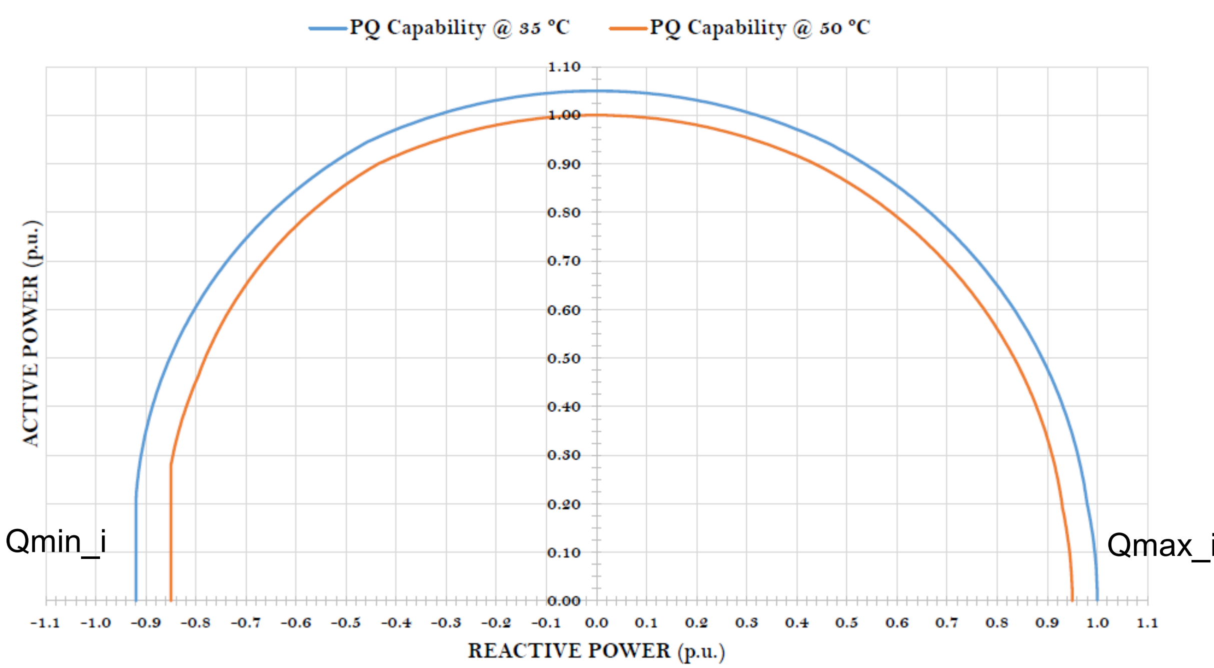
First, not part of PPC model itself, it is recommended to add one more generator reactive capability calculation mode:

- calculated from the active power output and the MVA rating, i.e.

Qmax_c = min (Qmax_i, $\sqrt{MVA^2 - PGEN^2}$)

Qmin_c = max (Qmin_i, $-\sqrt{MVA^2 - PGEN^2}$)

Where Qmax_i and Qmin_i are reactive power limits at the lowest active power output. See illustration below.



3.2.1 Generator Q Limit Model Specification

Following is the software specification to implement this Q limit calculation. Changes to the current model is highlighted in red.

- With generator cont_mode = 0, voltage at regulated bus is held constant within Q limits of generator specified by (Qmin, Qmax) or Q table or MVA calculation.
- The qtab field in the generator table selects the Q limits calculation

- qtab = 0: use Qmin and Qmax
- qtab = non-zero positive value: use the qtable
- qtab = -1: use MVA calculation

- In MVA calculation mode, the three quantities Qmax_i, Qmin_i and MVA are entered using the existing fields of qmax, qmin and mva_base in the generator table.
- In MVA calculation mode, qmx and qmn are calculated as

  qmx = min (qmax, $\sqrt{mva\_base^2 - pgen^2}$)

