Operational Reserve Requirements for Variable Wind Generation

Daniel McGinn
Energy Technology
12 June, 2017

Wind Power Variability

- Discrete disturbances: generation and transmission line disturbances
- Continuous disturbances: stochastic fluctuations in electricity demand
- Wind generator forecast errors can be as much as 20-50%
- Large variations are quite rare with 99% of variations less than 500 MW

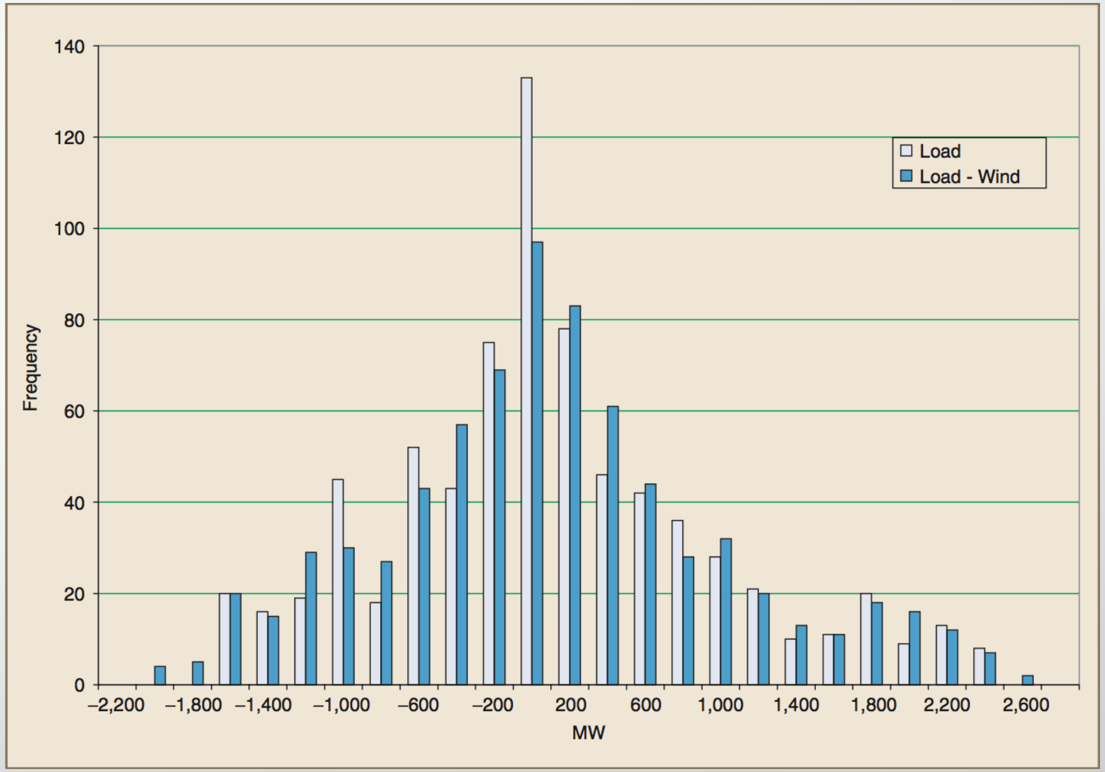

Figure 1: Distribution of Hourly Variations in Wind Capacity in the United States

Major Integration Problems

THE UNIVERSITY OF AUCKLAND NEW ZEALAND

- Typical operating scheme
  - Unit commitment a day in advance
  - Real-time operation to match the actual system load
  - Market settlement to adjust compensation based on imbalances of expected and actual power generation
- In conventional power systems, sufficient reserves are procured to cover the loss of the single largest generating unit
- Due to the uncertainty of wind, it is difficult to accurately predict energy outputs a day in advance and more reserves are required as amounts greater than the largest infeed are often lost

Integrating Wind Power in New Zealand

THE UNIVERSITY OF AUCKLAND NEW ZEALAND

- New Zealand wholesale electricity market
  - Offer-based merit-order dispatch using location based marginal pricing
  - Prioritizes wind generation over conventional plants
  - Reserve carried is equal to the largest infeed
- Wind farms in New Zealand do not provide frequency keeping and generation reserves.

