Long Range Plan

Additional Solar PV analysis

vermont electric power company

VELCO

VSPC Meeting
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Comments since previous VSPC meeting

- Timing of SHEI boundary expansions
- System impacts under different solar PV distributions
- System impacts under different load and generation conditions
- Optimal solar PV distribution from a system capacity perspective

ISO-NE solar PV forecast

Final 2018 PV Forecast

Nameplate Capacity, MW_{ac}

States	Annual Total MW (AC nameplate rating)											Totals
	Thru 2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	
CT	365.6	88.6	86.8	89.8	80.6	72.9	53.7	52.2	50.6	49.0	47.4	**1,037.3**
MA	1602.3	**296.7**	228.0	228.0	215.3	215.3	215.3	215.3	135.1	130.9	126.7	**3,608.9**
ME	33.5	10.2	10.2	10.2	9.6	9.6	9.6	9.6	9.6	9.6	9.6	**131.4**
NH	69.7	13.8	13.8	13.8	13.1	13.1	13.1	13.1	13.1	13.1	13.1	**202.7**
RI	62.2	34.5	34.5	31.4	29.6	29.6	29.6	29.6	29.6	29.6	29.6	**370.2**
VT	257.2	**31.5**	22.5	22.5	21.3	21.3	21.3	21.3	21.3	21.3	21.3	**482.5**
Regional - Annual (MW)	**2390.5**	**475.3**	**395.8**	**395.8**	**369.5**	**361.9**	**342.7**	**341.1**	**259.3**	**253.5**	**247.7**	**5,832.9**
Regional - Cumulative (MW)	**2390.5**	**2865.8**	**3261.6**	**3657.4**	**4026.9**	**4388.8**	**4731.4**	**5072.5**	**5331.8**	**5585.3**	**5832.9**	**5,832.9**

Notes:

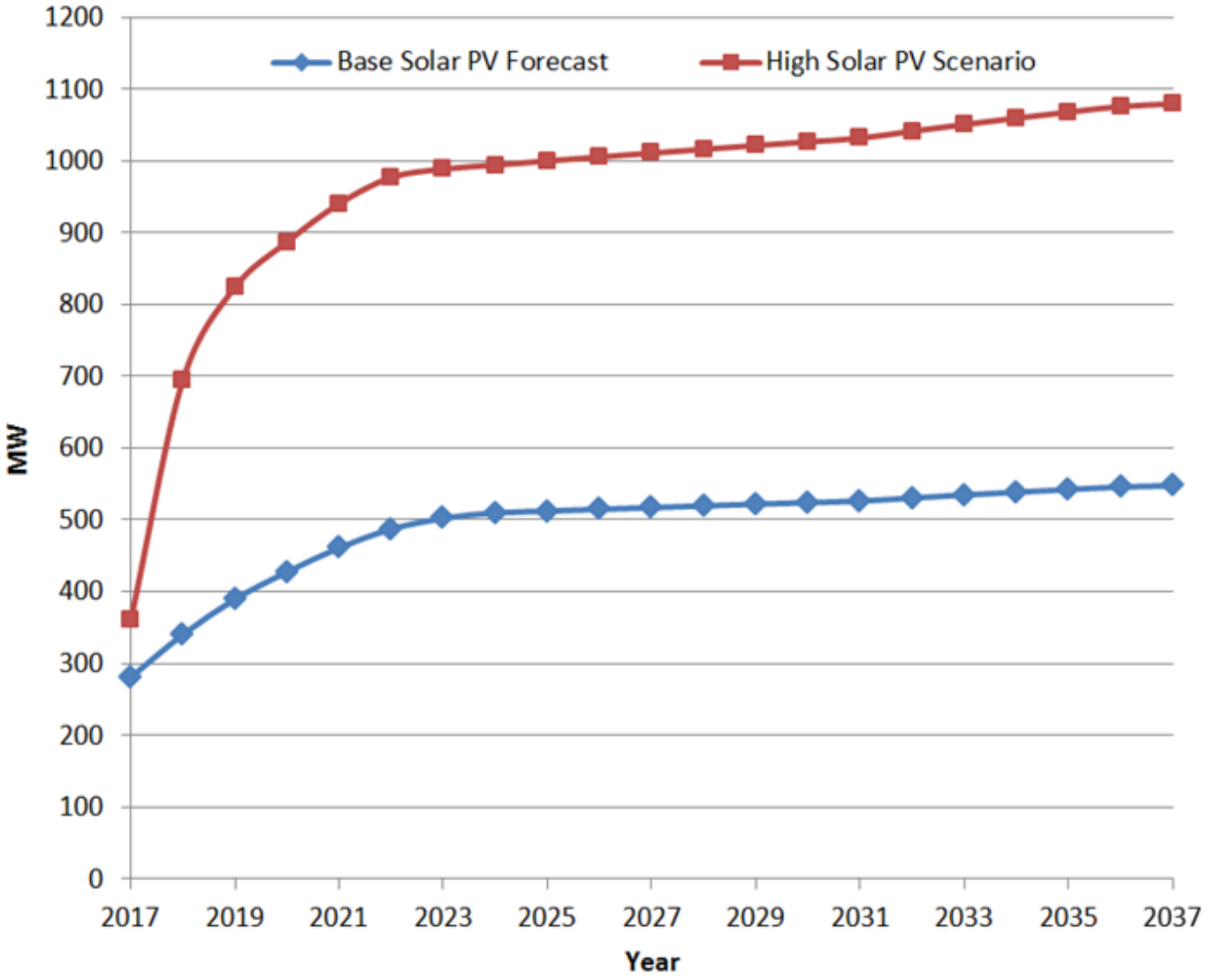
(1) Forecast values include FCM Resources, non-FCM Energy Only Generators, and behind-the-meter PV resources

