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Review of PREPA Technical Requirements for Interconnecting Wind and Solar Generation

Vahan Gevorgian and Sarah Booth

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Technical Report
NREL/TP-5D00-57089
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Contract No. DE-AC36-08GO28308

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Abstract

The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have partnered with the Government of Puerto Rico to assist in addressing barriers to the deployment of energy efficiency and renewable energy in Puerto Rico. This document provides an overview of the minimum technical requirements (MTR) for interconnection of wind power and photovoltaic generation developed by the Puerto Rico Electric Power Authority (PREPA). Integrating a large amount of variable renewable generation such as wind and solar into an electrical grid presents several potential challenges for operating a power system, particularly with small island grids like the Puerto Rico electrical system. Establishing valid technical requirements for interconnection of variable renewable generation to the electric grid is an important step in overcoming such challenges. The interconnection requirements need to address several important aspects of renewable integration such as safety, impacts on power system reliability and performance, and costs. Being an isolated island system, PREPA does not fall under Federal Energy Regulatory Commission (FERC) jurisdiction, and therefore FERC interconnection standards are not required to be applied to generators in Puerto Rico. In this regard, PREPA has developed its own set of interconnection requirements with which all transmission-level wind and solar PV generators shall comply. In this report, NREL provides an impartial third-party review of PREPA's MTRs, drawing comparisons with other similar requirements and best engineering practices. Over the course of the collaboration on the MTR review (2012-2013), PREPA revised the MTRs based on the draft review. As such, PREPA's responses to the recommendations are also included in this report. The PREPA MTRs are anticipated to constantly evolve as the level of renewable penetration increases, modeling tools are improved, and experience with system performance increases. This review is intended to assist PREPA in this process.

Acknowledgements

The authors would like to acknowledge the substantial contributions to this report provided by staff at PREPA, the Governor's Office, and the Puerto Rico Energy Affairs Administration (PREAA). NREL worked closely with staff from PREPA, PREAA, and the Governor's Office throughout the technical review of PREPA's MTRs to ensure accurate understanding of Puerto Rico's electricity grid and the status of renewable energy integration. The authors would like to particularly thank Martin Pérez, Luis Francis, Alvin Román (PREPA) and Efraín O'Neill (Governor's Energy Affairs Advisor) for their significant contributions and support of this effort, especially for reviewing the recommendations and providing a summary of PREPA's responses. The authors would also like to thank Jennifer DeCesaro and Steve Lindenberg from DOE who sponsored this work, this effort could not have been completed without their support and involvement.

List of Abbreviations and Acronyms

AGC	automatic generation control
DER	distributed energy resources
DFIG	double-fed induction generator
ERCOT	Electric Reliability Council of Texas
FESTIV	Flexible Energy Scheduling Tool for Integration of Variable Generation
FRT	fault ride-through
HECO	Hawaiian Electric Company
HVRT	high-voltage ride-through
Hz	hertz
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical Engineers & Electronics Engineers
kV	kilovolt
LVRT	low-voltage ride-through
ms	millisecond
MTR	minimum technical requirements
MVA	mega volt ampere
MVAR	mega volt ampere reactive
MW	megawatt
NERC	North American Electric Reliability Corporation
PFR	primary frequency response
PSLF	Positive Sequence Load Flow
POI	point of interconnection
PQ	power quality
PPA	power purchase agreement
PRC	protection and control
PREPA	Puerto Rico Electric Power Authority
PSCAD	power systems computer aided design
PSS/E	power system simulation for engineering
PV	photovoltaic
RR	ramp rate
SCADA	supervisory control and data acquisition
SCR	short circuit ratio
STATCOM	static synchronous compensator
SVC	static VAR compensator
VAR	volt ampere reactive
VRS	voltage regulation system
WPP	wind power plant
WTG	wind turbine generator
ZVRT	zero-voltage ride-through

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1 Introduction

The Puerto Rico Electric Power Authority (PREPA) has established minimum technical requirements (MTR) for interconnection of wind turbine generation and photovoltaic (PV) power plants (see Appendices A and B). During a stakeholder workshop conducted by the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL), and the Government of Puerto Rico in May 2012, barriers to renewable energy deployment were discussed. The stakeholders, including PREPA, the Puerto Rico Energy Affairs Administration, and representatives from the Governor's Office, requested DOE and NREL assistance in a technical review of the MTRs for variable renewable energy generation.

NREL has conducted a review of these requirements based on generic technical aspects and electrical characteristics of wind and PV power plants, and on existing requirements from other utilities in both the United States and Europe. The purpose of this review is to analyze each aspect of the PREPA MTRs, comparing and contrasting with interconnection requirements from similar power systems, identifying areas of concern, and generating recommendations and suggestions for improvements or additional study.

Over the course of the collaboration on the review of the MTRs (2012-2013), PREPA staff reviewed the draft recommendations and incorporated some of the recommendations into the 2012 revisions of the MTRs (see Appendices C and D). In addition, PREPA engineers responded to the NREL recommendations by providing a technical rational based on their operational experience or previous modeling results for not modifying some of the requirements. Each section of this report provides the recommendations for revisions to be made to the original MTRs based on industry best practices as well as PREPA's response to how the recommendations were addressed in the MTRs revised in August 2012. For the sake of convenience, in this report we shall refer to the June 14, 2012, version of the PREPA MTR document as the "original" MTR, and to the August 15, 2012, version as the "modified" MTR.

2 Voltage Fault Ride-Through

In the original MTR document, PREPA's low-voltage ride-through (LVRT) requirements for both wind and PV are similar. Wind and PV plants are supposed to remain online and ride-through zero-voltage faults for up to 600 milliseconds (ms); this is essentially a zero-voltage ride-through (ZVRT) requirement. The no-trip zone is bounded by linear voltage recovery for up to 3 seconds. PREPA sets high-voltage ride-through (HVRT) requirements for maximum high voltage at 140% of nominal for up to 1 second. A comparison between LVRT and HVRT requirements for PREPA, North American Electric Reliability Corporation (NERC), and other islands systems such as the Hawaiian Electric Company (HECO) and EirGrid are shown in Figure 1.

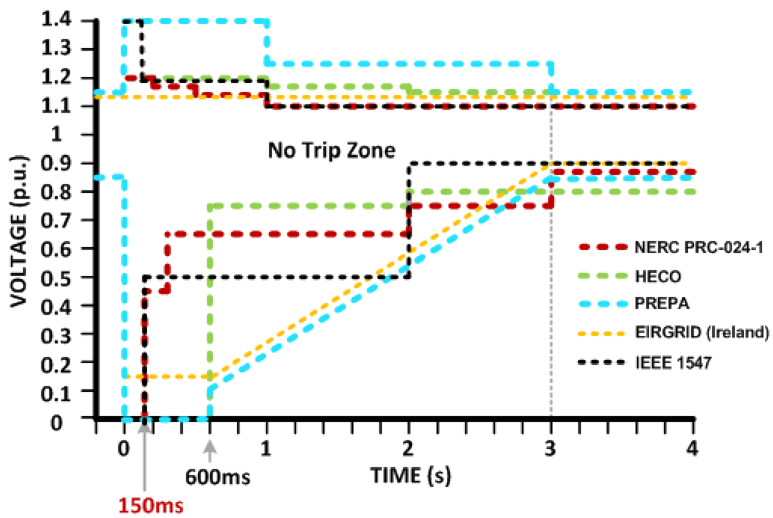

Figure 1. Comparison of LVRT and HVRT requirements

The draft NERC Protection and Control (PRC) Standard PRC-024-1 requires 150 ms ZVRT. Such ZVRT is a typical requirement for transmission-connected wind power plants (WPP) in the United States. The Federal Energy Regulatory Commission Order 661A also requires 150 ms ZVRT, but recovery time is determined on a site-by-site basis depending on the local grid characteristics and protection schemes. Longer ZVRT requirements are necessary for WPPs connected to weaker lines (typical for smaller island grids). A 600 ms ZVRT requirement is implemented in the HECO system. EirGrid also requires 600 ms ride-through but at 15% voltage and with longer recovery time. Such longer zero-voltage requirements and slower rate of recovery suggested by PREPA is justified for weaker island systems to avoid tripping of the wind generators.

Currently, most U.S. utilities have adopted the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 for interconnecting distributed resources on the distribution system. IEEE 1547 covers interconnection of all types of distributed energy resources (DER) up to 10 mega volt ampere (MVA) at the point of common coupling. IEEE 1547 clearing times are also shown in Figure 1.

Voltage during the fault is measured at the plant point of interconnection (POI), which is typically at the transmission interface, and is separated from wind turbine generators (WTG) by two transformers (turbine transformer and wind plant transformer). Combined impedances of two transformers result in voltages at individual turbine terminals to be 15% to 20% higher than transmission voltage. From this perspective, no zero-voltage conditions exist at turbine terminals even during a ZVRT event if the turbine stays online and produces fault current. The fault voltage is normally interpreted as the positive sequence component at the POI. For unbalanced faults the positive sequence voltage may differ from the average phase voltage.

It is important to note that International Electrotechnical Commission (IEC) 61400-21 for power quality testing of grid-connected wind turbines requires testing of individual WTG exposed to rectangular balanced and unbalanced voltage faults at turbine terminals with durations of 200 to 500 ms, and voltage magnitudes of 20% to 90% of nominal (see Table 1). This means that some WTGs that have been certified to this standard will not by default meet PREPA's LVRT requirements shown in Figure 1. Some hardware modifications might be needed for certain wind turbine models to enhance their LVRT performance and meet PREPA's requirements. However, major wind turbine manufacturers (Siemens, General Electric, etc.) have turbine designs capable of performing accordingly.