		North Island	South Island
Installed Capacity	Synchronous	5300	3400
	Asynchronous Wind	260	58
Demand	Peak	4620	2330
	Minimum	1680	1300
HVDC link Capacity (MW)	North to South	626	600
	South to North	960	1040

Table 1: New Zealand Power System Generation and Demand

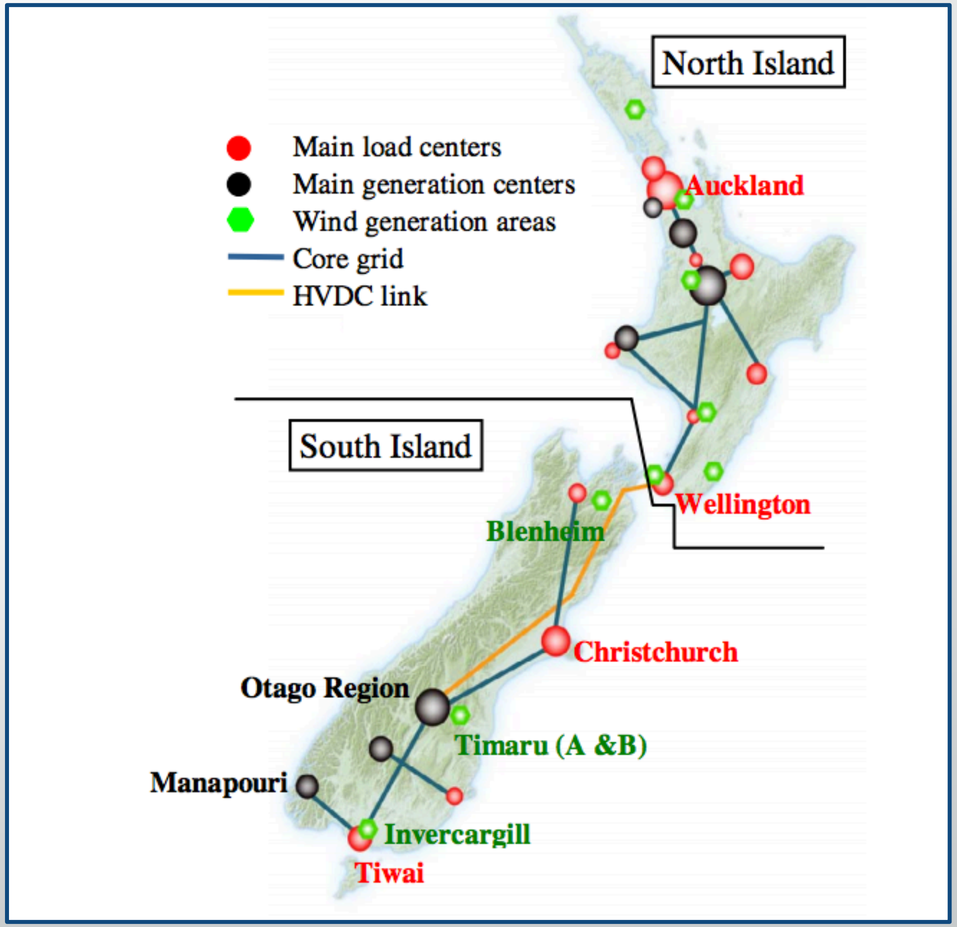

Figure 2: New Zealand Wind Power System

Quantifying Necessary Reserves

- Researchers in the Republic of Ireland developed a system to quantify necessary reserves
- As the wind power increases, system reserve levels must also increase
  - 1500 MW of installed wind capacity necessitates a 20% increase in reserves required

Category	Time Frame	σ_{Total} (MW)
Primary	5 – 15 sec	6.0
Secondary	15– 90 sec	14.8
Tertiary 1	90 sec – 5 min	27.0
Tertiary 2	5 - 20 min	54.0
One Hour	20 min - 1 hour	93.4

Table 2: Standard Deviation of System Forecasting Error Within Timeframe For 1500 MW of Installed Wind Capacity

