21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2015 Grid of the Future Symposium

Targeted Deployment of Solar Generation using Advanced Inverters

J. VALENZUELA J. WOODARD J. SALSMAN
National Grid
USA

SUMMARY

The following paper presents the procedure that National Grid created to implement its Solar Phase II program in the state of Massachusetts. The program includes up to 20 MW of solar capacity and is an extension of the initial 5 MW utility-owned deployment (Solar Phase I). The proposal received a pre-approved by the Massachusetts Department of Public Utilities (DPU) that considered it to be in the best interest of the public and consistent with Massachusetts energy policies. By using a targeted deployment of solar installations with inverters including advanced functionalities, National Grid expects to gain valuable experience while maximizing the benefits for its customers. It is expected that this methodology, and the lessons obtained from the pilot's implementation, will help to modify current interconnecting practices and to advise the utility industry on the use of inverter functionalities that are new to their service territory.
18 solar sites, totaling 16 MW of capacity, are currently being deployed across several towns in Massachusetts as part of this program. The construction is expected to be completed as early as Dec of 2015 when some of the testing protocols, currently being developed, will start to be implemented.

KEYWORDS

Solar Generation, PV, Advanced Inverters, Distributed Energy Resources

Jorge.valenzuela@nationalgrid.com

1. INTRODUCTION

Under the Massachusetts' Green Communities Act of 2008 [1], electric utilities are allowed to construct, own, and operate up to 25 MW of solar generation facilities. National Grid saw a significant potential for knowledge growth by operating solar facilities within its electrical distribution service territory. The beginning of National Grid's initiatives created the Solar Phase I program, which resulted in the development of 5 MW of utility-owned solar on underutilized sites and remediated brownfields.

National Grid intends to stimulate the growth of renewables in Massachusetts once again, by implementing a second phase of its solar deployment (Solar Phase II). With this deployment, National Grid will own, operate and test on company and customer properties up to an additional 20 MW of solar generation facilities using equipment with advanced functionalities.

As described in National Grid's filling and testimony [2], part of the objectives of the Solar Phase II program is to test the operation and value of advanced inverters to gain an understanding of whether the technology provides the opportunity for higher penetration of solar generation in National Grid's territory. The successful implementation of this program will help National Grid and the industry to improve its renewable generation integration practices to effectively support the goals of customers, states and government agencies.

Some of the principles behind National Grid's implementation of this program are based on the following concepts:

- Targeted deployment of solar generating sites to maximize potential benefits
- Configuration of individual sites to minimize adverse impact and improve operational conditions
- Test of communication and control schemes to minimize or eliminate significant integration costs
- Coordination of solar sites to improve system conditions and assets utilization

The following paper describes the process and philosophy followed by National Grid to select the locations where the Solar Phase II sites were deployed.

2. PHILOSOPHY

As mentioned in the introduction, by using a targeted deployment approach, National Grid is seeking to maximize the benefits of the program while gaining valuable experience that could be used to improve its current integration process and further incentivize the development of solar in certain areas of its territory. Through preliminary analysis of its system, National Grid identified locations for solar installations where the benefits described in Table 1 could be obtained.

The overall process to determine the final locations for the sites can be seen in Figure 1. The process was broken down into three stages:

1. Analysis of National Grid's overall distribution system: The objective of this step was to generate a list of feeders and stations where solar installations would be preferred. National Grid then grouped these results by towns to facilitate the bidding process
2. Request For Proposals (RFP): Public call for proposals for the towns selected [3]
3. Proposals' evaluation: National Grid selection of the proposals based on overall value

Table 1 Description of benefits pursued by the implementation of the Solar Phase II program

Benefit	Description
Capacity relief	Potential for reduction of assets' loading during peak conditions. Capture of operational and weather data that indicates availability of solar generation during peak conditions for Massachusetts. Will provide guidance on the potential for Utility deployments used for capacity deferment.
Improvement of operational conditions	Improvement of operational conditions in areas with existing or potential Power Quality problems. Capture of detailed data of advanced inverter functions' activation for system support. Will provide information for future Utility deployment or targeted customer conversion (could trigger interconnection agreement review for customer compensation, etc.).
Advanced functionality analysis under special conditions	Analysis of inverter behavior under Light Load and High PV circuits. This will provide detailed information of the behavior of advanced inverters in scenarios where interconnection of additional resources normally translate into higher costs due to system upgrades. This will provide information on the limitations of the advanced inverter functionalities and help to set up the expectations about their impact on integration costs reduction.