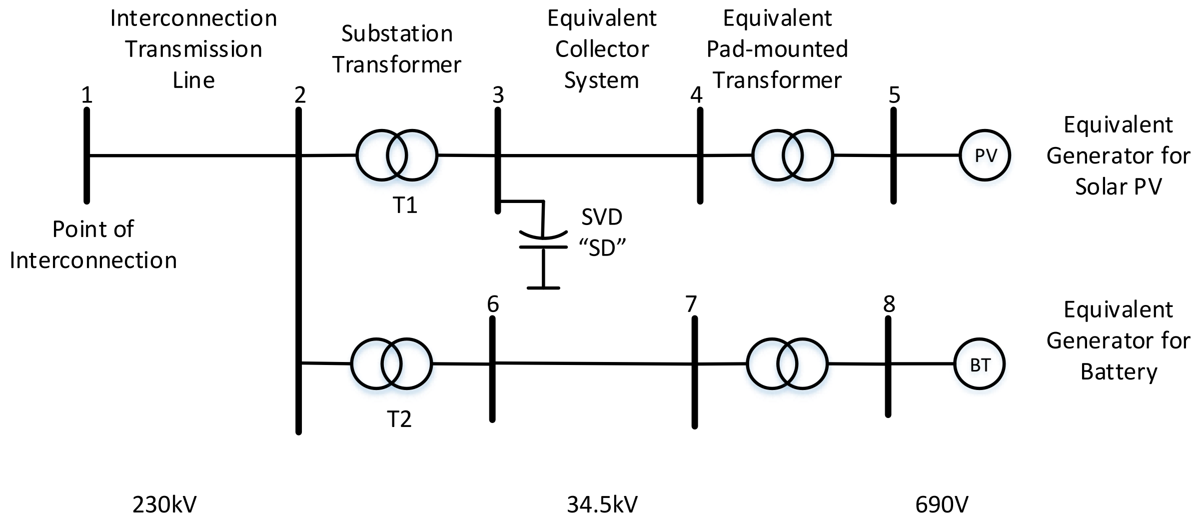
  qmn = max (qmin, $-\sqrt{mva\_base^2 - pgen^2}$)

  if pgen > mva_base, qmx = qmn = 0

Building upon the existing modeling capability and the voltage droop control developed by Power World, the REMTF recommends a broader power plant controller being implemented across all software platforms.

3.3 Power Plant Controller (PPC)

Consider as an example a power system as depicted in the following figure.



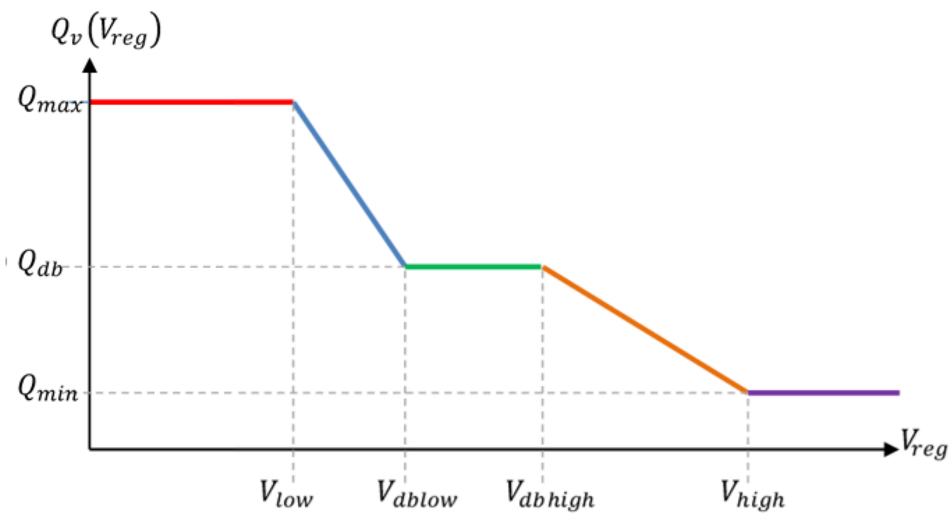
The assumption is that the generator at PV and BT are configured to regulate the bus voltage at Bus 2 in this example. The traditional "point of interconnection" is at Bus #1. The Power Plant Controller (PPC) is going to specify the characteristics of how the devices regulate the voltage at bus 2. The branches that will be used to measure the MW and Mvar that are controlled by the Plant Controller will be the transformers from buses 3 – 2 and 6 – 2. The MW and Mvar will be measured as those arriving at the regulated bus at bus 2. These branches will be called the *Arriving Branches*.

