Voltage Droop Control in Power Flow Solutions

Jamie Weber, Ph.D.
Director of Software Development
217 384 6330 ext 13

PowerWorld Corporation

2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

weber@powerworld.com
http://www.powerworld.com

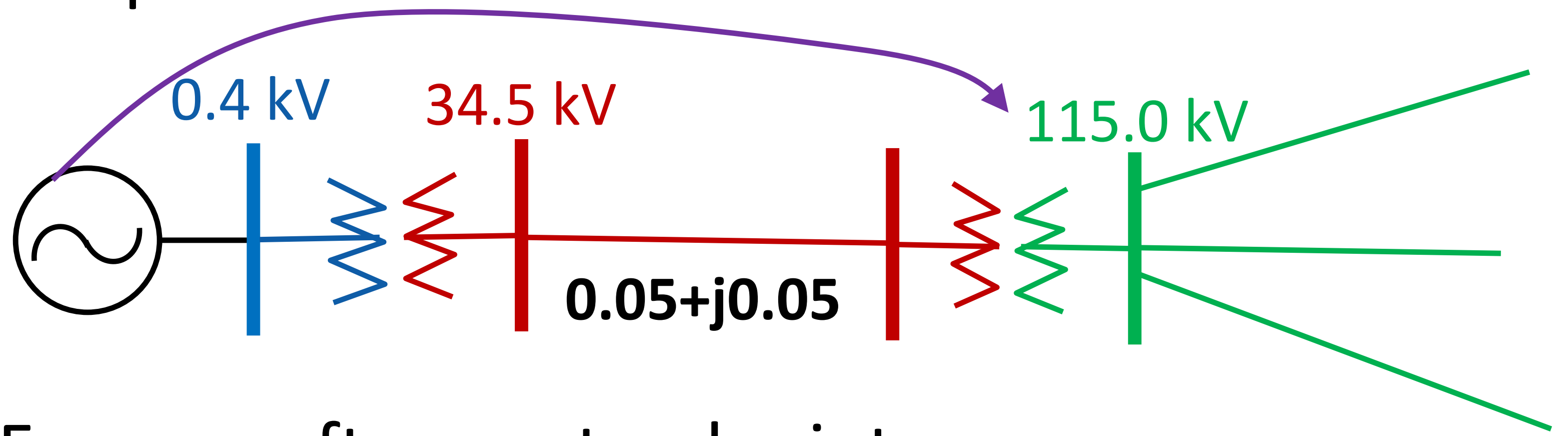
Presentation Outline

- History: Line Drop Compensation in Power Flow
- Need: Renewable Plants Q-V characteristic at point of interconnection
- Solution: Introduction of Voltage Droop Control (with deadband)
- Implementation Details
  - Presentation and white paper are available on our public website
    - https://www.powerworld.com/knowledge-base/renewable-generators-voltage-droop-control-with-deadband-in-power-flow-solution

History: Line Drop Compensation in Power Flow

Renewable Generator Questions started in 2013

- Renewable generators regulate a point closer to the point of interconnection



- From a software standpoint
  - Regulation point is a fixed impedance away from the generator terminal
  - This looked similar to "Line Drop Compensation" which was added in 2002 and improved in 2014
  - Used <u>*Complex Power*</u> to model "droop"

Generator Fields

- Line Drop Compensation Fields from 2002
  - Use LDC_RCC
  - XLDC
  - RLDC : added in 2014
- This works on a bus because we know <u>*the flow associated with line drop is the generator output*</u>

	Number of Bus	Name of Bus	Nom kV of Bus	ID	Use LDC_RCC	RLDC_RCC	XLDC_RCC
10	10318	My name 1	22.00	1	NO	0.00000	0.00010
11	10319	My Name 2	24.00	1	YES	0.04500	0.08000
12	10320	My Name 3	22.00	1	NO	0.00000	0.00010
13	10321	My Name 4	22.00	1	YES	0.04500	0.08000
14	10394	My Name 8	18.00	1	NO	0.00000	0.00010

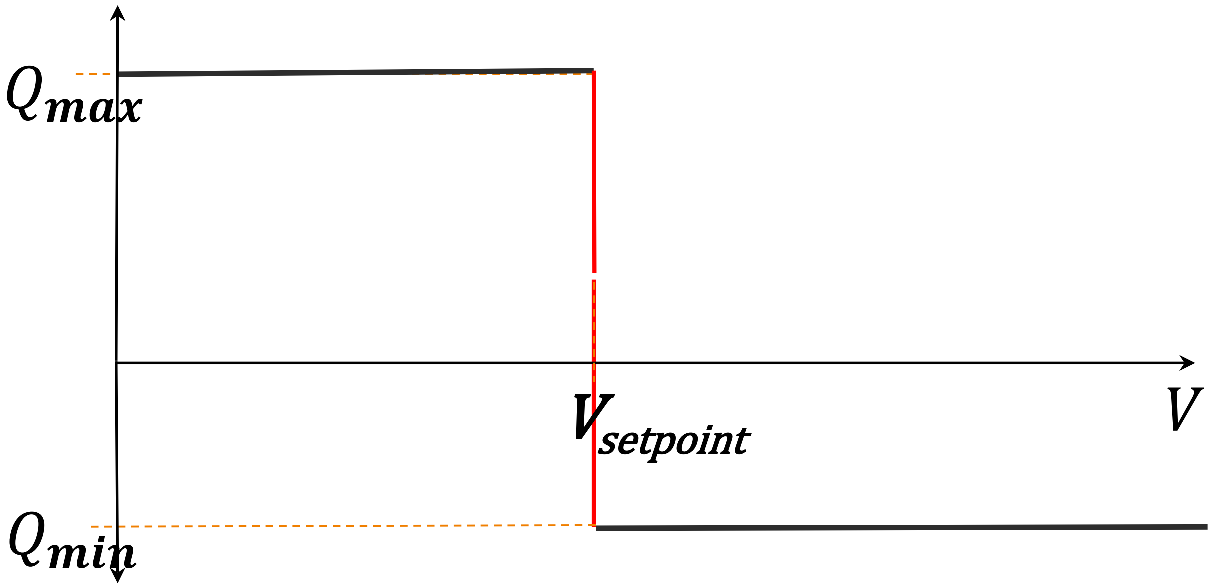
Need: Renewable Plants Q-V characteristic at point of interconnection

Similar questions for renewables continue

- In 2014 started to get questions about Solar PV plant voltage control
  - Also similar for wind farms
- Software users were asking how to implement this control in the power flow solution
- This was happening more starting in 2018

