Clarification on Proper Use of REPC models:

The Renewable Energy Modeling Work Group (REMWG)[1] of the WECC Modeling Validation Subcommittee[2] has, over the past 10 years, been developing a series of modularized, standard, and publicly available set of dynamic models for use in large system planning studies for the main forms of renewable energy systems (RES) [1]. The REMWG has published various guidelines and model specification documents [2], [3] , [4] , [5] , [6] , [7]. As these models are being widely used in the planning studies, misunderstanding and misuse of REPC models, especially REPC_B, have been observed. REPC_B is a complex-plant controller to coordinate controls among multiple devices, primarily for modeling hybrid power plants that have several different technologies in the same plant; e.g., a combination of solar PV and battery energy storage facilities. The model can also be used to model RES that have several groupings of inverter-based resource (IBR) generation that are modeled as multiple aggregated units but are all controlled by one centralized power plant controller (PPC). As the hybrid plants become more common and with the possibility of future renewable energy development, the REPC_B model is being used more often. The intent of this paper is to clarify and promote proper use of the REPC_B model for hybrid plants. However, as stated above the REPC_B model can also be used to model the PPC for a plant with a single IBR technology in which multiple aggregated IBR unit models are used. All the concepts in the paper apply to both applications. In addition, some clarification also applies to the REPC_A model.

REPC_B Model Clarification

Figure 1 shows the control block diagram for the REPC_B model. Please note:

1. Pmax and Pmin are defined for the entire plant. These represent the contractual active power output range, which is equal to or smaller than the sum of individual inverter active power output range.
2. Qmax and Qmin are defined for the entire plant. These represent the plant-level reactive capability to be used under the steady-state and small disturbances, which is equal to or smaller than the sum of individual inverter reactive capability.

[1] Previously called the Renewable Energy Modeling Task Force
[2] Previously called the Modeling and Validation Working Group

3. Plant controller active power reference Pext is distributed to multiple generators by weighting factors of Kzi.
4. Plant controller reactive power/voltage reference Wext is distributed to multiple generators by weighting factors of Kwi.