The following data are specified to define a PPC model:

- A new object which has a `Name` field will define the PPC. The PPC will also define a QV characteristic curve.
- Individual devices such as generators, SVDs, and other controllable reactive devices will be configured so that they can be assigned to the Power Plant Controller (PPC)
- Transformers that control tap will *not* be part of the PPC (explained later in this document)
- The PPC will have a *Regulated Bus* which will be obtained described below.
- Software will solve to an operating point such that the Mvar being injected at the *Regulated Bus* from the devices in the PPC will follow a QV characteristic with a deadband.
- Software will also ensure that Mvar limits of individual devices are enforced such as the generator MvarMax and MvarMin limits.
- Software also have a *Limit Bus* and provide a mechanism to specify real MW power limits.
- Software will provide a mechanism to indicate if the MW being injected at the *Limit Bus* from the devices in the PPC are exceeding these MW power limits.

3.3.1 New object specification for the software tool

The object will have input parameters that are used to define a QV characteristic of PPC Mvar versus per unit voltage at the *Regulated Bus*. The characteristic will look as follows.



The new object will have the following input parameters

Parameter	Description
Name	String names of the Power Plant Controller
Enabled	This value is either set to YES or NO. If set to YES, then the power flow solution will attempt to solve to meet the QV characteristic. If set to NO, then the devices that are assigned to this PPC will default back to their original behavior of controlling a regulated bus to a voltage. This field does not affect the MW monitoring function of the PPC. MW monitoring function is always on.
RegBus	If specified this will be the *Regulated Bus* of the Power Plant Controller. If not specified, then the software will automatically determine a *Regulated Bus* from the devices that belong to the PPC. For instance, generators already have a regulated bus so this will be obtained from those. The software will automatically build groups of devices that regulated the same *Regulated Bus* and enforce a voltage droop equation with those groups.
Qmax	Maximum reactive power in Mvar at the *Regulated Bus* being contributed by the devices in the Power Plant Controller
Qmin	Minimum reactive power in Mvar at the *Regulated Bus* being contributed by the devices in the Power Plant Controller
Qdb	Reactive power in Mvar at the *Regulated Bus* when the voltage is between Vdblow and Vdbhigh
Vlow	Per unit voltage at the *Regulated Bus* at *QmaxUsed (defined below)*
Vdblow	Low end of the per unit voltage range at the *Regulated Bus* when operating at Qdb
Vdbhigh	High end of the per unit voltage range at the *Regulated Bus* when operating at Qdb