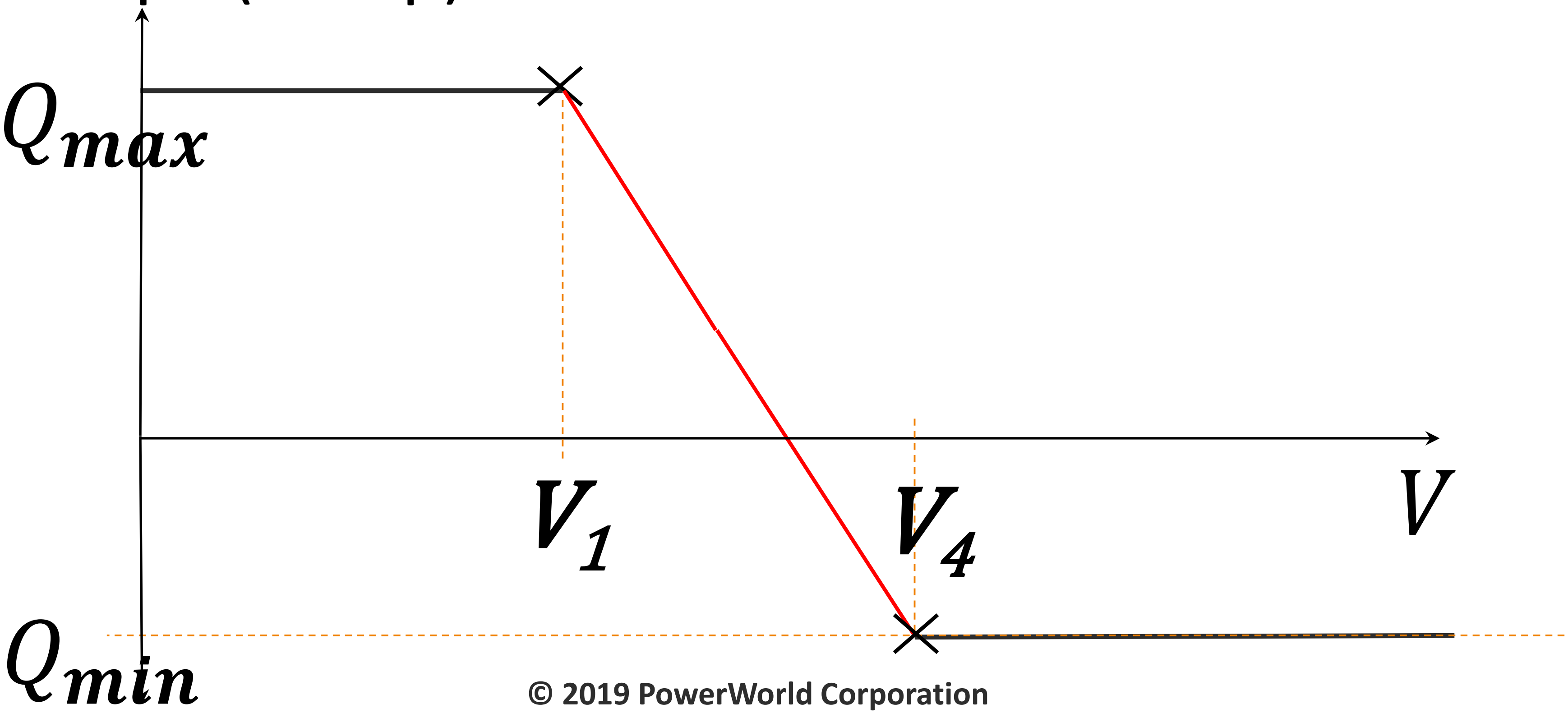
Traditional Generator Power Flow Model

- PV and PQ bus
  - Either meeting the voltage setpoint (PV)
  - Or at a Qmax or Qmin limit (PQ)



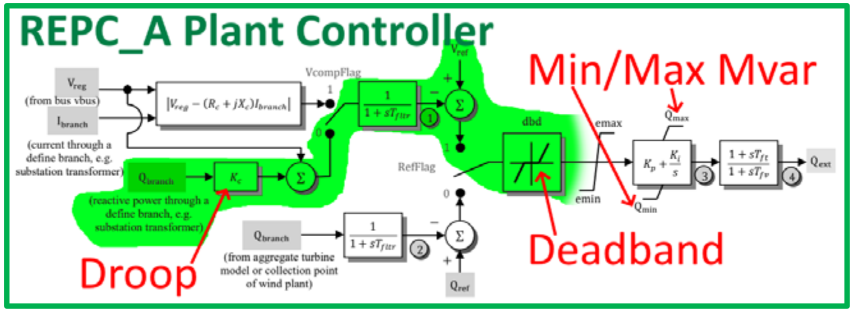
Slope Control

- Getting questions about solar farms that have voltage control that is not a setpoint, but has a slope (droop)

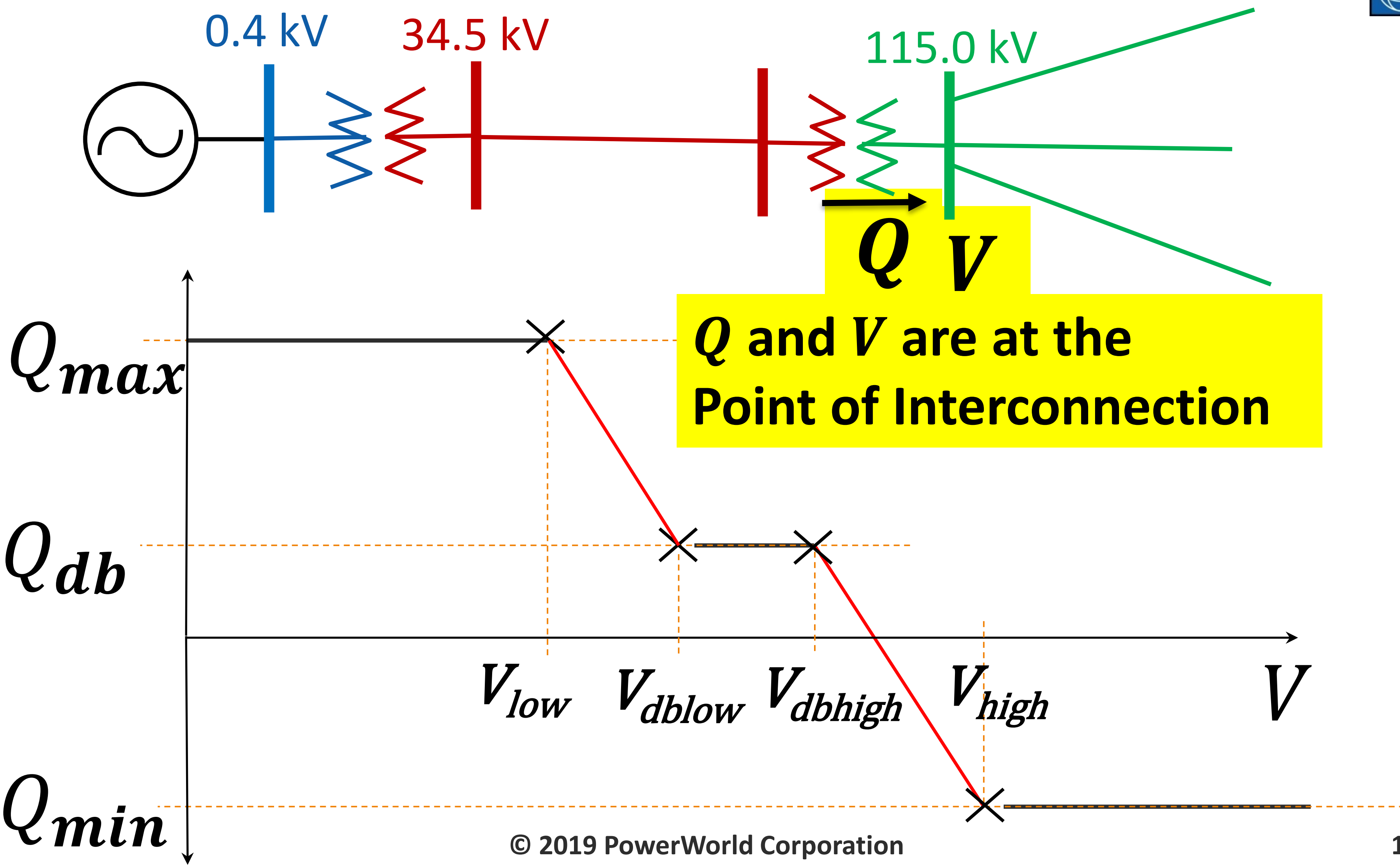


Slope Control with Deadband

- Getting questions about solar farms that have voltage control that is not a setpoint
- A deadband is given
  - 0.98 to 1.02 per unit voltage – provide zero Mvars (or a constant value)
- Once outside the deadband, a negative slope characteristic is followed
- Maximum and Minimum Mvar will be hit eventually
- The various transient stability models have features like this (REPC_A) →
  - power flow however does not