Table 1. IEC 61400-21 LVRT Test Matrix for Wind Turbines

Fault Type	Voltage drop (fraction of nominal L-to-L voltage)	Fault Duration (ms)
Three-phase, balanced	0.9	500
Three-phase, balanced	0.5	500
Three-phase, balanced	0.2	200
Two Line-to-Line (L-L), unbalanced	0.9	500
Two Line-to-Line, unbalanced	0.5	500
Two Line-to-Line, unbalanced	0.2	200

Although it is not necessary for the converter to produce fault current during the fault in the United States, fault voltage support is required by European grid codes. The turbine converter injects reactive current into the fault as a function of percentage of voltage drop. For example, German utility operator E-ON requires reactive current injection according to the droop line shown in Figure 2 (a minimum of 2% positive sequence reactive current for every percent of voltage drop below 100%). This implies that for faults with voltage drops of 50% or lower, the reactive component of current goes to 100% or higher (depending on the current rating of the converter–usually 1.1-1.2 p.u.).

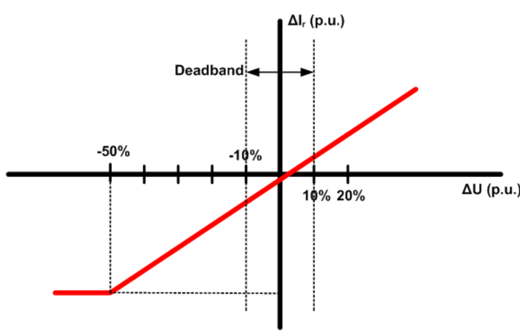

Figure 2. E-ON reactive current droop

In case of unbalanced faults, the general approach is to inject reactive current support as a positive sequence current.

Recommendation #1:
We recommend PREPA further examine the reactive current injection requirement and consider implementation of a similar droop. Currently, PREPA requires that "during the fault conditions, the wind generation facility shall operate on maximum reactive current injection mode."

In some cases, injecting maximum reactive current may have the opposite effect and cause voltage instability in WPP or PV feeder/collector systems. Implementing reactive fault current droops will help avoid potential instabilities.

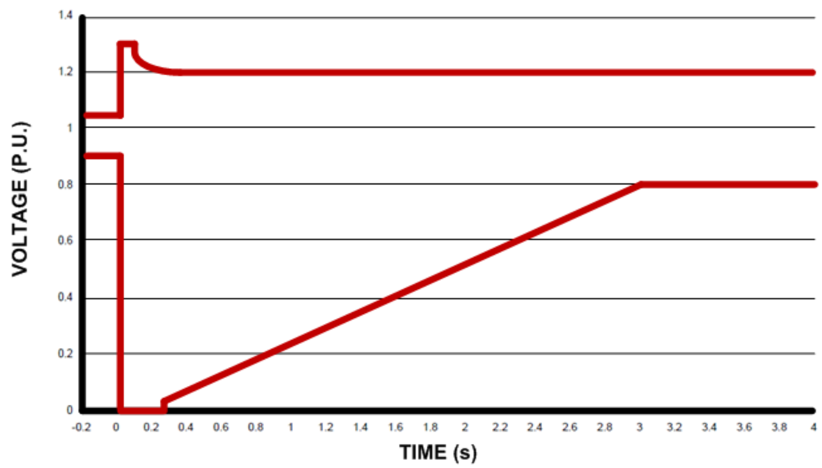

Figure 3. Envelope of international LVRT/ZVRT/HVRT requirements

Situations with over-voltages may arise due to sudden load loss, unbalanced faults, and other conditions. The resulting over-voltages may have different magnitudes and durations depending on the scenario. PREPA HVRT requirements (as shown in Figure 1) are the highest compared to various grid codes that can be found in literature [1]. The highest HVRT requirements in some power systems are limited at 130% of rated voltage. In other island systems (such as HECO or EirGrid) the HVRT is limited at 115% to 120%. There are some grids that require 130% HVRT. Boundaries of fault ride-through (FRT) requirements from several European utilities listed in [1] are shown in Figure 3 for reference purposes.

PREPA's Response to Recommendation #1:
In accordance with NREL's recommendation to further examine the reactive current injection requirement and consider implementation of a similar droop, PREPA revised the MTRs to include the following in the section 1.a.iv:

"During the low voltage fault conditions, the wind generation/PV facility shall operate on reactive current injection mode. This mode of operation shall be implemented with a reactive current droop characteristic which shall have an adjustable slope from 1 to 5%. A dead band of 15 % is required."

Recommendation #2:
The universal requirement of 1-second 140% HVRT by PREPA seems to be excessively strict and may not be necessary for all renewable project locations. Such requirements may cause unnecessary increases in project costs since project developers will have to cover expenses for system upgrades or additional VAR support devices. We recommend PREPA look closely at HVRT requirements and consider also the option of setting them on a site-by-site basis for both wind and PV systems as an alternative.

PV plants using inverters that are IEEE 1547/UL 1741 compliant will not contribute fault current. A resolution of this issue is expected later in 2013 from the UL/IEEE 1547.8 working group, with cooperation from the NERC Integration of Variable Generation Task Force (Task Force 1.7).

PREPA's Response to Recommendation #2:
Based on NREL's recommendation to review the HRVT requirements, PREPA revised the MTRs by reducing the 140% overvoltage ride-through (OVRT) time to 150 ms, and also included a new OVRT range of 130%-125%. The modified section 1.b.i incorporates this new requirement into the following table:

Overvoltage (pu)	Minimum time to remain online
1.4 – 1.3	150 ms
1.3– 1.25	1 s
1.25 – 1.15	3 s
1.15 or lower	Indefinitely

3 Voltage Regulation System, Reactive Power, and Power Factor Requirements

IEEE 1547/UL 1741 compliant PV inverters typically do not have reactive power capability and operate with a unity power factor. To meet PREPA requirements for reactive power and voltage control, a substation level reactive power compensation system will need to be applied [static synchronous compensator (STATCOM)] for IEEE 1547 inverters.

Voltage regulation can be achieved by either regulating the inverter's terminal voltage on the low side of the transformer or by adjusting reactive output according to a droop characteristic. For the purposes of voltage regulation, PREPA requires deployment of a voltage regulation system (VRS) with adjustable set point between 95% and 105% of rated POI voltage. The VRS employs an adjustable 0% to 10% reactive droop with accuracy of control within +/-0.5% of set point.

Recommendation #3:
Such reactive droop controls have been implemented by some wind turbine manufacturers on individual wind turbine and plant levels. The reactive droop capabilities by PV inverters are also offered by some inverter manufacturers, but still need large-scale demonstrations of control schemes in the field. Reactive droops are usually in the range of 2% to 10%. PREPA's requirement of reactive droop below 2% is essentially a "bang-bang" voltage control that may introduce some stability problems and deplete reactive reserves for contingencies. Such small droops are usually not recommended and should generally be avoided for this reason. They still might be justified in weak systems, but require careful evaluation so voltage stability and reliability is not compromised.

PREPA's Response to Recommendation #3:
PREPA decided to keep the complete voltage droop range (0% to 10%) based on the experience with actual renewable projects operating in Puerto Rico and to permit more interconnection site options (from "strong" to "weak" system sites). For example, one existing PV facility is actually regulating with a voltage droop of 0% and the performance of their voltage regulator system (VRS) has been as expected. The MTR language was revised by removing "… and must also be adjustable by PREPA's Energy Control Center via SCADA" from 2.d.

The new version of item 2.d now reads:

"The VRS controller regulation strategy shall be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop shall be adjustable from 0 to 10%."

Recommendation #4:
Reactive droops usually have voltage dead bands (+/-1% for example) that are not specified in PREPA's requirements. Having voltage dead bands may affect the ability to control voltage with +/- 0.5% accuracy. In some case, slower communications may also limit the reactive power response time and affect required accuracy.

PREPA's Response to Recommendation #4:
Following NREL's recommendation to specify voltage dead bands, PREPA revised Section 2 in the MTRs by adding a new subsection 2.h as follows:

"The VRS dead band shall not exceed 0.1%."

Recommendation #5:
Some examples of closed-loop voltage regulation for PV power plants are shown in Figure 4 and Figure 5 where PV inverters are connected to a 13.8 kilovolt (kV) collector bus, and then to PREPA's 115 kV transmission system via medium voltage (MV) feeder and step-up transformer. The closed loop voltage regulation is performed by a PV plant controller that senses remotely the voltage at the POI. This control loop allows for the best mitigation of voltage fluctuations since it allows eliminating voltage impacts in one location. In the case of other existing feeder voltage regulation (switched capacitors, tap-changing transformers, etc.), there may be some difficulties coordinating PV inverter controls with existing feeder voltage regulation. Care must be taken for PV not to carry an excess share of reactive demand of other feeder loads, avoiding interactions between controls and addressing hunting regulator stability issues.

In cases where voltage control capability of PV inverters is absent (IEEE 1547 compliance) or limited, additional devices such as STACOM or Static VAR Compensator (SVC) can be implemented on both PV plant collector (Figure 4) or transmission bus (Figure 5) levels. We think that switched capacitor banks or tap changer transformers (in case they already exist in that particular feeder) can be accepted, and in some cases can eliminate a need for additional STATCOM devices. Different regulation strategies can be implemented with these schemes. For example, fast voltage fluctuations can be mitigated with PV inverters, and slower ones can be addressed by the existing feeder equipment. Appropriate time constants must be chosen to coordinate these various controls.