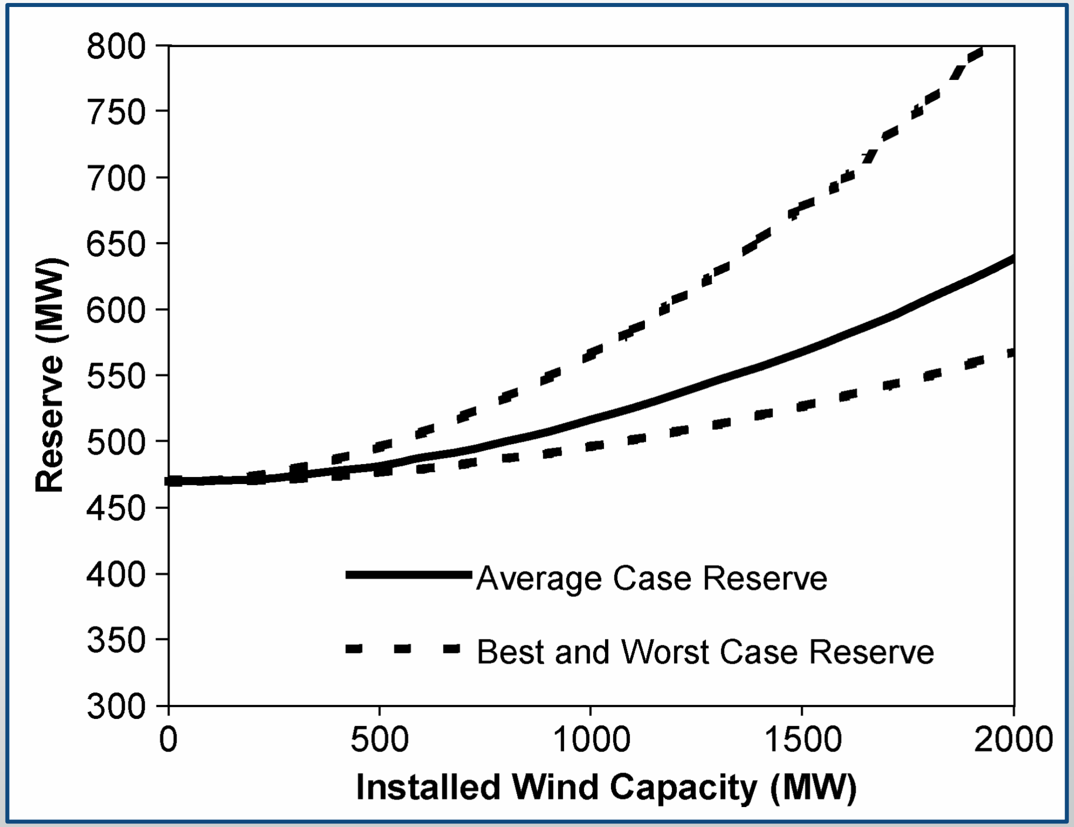

Figure 3: System Reserve Levels for 3 Hour Forecasting Versus Installed Wind Capacity

Stochastic Forecasting

- Two stage model with the aim to minimizes day ahead commitment costs and hour ahead commitment and dispatch costs
- A forecasting model of 122 California generators suggests that optimal reserve requirements for is between 20% and 30% of maximum load depending on wind integration levels
- Stochastic forecasting allows wind farms to more accurately predict power output, which improves unit commitment and informs how much reserves should be held