Droop Curve:
Reactive Power as Function of Voltage



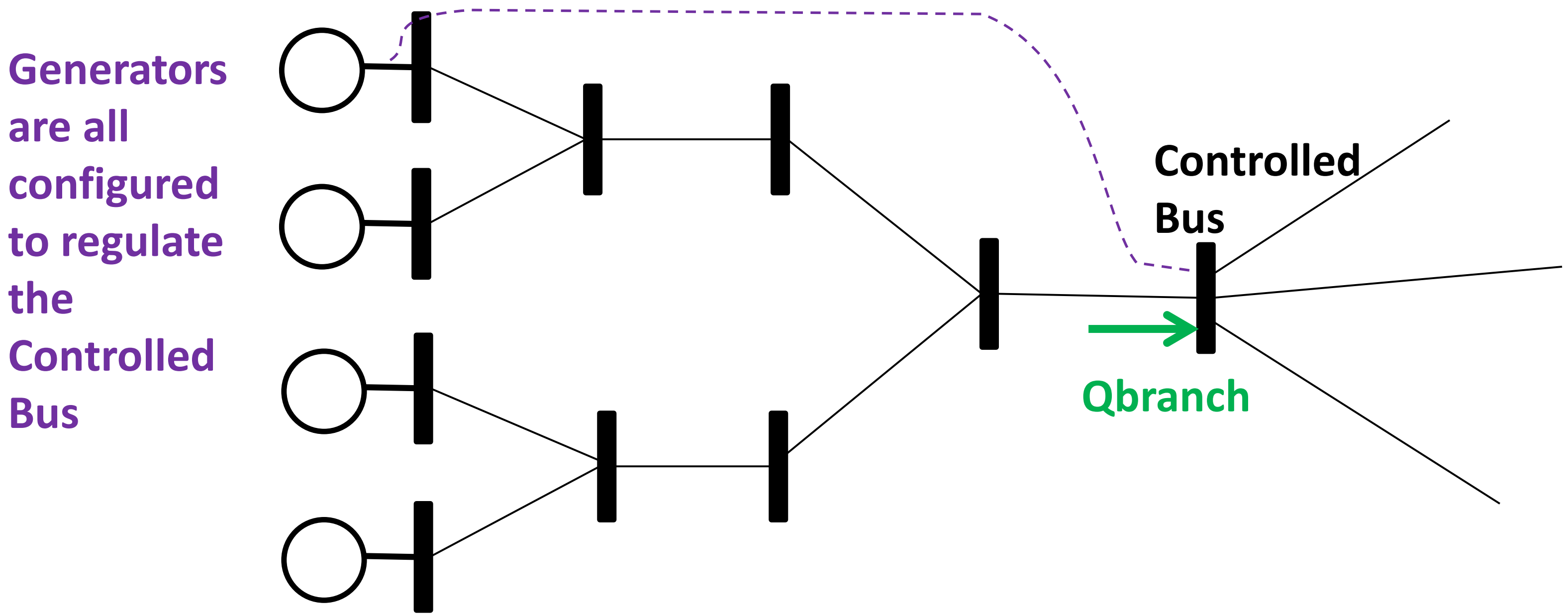
Conclusion in Power Flow

- Existing line-drop compensation with an impedance has limitations
  - Will not match Q/V characteristic exactly because MW Power affects the calculation using impedance
  - No deadbands possible
  - Can not coordinate between multiple generators
- Implemented a new software feature to fully model this
  - Completed and added to PowerWorld Simulator Version 21 which will be released in Summer 2019

Solution: Introduction of Voltage Droop Control (with deadband)

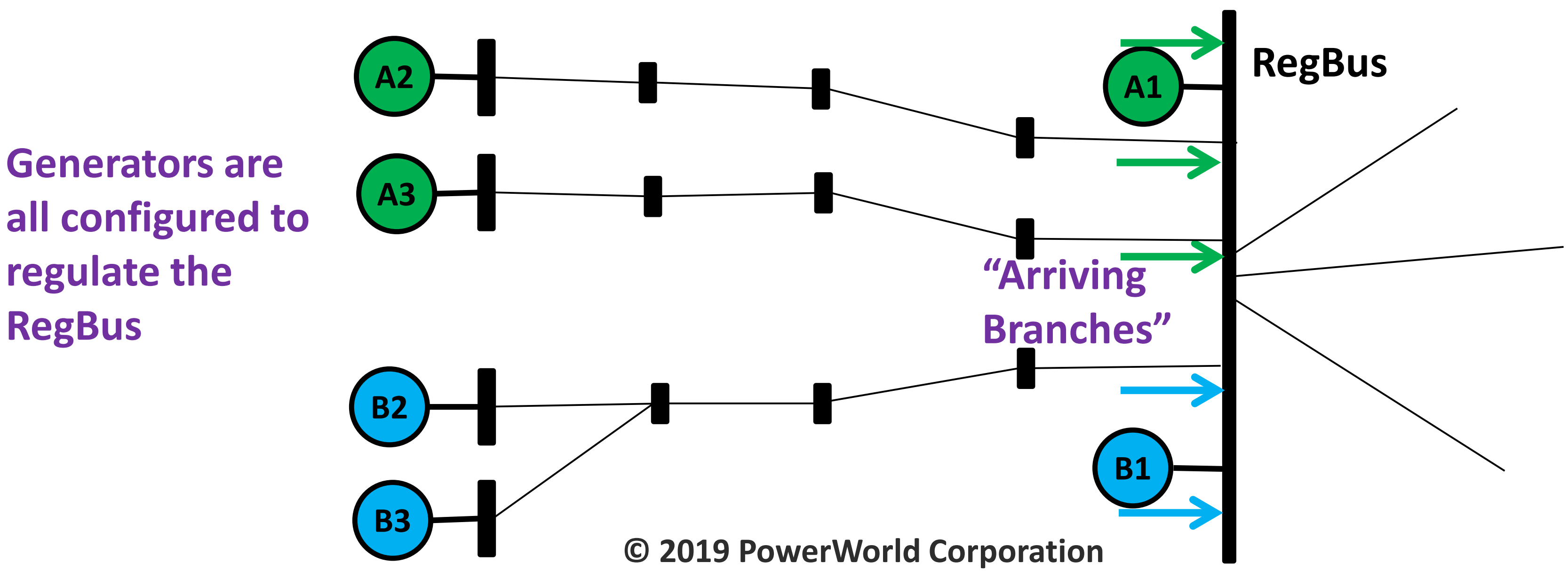
Merge this with remote regulation: What extra data is needed?

- What voltage is being controlled?
  - Use the regulated bus specification with generators
- *What reactive power is being used in compensation calculation?*
  - User does **not** need to provide this. Software will look at the topology of the system to figure this out



Extra Data for a Generator

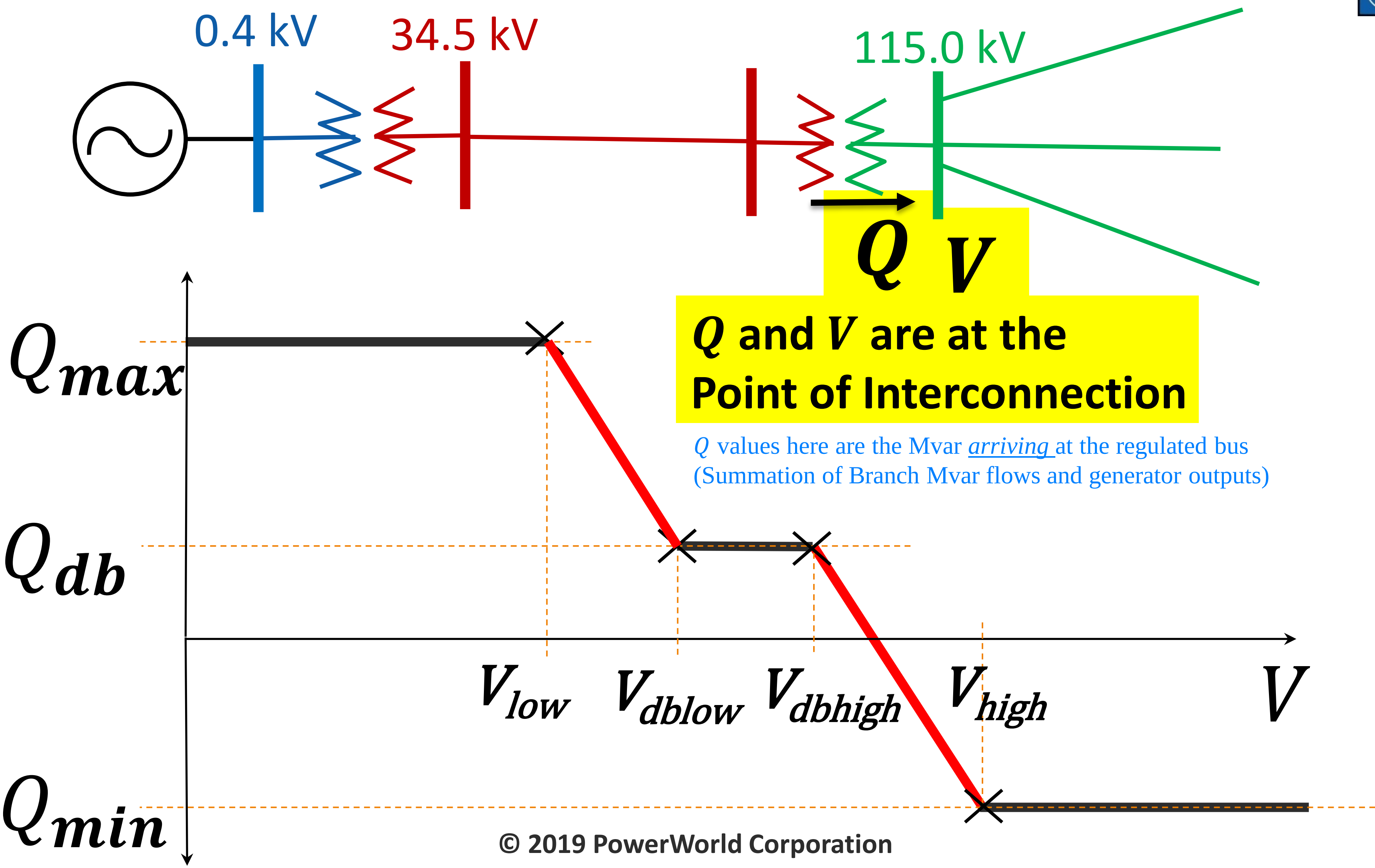
- You might have two separate groups of generators that regulate the same bus, but operate on different Droop Curves
  - Green and Blue generators in separate groups
  - This is OK, because of the Droop! Not a voltage setpoint