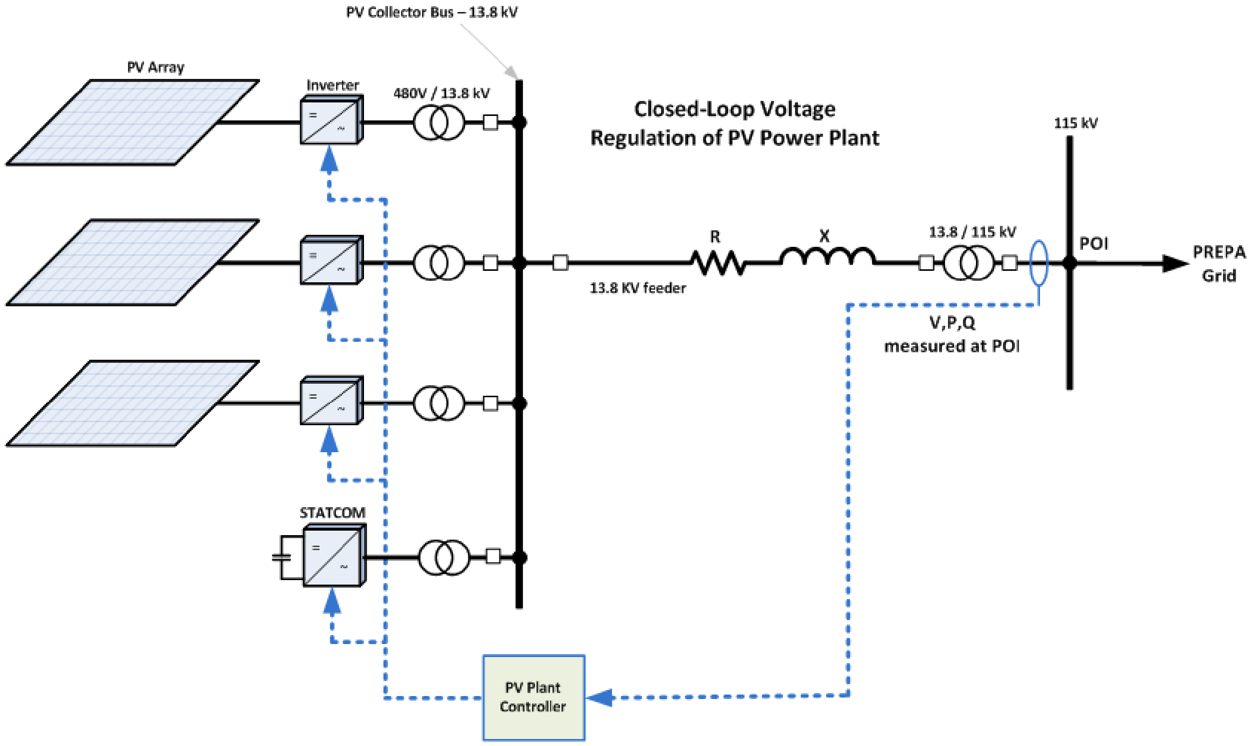

Figure 4. Example of PV plant interconnection with STATCOM on PV collector bus

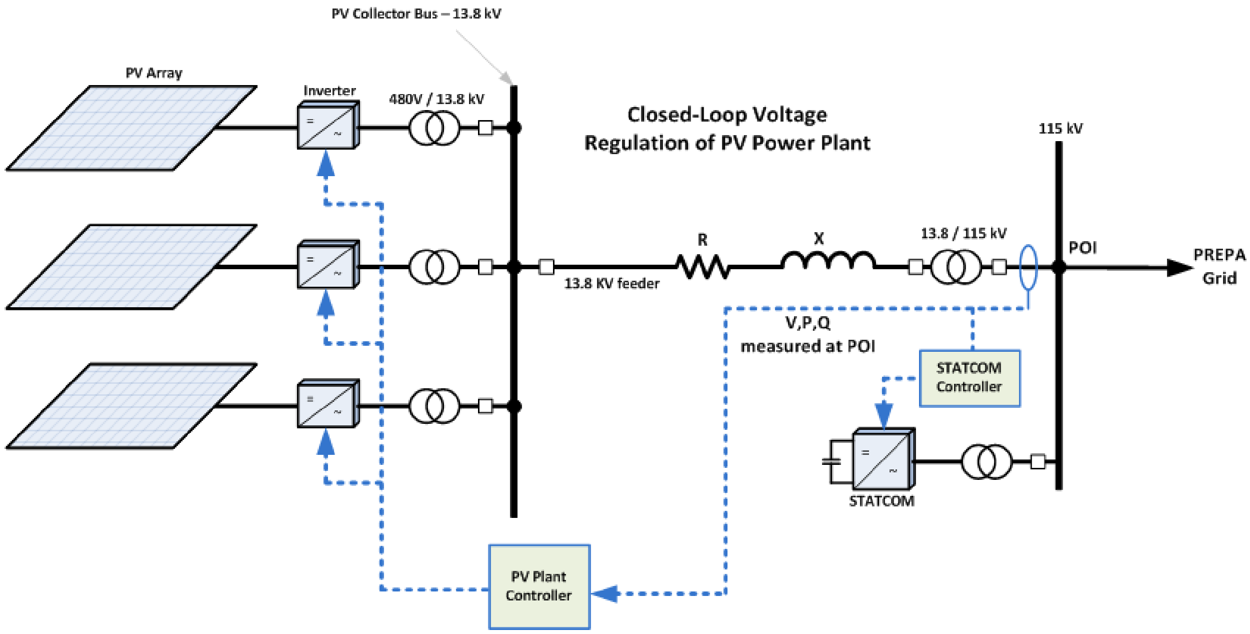

Figure 5. Example of PV plant interconnection with STATCOM on transmission bus

PREPA's Response to Recommendation #5:
PREPA's MTR's are specific to transmission (115 kV) and sub-transmission (38 kV) level systems. In PREPA's actual applications, the feeders used by the PV and wind facilities are internal; excess share of reactive demand of other feeder loads is not expected. NREL's comments regarding this issue seem to be more applicable to distribution system feeders. The MTR's actual reactive power requirements provide flexibility for different types of technologies at the renewable energy facility. These technologies include combinations of different equipment like inverters, STATCOMs, SVCs and capacitor banks. As a result, no changes were made to the MTRs.

Recommendation #6:
PREPA requires VRS to operate only in a voltage set point control mode and does not permit power factor control mode. Note, however, that in some cases plant level power factor control can be an effective tool for mitigating both steady-state and transient voltage impacts of PV, minimizing control interactions with other feeder devices, and is IEEE 1547 compliant. The voltage variations at the POI shown in Figure 4 and Figure 5 depend on real/reactive power variations (ΔP and ΔQ) and feeder parameters R and X:

$$\Delta V \approx \frac{\Delta P \cdot R - \Delta Q \cdot X}{V}$$

In order to maintain $\Delta V \approx 0$, a constant ratio between active and reactive power variations must be maintained:

$$\frac{\Delta Q}{\Delta P} \approx \frac{R}{X} = const$$

Reactive power needed to maintain constant voltage is at an approximately constant ratio to real power at typical short-circuit ratios. Operating at fixed Q/P ratio essentially means operating at constant power factor. Of course, this method has its disadvantages due to some nonlinearities of the P-Q curve. Also, the desired power factor may change if the feeder is reconfigured. This method is not feasible with feeders that have other large loads connected to it since feeder reactive demand may increase during high-load conditions.

Wind and PV power converters have reactive capabilities that are different from those of conventional synchronous generators. Unlike power-limited synchronous generators, the power converter-based generation is also limited by internal voltages, temperatures, and currents. Different types of reactive power capabilities can be implemented for power converter-based generation depending on power system requirements, inverter limits, etc.

Both double-fed induction generators (DFIG) and full-converter WTGs may come with a variety of V-shape, rectangular, D-shape, or U-shape reactive power characteristics as shown in Figure 6. In some cases, reactive power characteristics can be non-symmetric. One advantage of WTGs with rectangular and D-shape reactive capabilities is the possibility of providing voltage regulation service during no-wind periods. The same is true for PV inverters because they can provide voltage regulation at night by operation in a STATCOM mode.

PREPA's Response to Recommendation #6 (similar to #5 above):
PREPA's MTR's are specific to transmission (115 kV) and sub-transmission (38 kV) level systems. In PREPA's actual applications, the feeders used by the PV and wind facilities are internal; excess share of reactive demand of other feeder loads is not expected. NREL's comments regarding this issue seem to be more applicable to distribution system feeders.

The MTR's actual reactive power requirements provide flexibility for different types of technologies at the renewable energy facility. These technologies include combinations of different equipment like inverters, STATCOMs, SVCs and capacitor banks. As a result, no changes were made to the MTRs.

Recommendation #7:
It is important to note that PV inverters have historically been predominantly designed for deployment in distribution systems in accordance to IEEE 1547, which does not allow voltage regulation. The wind generation was predominantly designed to operate at transmission level, so it is more common for WTGs to come with standard reactive power capabilities similar to ones shown in Figure 6. For PV systems such functionality is not standard and must be explicitly specified in the design stage of the project and in the power purchase agreement (PPA). Also, during periods of no wind or solar resource, both wind and PV generators can still provide reactive power support to PREPA's grid. It makes sense to take this fact into consideration when specifying the reactive power capability since wind and PV inverters may be disconnected from the grid during the periods of no production.

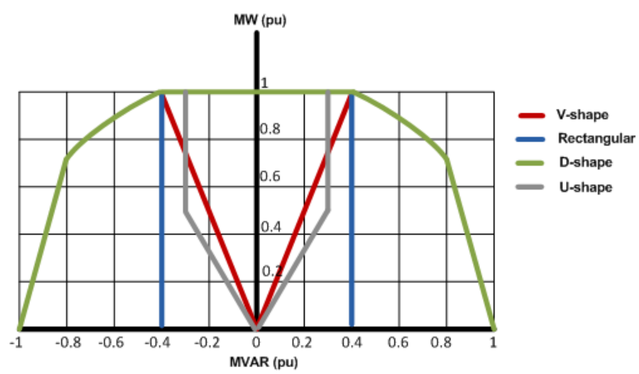

Figure 6. Types of reactive power capability curves for wind generators

In its minimum interconnection requirements PREPA specifies a rectangular reactive power capability curve for both dynamic and total ranges. A comparison of reactive power capabilities between HECO, PREPA, and EirGrid is shown in Figure 7. Similar rectangular reactive power curves are required by HECO in their model PPA document [2]. EirGrid implemented a U-shaped reactive capability curve that uses a reduced power factor range [or a permissive mega volt ampere reactive (MVAR) range] below 50% or rated power.