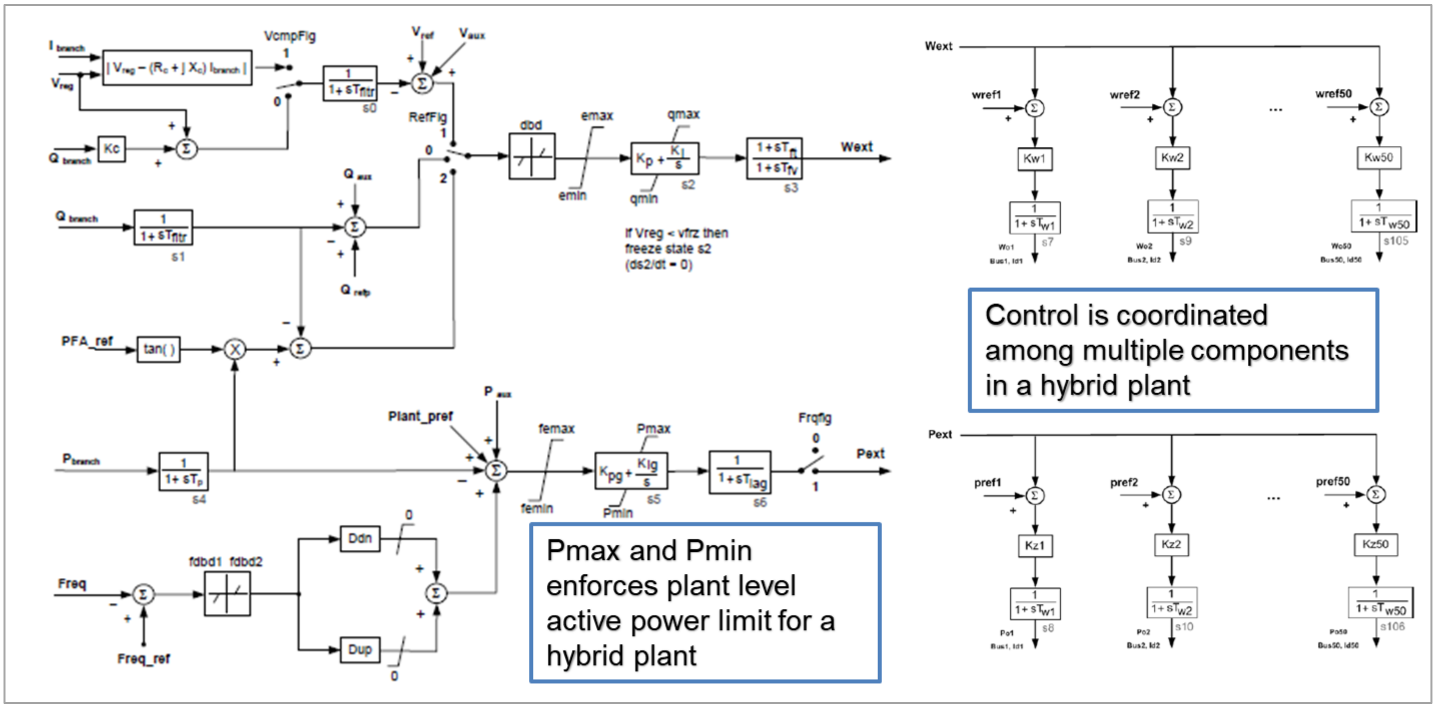

Figure 1: REPC_B control block diagram

To control multiple devices, the design of REPC_B is different from the rest of the RES model suite. Special attention is needed when setting up the REPC_B model:

- In some software implementations, the model is always on the system MVA base. All the per-unit parameters should be provided on the proper MVA base. For software packages in which the model has its own MVA base, it is preferable to use the MVA base of the entire plant.
- Pext and Wext initialize to "0." For this reason, all the control quantities are deviations from their initial values. Therefore, all the limits in the model are relative or deviation limits.
- Qmax and Qmin could be either reactive power deviation limits or voltage deviation limits, depending on the configuration of the downstream REEC_* models of the controlled generators.
- The weighting factors Kzi and Kwi are not normalized by the software. The user must appropriately scale or normalize these according to the MVA base on the downstream devices.

- The generator to which REPC_B is attached should be online. A monitor branch should be included in the REPC_B invocation. **Note**: In some software tools, the model is a bus model (i.e., connected to a bus and not a generator). In these cases, the invocation is not from a generator, so, if any of the generators are out of service, the status of the model is not affected.

Model MVA Base

Different software implement the REPC_B model differently. Some software provide an option to specify the model MVA base; some do not. Table 1 shows the major software implementation.

Table 1: REPC_B Implementation in Major Software

	Model Name	MVA Base
PSLF	REPC_B	System MVA base only
PSS/E	PLNTB	System MVA base or user specified model MVA base
PowerWorld	REPC_B	System MVA Base or user specified model MVA base (Supporting PSLF REPC_B and PSS/e PLNTB)
TSAT	REPC_B	System MVA Base or user specified model MVA base (Supporting PSLF REPC_B and PSS/e PLNTB)

When the model uses the system MVA base, all the parameters in per unit should be expressed on the system MVA base, i.e.:

$$Plant\ Pmax = \frac{Plant\ Maximum\ Output\ per\ Generation\ InterconnectionAgreement}{System\ MVA\ Base}$$

$$Plant\ Pmin = \frac{Plant\ Minimum\ Output\ per\ Generation\ InterconnectionAgreement}{System\ MVA\ Base}$$

$$Plant\ Qmax = \frac{Plant\ Maximum\ Reactive\ Output\ under\ Steady\ State\ and\ Small\ Disturbance}{System\ MVA\ Base}\ \text{(See footnote 3)}$$

$$Plant\ Qmin = \frac{Plant\ Minimum\ Reactive\ Output\ under\ Steady\ State\ and\ Small\ Disturbance}{System\ MVA\ Base}\ \text{(See footnote 3)}$$

$$dup = ddn = \frac{1}{droop} \times \frac{\sum_{all\ gens\ on\ REPC\_B} Generator\ Pmax}{system\ MVA\ base}$$

Note: Generator Pmax in the above equation means the nameplate rated megawatt capability of each generator.

[3] The equations are applicable when Qmax and Qmin are reactive limits. See discussion later about reactive power or voltage limits.

In addition, if line drop compensation is used for volt/var control, the compensation impedance should be per unit value on the MVA base used. If voltage droop is used, the droop gain kc should be per unit value on the MVA base used.

Relative Limits

The reactive power command Wext and active power reference Pext initialize to "0." They are changes from the initial value. Therefore, *Pmax/Pmin* and *Qmax/Qmin* should be relative or deviation limits in per unit:

$$[repc\_b].Pmax = Plant\ Pmax\ - Initial\ Pgen$$

$$[repc\_b].Pmin = Plant\ Pmin\ - Initial\ Pgen$$

$$[repc\_b].Qmax = Plant\ Qmax\ - Initial\ Qgen \text{ (See footnote 3)}$$

$$[repc\_b].Qmin = Plant\ Qmin - Initial\ Qgen \text{ (See footnote 3)}$$

where Initial Pgen and Initial Qgen are the sum of the Pgen and Qgen of generators controlled by the REPC_B model.