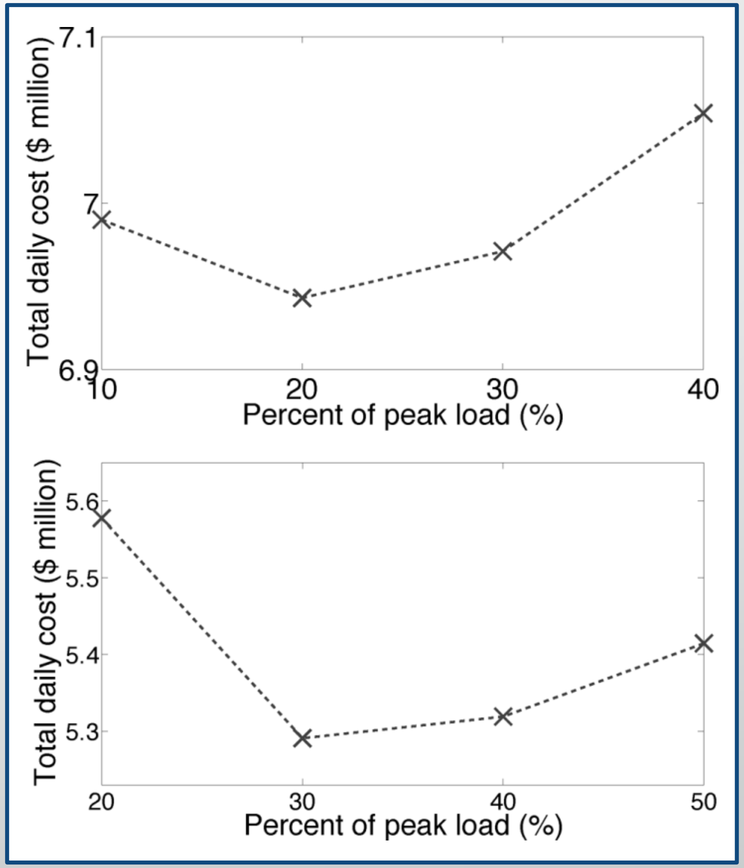

Figure 4: Cost due to Total Reserve Requirements for 7.1% Wind (Top) and 14% Wind (Bottom)

Wind Generation in New Zealand

- New Zealand wind farms must adopt frequency keeping and generation reserves to increase the reliability of the grid as wind generation increases.
- More accurate wind forecasting techniques conjunction with reserve forecasting, improves the reliability of wind generation while keeping costs low
- The use of Stochastic Forecasting can improve the efficiency of wind generation by accurately predicting a safe quantity of reserve power in order to maintain a second-by-second balance between generation and demand

Works Cited – Wind Transmission

DeMeo, E. A., Grant, W., Milligan, M. R., & Schuerger, M. J. (2005). Wind plant integration [wind power plants]. IEEE Power and Energy Magazine, 3(6), 38-46.

Doherty, R., & O'Malley, M. (2005). A new approach to quantify reserve demand in systems with significant installed wind capacity. *IEEE Transactions on Power Systems*, *20*(2), 587-595.

Papavasiliou, A., Oren, S. S., & O'Neill, R. P. (2011). Reserve requirements for wind power integration: A scenario-based stochastic programming framework. IEEE Transactions on Power Systems, 26(4), 2197-2206.

Piwko, R., Osborn, D., Gramlich, R., Jordan, G., Hawkins, D., & Porter, K. (2005). Wind energy delivery issues [transmission planning and competitive electricity market operation]. IEEE Power and Energy Magazine, 3(6), 47-56.

Vowles, D. J., Samarasinghe, C., Gibbard, M. J., & Ancell, G. (2008, July). Effect of wind generation on small-signal stability—A New Zealand example. In Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE (pp. 1-8). IEEE.

"Wind and Back up Generation." *New Zealand Wind Energy Association*. N.p., n.d. Web.

Zavadil, R., Miller, N., Ellis, A., & Muljadi, E. (2005). Making connections [wind generation facilities]. IEEE Power and Energy Magazine, 3(6), 26-37.

Impact of Solar Photovoltaic Generation Variability on Distribution Network

Daniel McGinn
Energy Technology
12 June, 2017

Causes of Voltage Variance in PV-DG

- Variation in power generation is due to changing weather conditions and can introduce extreme voltage variation
- Operational constraints of solar photovoltaic distributed generation (PV-DG) systems typically allow voltage fluctuation of 5%