PREPA's Response to Recommendation #7:
A complete description of the voltage regulation system (VRS) requirement is specified in section 2 of the MTRs. As part of this requirement, a complete and detailed description of the VRS control strategy shall be submitted by the project designer for PREPA's evaluation.

Recommendation #8:
We agree with PREPA that rectangular reactive capability is more beneficial. However, a requirement to maintain reactive power range at full output by PV inverters represents a change with respect to historical industry practice and has some cost impact associated with it. This cost impact could be substantial if the PV plant relies on inverters to provide all required reactive power since additional inverter capacity will be needed. For example, PV inverters would need 11.1% of additional capacity to meet PREPA's dynamic reactive power capability and 17.6% of additional capacity to meet the steady-state reactive power capability. Otherwise, the plant has to be de-rated or external reactive power support needs to be installed.

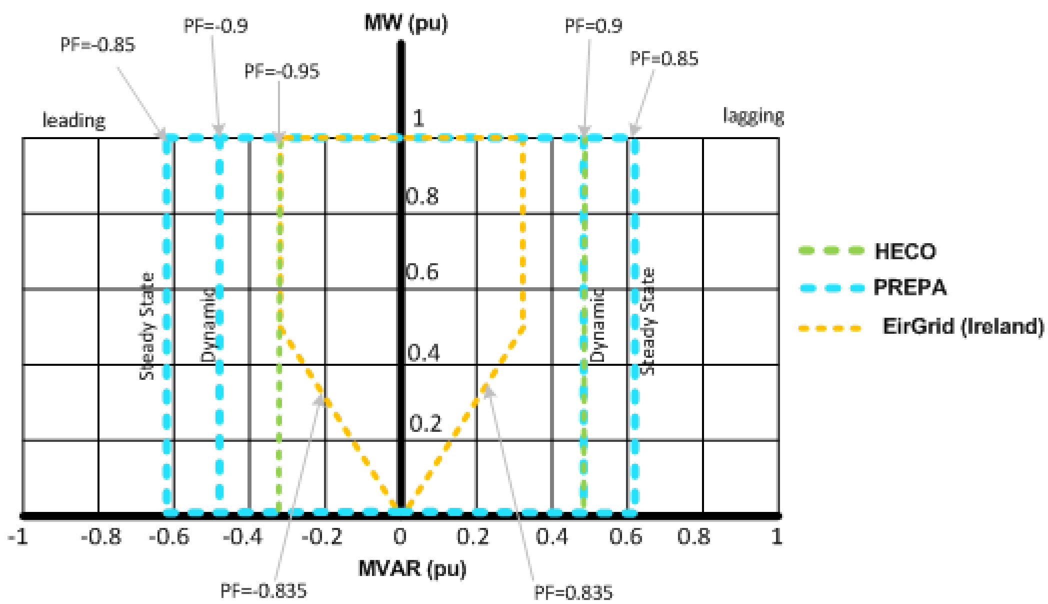

Figure 7. Comparison of reactive power curves

For some DFIG wind turbine topologies the reactive power capability curves are not symmetrical, as shown in Figure 8 (option 2). This is why permissive MVAR ranges as shown in Figure 7 for EirGrid make sense for systems with DFIG-dominated wind power.

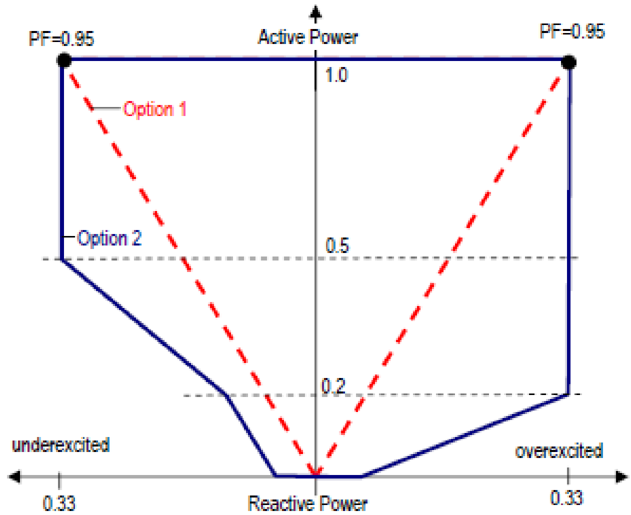

Figure 8. Two types of DFIG WTG reactive power capabilities [3]

Source: University Duisburg-Essen

PREPA's Response to Recommendation #8:
The requirement to maintain reactive power range at full output (rectangular reactive capability) is based mainly on the significant displacement of conventional generation units and their corresponding regulation capabilities due to the expected high penetration levels of renewable projects. As a result, no changes were made to the MTRs.

4 Short Circuit Ratio

Short circuit ratio (SCR) is one of the important limiting factors for wind power installations and has a great influence on the power quality impacts from variable renewable generation. SCR has an influence on LVRT characteristics of wind turbine generators.

Recommendation #9:
PREPA limits SCR=5 as the minimum permissible level for interconnecting both wind and PV projects. We think this level is adequate. However, we'd like to point out that in some cases even lower SCR might be reasonable assuming LVRT requirements set by PREPA as shown in Figure 1. An example of LVRT sensitivity to SCR for a DFIG wind farm is shown in Figure 9. The turbine speed of recovery degrades as SCR is decreased, but the LVRT requirement is still met even at SCR=2.

PREPA's Response to Recommendation #9:
PREPA maintained the SCR limit on 5. Studies indicate that SCR levels below 5 can cause VRS control instabilities in some applications.

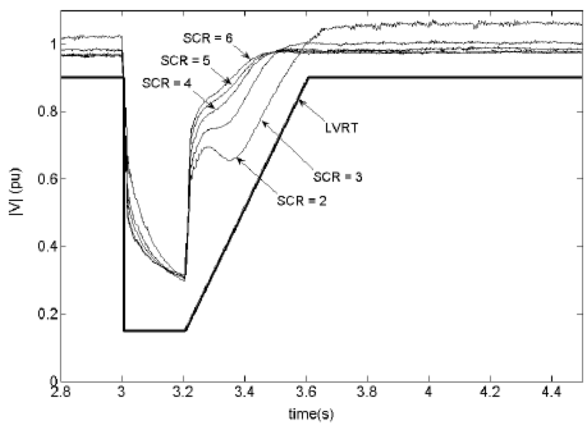

Figure 9. LVRT sensitivity to SCR [4]

Source: IEEE

5 Frequency Ride-Through

PREPA's frequency ride-through (FRT) requirements align with standards in other island systems. A comparison between PREPA, HECO, NERC, and IEEE requirements is shown in Figure 10. PREPA allows adequate frequency range and clearing time typical for weaker islanded systems.

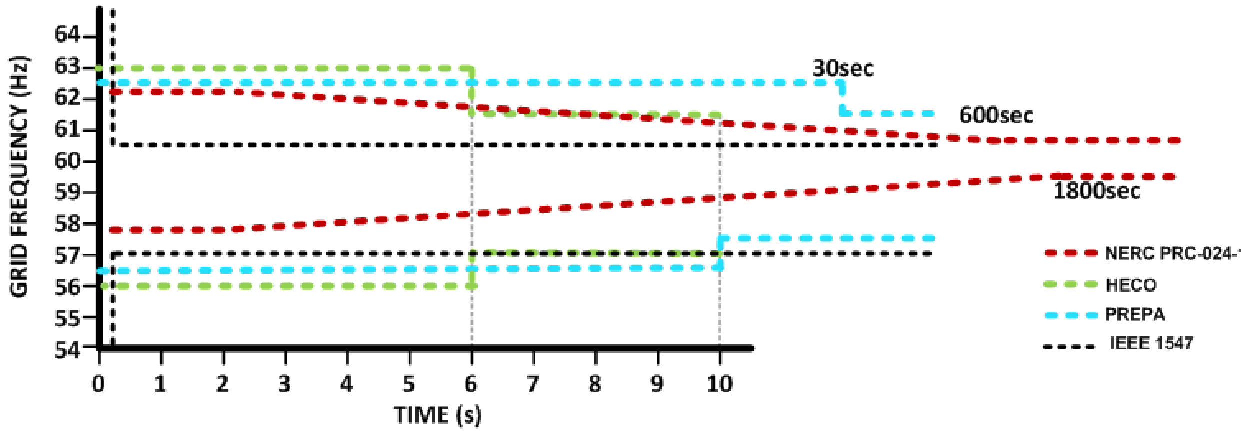

Figure 10. Comparison of frequency FRT requirements

6 Frequency Response

PREPA requires 5% frequency droop for primary frequency control from both wind and PV plants for up and down regulation similar to conventional synchronous generators. This is a symmetrical droop requirement, and PREPA does not specify any dead bands or type of droop characteristic for wind and PV generation. We would like to point out that there are several types of droop characteristics that can be implemented as shown in Figure 11. The Smooth Droop 1 with dead bands is the most common droop used in conventional synchronous generation. The droop curve with power step change is also possible but may cause some stability issues during certain contingency scenarios.