PowerWorld Simulator: New Object: VoltageDroopControl

Field	Type	Description
Name	String	Unique Identifier for the Object
Enabled	Boolean	Indicates if the control is turned on or off for the control
QAuto	Boolean	NO means to use the Qdb, Qmax, and Qmin values directly. If set to YES, then the values of Qdb, Qmax and Qmin are automatically calculated based on the summation of generator Qmax and Qmin
VDeviation	Boolean	NO means to use the values of Vlow, Vdblow, Vdbhigh, and Vhigh directly. If set to YES, then the input values of Vlow, Vdblow, Vdbhigh, and Vhigh are interpreted as deviations away from the voltage setpoints of the generators
Qdb	Float	The reactive power in Mvar between *Vdblow* and *Vdbhigh*
Qmax	Float	The maximum reactive power in Mvar for voltages below *Vlow*
Qmin	Float	The minimum reactive power in Mvar for voltages above *Vhigh*
Vlow	Float	Voltage in per unit below which the reactive power is *Qmax*
Vdblow	Float	Voltage in per unit above which the reactive power is *Qdb*
Vdbhigh	Float	Voltage in per unit below which the reactive power is *Qdb*
Vhigh	Float	Voltage in per unit above which the reactive power is *Qmin*

Droop Curve: Reactive Power as Function of Voltage



Droop Curve:
Reactive Power as Function of Voltage

- When **Qauto=YES**, this means

```
QmaxUsed = Summation of Generator MvarMax
QminUsed = Summation of Generator MvarMin
QdbUsed  = 0
```

- When **Vdeviation=YES**, this means

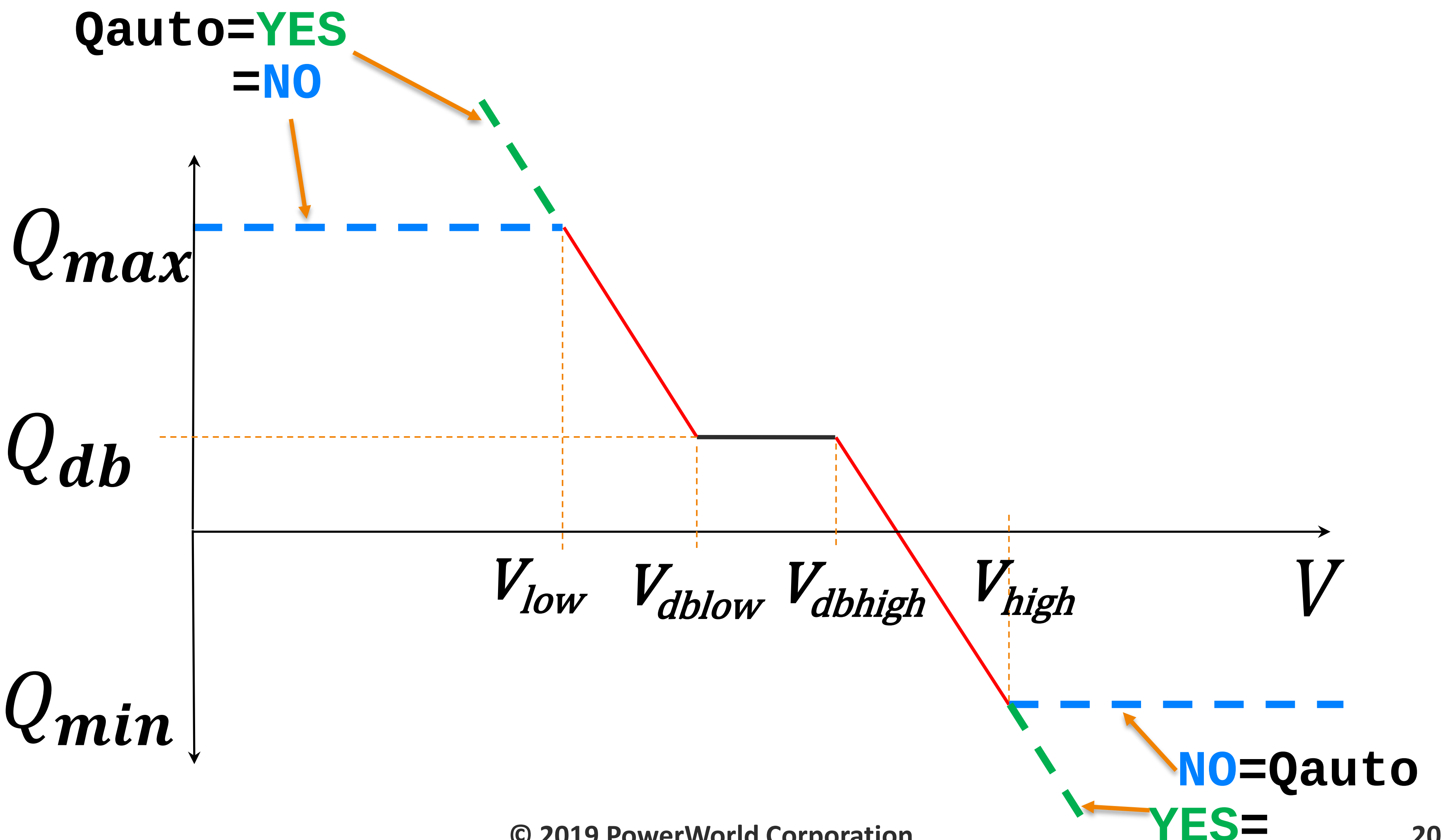
```
Vset = Voltage setpoint from generators
VlowUsed     = Vset + Vlow
VdblowUsed   = Vset + Vdblow
VdbhighUsed  = Vset + Vdbhigh
VhighUsed    = Vset + Vhigh
```

- White paper spells out special cases as well

Comment about “Qmax” and “Qmin”

- For renewable energy plants, “Plant Qmax” and “Plant Qmin” is not always equal the summation of the individual generator MvarMax and MvarMin
  - Thus we enforce the curve as shown regardless
- When using the flag **`Qauto=YES`** however, we follow the slope based on the Vhigh and Vlow points

Droop Curve: Reactive Power as Function of Voltage



New Field for a Generator: VoltageDroopControl

- **VoltageDroopControl** is a string field for a generator
  - This references the name of the **VoltageDroopControl** object to which the generator belongs
  - A blank string indicates it does not belong to such a control (default is blank)

Things that are NOT extra inputs

- The following are <u>automatically</u> determined <u>*by the software*</u>
  - The regulated bus (RegBus) of the **VoltageDroopControl** is determined by looking at the RegBus of the generators that are assigned to the **VoltageDroopControl** object
    - Also any buses connected by very low impedance branches are considered the same RegBus by the software
    - This uses the "ZBR Threshold" which defaults to 0.0002 in PowerWorld Simulator
  - A list of "Arriving Branches" will be automatically determined by looking at the network which connects the generators in the **VoltageDroopControl** to the RegBus