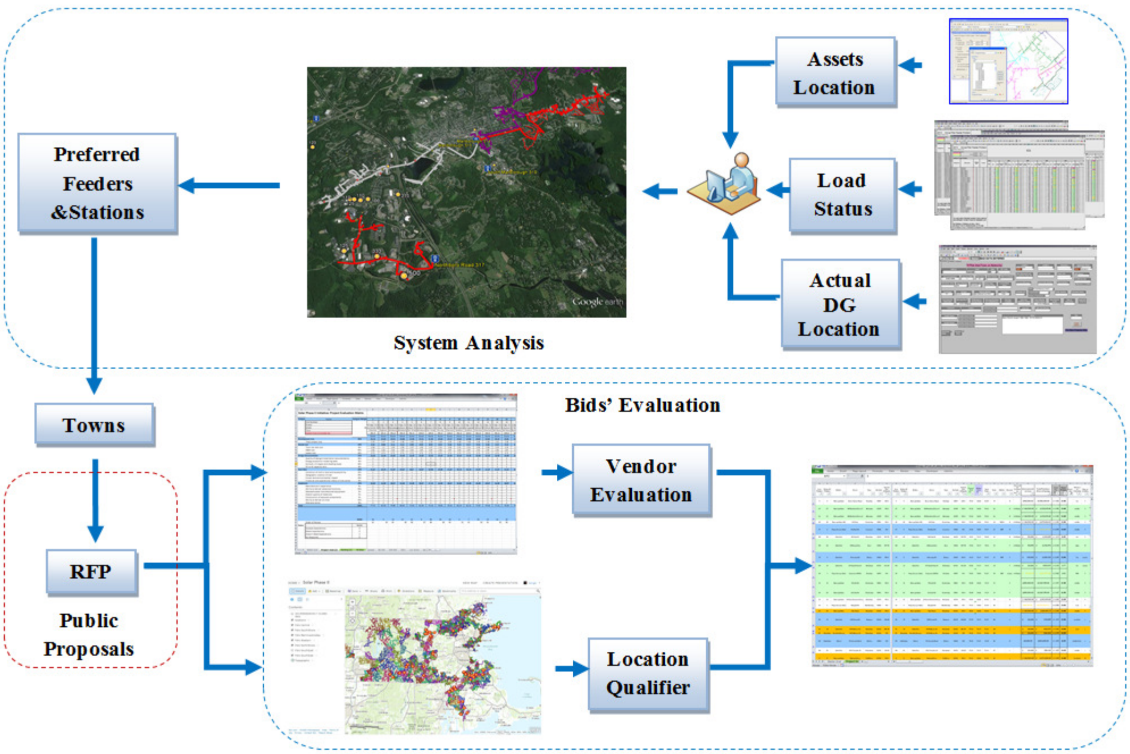

Figure 1 Overview of the process followed to determine the Solar Phase II deployment locations

3. PROCESS IMPLEMENTATION

The process to select the final locations for the sites can be summarized as follows:

System Analysis:

An initial assessment of the loading of all the feeders and transformers in Massachusetts was conducted. The following parameters were used to make a feeder and substation selection for this particular project:

- Feeders with Summer Normal capacity above 9 MW and expected to be loaded beyond 90% by 2015 (Capacity Relief candidate)
- Transformer with Summer Normal capacity above 20MW and expected to be loaded above 95% on normal conditions or expected to be loaded above 100% under contingency by 2015 (Capacity Relief candidate)
- Feeders with an expected peak load (Summer Normal) below 4MW (Advanced Inverter functionality testing)
- Feeders with high levels (above 5MW nameplate) of PV generation (Advanced Inverter functionality testing). This required the collection and correct geographical placement of all the existing and projected solar generation sites in National Grid's territory

The feeders and stations identified were then grouped into towns where the RFP process was targeted.