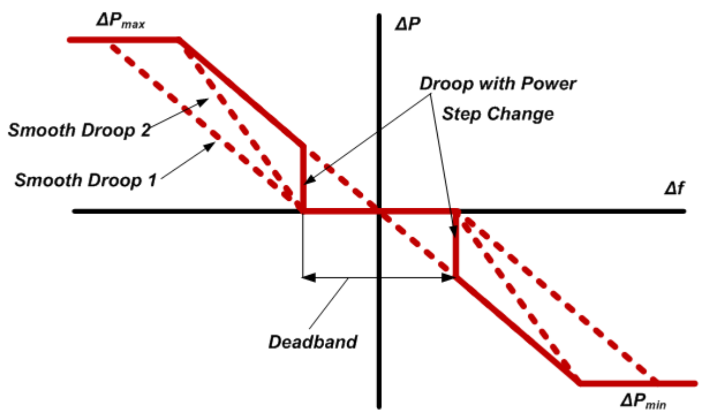

Figure 11. Various frequency droop characteristics

Recommendation #10:
We think that more detailed specifications on the exact type of droop and dead bands would be necessary to remove any ambiguities and misinterpretations for project developers. Primary frequency response (PFR) is one of the most expensive services for renewable generation operators since power reserves must be constantly maintained for up regulation by curtailment (loss of production) or by the use of energy storage devices (extra investment cost).

We would also like to point out that both WTG and PV power plants can reduce their power outputs very effectively so non-symmetric droop characteristics similar to the one shown in Figure 12 can be implemented. Both positive and negative droops and frequency dead bands can be controlled and set by a wind or PV power plant SCADA system to provide aggregate plant PFR that meets power system needs. We recommend PREPA consider the possibility of requesting an option of setting PFR parameters (dead bands, droops, reserve margins) remotely. PFR responses by wind and PV power are additional controls that can be tuned to provide optimum performance and maximum reliability to the PREPA power system and can become a source of additional control flexibility for PREPA system operators.

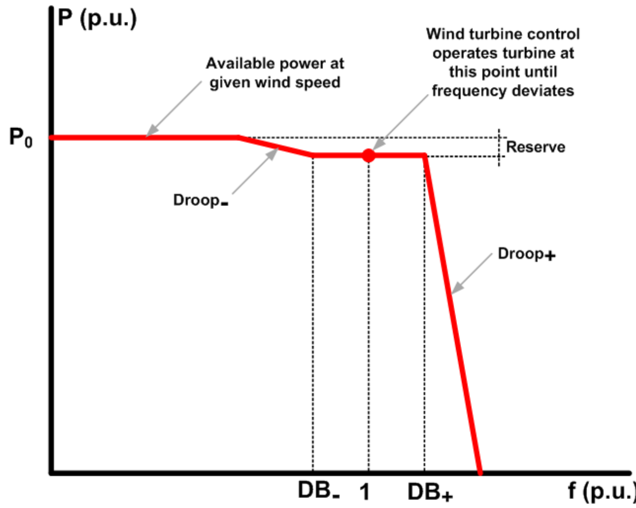

Figure 12. Non-symmetrical frequency droop by wind turbines

It is important to note that there are no active requirements in the United States for wind and PV generation to provide PFR. This is partly due to low penetration levels and lack of incentives (no ancillary service market structures for variable generation to provide PFR). The Electric Reliability Council of Texas (ERCOT) has started implementing a PFR requirement for their inverter based generation. Some of the ERCOT PFR requirements include [5]:

- Minimum 5% and maximum 2% droop performance with maximum allowable dead-band of ±0.0166 Hertz (Hz)
- Governors must remain in service and be allowed to respond
- 70% of response has to be delivered within 16 seconds after disturbance to meet the PFR requirements
- Full response must be deployed within an additional 30 seconds after an initial 16 seconds of a total 46 seconds after disturbance.

PREPA's Response to Recommendation #10:
Per NREL's recommendation, PREPA added the following clarifications to Section 6:

- The frequency response dead band shall not exceed 0.02%.
- If energy storage systems are utilized to comply with the frequency regulation requirements, and during a disturbance the system frequency stays below 59.7Hz, the facility frequency response shall be maintained for at least 10 minutes.

Recommendation #11:
For large frequency deviations (more than 0.3 Hz), PREPA requires an immediate increase in active power production of at least 10% of alternating current-rated capacity of both wind and PV power plants for at least 10-minute time periods. The response time of these services should be no more than 1 second. This requirement is somewhat ambiguous: Does this mean that a

renewable plant must provide a 10% increase in power production at any time when frequency declines by 0.3 Hz? What if this frequency decline happens during periods of no wind for wind generation, or during nights for PV? Do they still need to provide this 10% increase? If so, then at least 10-minute energy storage will be required. This requirement definitely needs more clarification since it is the most important requirement for wind and PV integration.

PREPA's Response to Recommendation #11:
In accordance with NREL's recommendation, PREPA included the following clarification in the fourth paragraph of section 6:

"The operational range of the frequency response and regulation system shall be from 10% to 100% of the maximum AC active power capacity (established in the contract)."

Recommendation #12:
Further, PREPA requires WTG controls to provide inertial response. This requirement also needs more detailed explanation. The main questions here are:

1. What is the priority of inertial response over 10% real-power increase during large frequency declines (more than 0.3 Hz)?
2. What are the dead bands for inertial response for smaller frequency declines?
3. Transition from inertial response to PFR must be specified.

Inertial response by wind power is highly dependent on initial pre-fault conditions of each individual wind turbine (revolutions per minute and wind speed). The aggregate inertial response of the whole WPP will be different than individual WTGs.

Inertial response by wind power is "energy neutral." Initial periods of overproduction triggered by utilizing rotor inertia are followed by a period of underproduction (someone else needs to meet the load during this period) as shown in Figure 13 and Figure 14. Nevertheless, the overall benefit of such inertial response is significant because it helps the power system in the form of arresting initial rate of change of frequency and "gaining time" for a slower PFR of conventional generation.

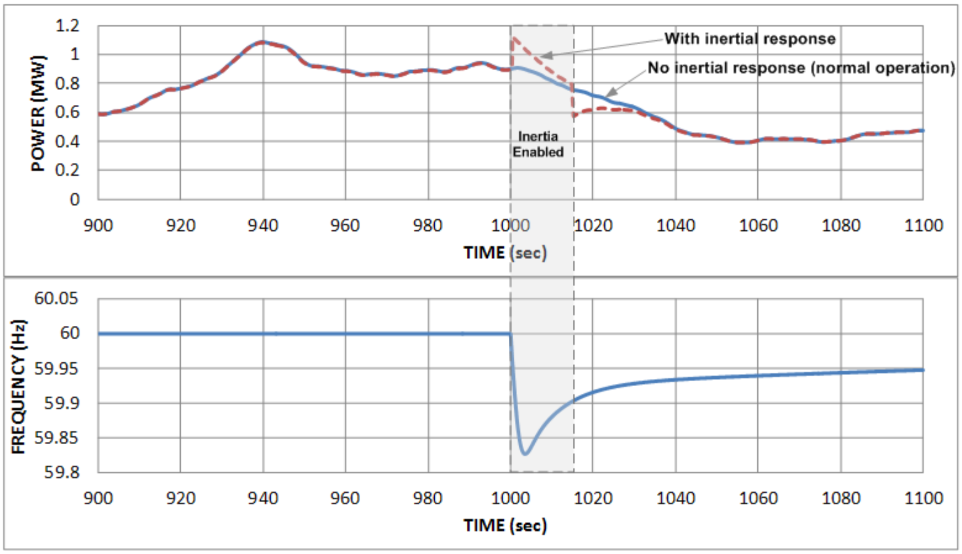

Figure 13. Inertial response by type 3 WTG at lower wind speed (NREL model)

The recovery period and return to normal operations after providing inertial response can be different depending on the available wind resource. At rated wind speed (Figure 14) the return to pre-disturbance level is much faster than at lower wind speed (Figure 13) because of more favorable conditions (there is power available from wind to provide incremental electric power).

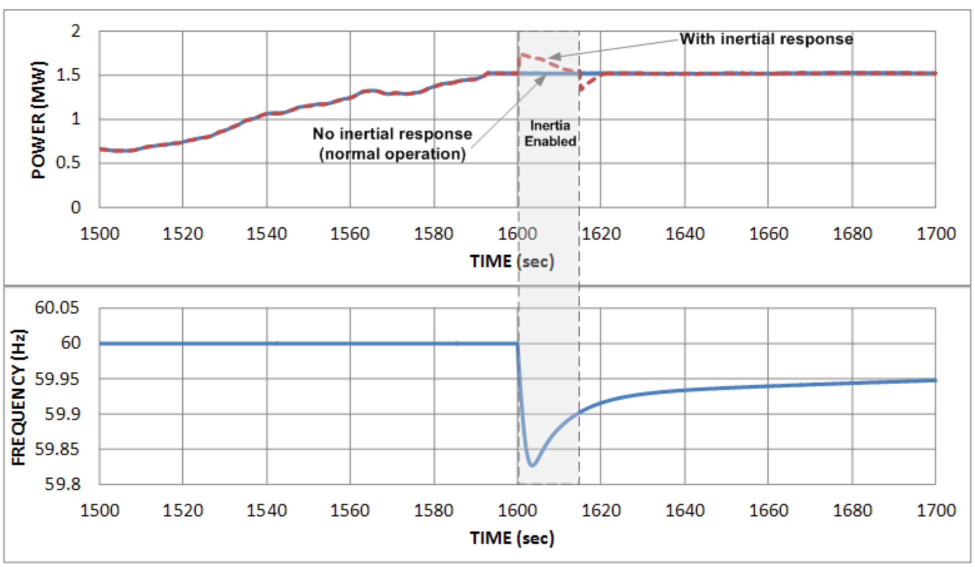

Figure 14. Inertial response by type 3 WTG at rated wind speed (NREL model)

PREPA's Response to Recommendation #12:
PREPA understands the value and importance of inertial control by wind. While revisions relating to this recommendation have not been made to the MTRs, this requirement will be considered in the future.