(2) The forecast values are net of the effects of discount factors applied to reflect a degree of uncertainty in the policy-based forecast

(3) All values represent end-of-year installed capacities

(4) Forecast does not include forward-looking PV projects > 5MW in nameplate capacity

VELCO solar PV forecast



Study assumptions

- Substation loads at 620 MW, not including 30 MW of system losses without small-scale solar PV
- Tie flows
  - Plattsburg-Sand Bar flow at 0 MW
    Comerford-Granite flow at 100 MW
  - Highgate at 225 MW capacity (227 MW at border)
- Maximum renewable generation

Generation	Amount	Generation	Amount
Utility-scale wind	151 MW	Landfill methane	11 MW
Utility-scale hydro	155 MW	Coolidge solar PV	20 MW
Utility-scale biomass	70 MW	Diesels and GTs	0 MW

Results of base solar PV forecast (about 510 MW using 2018 solar PV distribution)

- System losses increased by about 13 MW
- Increased SHEI impacts
  - Voltage collapse within SHEI and additional sections of K42 Highgate–St Albans–Georgia line overloaded
  - Overloads south of Georgia depending on the PV20 Plattsburg-Sand Bar tie flow

Zone names	Gross MW loads	MW AC solar PV capacity	Net MW loads
Newport	26.6	14.5	12.1
Highgate	36	20.3	15.7
St Albans	28.4	30.1	-1.7
Johnson	14.7	8.3	6.4
Morrisville	42.5	8.8	33.7
Montpelier	64	45.1	18.9
St Johnsbury	10.7	7.2	3.5
BED	57.4	9.2	48.2
IBM	60.6	0.0	60.6
Burlington	80.2	106.5	-26.3
Middlebury	7.8	45.4	-37.6
Central	36.8	74.3	-37.5
Florence	22.9	0.4	22.5
Rutland	51	58.4	-7.4
Ascutney	37.3	22.4	14.9
Southern	42.1	61.3	-19.2
Total	619	512.2	106.8
Losses	33.6	N/A	46.5