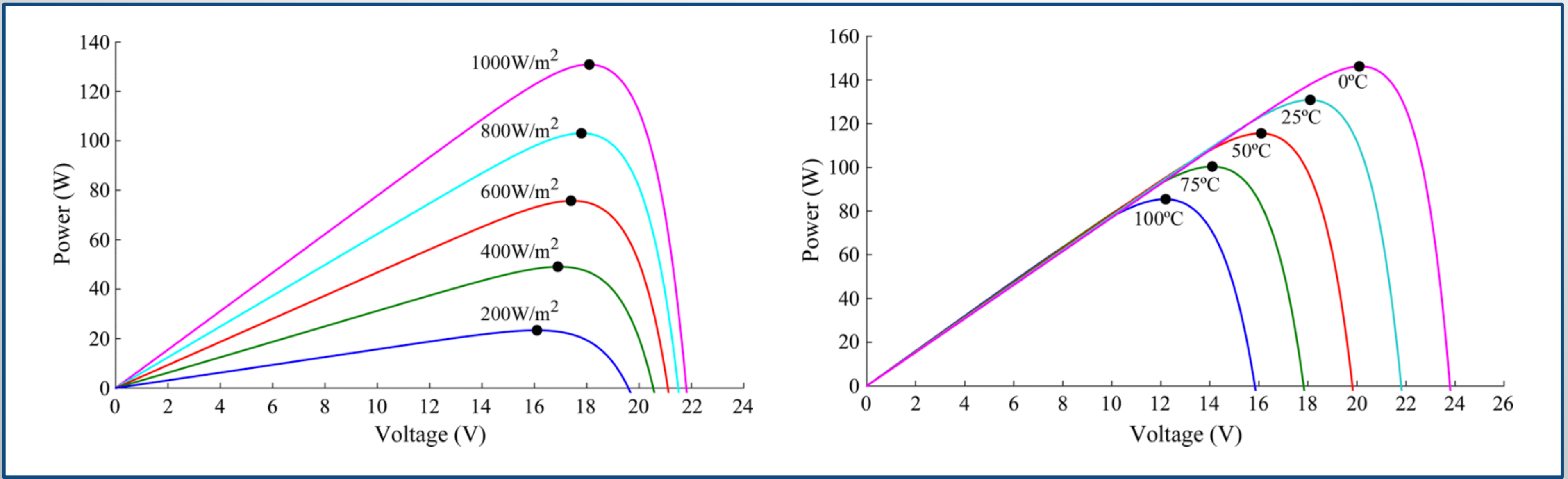

Figure 5: P-V Curves at Different Irradiations (25° C) (Left) & at Different Temperatures (1000 W/m²) (Right)

Distribution Integration Problems

- PV-DG systems have intermittent characteristics that vary power output depending on sun conditions
- PV-DG requires DC generation to be converted to AC power via inverters
- High PV penetration increases no-load losses of distribution transformers
- PV integration can cause
  - Voltage imbalance
  - Frequent operation of voltage control devices