7 Ramp Rate Control

Recommendation #13:

PREPA requires a 10% of rated capacity limit on 1-minute ramp rates (RR) by both wind and PV generation. Some clarification is needed on how PREPA calculates these 1-minute RRs since there are several ramp calculation methods described in technical literature (difference between two endpoints of any 60-second interval, minimum/maximum values between two endpoints, etc.). A 10% per minute RR limit seems to be reasonable. For reference, EirGrid limits positive ramps up to 30 MW/minute. HECO limits its ramps at +/- 2 MW per minute during all times (except for 12:00–4:00 a.m. and 4:00–8:00 p.m. when ramps are limited to +1 MW and -1 MW per minute respectively for wind projects less than 50 MW). In Germany, transmission system operators require a similar 10% limit of rated power per minute for positive ramps. Some grid operators set limits not only for 1-minute RRs, but also on instantaneous power fluctuations calculated at every scan. For example, HECO sets 1 MW/2-second limits for every 2-second scan.

PREPA's Response to Recommendation #13:

Based on NREL's recommendation, PREPA modified section 7 by adding the following statement:

"The ramp rate control tolerance shall be +10%."

Regarding the ramp rate calculation methods, the Agreed Operating Procedure (AOP) of the project will include the ramp rate calculation method used by PREPA.

8 Power Quality

The power quality test report, in accordance with IEC 61400-21 ed.2, must present wind turbine test data conducted on 60-Hz grids (some European wind turbine manufacturers still do not have 60-Hz reports). NREL is performing Power Quality (PQ) certification testing for some manufacturers (Alstom, Gamesa, etc.) to produce 60-Hz reports. NREL is accredited by the American National Standard Institute and can perform the whole suite of IEC PQ testing for wind turbine testing, with the exception of LVRT tests. LVRT capability has been developed and commissioned at NREL in 2013.

IEC 61400-21 requires active and reactive power set point tests that demonstrate ability of individual WTG to participate in load-frequency or voltage control. This standard does not require testing of the whole wind farm for the same purposes, so wind farm level control data must be provided separately by manufacturers. The same plant level control data must be provided for PV projects as well.

9 Other Considerations

Recommendation #14:
One important question that might affect the MTRs is if PREPA envisions wind and PV participation in automatic generation control (AGC) at some point in the future. If so, then such capability must be requested in the requirements. An example of wind power participation in AGC is shown in Figure 15, where a wind turbine is able to follow AGC signals by having available reserve margins for up regulation.

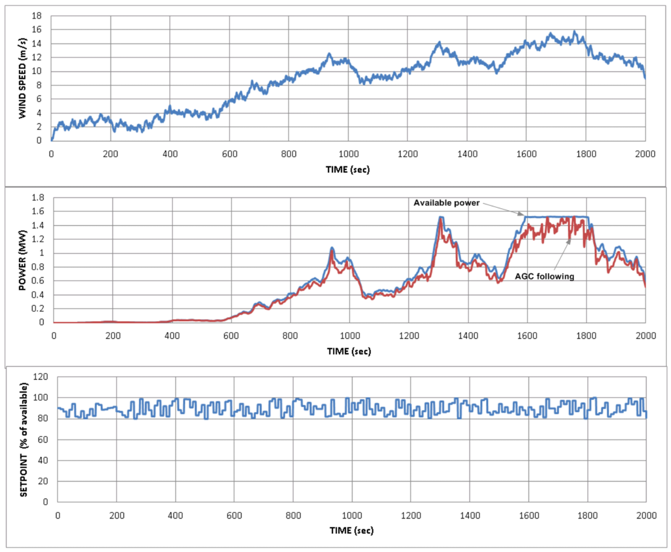

Figure 15. Wind power participation in AGC (NREL model)

There are other active power control schemes for wind power rather than inertial/PFR and RR limiting. If required, wind power can operate with spinning reserves as shown in Figure 16. It can provide continuous reserves as a percentage of available power or absolute reserves in megawatts.

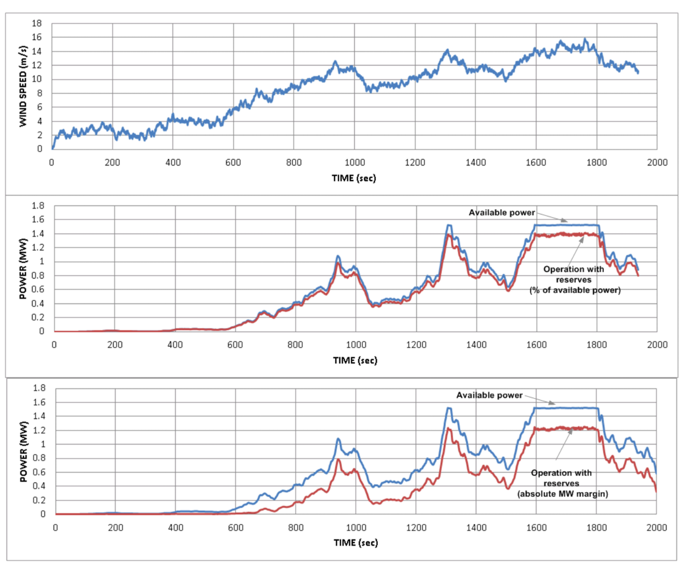

Figure 16. Examples of wind power operations with reserves

Such advanced active power control schemes might be beneficial to PREPA under certain circumstances. During periods of high wind production at light loads, fossil fuel units may need to be forced offline due to the excessive wind power, which leads to another problem of inadequate unit dispatch capability in system operations. The excessive wind power could serve as a dispatchable reserve rather than just curtailing for security concerns. In addition, such capability could release the regulation of diesel and other combustion generation when a high concentration of wind power is installed in an isolated island grid.

PREPA's Response to Recommendation #14:
PREPA asked for the minimum known necessary technical requirements that were important for optimizing the power system performance under high levels of renewables penetration, while providing the necessary mitigation to the impact of these resources on the electric system. Recognizing the level of complexity that the implementation of such advanced active power control schemes might have on the projects, PREPA has decided not to require renewables to provide or participate in AGC at this point in time. However, PREPA understands the benefits of these services by renewables, and may require them in the future if necessary.

10 Conclusions

In general, PREPA's MTR documents are well written and cover all interconnection-related topics for wind and PV generation. It is important to note that both MTR documents for wind and PV are very similar to each other with some minor differences specific to each technology. It may make sense to combine them both into one general MTR document that includes a few provisions specific to wind or PV.

As mentioned throughout this document, some aspects of the existing MTRs suggest further clarifications and better explanations are needed. Such "fine tuning" of interconnection requirements is important to avoid ambiguities in interpretation of the MTRs and help potential vendors and project developers to better meet PREPA's reliability criteria.

One important aspect that still needs to be included in the MTRs is the "borderline" for projects that need to be compliant with MTR requirements. Such a borderline can be formulated either in megawatt capacity of the project or voltage level at the POI.

Additionally, PREPA may find it useful to evaluate various aspects of interconnection technical requirements, including:

- Using transient modeling of wind and PV plants for the purposes of FRT analyses
- Conducting sub-hourly modeling and optimization of the power system
- Developing sub-hourly solar power output data sets with realistic spatial and temporal correlations
- Improving wind and solar resource forecasting
- Increasing the internal capacity to incorporate dynamic models for wind generators and PV inverters into the current power system simulations conducted to model power flow/stability and frequency response.

PREPA made many revisions to the MTRs in August 2012 based on the initial recommendations provided during discussions with DOE and NREL. It is anticipated that PREPA will continue to revise the MTRs as technology evolves and PREPA's experience with renewable energy on the Puerto Rico grid increases. PREPA is in a unique position as 64 renewable energy PPAs and master agreements have been signed between 2009 and 2012, totaling approximately 2,200 MW. If completed, this installed capacity would represent approximately 70% of the system peak load (3159 MW) of Puerto Rico.

The utility and other government officials are currently reviewing many of these agreements and PREPA is working to determine how to safely incorporate large amounts of renewable energy onto the grid. As the amount of renewable energy on the grid increases, PREPA will gain valuable experience in understanding how high penetrations of renewables impact the grid. The increased experience operating the power system at different levels of renewable penetration will likely inform future revisions to the MTRs. Hopefully, the recommendations, based on industry best practices, will also be useful to PREPA when making future revisions to the MTRs.

References

[1] *Generator Fault Ride-Through (FRT) Investigation - Stage 1.* (2009). Transpower New Zealand Limited. http://www.nerc.com/docs/pc/ivgtf/GEN-FRT-Stage1-Lit-review%20(2-4Task%20Force).pdf.

[2] *Model Power Purchase Agreement for Renewable Energy Projects.* (2008). HECO. http://www.heco.com/vcmcontent/GenerationBid/HECO/FinalRenewableModelPPA.pdf.

[3] Erlich, I., et al. *Reactive Power Generation by DGIF Based Wind Farms with AC Grid Connection.* (2007). University Duisburg-Essen. http://www.uni-due.de/ean/downloads/papers/wilch2007a.pdf.

[4] Abbey, C.; Joos, G. *Effect of Low Voltage Ride-Through (LVRT) Characteristics on Voltage Stability.* (2005). IEEE. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=01489659.

[5] *Real Power Balancing Control Performance.* (August 2010). Texas Reliability Entity. http://texasre.org/CPDL/BAL-001-TRE-1%20Second%20Draft%20-%20Clean.pdf.