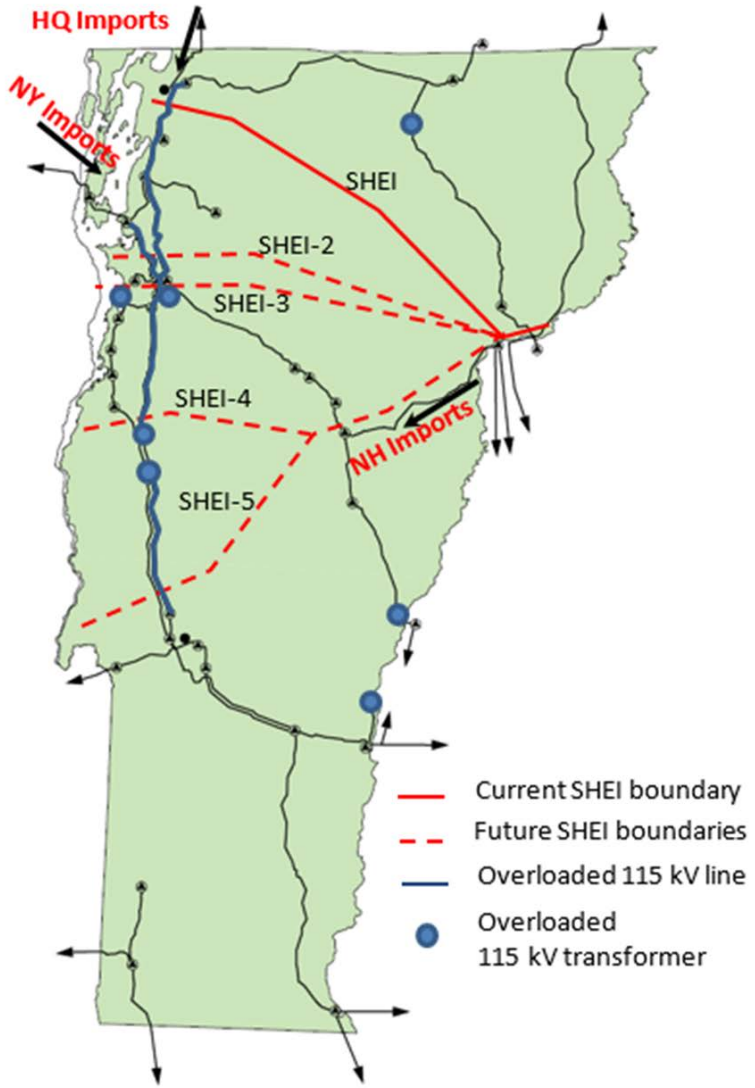
Tested 3 solar PV distributions for 1000 MW solar PV scenario

		Same as 2018 solar PV distribution		MW load ratio share		MWh load ratio share	
Zone names	Gross loads	MW AC PV capacity	Net loads	MW AC PV capacity	Net loads	MW AC PV capacity	Net loads
Newport	26.6	27.1	-0.5	36.9	-10.3	40.0	-13.4
Highgate	36	34.9	1.1	39.1	-3.1	38.0	-2.0
St Albans	28.4	58.0	-29.6	68.2	-39.8	63.6	-35.2
Johnson	14.7	17.0	-2.3	11.5	3.2	12.0	2.7
Morrisville	42.5	18.2	24.3	35.1	7.4	36.7	5.8
Montpelier	64	91.2	-27.2	86.0	-22.0	91.3	-27.3
St Johnsbury	10.7	13.3	-2.6	26.2	-15.5	28.9	-18.2
BED	57.4	20.4	37.0	61.9	-4.5	61.8	-4.4
IBM	60.6	0.0	60.6	62.4	-1.8	70.5	-9.9
Burlington	80.2	203.8	-123.6	164.5	-84.3	142.4	-62.2
Middlebury	7.8	93.0	-85.2	36.1	-28.3	30.5	-22.7
Central	36.8	147.1	-110.3	67.5	-30.7	67.2	-30.4
Florence	22.9	0.9	22.0	25.6	-2.7	34.1	-11.2
Rutland	51	112.7	-61.7	93.0	-42.0	92.8	-41.8
Ascutney	37.3	45.7	-8.4	71.7	-34.4	69.7	-32.4
Southern	42.1	117.0	-74.9	114.4	-72.3	120.4	-78.3
Total	619	1000.3	-381.3	1000	-381	1000	-381
Losses	33.6	N/A	82.8	N/A	74.1	N/A	72.9

Results of high solar PV scenario (using 2018 solar PV distribution, MW or MWh ratio)