Example

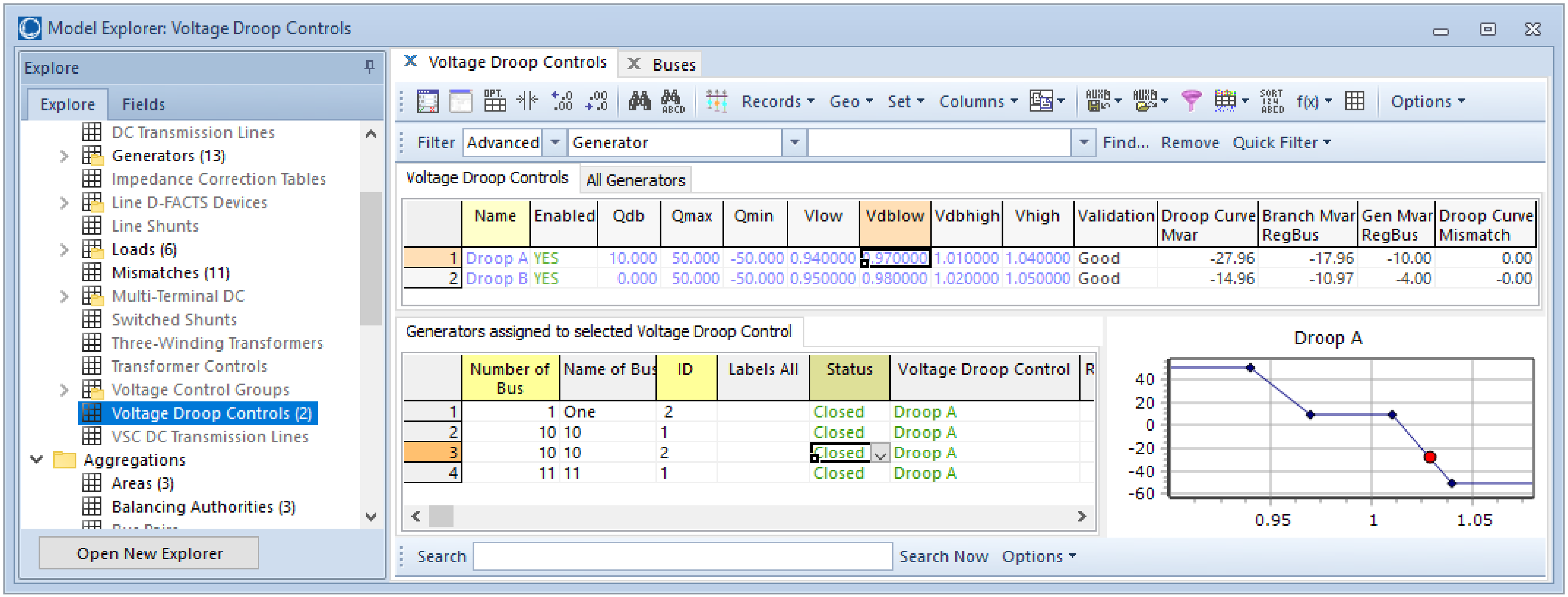
- 2 **VoltageDroopControls** : “Droop A”, “Droop B”

	Name	Enabled	Qdb	Qmax	Qmin	Vlow	Vdblow	Vdbhigh	Vhigh	Gen Mvar RegBus	Branch Mvar RegBus	Droop Curve Mvar
1	Droop A	YES	10.0	50.0	-50.0	0.940	0.970	1.010	1.040	-10.00	-17.9597	-27.9577
2	Droop B	YES	0.0	50.0	-50.0	0.950	0.980	1.020	1.050	-4.00	-10.9654	-14.9647

- Several generators assigned to these

	Number of Bus	ID	Voltage Droop Control	Gen MW	Gen Mvar	Remote Reg %
1	1	1	Droop B	15.00	-4.00	4.000
2	1	2	Droop A	5.00	-10.00	2.000
3	1	3		0.00	10.00	100.000
4	9	1	Droop B	35.00	-8.00	8.000
5	10	1	Droop A	10.00	-15.00	3.000
6	10	2	Droop A	20.00	-5.00	1.000
7	10	3		0.00	-6.00	100.000
8	11	1	Droop A	15.00	-5.00	1.000
9	11	2		0.00	22.00	100.000

Voltage Droop Control Dialog



Coordination Between Generators

- The implementation in the power flow solution is similar to the implementation for coordination of remotely regulating generators that maintain a voltage setpoint (PV bus concept)
  - Same concept is used for *sharing Mvar between multiple generators* assigned to same VoltageDroopControl and Regulated Bus
- Then just replace the voltage equation with an equation representing the voltage droop curve
  - Multiple **VoltageDroopControls** sharing a regulated bus adds some complexity though

VoltageDroopControl Equation

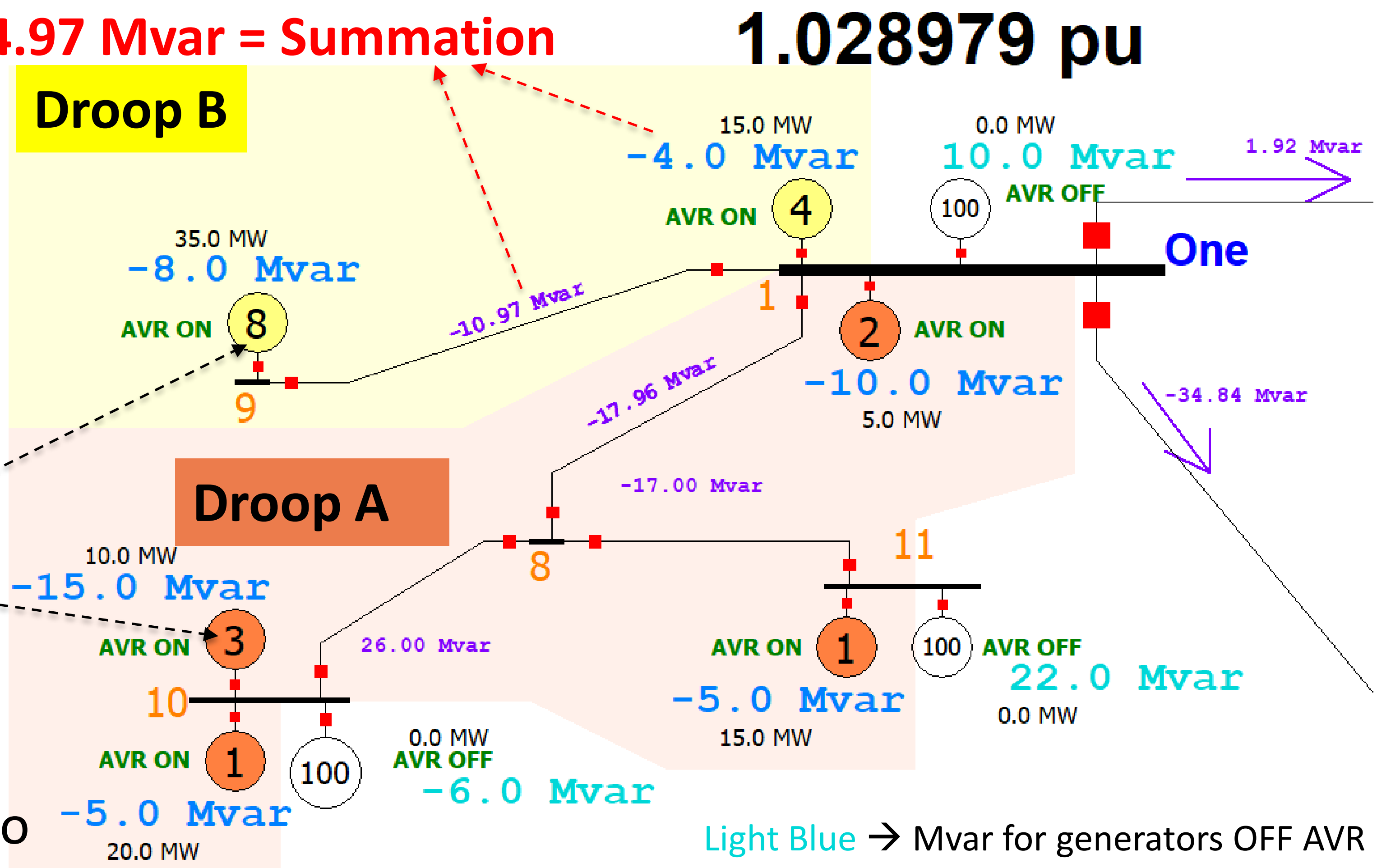
- Define the following
  - MvarArriving = Summation of Mvar on AC branches arriving at Regulated Bus coming from the generators
  - MvarGenRegBus = Summation of Mvar for Generators assigned to the Voltage Droop Control that are at the regulated bus
    - Note: This includes generator with AVR=NO.
    - Any generator in the VoltageDroopControl contributes to the Mvars regardless
  - MvarDroopCurve = Evaluation of the Droop Characteristic Curve at the per unit voltage at the regulated Bus
- **VoltageDroopControl** will enforce an equation that