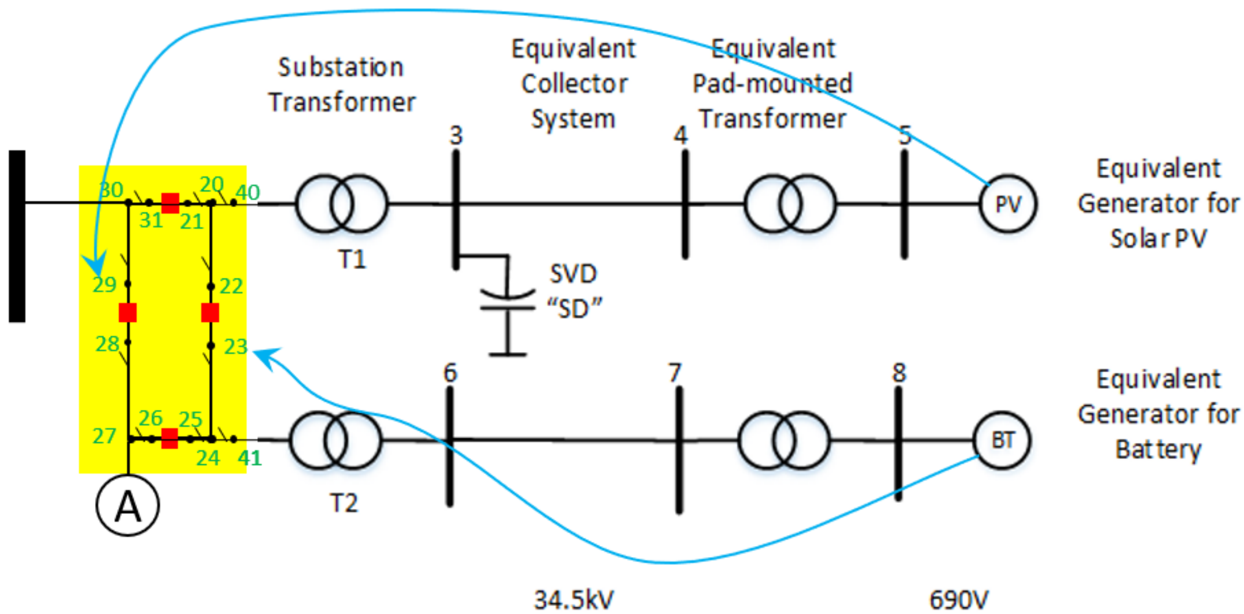
Vhigh	Per unit voltage at the *Regulated Bus* at *QminUsed (defined below)*
VDeviation	This value is either set to YES or NO. This determines how the input parameters for voltage Vlow, Vdblow, Vdbhigh, and Vhigh are treated. • NO : the parameters are absolute voltage in per unit value. • YES: the parameters are a deviation away from the voltage setpoint for the individual devices that are in this Power Plant Controller. By using VDeviation = YES, the user can modify the voltage setpoint as they have in the past and the QV curve will simply shift in response to this.
QAuto	This will be a discrete input that has 3 choices. • User: means to use the *Qmax* and *Qmin* specified above, i.e. *QmaxUsed* = *Qmax, QminUsed* = *Qmin* For software using an integer flag, denote this using a value of 0. • Sum: calculate *QmaxUsed* and *QminUsed* by taking a summation of the individual device max and min reactive power. For software using an integer flag, denote this using a value of 1. When using the Sum option then the strict limit on *QmaxUsed* and *QminUsed* for this curve will not be enforced by the Power Plant Controller and the sloped line between the Vdblow and Vlow will extend upward past Vlow (and similar on the high side). This is done because we assume in this mode that the enforcement of Mvar limits is handled by the individual devices instead. • PF: calculate the *QmaxUsed* and *QminUsed* taking a summation of the individual device present MW output and then calculating a *QmaxUsed* and *QminUsed* by assuming a constant power. Thus *QmaxUsed* = $\frac{\lvert\sum PgenMW\rvert(1-\mathrm{PF}^2)}{\mathrm{PF}^2}$ and *QminUsed* = –*QmaxUsed*. For software using an integer flag, denote this using a value of2.
PF	The power factor used in the *QmaxUsed* equation when QAuto = PF
LimitBus	MW Point of Limitation: bus where the plant MW injection limit is applied. If this is left unspecified, then the software will default back to use the *Regulated Bus* instead.
Pmax	Maximum real power in MW for the plant.
Pmin	Minimum real power in MW for the plant.

Values Reported by the software for each PPC will at a minimum be the following. The percent fields can be used to alert the user to when a MW value is exceeded.

Calculated Value	Description
MW	Total MW from the PPC. This is equal to MWArriving + MWGenRegBus
MWDevice	Summation of the MW injection for all devices in the PPC
MWArriving	Summation of the MW arriving at the *MW point of limitation* on branches that connect the devices in the PPC and have only one terminal in the *MW point of limitation Group*.
MWGenRegBus	Summation of the devices MW injection for devices in the PPC which are directly connected to the *Regulated Bus*
MWPercent	= 100(MW – Pmin)/(Pmax – Pmin)
MWDevicePercent	= 100(MWDevice – Pmin)/(Pmax – Pmin)
Mvar	Total Mvar from the PPC. This is equal to MvarArriving + MvarGenRegBus
MvarDevice	Summation of the Mvar injection for all devices in the PPC
MvarArriving	Summation of the Mvar arriving at the *Regulated Bus Group* on branches that connect the devices in the PPC and have only one terminal in the *Regulated Bus Group*.
MvarGenRegBus	Summation of the devices Mvar injection for devices in the PPC which are directly connected to the *Regulated Bus*
MvarPercent	= 100(Mvar – *QminUsed*)/(*QmaxUsed* – *QminUsed*)
MvarDevicePercent	= 100(MvarDevice – *QminUsed*)/(*QmaxUsed* – *QminUsed*)
RegBusNumUsed	This field will show the number of the bus actually used as the *Regulated Bus* in the power flow solution