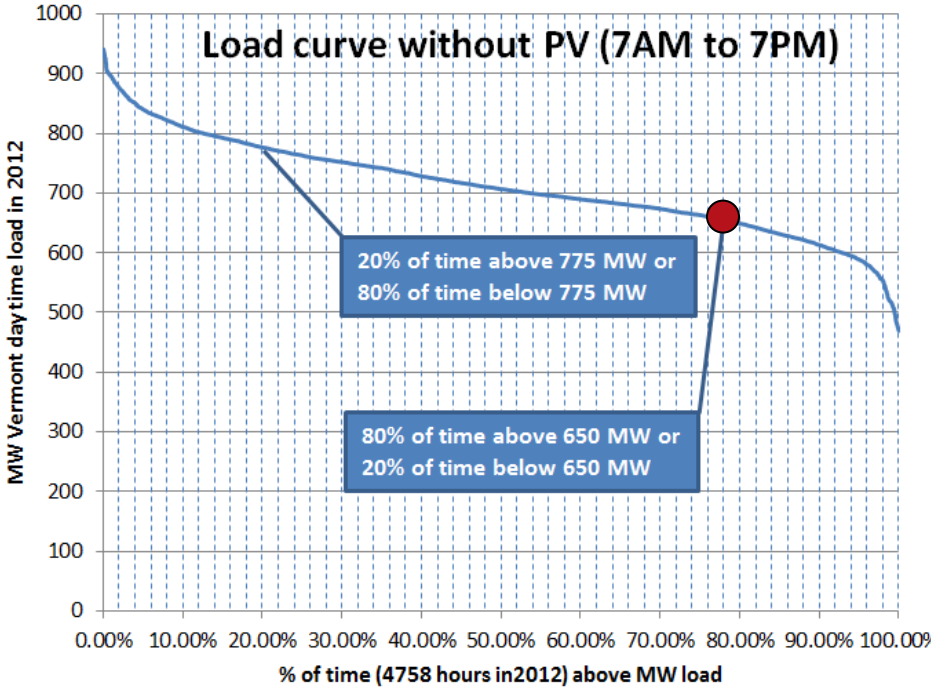
- 2018 distribution will introduce major operational challenges
  - Very large flows pre-contingency
  - System losses increased by about 50 MW
  - Transmission overloads extend south of SHEI towards Rutland
    - Even with Plattsburg-Sand Bar tie flow at 0 MW
    - May run out of angle range on Sand Bar phase angle regulator to maintain flows low enough to prevent overloads under some conditions
    - Any reduction in Northern Vermont generation will be annulled by NY–VT tie flows
  - Low voltage on bulk system and high voltage on subsystem
    - Managing pre- and post-contingency voltages will require dynamic voltage support
- MW or MWh ratio distribution results same as 2018 distribution, but with fewer transmission and distribution transformer overloads

Bulk and predominantly bulk concerns in high solar scenario (2018 solar PV distribution)



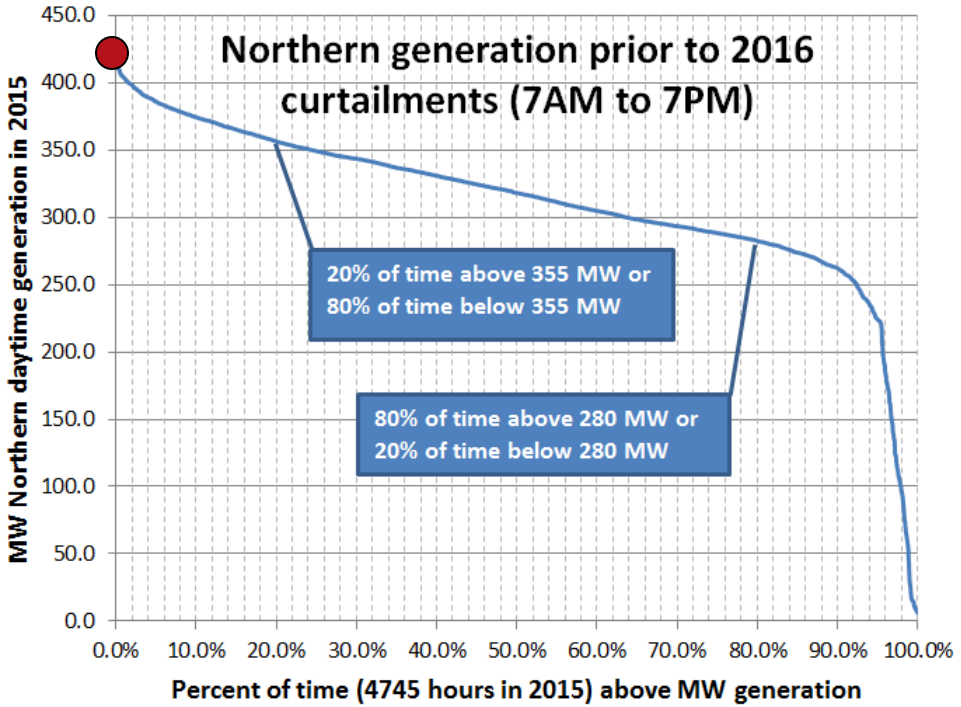
- SHEI is current constraint interface
- SHEI-1 to SHEI-5 are expansions of constraint
- Timing of expansion is unknown
  - Depends on how quickly solar PV is installed in individual zones
  - Not necessarily sequential—SHEI-3 could occur before SHEI-2 and so on
  - Optimal solar PV distribution gives some insights