MvarDroopCurve = MvarArriving + MvarGenRegBus

  - This replaces the voltage equality that is used in remotely regulated *voltage* equations that have always existed

Example Operating Point

Droop A = -27.96 Mvar
Droop B = -14.97 Mvar = Summation



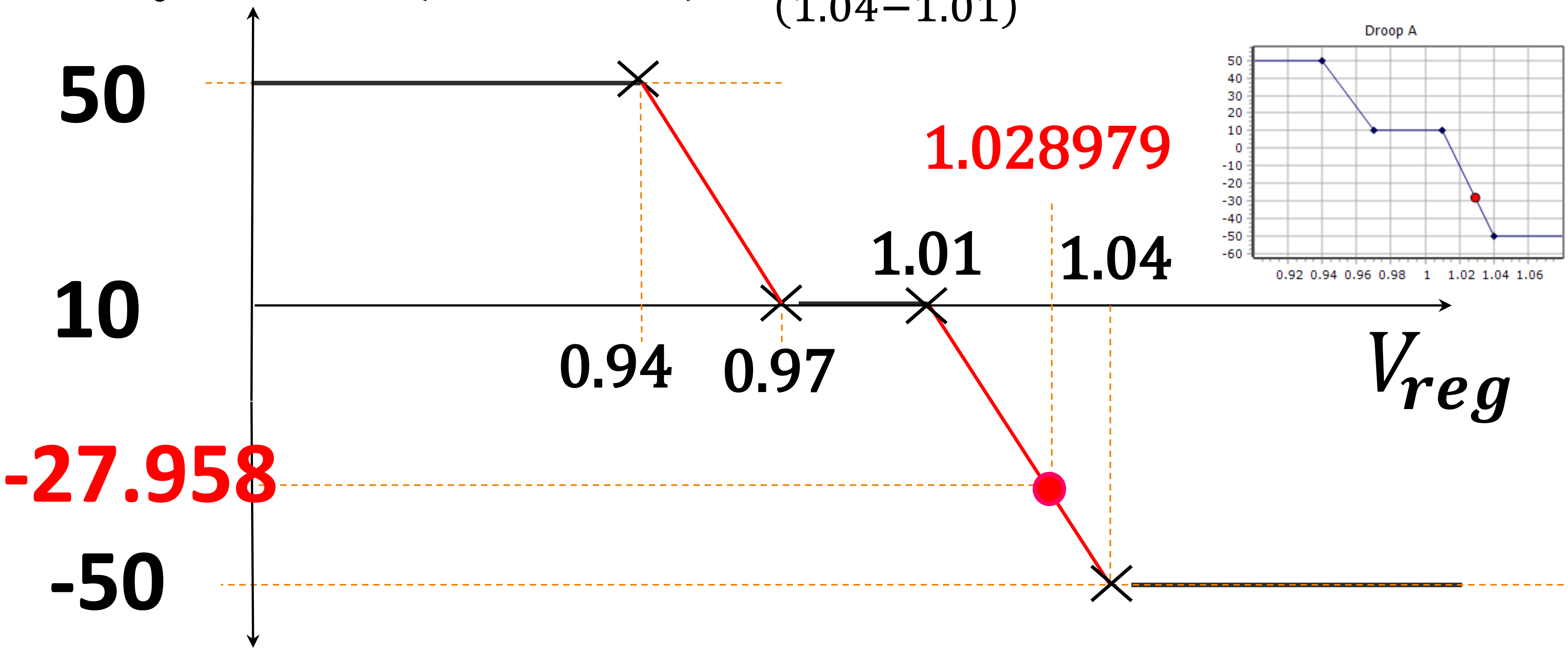
Remote Reg %

Mvars are proportional to Remote Reg %

Light Blue → Mvar for generators OFF AVR
Dark Blue → Mvar for generators ON AVR

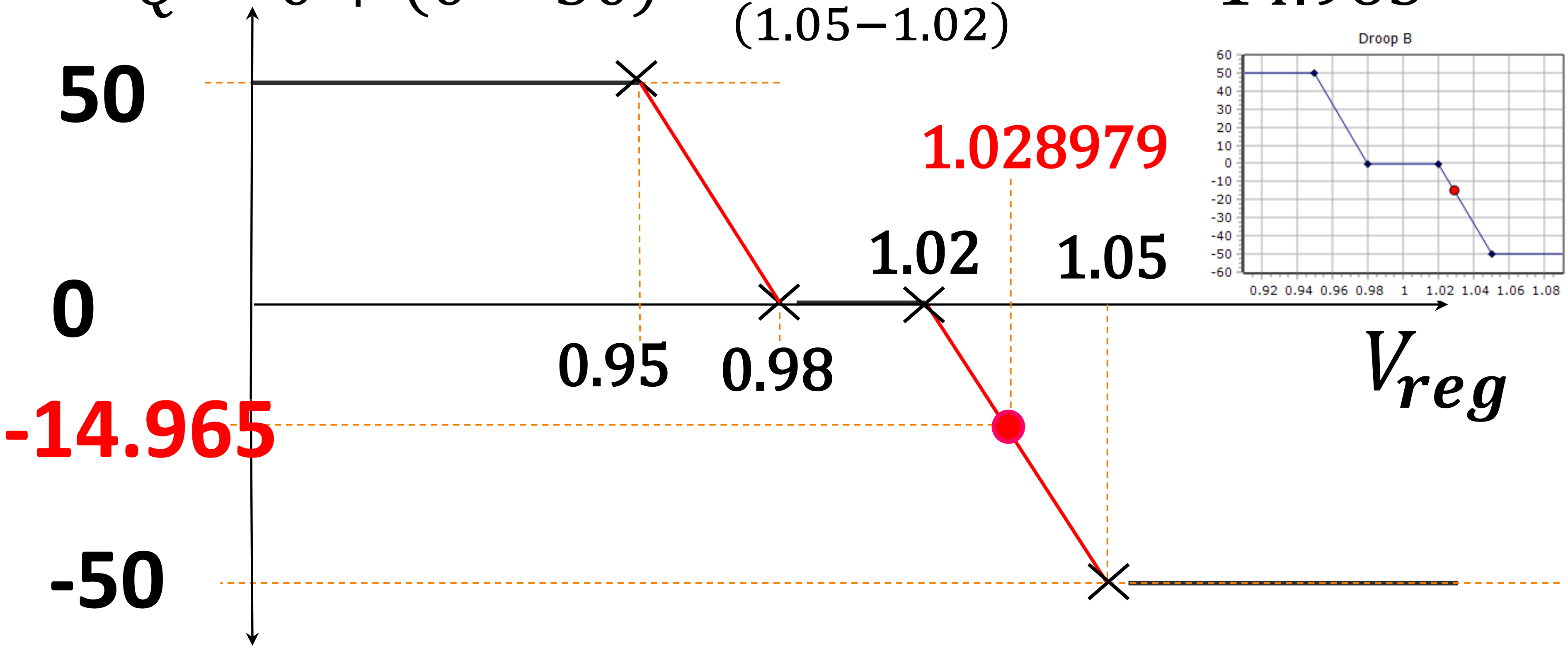
Droop A:
Example Vreg=1.028979

- Example Operating Point For "Droop A"
- $Q = 10 + (-50 - 10)\frac{(1.028979 - 1.01)}{(1.04 - 1.01)} = -27.958$