3.3.2 Network Topology Discussion for *Regulated Bus* and *Arriving Branches*

Some network topologies will have groups of generators in the same PPC which do not share the exact same specification of a regulated bus. This may occur when models include very low impedance branches or when modeling full-topologies such as in an EMS system model. For example, the model may have a ring bus explicitly modeled such that the topology instead looks like the following.



In the example situation the BT generator is configured to regulate bus 23 and the PV is configured to regulate bus 29. In addition, there is a third generator "A" at bus 27 which regulates its own terminal bus. All the AC branches within the yellow highlighted region are very low impedance branches (as defined by the impedance threshold that all software tools use for defining that), or in full-topology models they may represent switching devices such as disconnects or circuit breakers. In this situation, the software needs to make accommodations so that the yellow highlighted region is treated as a single regulated point. In the discussion below the "*Regulated Bus*" is this entire group of buses connected by low impedance branches. For this discussion you could call this the "Regulated Bus Group".

The software will then also automatically calculate what the AC transmission branches that connect the devices in the PPC to a bus inside the "Regulated Bus Group". In this example it will be the transformers from buses 3 – 40 and 6 – 41. There are no topologies for which it will make sense for the *Arriving Branches* used in the QV characteristic to not be branches that connect to one of the buses in this *Regulated Bus Group*. For numerical reasons in the power flow solution algorithms it is important to choose branches that are not very low impedance branches as the *Arriving Branches* (for example choosing the branchs from 40 – 20 and 41 – 24 in this example may appear fine, but this would cause numerical problems). The software will never choose a very low impedance branch because by definition that branch would be inside the *Regulated Bus Group*. It is recommended that the software look for invalid topologies that would make the solution impossible as part of solution validation.

If the *Limit Bus* is set differently than the *Regulated Bus*, then the software will similarly automatically determine a list of buses in a "Limit Bus Group" which are connect to the Limit Bus by very low impedance branches. Again similarly, the software will automaitcally determine a list of AC transmission branches that connect the devices in the PCC to a bus inside the Limit Bus Group. Also the software will internally calculate a list of *Arriving MW Branches*.

3.3.3 Sharing of Device Mvar between generators in the same PPC

The sharing of Mvars between devices in the same PPC will be handled in the same manner that existing remote voltage regulation share Mvars across generators in power flow tools. This can be done using a Remote Regulation Factor specified with a generator or a bus. Or it can be done by ensuring that all devices are within the same relative point within their minimum to maximum Mvar range. The proposal does not change how different software tools handle the Mvar sharing. The user shall use the existing software capability to reflect how the PPC allocate Mvar target among the generators.

3.3.4 Treatment of SVD or Switched Shunt Models

If a shunt is assigned to the PPC, the shunt will be switched to meet the PPC control target. Implementation of switched shunt control varies among different software tools. This proposal does not change the current implementation with the expectation that the shunt control should align with and assist the PPC volt/var control.

3.3.5 Treatment of Transformer Tap ratios will not be part of the PPC

Consider a transformer tap ratio control enabled inside the network between the regulated bus and the devices in the PPC. Changing a transformer tap will not impact the final Mvar flow arriving at the *Regulated Bus* because the QV characteristic curve discussed above will be met regardless. The only thing that the transformer tap could do is control the per unit voltage in the low voltage system. In the earlier example, the transformer T1 and T2 could be configured to regulate the voltage at buses 5 and 8, but they can not regulate any voltage at the Regulated Bus or the point of interconnection because the QV characteristic will be met regardless. Because of this, the transformer does not need to be part of the PPC object and can simply be configured for normal voltage control.