Appendix A: Minimum Technical Requirements of Interconnection of PV Facilities (ver. June 14, 2012)

MINIMUM TECHNICAL REQUIREMENTS FOR INTERCONNECTION OF PHOTOVOLTAIC (PV) FACILITIES

The proponent shall comply with the following minimum technical requirements:

1. VOLTAGE RIDE-THROUGH:

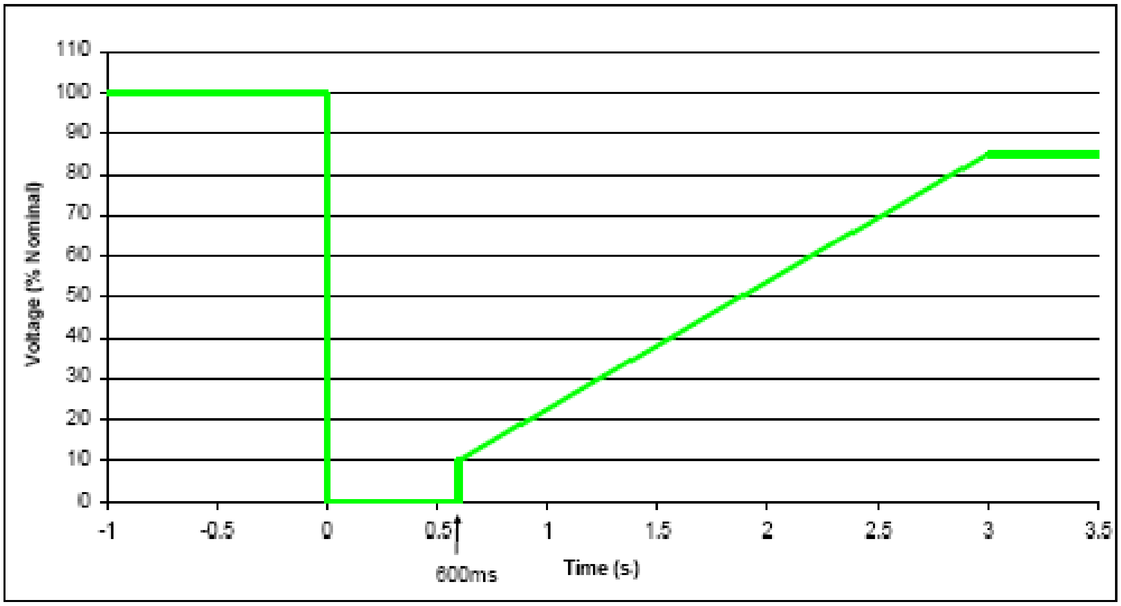

Figure 1 Low Voltage Ride-Through Requirements

a. PREPA's Low Voltage Ride-Through (LVRT) Requirements:

   i. From Figure 1, PREPA requires all generation to remain online and be able to ride-through three phase and single phase faults down to 0.0 per-unit (measured at the point of interconnection), for up to 600 ms.

   ii. All generation remains online and operating during and after normally cleared faults on the point of interconnection.

   iii. All generation remains online and operating during backup-cleared faults on the point of interconnection.

iv. During the fault conditions, the PV facility shall operate on maximum reactive current injection mode.

b. PREPA's Overvoltage Ride-Through (OVRT) Requirements:

i. PREPA requires all generation to remain online and able to ride-through symmetrical and asymmetrical overvoltage conditions specified by the following values:

Overvoltage (pu)	Minimum time to remain online (seconds)
1.4 – 1.25	1
1.25 – 1.15	3
1.15 or lower	indefinitely

2. Voltage Regulation System (VRS)

Constant voltage control shall be required. Photovoltaic System technologies in combination with Static Var Controls, such as Static Var Compensators (SVCs), STATCOMs, DSTATCOMs are acceptable options to comply with this requirement. A complete and detailed description of the VRS control strategy shall be submitted for evaluation.

a) Photovoltaic Facilities (PVF) must have a continuously-variable, continuously-acting, closed loop control VRS; i.e. an equivalent to the Automatic Voltage Regulator in conventional machines.

b) The VRS set-point shall be adjustable between 95% to 105% of rated voltage at the POI. The VRS set-point must also be adjustable by PREPA's Energy Control Center via SCADA.

c) The VRS shall operate only in a voltage set point control mode. Controllers such as Power Factor or constant VAR are not permitted.

d) The VRS controller regulation strategy shall be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop shall be adjustable from 0 to 10% and must also be adjustable by PREPA's Energy Control Center via SCADA.

e) At zero percent (0%) droop, the VRS shall achieve a steady-state voltage regulation accuracy of +/- 0.5% of the controlled voltage at the POI.

f) The VRS shall be calibrated such that a change in reactive power will achieve 95% of its final value no later than 1 second following a step change in voltage. The change in reactive power should not cause excessive voltage excursions or overshoot.

g) The generator facility VRS must be in service at any time the PVF is electrically connected to the grid regardless of MW output from the PVF.

3. Reactive Power Capability and Minimum Power Factor Requirements

The total power factor range shall be from 0.85 lagging to 0.85 leading at the point of interconnection (POI). The reactive power requirements provide flexibility for many types of technologies at the Renewable Energy Facility. The intent is that a PVF can ramp the reactive power from 0.85 lagging to 0.85 leading in a smooth continuous fashion at the POI.

The +/- 0.90 power factor range should be dynamic and continuous at the point of interconnection (POI). This means that the PVF has to be able to respond to power system voltage fluctuations by continuously varying the reactive output of the plant within the specified limits. The previously established power factor dynamic range could be expanded if studies indicate that additional continuous, dynamic compensation is required. It is required that the PVF reactive capability meets +/- 0.85 Power Factor (PF) range based on the PVF Aggregated MW Output, which is the maximum MVAr capability corresponding to maximum MW Output. It is understood that positive (+) PF is where the PVF is producing MVAr and negative (-) PF is where the PVF is absorbing MVAr.

This requirement of MVAr capability at maximum output shall be sustained throughout the complete range of operation of the PVF as established by Figure 2.

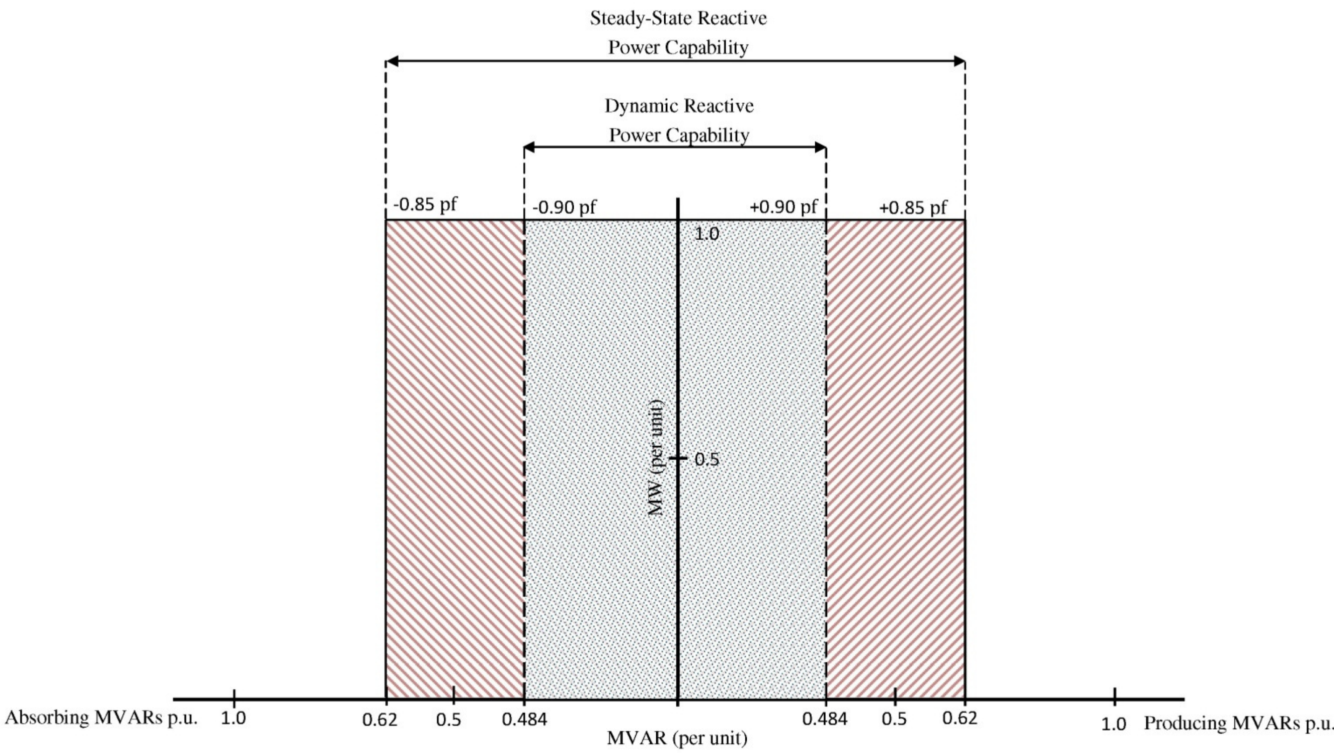

Figure 2 Reactive Power Capability Curve

4. Short Circuit Ratio (SCR) Requirements:

Short Circuit Ratio values (System Short Circuit MVA at POI/PV Facility MVA Capacity) under 5 shall not be permitted. The constructor shall be responsible for the installation of additional equipment, such as synchronous condensers, and controls necessary to comply with PREPA's minimum short circuit requirements.

5. Frequency Ride Through (FRT):

- 57.5 - 61.5 Hz No tripping (continuous)
- 61.5 - 62.5 Hz 30 sec
- 56.5 - 57.5 Hz 10 sec
- < 56.5 or > 62.5 Hz Instantaneous trip

6. Frequency Response/Regulation:

PV facility shall provide an immediate real power primary frequency response, proportional to frequency deviations from scheduled frequency, similar to governor response. The rate of real power response to frequency deviations shall be similar to or more responsive than the droop characteristic of 5% used by conventional generators. PV facility shall have controls that provide both for down-regulation and up-regulation. PV technologies, in combination with energy storage systems such as, but not limited to BESS, flywheels, hybrid systems are acceptable options to comply with PREPA's frequency response and regulation requirements.