These parameters depend on the generation dispatch, which is subject to changes in the planning studies and unknown to the Generator Owners (GO) who provide the models. To resolve this issue, the GOs set the absolute limits in the model, i.e., as if initial Pgen and Qgen are "0." The Transmission Planners will offset the limits by the initial conditions when performing planning studies.[4] In other words, the GOs enter *Plant Pmax*, *Plant Pmin*, *Plant Qmax*, and *Plant Qmin* in the dynamic models. They will be converted to *[repb_b].pmax*, *[repc_b].pmin*, *[repc_b].qmax* and *[repc_b].qmin* at the time of simulation.

Reactive Power or Voltage Limits

The output Wext could be either reactive power command or a voltage signal, depending on the electrical controller (REEC_*) models for the generators controlled by the REPC_B model. If the REEC models are in local voltage control mode (pfflag =0, vflag = 0, qflag = 1), Wext is a voltage signal; otherwise, it is reactive power. This requires all the generators controlled by REPC_B to take the same type of signal: voltage or reactive power. There should not be a mix of local voltage control mode with other voltage/reactive power control modes among the REEC models connecting to the same REPC_B model. When Wext is voltage signal, Qmax/Qmin should be voltage deviation limits instead of reactive power deviation limits.

[4] Each software has its way of automating this. In case of PSLF platform, it can done through a pre-run epcl in each of the transient simulation run. The pre-run epcl calculates the initial total Pgen and Qgen and subtracts the initial values from the Pmax/Pmin and Qmax/Qmin in REPC_B models.

Kzi and Kwi

The software does not normalize the weighting factors Kzi and Kwi. It is up to the model users to set them up properly based on the control coordination in the actual power plant controller. Careless settings could cause unexpected results. For example, we have a power plant containing two generators that are 100 MVA and 200 MVA respectively and controlled by a REPC_B model on 100 MVA base. Say we intend to control the two generators' real power output proportionally based on their generator size but set kz1 = kz2 =1. When the REPC_B model produces a command of Pext = 0.2, it is meant to increase active output from the power plant by 20% of 100 MVA, which is 20 MW. But with kz1 = kz2 =1, we get 40 MW total output increase from the power plant, with the first generator providing 20% of its capacity (20 MW out of 100 MVA) and the second generator only contributed 10% of its capacity (20 MW out of 200 MVA). Another scenario is that one or more generators controlled by REPC_B are dispatched offline in a planning study. The Kzi and Kwi are not normalized among the online generators, which could introduce inaccuracy.

Model Invocation

The REPC_B model is attached to a generator in some software (PSLF, TSAT™, PowerWorld) and to a bus in others (PSS®E). In the case of it being attached to a generator, that generator must be online in the power flow model; otherwise the REPC_B model is turned off and not used. There is no good solution for this yet. The planners performing studies need to either keep the generator online, even at 0 MW output, or modify the dynamic model to invoke the REPC_B from a different online generator. A dummy generator that has 0 MW and MVAR capability and is always on may be added in each plant to attach the REPC_B model. Another key point about REPC_B invocation is that it should always include the monitored branch. Although REPC_B could still run without a monitored branch, it is incorrect, especially for hybrid plants that have plant-level output limits and provide the frequency response.

REPC_A Model Clarification

Monitored Branch in Model Invocation

REPC_A invocation should always include the monitored branch. Without the monitored branch, the frequency response is incorrect.

Per-Unit Flag

In some software platforms (e.g., GE PSLF and PowerWorld), there is a parameter puflag in REPC_A that allows for the model being on the model MVA base or system MVA base. If puflag is set to "0," the inputs pbranch and qbranch are on system MVA base and the parameters should be on system MVA base as well. The same calculation in the Model MVA Base section for REPC_B should be done. It is recommended to set puflag to "1" to avoid inconsistent parameters.

Other software platforms do not have puflag in REPC_A. All parameters, including compensation impedance, are on the specified model MVA base.

Conclusion

As the only available power plant controller model for AC-coupled hybrid plants, REPC_B will see increased use in the near future. There are some inherent limitations that require more diligence to parameterize the models correctly and use the models properly in the planning studies. The REMWG is working on model enhancement to improve the model robustness and usability. A new power plant controller mode REPC_D will be developed and is anticipated to replace REPC_B in the future. It should be based on the newly developed REPC_C model and expanded to allow it to connect to multiple downstream models like REPC_B, but resolve the limitations of REPC_B mentioned above.

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