3.3.6 Example Power Plant Control with two generators acting together

Below is an example. The plant consists of 100 MW solar PV and 100 MW batteries. The total delivery at point of interconnection (Bus 1) is limited to 100 MW. The reactive power capability is measured at the high side of the substation transformer (Bus 2).

Figure 3: An example of AC coupled solar PV and battery hybrid plant

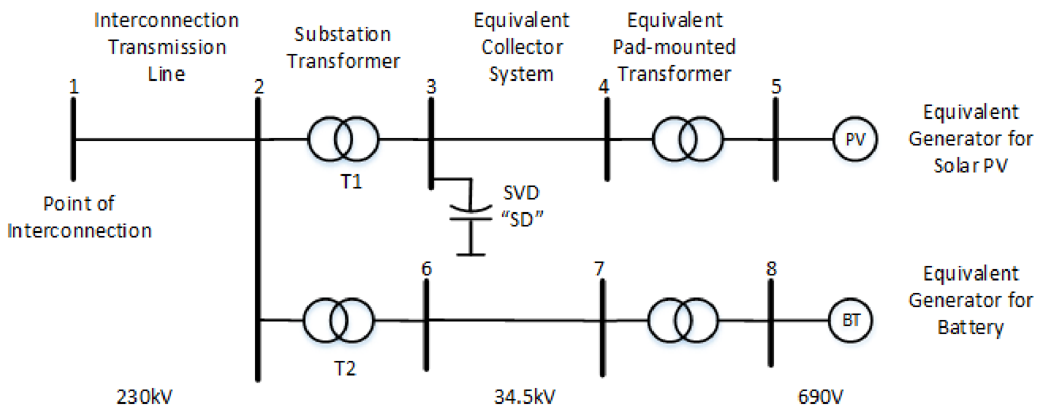
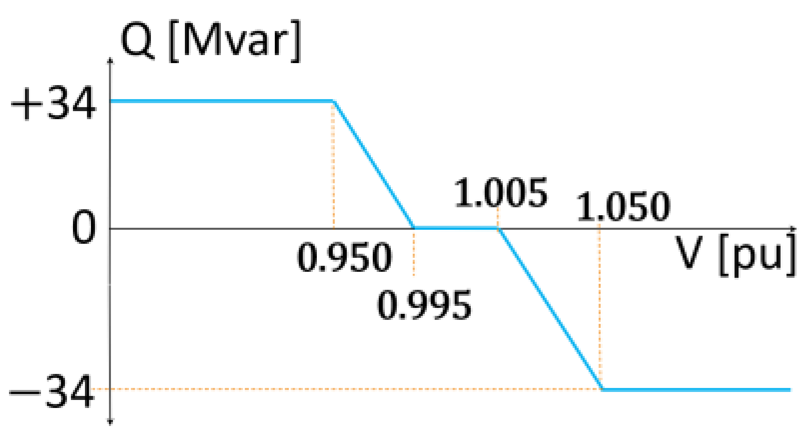


Table 3: Association of Power Plant with Devices

PPC	Devices	Device Type
Solar-BESS	Bus 5 "PV"	Generator
	Bus 8 "BT"	Generator
	Bus 3 "SD"	SVD

Table 4: Plant MW and Mvar Setup

Name	Solar-BESS
Enabled	YES
Qmax	34
Qmin	-34
Qdb	0
Vlow	0.950
Vdblow	0.995
Vdbhigh	1.005
Vhigh	1.050
VDeviation	NO
QAuto	User
PF	0.95
MWPOL	Bus 1
Pmax	100
Pmin	-100



The *Regulated Bus* will be bus 2 and that is inherited by the Power Plant Controller from the fact that the generators and SVD are all configured to regulate bus 2. The *Arriving Branches* used in the solution algorithm will be the Mvar measured at bus 2 on the transformer from 3 – 2 and 6 – 2 and these arriving Branches will be automatically determined by the software tool. The *MWarriving* calculatd from the solution is the MW flow at bus 1 from 2-1.

3.3.7 Alternate Example with 2 Independent Power Plant Controller

Another example is there are two separate Power Plant Controllers for two separate wind farms. For example a new wind farm may be added connecting to a same substation as an old wind farm installed 15 years ago. This is depicted in the figure below.