Tested several load and generation levels



●: Results discussed on prior slides

Load without losses	MW generation and Highgate imports		
620 MW	**425**	355	280
745 MW	425	355	280



Northern generation

- Highgate HVDC
- Wind: Sheffield, KCW, Georgia
- Hydro: Sheldon Springs, Highgate Falls, Lamoille Composite, E Fairfax, Essex, Gorge, Winooski 1, Vergennes
- Wood: McNeil
- Landfill methane: Coventry

Summary of thermal* results for different load and generation levels

	2018 solar PV distribution	MW ratio solar PV distribution					
	620 MW load	620 MW load			745 MW load		
	425 MW gen	425 MW gen	355 MW gen	280 MW gen	425 MW gen	355 MW gen	280 MW gen
Transmission line miles	49	49	49	49	49	49	11
Subtransmission line miles	87	75	60	29	46	31	29
number of transmission transformers	5	1	1	1	1	1	1
number of subtransmission transformers	9	1	1	1	1	1	1

* Voltage control will also be a concern

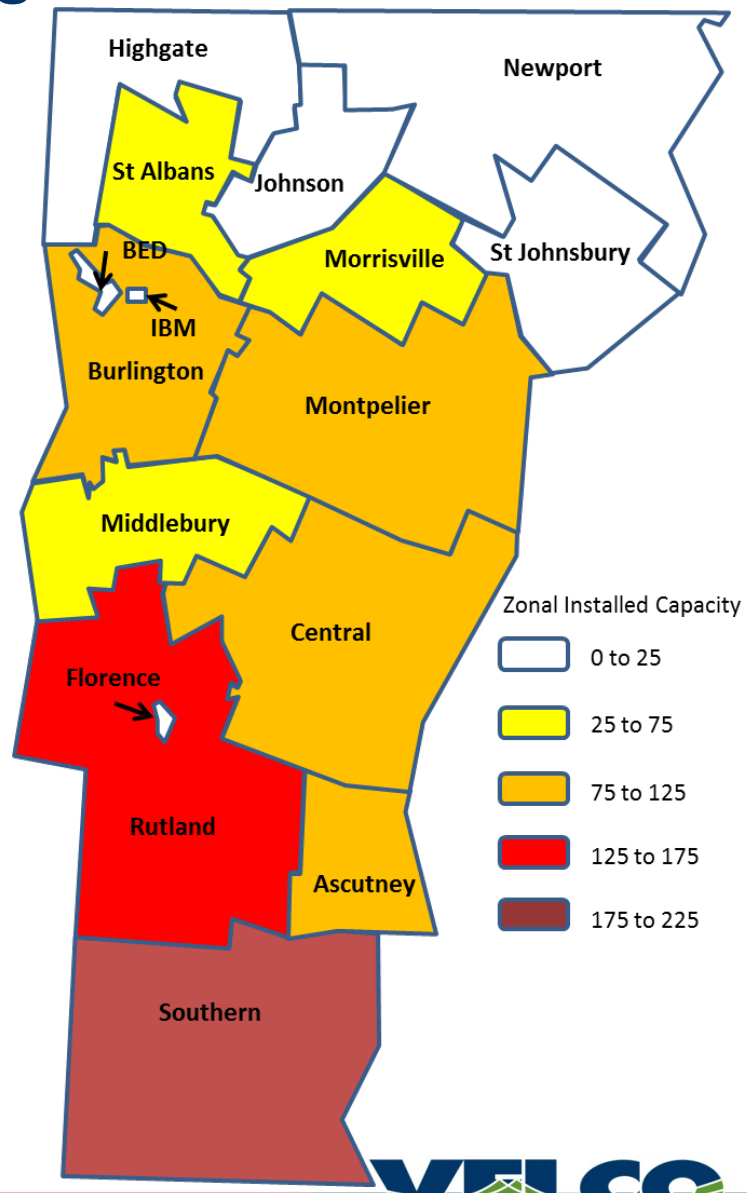
Assumptions affecting optimal PV distribution