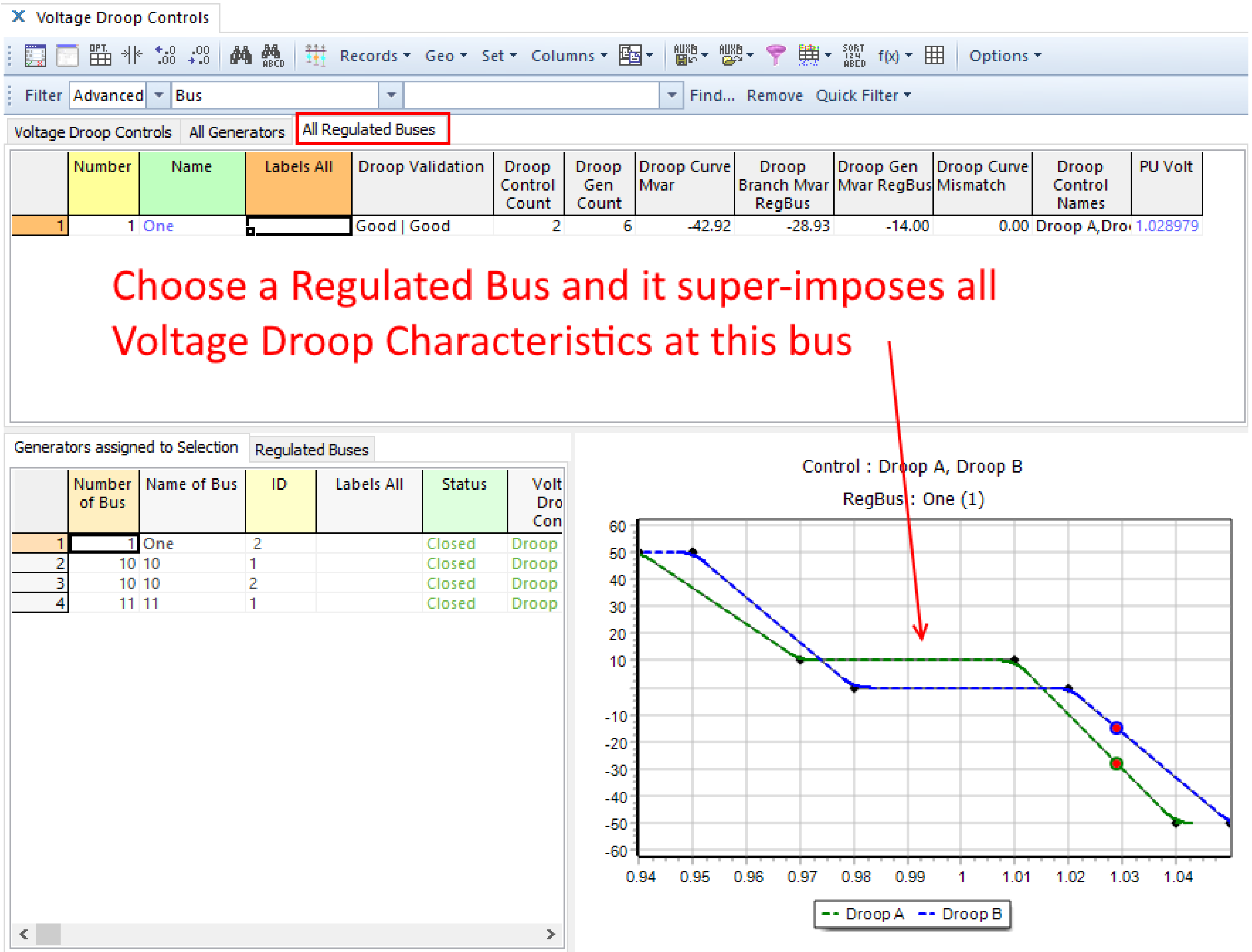


Droop B: Example Vreg=1.028979

- Example Operating Point For "Droop B"
- $Q = 0 + (0 - 50)\frac{(1.028979 - 1.02)}{(1.05 - 1.02)} = -14.965$