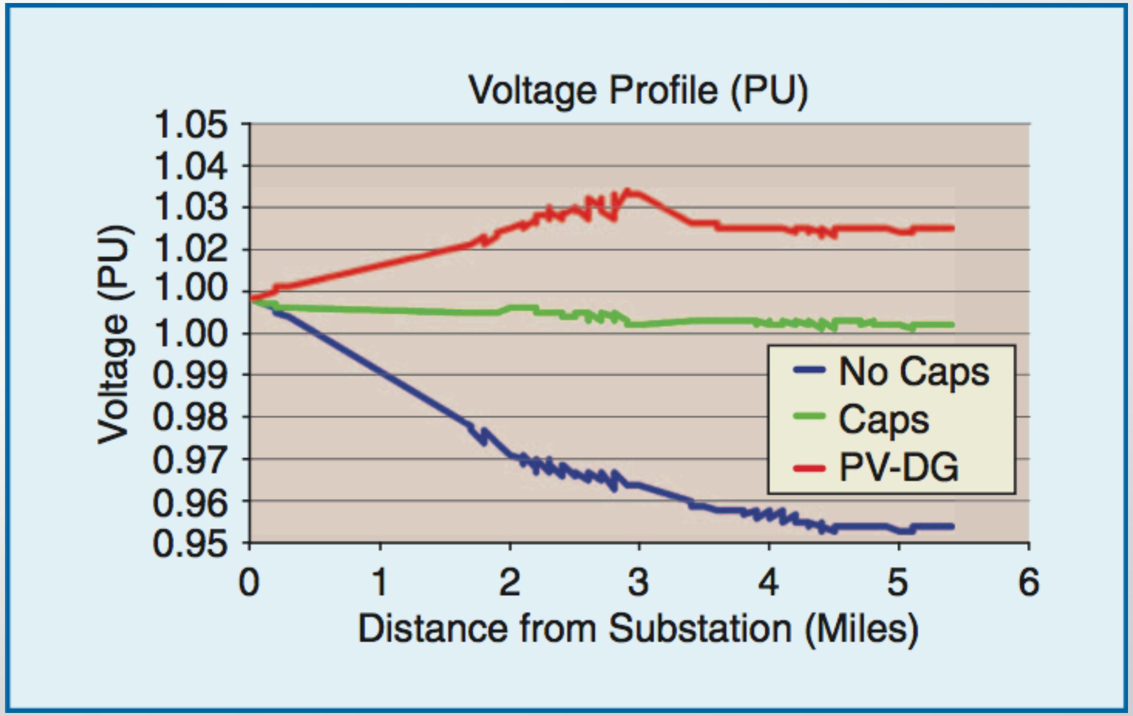

Figure 6: Feeder Voltage Profile of PV-DG

Solar Distribution in New Zealand

THE UNIVERSITY OF AUCKLAND NEW ZEALAND

- Installation rates of PV systems increased by a factor of nine between 2012 & 2016
- 78% of capacity installed in 2016 was installed in households
- Vector Distribution Network (Auckland)
  - A 11.65 kWh Sunverge storage solution has been deployed in Auckland totaling 300 in-home storage units as part of a behind-the-meter trial for residential and commercial customers

	2013	2014	2015	2016
PV Generated (MWh)	9,718	24,938	42,621	53,039
PV customers connected	2,119	5,087	8,914	11,217
Installed Capacity (MW)	7.92	20.33	34.75	43.25
Average System Size (kW)	3.74	4.00	3.90	3.84

Table 3: Current PV Statistics in New Zealand

Voltage Management

- Mitigation Strategies
  - Modify capacitor banks to ensure that they are off during maximum PV-DG output
  - Avoid using fixed capacitor banks
  - Lower the voltage reference on LTCs and line voltage regulators
- DNO must be in communication with the inverter to estimate reactive and active power output from storage systems

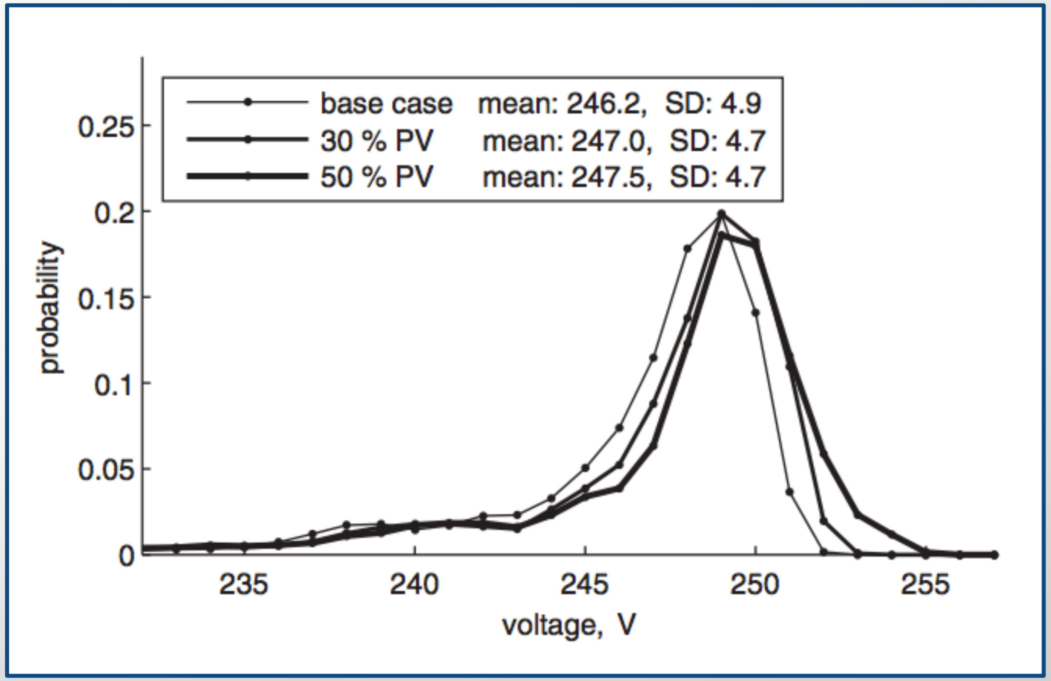

Figure 7: Probability Distribution of ten-minute-average voltages for PV systems in the UK

Customer-Side Energy Storage

- A distribution network operator controls the output of a customer-side energy storage system in exchange for a subsidy covering a part of the initial cost of the storage system
- Storage system inverter provides reactive power compensation to prevent voltage constraint violations
- Active power output increases until it achieves economical efficiency
- Costs include voltage regulator and inverter subsidy