- AC tie line imports are reduced to 0 MW, which may not always be possible
- Solar PV provides voltage control, which is essential to maximize solar PV
- Daytime load is not reduced below current levels—every MW load reduction results in a reduction in maximum zonal solar PV
- Equipment thermal capacity is allowed to be exceeded by 5%, which accounts for occasional curtailments, future storage, load management, and other network management measures
- Existing system concerns, not related to solar PV additions, will be addressed by system upgrades—this is necessary to maximize solar PV
- Distribution system concerns are addressed—distribution system concerns may limit solar PV below levels indicated in analysis
- Larger scale ISO-NE interconnected generation or elective transmission projects are not implemented—unlikely because of economics and FERC open access requirements
- Solar PV will be installed exactly as laid out in this optimized distribution—unlikely because of several objectives or constraints including project economics, aesthetic impacts, regional acceptance of solar PV levels significantly higher than regional loads, and so on
  - Maximum zonal solar PV levels are interdependent, meaning that the amount of solar PV in one zone will affect the amount that can be installed in other zones

Maximum amount of solar PV that may be hosted with minimal system upgrades

Dependent on assumptions on previous slide

Zone names	Gross MW loads	MW AC solar PV capacity	Net MW loads
Newport	26.6	10.4	16.2
Highgate	36	15.5	20.5
St Albans	28.4	42.9	-14.5
Johnson	14.7	16.4	-1.7
Morrisville	42.5	50.7	-8.2
Montpelier	64	104.9	-40.9
St Johnsbury	10.7	12.1	-1.4
BED	57.4	5.6	51.8
IBM	60.6	20.0	40.6
Burlington	80.2	107.4	-27.2
Middlebury	7.8	57.7	-49.9
Central	36.8	91.2	-54.4
Florence	22.9	21.2	1.7
Rutland	51	164.6	-114
Ascutney	37.3	112.8	-75.5
Southern	42.1	224.9	-183
Total	619	1058.4	-439
Losses	33.6	N/A	53.4



Results summary

- Additional system concerns if future solar PV distribution is similar to 2018 PV distribution, starting in SHEI
- 1000 MW solar PV results change slightly if we assume a MW ratio or MWh ratio distribution
- 1000 MW solar PV results change with different load and generation levels
  - Subtransmission line overloads reduced as generation is reduced
  - Transmission line overloads do not change except if the load level is increased and generation level is reduced sufficiently
- System will be unable to host 1000 MW without drastic change in solar PV distribution and other measures
  - Some combination of storage, curtailment, load management, grid upgrades, operational changes, etc.
  - Voltage control from solar PV inverters is necessary
  - Statewide coordinated plan for solar PV growth should be considered

Summary table of solar PV distributions in this analysis

Zone names	Gross loads	Installed solar PV as of 2018	Base solar PV forecast using 2018 distribution	1000 MW solar PV using 2018 distribution	1000 MW solar PV using MW ratio distribution	1000 MW solar PV using MWh ratio distribution	1000 MW solar PV optimized for system capacity
Newport	26.6	10.3	14.5	27.1	36.9	40.0	10.4
Highgate	36	15.5	20.3	34.9	39.1	38.0	15.5
St Albans	28.4	20.9	30.1	58.0	68.2	63.6	42.9
Johnson	14.7	5.4	8.3	17.0	11.5	12.0	16.4
Morrisville	42.5	5.7	8.8	18.2	35.1	36.7	50.7
Montpelier	64	29.9	45.1	91.2	86.0	91.3	104.9
St Johnsbury	10.7	5.1	7.2	13.3	26.2	28.9	12.1
BED	57.4	5.6	9.2	20.4	61.9	61.8	5.6
IBM	60.6	0.0	0.0	0.0	62.4	70.5	20.0
Burlington	80.2	74.4	106.5	203.8	164.5	142.4	107.4
Middlebury	7.8	29.7	45.4	93.0	36.1	30.5	57.7
Central	36.8	50.2	74.3	147.1	67.5	67.2	91.2
Florence	22.9	0.2	0.4	0.9	25.6	34.1	21.2
Rutland	51	40.6	58.4	112.7	93.0	92.8	164.6
Ascutney	37.3	14.8	22.4	45.7	71.7	69.7	112.8
Southern	42.1	42.9	61.3	117.0	114.4	120.4	224.9
Total	619	351.2	512.2	1000.3	1000	1000	1058.4