Figure 4: An example of AC coupled solar PV and battery hybrid plant

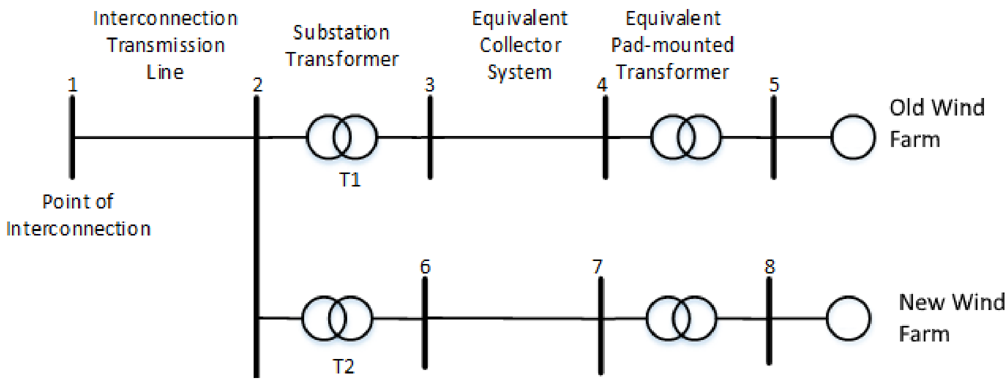
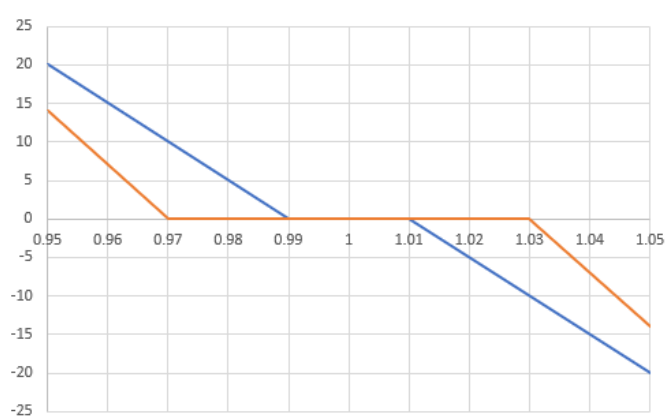


Table 5: Association of Power Plant with Devices

Devices	PPC
Bus 5 "O"	Old Farm
Bus 8 "N"	New Farm

Table 6: Plant MW and Mvar Setup

Name	Old Farm	New Farm
Enabled	YES	YES
Qmax	20	14
Qmin	-20	-14
Qdb	0	0
Vlow	0.950	0.950
Vdblow	0.970	0.990
Vdbhigh	1.030	1.010
Vhigh	1.050	1.050
VDeviation	NO	NO
QAuto	User	User
PF	0.95	0.95
MWPOL	Bus 2	Bus 2
Pmax	60	40
Pmin	0	0



The *Regulated Bus* for both wind generators is configured to be bus 2 and that is inherited by each Power Plant Controller. The *Arriving Branch* for the old wind farm is transformer from 3 – 2 and for the new wind farm is the transformer from 6 – 2. By appropriately setting the voltage values for the QV characteristic for each PPC you can bias the control so that the New Wind Farm provide Mvar before the Old Wind Farm. This is depicted in the image QV curves above. Starting below 0.99 per unit voltage the New Wind farm Mvar will begin to pickup and the Old Wind Farm will start at 0.97.

3.3.8 Software Implementation of QV characteristic in the power flow algorithms

The actual implementation of this QV characteristic inside the traditional power flow solution algorithms that have existed since the 1960s can become difficult because the dead-band introduces discontinuous derivatives. This is beyond the scope of this specification, but it is understood that around these corner points approximations will be made to smooth the transition between the sloped droop portion of the QV characteristic and the flat portions.