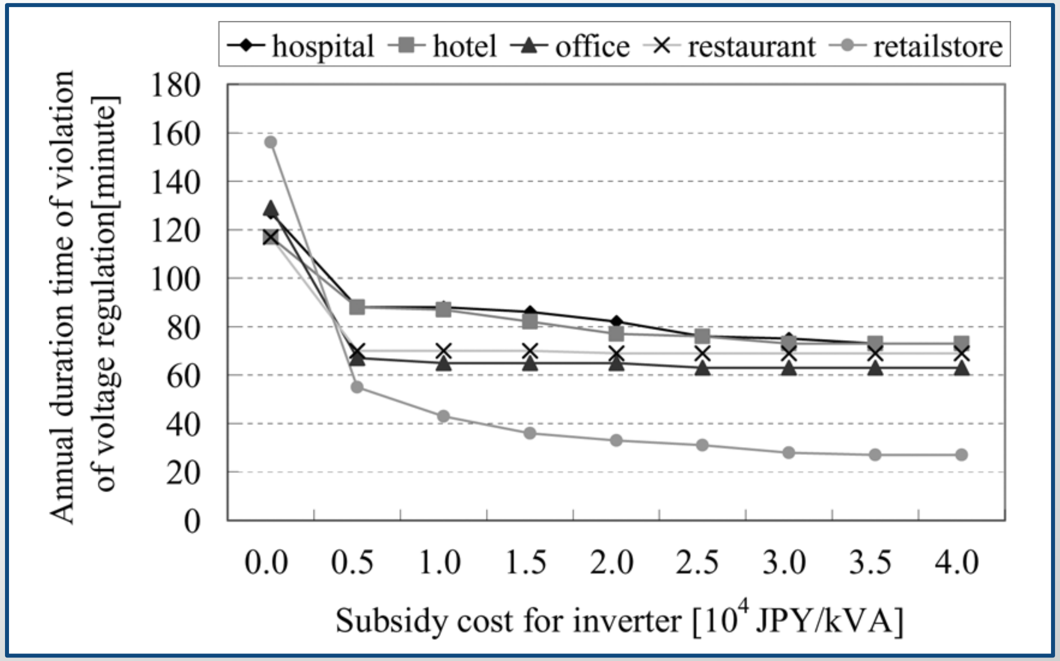

Figure 8: Duration of Voltage Regulation Violations per Year When Reactive Power Compensation is Performed by Energy Storage Systems

Solar Distribution in New Zealand

- It is in the financial interest of New Zealand energy providers to pursue the opportunities that distributed energy presents rather than attempting to maintain the convention “top down” energy structure
- Vector is already embracing customer-side storage systems
  - Sun Genie: app that allows customers to monitor their home energy system
  - Partnership with Tesla to provide battery storage to customers
  - Partnership with Power Ledger to allow customers to buy and sell electricity without a retailer

Works Cited – Solar Distribution

Canova, A., Giaccone, L., Spertino, F., & Tartaglia, M. (2009). Electrical impact of photovoltaic plant in distributed network. *IEEE Transactions on industry applications*, *45*(1), 341-347.

Benefits of Distributed PV in NZ. (2016.) Web. http://d3n8a8pro7vhmx.cloudfront.net/seanz/mailings/87/attachments/original/Solar_PV_and_Batteries_Report.pdf?1479682506

Katiraei, F., & Aguero, J. R. (2011). Solar PV integration challenges. *IEEE Power and Energy Magazine*, *9*(3), 62-71.

Kjaer, S. B., Pedersen, J. K., & Blaabjerg, F. (2005). A review of single-phase grid-connected inverters for photovoltaic modules. *IEEE transactions on industry applications*, *41*(5), 1292-1306.

Lin, C. H., Hsieh, W. L., Chen, C. S., Hsu, C. T., Ku, T. T., & Tsai, C. T. (2011). Financial analysis of a large-scale photovoltaic system and its impact on distribution feeders. *IEEE Transactions on Industry Applications*, *47*(4), 1884-1891.

Sugihara, H., Yokoyama, K., Saeki, O., Tsuji, K., & Funaki, T. (2013). Economic and efficient voltage management using customer-owned energy storage systems in a distribution network with high penetration of photovoltaic systems. *IEEE Transactions on Power Systems*, *28*(1), 102-111.

Thomson, M., & Infield, D. G. (2007). Impact of widespread photovoltaics generation on distribution systems. *IET Renewable Power Generation*, *1*(1), 33-40.