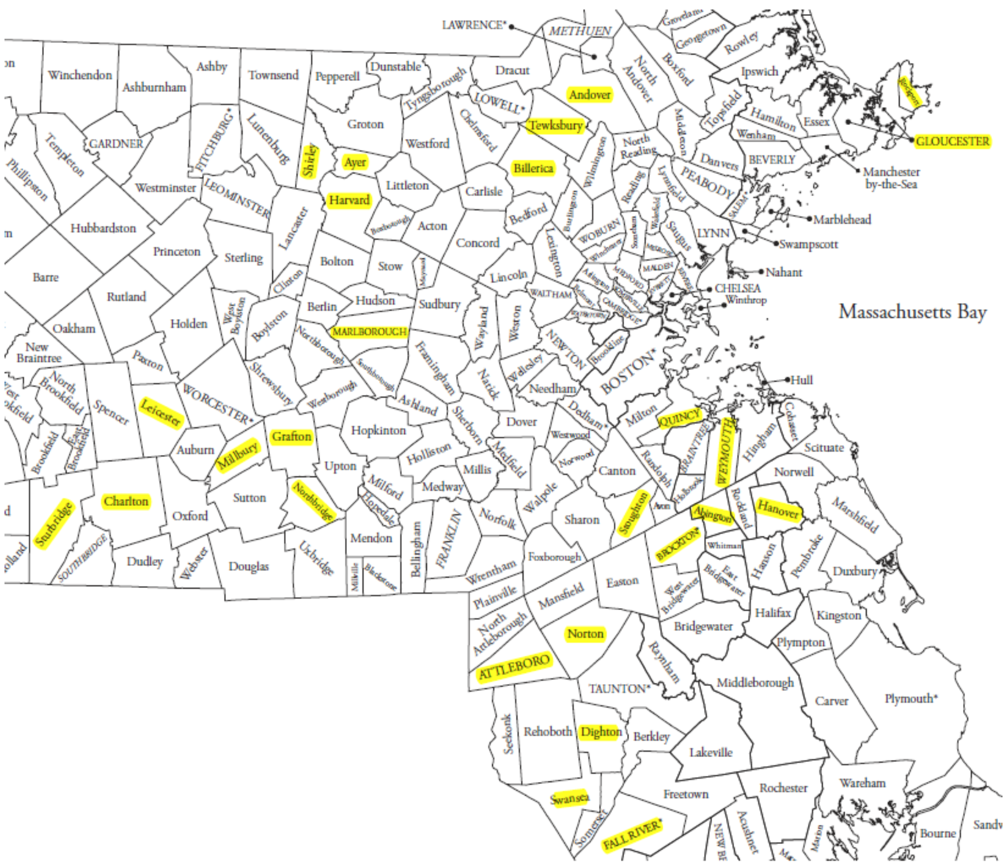

Figure 2 Towns (25) targeted for the RFP process

Public Proposals:

Some of the main requirements included in the RFP can be summarized as follows:

- The size of the solar arrays should be between 60 kW and 1,000 kW (except for National Grid owned facilities)
- Solar PV Array host properties may include, but are not limited to: Commercial and industrial facilities (e.g., office buildings, manufacturing facilities, "big box" retail stores, commercial buildings, warehouses, etc.), municipal properties (e.g., town/city owned buildings, garages,

schools, landfills, excess land, etc.) and land (e.g., undeveloped, parking lots, Brownfield, etc.)