In addition to this if the slope of the QV characteristic becomes too large this also can create numerical problems for the solutions algorithms. For example, if Vdblow = 0.9991 and Vlow = 0.9990 then the slope of the QV characteristic become very large such the PPC would transition from Qdb all the way to maximum Mvar output over a voltage change of 0.0001 per unit. These are erroneous and silly input parameters, but the software should prevent these user input mistakes.

Different software may have different techniques handling the numerical challenges. As an example, detailed implementation in PowerWorld can be found in reference [3].

4 Dynamic Modeling Capability Enhancement

The control coordination among different generators in an AC-Coupled hybrid plant is achieved through REPC_B model. The frequency control is also implemented and only exists in the REPC model. For a hybrid plant, it is common that different fuel type generators have different frequency responses. All generators respond to high frequency by reducing active output. But only the battery has the operating headroom to increase active output under low frequency. With the current REPC_B model structure, this requires different weighting factors for the generators to be set up for different disturbances being studied. To resolve the issue, it is recommended to use the base load flag in the power flow model to block the upward frequency in the electrical control (reec). The base load flag is set to one of the following values in the power flow model:

0 – not blocked; pgen could be increased or reduced in response to frequency changes

1 – blocked from upward response; pgen could only be reduced

2 – blocked; pgen does not change in response to frequency changes

4.1.1 REEC and REPC Model Specification

During initialization of reec and repc models, pmax is set to the initial value of pgen if base load flag is 1 or 2 and pmin is set to the initial value of pgen if base flag is 2. See Table 7 below for implementation in different software platforms. This feature will be implemented in the previously approved REEC_A, REEC_C and REPC_A models as well as the upcoming REEC_D and REPC_C model and future REEC models as appropriate. It will not be implemented in the REPC_B model. For hybrid plants that use a common PPC to control multiple generators, REEC should be used in conjunction with REPC_B to block or enable frequency response at the generator level. Furthermore, in the case of REPC_B since the $P_{command}$ of the main controller always initialize to zero (see model specification and/or software user-manuals), the Pmax/Pmin and on the main controller is a limit on the total change in power and so if either Pmax or Pmin are set to zero this will prevent REPC_B from increasing or decreasing the plant power. Thus, care should be taken in setting these values for REPC_B since they do not represent the absolute values of maximum and minimum plant power. Of course, all this is irrelevant if the plant has not frequency response capability at all (which is true of the vast majority of plants built prior to 2018) and for which the *frqflag* parameter is set to 0.

Table 7: Blocking Frequency Response in Different Software Platforms

	PSLF	PowerWorld	PSS/E	TSAT	Interpretation in Code
Name of Generator Field in Software Tool	Baseload Flag	Governor Response Limits	Baseload Flag	Baseload Flag	In the initialization of the REEC model the following changes are made to the control limits

Leave the traditional MW response	0	Normal	0	0	Do nothing
Do not allow generator to go up, but do allow down	1	Down Only	1	1	[reec_*, repc_a, repc_c]: Pmax = PgenInitial
Do not allow generator to go up or down	2	Fixed	2	2	[reec_*, repc_a, repc_c]: Pmax = Pmin = PgenInitial

This specification requests that models REEC_A, REEC_C, and REPC_A be modified to follow the baseload flag associated with the generator record. This means that model behavior will be changed for renewable plants that have the baseload flag configured to block real power response and which have the real-power frequency response configured in the REPC_A model (Freq_Flag = 1). It is recognized that a simulation run in previous software versions may give different results after this change is made. This is considered more accurate by WECC because the base load flag is required to reflect generator frequency response per WECC base case preparation manual. Also, this added ability is important to the user community and it will also be less confusing if all REEC_* models use the baseload flag in the same manner.

5 Reference

[1] NERC, *Reliability Guideline of performance, modeling and simulations of BPS-connected battery energy storage system and hybrid power plants,* to be published

[2] WECC, *Solar PV Power Plant Modeling and Validation Guideline,* https://www.wecc.org/Reliability/Solar%20PV%20Plant%20Modeling%20and%20Validation%20Guidline.pdf

[3] PowerWorld Corporation, *Detailed Documentation of Software Implementation of Voltage Droop with Deadband in Power Flow Calculation,*

https://www.powerworld.com/files/VoltageDroopControl_Software_Implementation.pdf