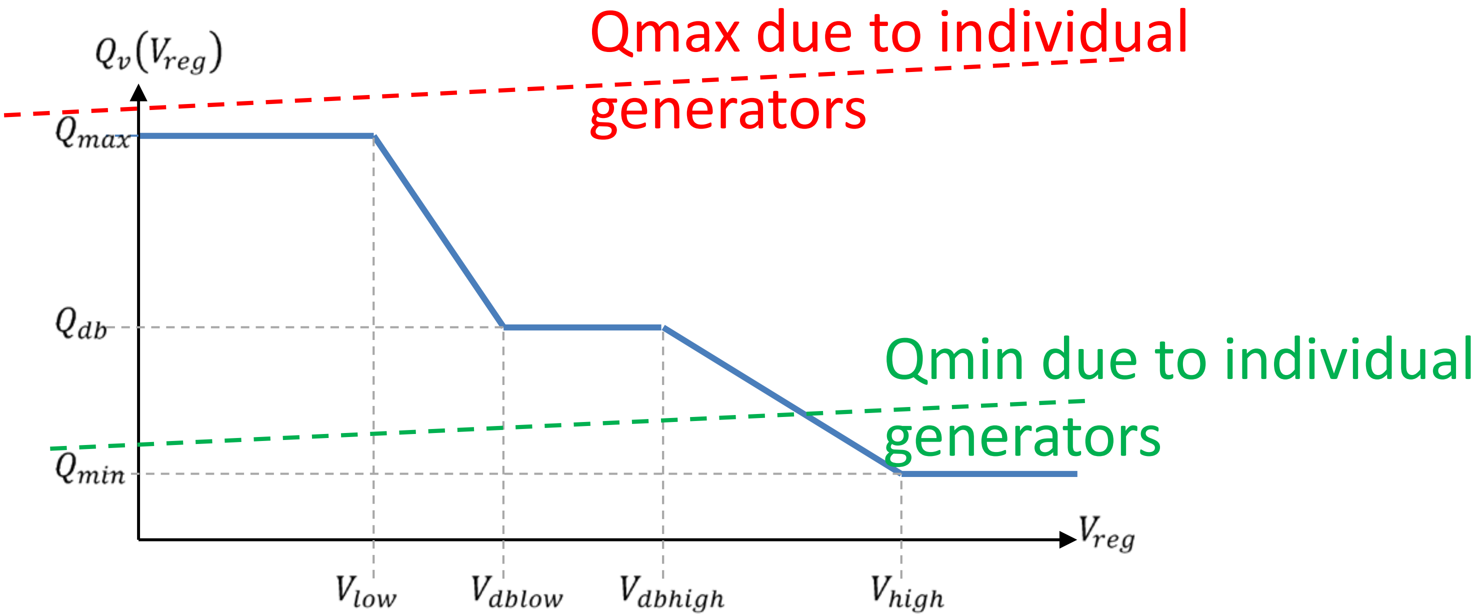


PowerWorld shows multiple characteristics at Regulated Bus



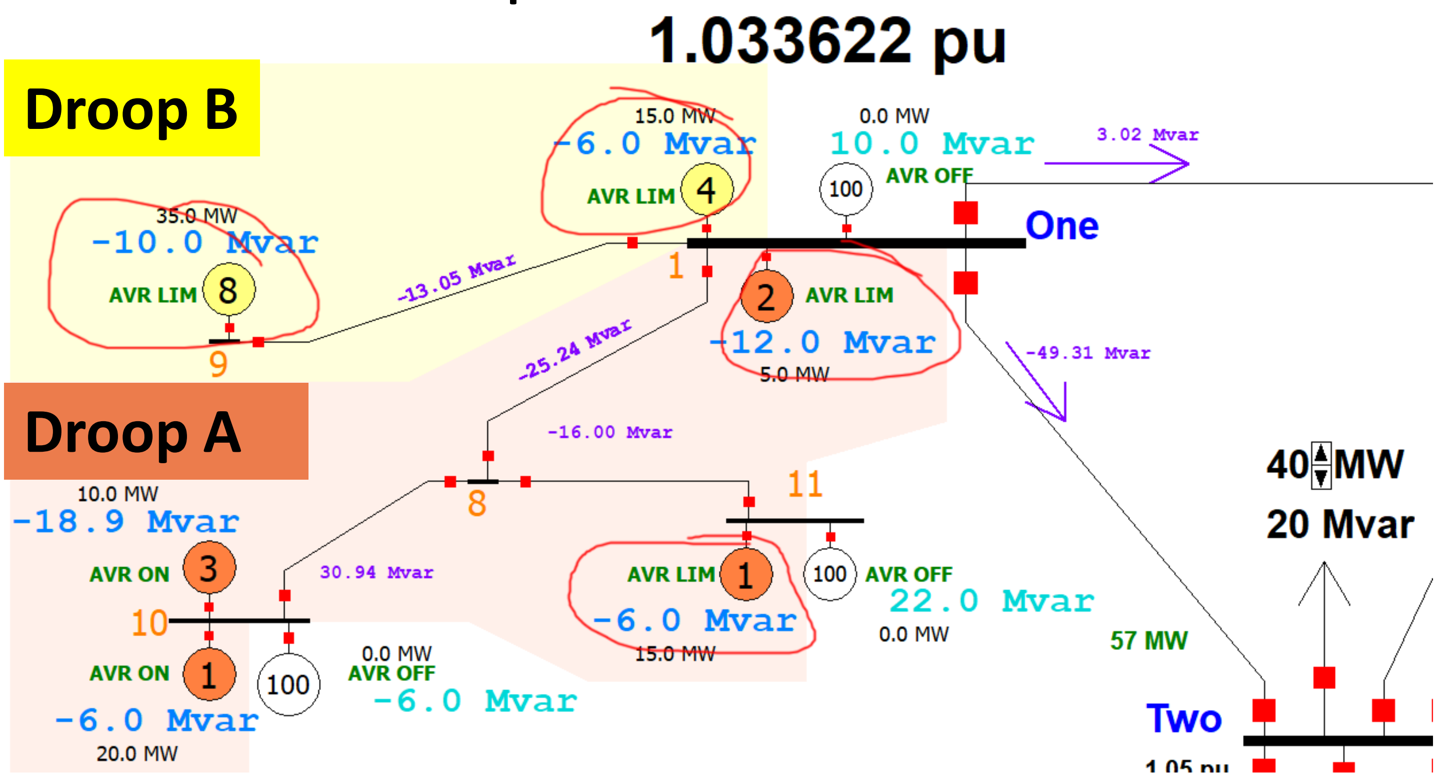
Generator Limits: Same as before

- Handling individual generator limits must still be handled
  - Same as existing remotely regulating voltage control
  - Also need to handle that there can be generators at the regulated bus that belong to the same VoltageDroopControl



Generators Hitting Limits

- Change voltage setpoint at bus 2 to 1.05 per unit
- Generators at bus 1, 9, and 11 all hit Mvar Limits
- All generators in “Droop B” are at limits



Droop B at Mvar limits

- Droop B no longer operating on the Curve

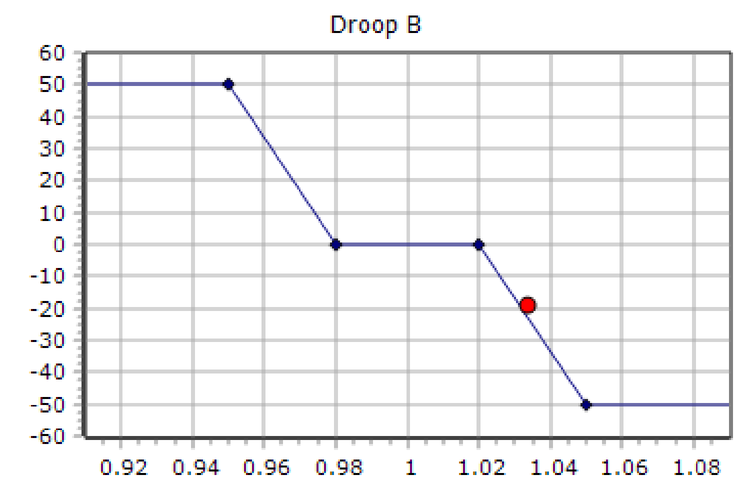
Voltage Droop Controls | All Generators

	Name	Enabled	Qdb	Qmax	Qmin	Vlow	Vdblow	Vdbhigh	Vhigh	Validation	Droop Curve Mvar	Branch Mvar RegBus	Gen Mvar RegBus	Droop Curve Mismatch
1	Droop A	YES	10.000	50.000	-50.000	0.940	0.970	1.010	1.040	Good	-37.24	-25.24	-12.00	0.00
2	Droop B	YES	0.000	50.000	-50.000	0.950	0.980	1.020	1.050	Good	-22.70	-13.05	-6.00	-3.65

Mismatch = -3.65

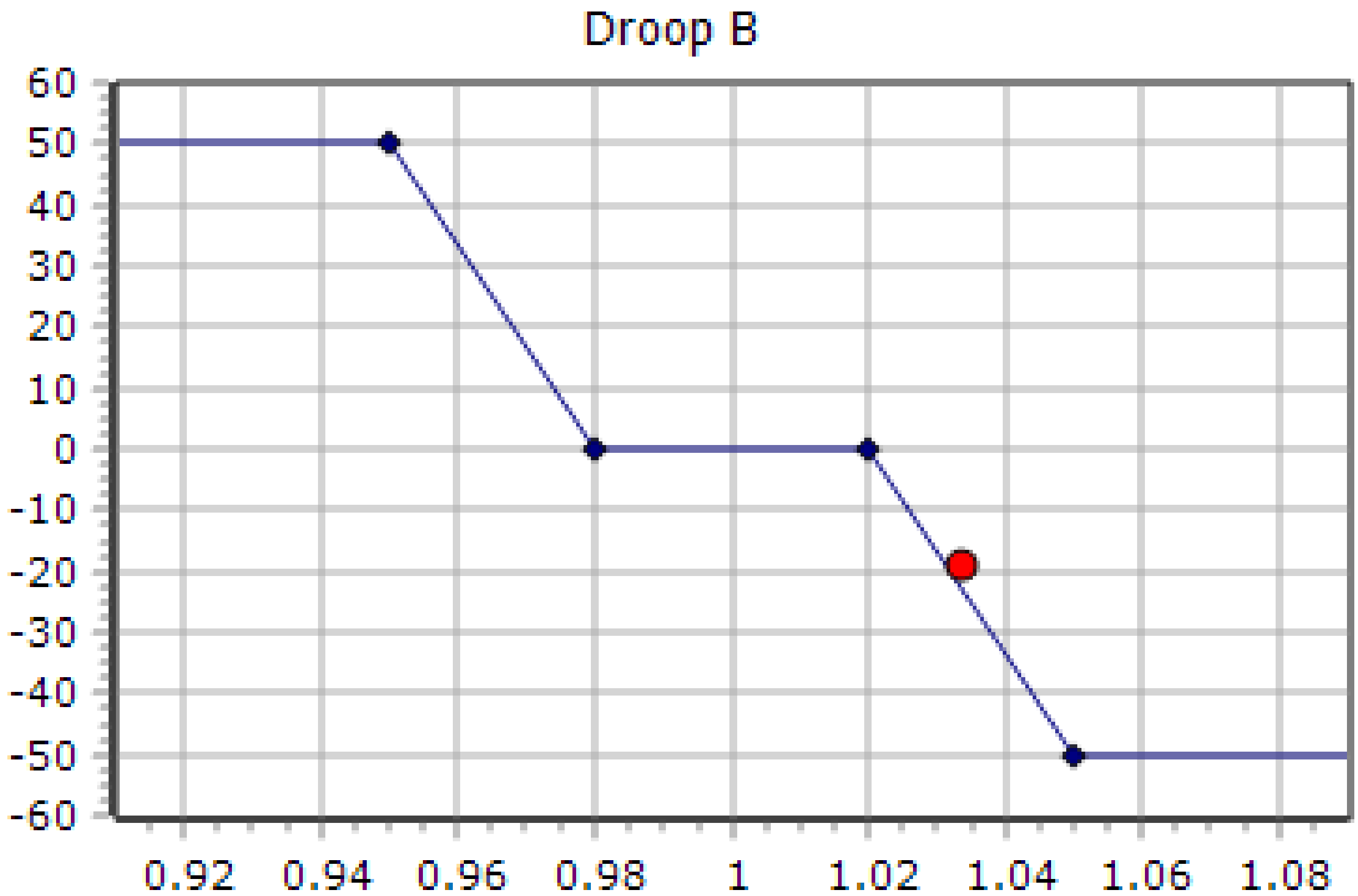
Generators assigned to selected Voltage Droop Control

	Numbe of Bus	Name of Bus	ID	Labels All	Status	Voltage Droop Control	Remote
1	1	One	1		Clos	Droop B	
2	9	9	1		Closed	Droop B	



Search | Search Now | Options

Closeup of Red Dot not on Curve



Conclusion

- PowerWorld Simulator Version 21 has implemented these new features
  - New Object: **VoltageDroopControl**
    - Has a Name and a QV Characteristic curve
  - New Field for Generator
    - Name of VoltageDroopControl
- This is something you should start modeling on your renewable energy plants