- The Solar generation facility should have communication and remote monitoring capabilities
- The Solar generating facility shall include inverters with the advanced functionalities described in Table 2

Table 2 Description of the advanced functionalities required for the inverters to be included

Functionality	Modes	Description
Active Power Control	Real Power Curtailment	Ability to limit the active power production of the PV site to a value below its potential
	Ramp Rate Control	Ability to limit the rate of change in magnitude of active power supplied
	Frequency Droop Response	Ability to curtail Active Power during higher than normal frequency at the PCC
	Power factor compensation - Power factor/active power characteristic curve PF(P)	Ability to establish a Power Factor level at the PCC based on actual Active Power production
Reactive Power Control	Fixed Power Factor: PF_{fixed}	Ability to maintain a power factor at the PV site's PCC by changing reactive power injection (under the right conditions)
	Fixed Reactive Setpoint: Q_{Fixed}	Ability to inject a fixed amount of reactive power (percentage of nameplate) at the PCC (under the right conditions)
	Voltage Compensation - Reactive power/voltage characteristic curve Q(U)	Ability to inject Reactive Power at the PCC based on actual Voltage level
	Voltage Regulation – closed loop regulation of the voltage	Ability to establish a Voltage level at the PCC by injecting Reactive Power (under the right conditions)
	Ramp Rate Control	Ability to limit the rate of change in magnitude of Reactive Power supplied
Low and High Voltage/Frequency Ride Through (LVRT) & (HVRT)		Ability to configure the tripping of the PV site during Under and Over Voltage/Frequency events at the PCC (beyond what UL1741 specifies)

129 proposals were received during the RFP process. Such proposals were then reviewed and scored based on the estimated value added to the program.

<u>Bid's Evaluation</u>

The evaluation of the bids included the review and classification based on two main areas: the economic aspect and the technical value of the proposal. Table 3 describes the qualifiers used to prioritize sites based in technical characteristics deemed to provide the best value for the program.

4. RESULTS

The process described in the previous section resulted on the selection of 18 sites with approximately 16 MW of Solar Capacity to be installed. A summary of the sites can be seen in Table 4. The actual schedule for implementation shows dates for construction completed as early as Dec 2015.

A map showing the location of the sites along the State can be seen in Figure 3. All of these sites will include communication capabilities and inverters with advanced functionalities from either: Solectria, SMA America or Schneider Electric.

Table 3 Description of qualifiers used to prioritize the proposals received

Concept/ ***Testing Objective***	**Qualifiers**	**Description**
Capacity relief/ ***Investment Deferment***	✓ Feeder Load (High) ✓ Transformer Load (High) ✓ Time of Peak ✓ Proximity to the station (Close)	National Grid will consider units that are proposed to be built closer to the feeding substation (to maximize the potential relief to the typical limiting elements) and in feeders where the peak load is registered earlier during the day (to obtain a bigger contribution from Solar to capacity relief). Since variability of the generation resource is a concern for this type of strategy, National Grid is looking for an opportunity to gather and analyze data that would help them to evaluate how much solar capacity can really be considered for relief of assets if installed at the right locations. This effort can provide future opportunities for "guided" development of Solar in areas where the electric system can see benefits from the Distribution Planning point of view. To maximize output during peak conditions at a certain time, azimuth and elevation angles of the solar panels can be adjusted to match the Sun's position at the time of peak during the previous year.
Lightly loaded area & High PV penetration/ ***Inverter R&D***	✓ Feeder Load (Low) ✓ High PV generation on feeder (compared to load)	Some of the main concerns when interconnecting customers in lightly loaded feeders or feeders with High PV penetration are related to the potential for non-conventional power flow direction (where distribution equipment doesn't support it), abnormal voltage conditions and protection related issues. By installing inverters with advanced functionalities in feeders with these characteristics, National Grid will have a better opportunity to test (and assess) the performance of capabilities such as Power Curtailment, Voltage Regulation and Anti-Islanding protection schemes. Since some of those control strategies are likely to be active during maximum active power generation, a reduction on energy production during those conditions is expected. The quantification of such reduction will be of significance during the analysis stage to understand how the minimization of upfront cost (due to the avoidance of upgrades during the interconnection process) will compare to the loss of revenue through the life of the solar system.
Voltage Regulation & Power Quality/ ***Inverter R&D***	✓ Proximity to the station (Close or Far) ✓ Voltage regulation equipment in the proximity (Capacitor,	In general, installations of big PV generation units in certain locations can have the potential of drastically changing the voltage profile through the feeder where they are connected. In particular, units that are connected at the beginning (where effects on feeder's regulators operation and voltage profile can be affected) or end of the feeder (where the mainline is progressively lightly loaded) can potentially cause the voltage at certain points of the feeder

	regulator) ✓ History of Power Quality problems	to reach abnormal levels. This is especially true in the presence of line regulators and fixed (or timed) capacitors. By installing devices on locations with these characteristics, National Grid will have a better opportunity to test the Voltage regulation capabilities of the inverter and how this will affect line regulators or capacitors' operation. By testing coordination with line devices, National Grid will have the opportunity to analyze and quantify the benefits of using advanced inverter functionalities and how (if possible) they could be used in the future to control the voltage profile on a feeder in a more distributed way.
Coordination/ *System Optimization*	✓ Other Solar Phase II sites on feeder ✓ Other Solar Phase II sites on same transformer	Since the RFP requirements included communication capabilities, National Grid would like to explore the value of coordinating resources at a feeder and station level based on a control strategy. Depending on the conditions of the system (ex: for voltage regulation purposes), National Grid would like to test schemes such as distributed reactive compensation, voltage profile adjustment, etc. Since National Grid does not have a DMS system (yet), the implementation of such coordination will require grouping of devices that are bounded by an electrical location (a feeder or a station) to make the monitoring and control logic viable.

Table 4 Summary of solar installation capacity by town

Town	Zip Code	Number of sites	System Size (KW_{AC})
Abington	02351	2	1650
Attleboro	02703	2	1672
Ayer	02703	1	1000
Charlton	01507	2	1684
Dighton	02715	1	1000
Grafton	01519	1	684
Leicester	01524	2	1368
Millbury	01527	1	684
Shirley	01464	4	4000
Sturbridge	01566	2	2000
	Total	**18**	**15742**

Some of the sites shown in Table 4 are actually being constructed in the same feeder or, in some instances, in the same transformer of a particular station. This will give National Grid the opportunity to analyze the coordination of resources that share a common electrical boundary. Such coordination is being designed on the basis of an overarching monitoring and control solution provided by Trimark [4], which has been included in the development plan of most of the sites considered for the program.

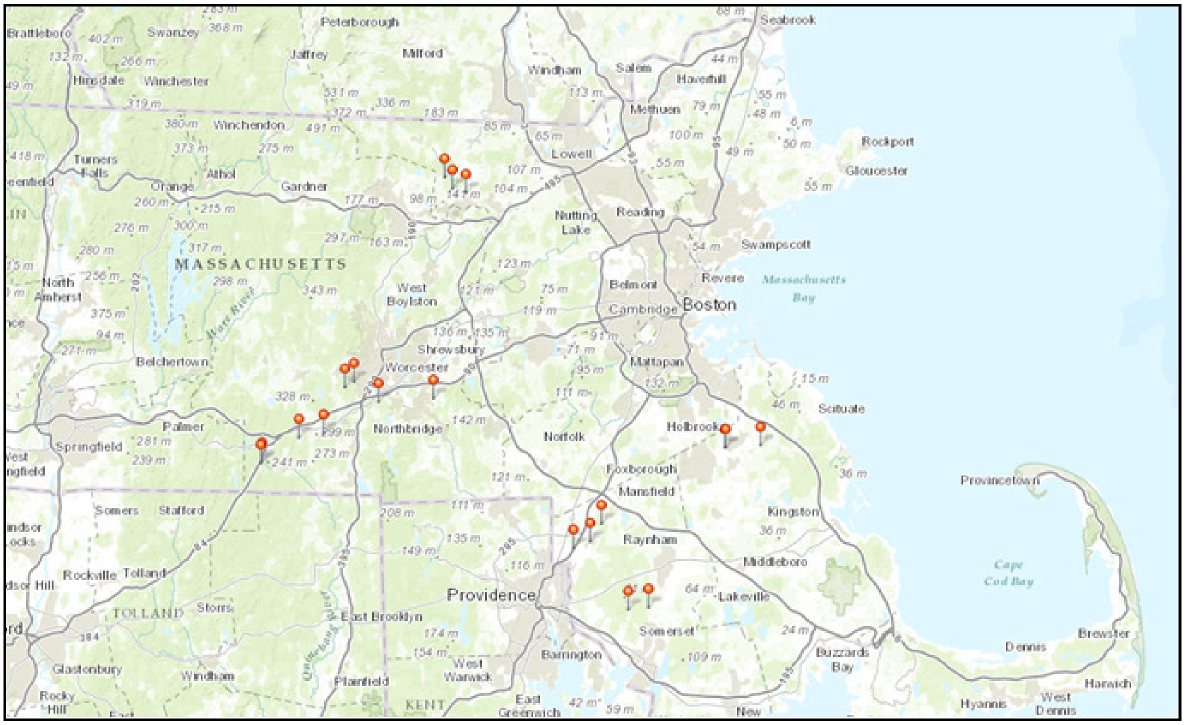

Figure 3 Map including the sites currently being developed (in yellow)

5. SUMMARY AND FUTURE WORK

On June 30, 2014 the Massachusetts DPU found the Company's filed Solar Phase II program to be in the best interest of the public and consistent with Massachusetts energy policies. The pre-approval of $97.6M for up to 20 MW granted by the DPU represents a significant step forward for the future of integration of renewable generation in Massachusetts. With this effort, National Grid is taking a leading approach among utilities nationally, seeking to maximize the operational benefits and minimize integration costs from the fastest-growing type of distributed generation.

By using a guided approach for a market driven deployment of solar generation, National Grid expects to maximize the technical benefits obtained by the program while maintaining the implementation cost as low as possible. This is of particular importance since the advanced inverter functionalities included in the program don't represent a significantly higher cost in equipment, but their use can support the reduction of future integration costs.

Currently, National Grid is designing the testing protocols and customizing the advanced inverter settings for each of the selected locations based on the classification shown to Table 1. This will provide a wide variety of scenarios and operational data that will be of great value for the company, government agencies and the utility industry in general. In addition, National Grid is currently reviewing several opportunities to incorporate additional components to the program, such as Power Line Carrier communication and Battery Storage. Those systems are expected to expand the learning opportunities by increasing the number of alternatives to lower the integration costs.

BIBLIOGRAPHY

[1] 188th General Court of the Commonwealth of Massachusetts, "AN ACT RELATIVE TO GREEN COMMUNITIES", (Available from https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter169, [Accessed July 2015]).

[2] Executive Office of Energy and Environmental Affairs (EOEEA), "Petition of Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid for approval by the Department of Public Utilities, pursuant to G.L. c. 164, § 1A(f), in connection with the second phase of the Company's solar program. DPU 14-01", (Available from http://web1.env.state.ma.us/DPU/FileRoomAPI/api/Attachments/Get/?path=14-01%2f1214ngrdptn.pdf, January 2014, [Accessed July 2015]).

[3] Solar Energy Industry Association, "National Grid Solar Phase II Program", (Available from http://www.seia.org/sites/default/files/resources/National%20Grid%20Solar%20Phase%20II%20Program%20%282%29.pdf, [Accessed July 2015]).

[4] Trimark Associates Inc., "PV Power Management", (Available from http://trimarkassoc.com/solutions/pv-power-management/, [Accessed July 2015]).