For large frequency deviations (for example in excess of 0.3 Hz), the PV facility shall provide an immediate real power primary frequency response of at least 10% of the maximum AC active power capacity (established in the contract) for a time period not less than 10 minutes. The time response (full 10% frequency response) shall be less than 1 second. During disturbances or situations that provoke the system frequency to stay below 59.7 Hz for 10 minutes or more, after the ninth minute the real power primary frequency response shall not decrease at a ramp rate higher than 10% of the maximum AC active power capacity per minute. For smaller frequency deviations (for example less than 0.3 Hz), the PV facility response shall be proportional to the frequency deviation, based on the specified 5% droop characteristic. The operational range of the frequency response and regulation system shall be from 10% to 100% of the maximum AC active power capacity (established in the contract). The PV facility power output at the POI shall never exceed the maximum AC active power (established in the contract).

7. Ramp Rate Control:

Ramp Rate Control is required to smoothly transition from one output level to another. The PV facility shall be able to control the rate of change of power output during some circumstances, including but not limited to: (1) rate of increase of power, (2) rate of decrease of power, (3) rate of increase of power when a curtailment of power output is released; (4) rate of decrease in power when curtailment limit is engaged. A 10 % per minute rate (based on AC contracted capacity) limitation shall be enforced. This ramp rate limit applies both to the increase and decrease of power output and is independent of meteorological conditions.

8. Power Quality Requirements:

The developer shall address, in the design of their facilities potential sources and mitigation of power quality degradation prior to interconnection. Design considerations should include applicable standards including, but not limited to IEEE Standards 142, 519, 1100, 1159, and ANSI C84.1. Typical forms of power quality degradation include, but are not limited to voltage regulation, voltage unbalance, harmonic distortion, flicker, voltage sags/interruptions and transients.

9. Special Protection Schemes:

PV facility shall provide adequate technology and implement special protection schemes as established by PREPA in coordination with power management requirements.

10. General Interconnection Substation Configuration:

An interconnecting generation producer must interconnect at an existing PREPA switchyard. The configuration requirements of the interconnection depend on where the physical interconnection is to occur and the performance of the system with the proposed interconnection. The interconnection must conform, at a minimum, to the original designed configuration of the switchyard. PREPA, at its sole discretion, may consider different configurations due to physical limitations at the site.

11. Modeling and Validation

The Contractor shall submit to PREPA a Siemens - PTI certified PSS/E mathematical model and data related to the proposed PV facility. When referred to the PV facility model, this shall include but is not limited to PV inverters, transformers, collector systems, plant controllers, control systems and any other equipment necessary to properly model the PV facility for both steady-state and dynamic simulation modules. It is required that the Contractor submits both an aggregate and detailed version of the PV facility model. At a later stage in the process, it is also required that the Contractor submits as-built PSS/E mathematical models of the PV Facility.

The Contractor shall be required to submit user manuals for both the PV inverter and the PV facility models including a complete and detailed description of the voltage regulation system (VRS) and frequency regulation system model implementation. The mathematical models shall be fully compatible with the latest and future versions of PSS/E. It is preferred that the models are PSS/E standard models. In the case that the Contractor submits user written models, the Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. The Contractor shall submit to PREPA an official report from Siemens - PTI that validates and certifies the required mathematical models, including subsequent revisions. The data and PSS/E model shall also be updated and officially certified according to PREPA requirements when final field adjustments and parameters measurements and field tests are performed to the facility by the contractor. The mathematical model (either PSS/E standard or user written model) of the PV facility shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete PV facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical model shall not be considered valid.

The Contractor shall be responsible to submit Siemens – PTI certified PSSE mathematical models of any kind of compensation devices (ie. SVC, STATCOMs, DSTATCOMs, BESS, etc.) used on the PV facility. It is preferred that the models are standard models provided with PSS/E. In the case that the Contractor submits user written models, the PV facility Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. In its final form, the mathematical model shall be able to simulate each of the required control and operational modes available for the compensation device and shall be compatible with the latest and future versions of PSSE. Final adjustments and parameters settings related with the control system commissioning process shall be incorporated to the PSSE mathematical model and tested accordingly by the PV facility Contractor and PREPA system study groups. The Contractor shall also perform on-site field tests for the identification, development, and validation of the dynamic mathematical models and parameters required by PREPA for any kind of compensation devices used at the PV facility. The mathematical models of the PV facility and its required compensation devices shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete PV facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from

Siemens – PTI, otherwise the mathematical models shall not be considered valid.

PV facility Owners that provide user written model(s) shall provide compiled code of the model and are responsible to maintain the user written model compatible with current and new releases of PSS/E until such time a standard model is provided. PREPA must be permitted by the PV facility Owner to make available PV Facility models if required to external consultants with an NDA in place.

12. Transient Mathematical Model

The Contractor shall be responsible of providing a detailed transient model of the PV facility and to show that it is capable of complying with PREPA's transient Minimum Technical Requirements.

13. Dynamic System Monitoring Equipment

The developer of the PV facility shall be required to provide and install a dynamic system monitoring equipment that conforms to PREPA's specifications.

Appendix B: Minimum Technical Requirements of Interconnection of Wind Facilities (ver. June 14, 2012)

MINIMUM TECHNICAL REQUIREMENTS FOR INTERCONNECTION OF WIND TURBINE GENERATION (WTG) PROJECTS

The proponent shall comply with the following minimum technical requirements:

1. VOLTAGE RIDE-THROUGH

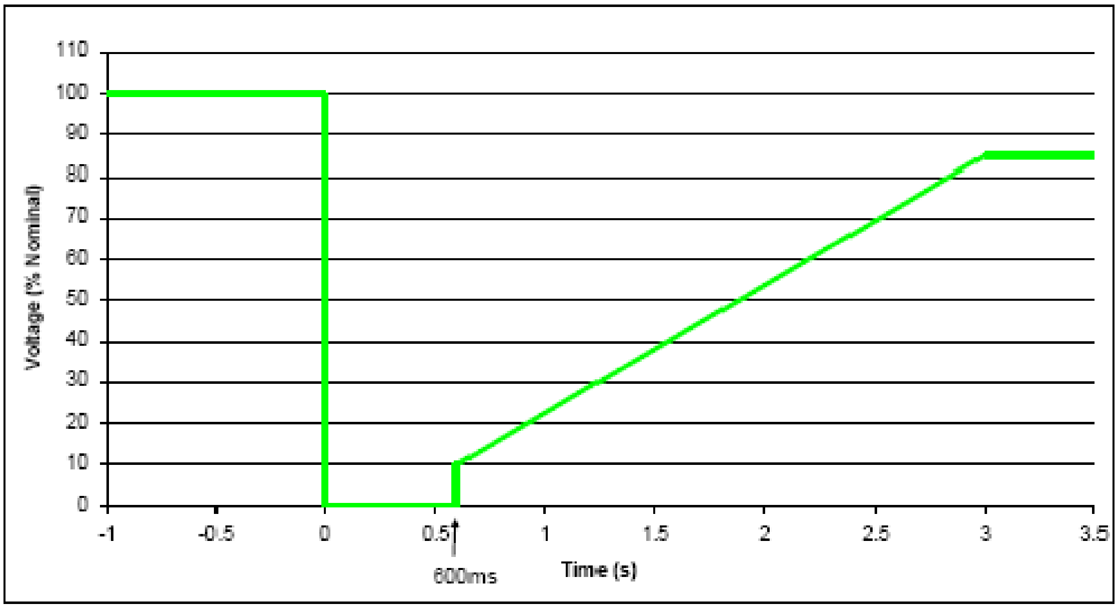

Figure 1 Low Voltage Ride-Through Requirements

a. PREPA's Low Voltage Ride-Through (LVRT) Requirements:

  i. From Figure 1, PREPA requires all generation to remain online and be able to ride-through three phase and single phase faults down to 0.0 per-unit (measured on the point of interconnection), for up to 600 ms.

  ii. All generation remains online and operating during and after normally cleared faults on the point of interconnection.

  iii. All generation remains online and operating during backup-cleared faults on the point of interconnection.

iv. During the fault conditions, the wind generation facility shall operate on maximum reactive current injection mode.

b. PREPA's Overvoltage Ride-Through (OVRT) Requirements:

i. PREPA requires all generation to remain online and able to ride-through symmetrical and asymmetrical overvoltage conditions specified by the following values:

Overvoltage (pu)	**Minimum time to remain online (seconds)**
1.4 – 1.25	1
1.25 – 1.15	3
1.15 or lower	Indefinitely

2. Voltage Regulation System (VRS)

Constant voltage control shall be required. Wind Turbine Generation (WTG) technologies in combination with Static Var Controls, such as Static Var Compensators (SVC), STATCOMs, DSTATCOMs are acceptable options to comply with this requirement. A complete description of the VRS control strategy shall be submitted for evaluation.

a) Wind Generation Facilities (WGF) must have a continuously-variable, continuously-acting, closed loop control VRS; i.e. an equivalent to the Automatic Voltage Regulator in conventional machines.

b) The VRS set-point shall be adjustable between 95% to 105% of rated voltage at the POI. The VRS set-point must also be adjustable by PREPA's Energy Control Center via SCADA.

c) The VRS shall operate only in a voltage set point control mode. Controllers such as Power Factor or constant VAR are not permitted.

d) The VRS controller regulation strategy shall be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop shall be adjustable from 0 to 10% and must also be adjustable by PREPA's Energy Control Center via SCADA.

e) At zero percent (0%) droop, the VRS shall achieve a steady-state voltage regulation accuracy of +/- 0.5% of the controlled voltage at the POI.

f) The VRS shall be calibrated such that a change in reactive power will achieve 95% of its final value no later than 1 second following a step change in voltage. The change in reactive power should not cause excessive voltage excursions or overshoot.

g) The generator facility VRS must be in service at any time the WGF is electrically connected to the grid regardless of MW output from the WGF.

Examples of possible VRS configurations:

The following examples serve as possible solutions for REF voltage regulation and reactive power compensation.

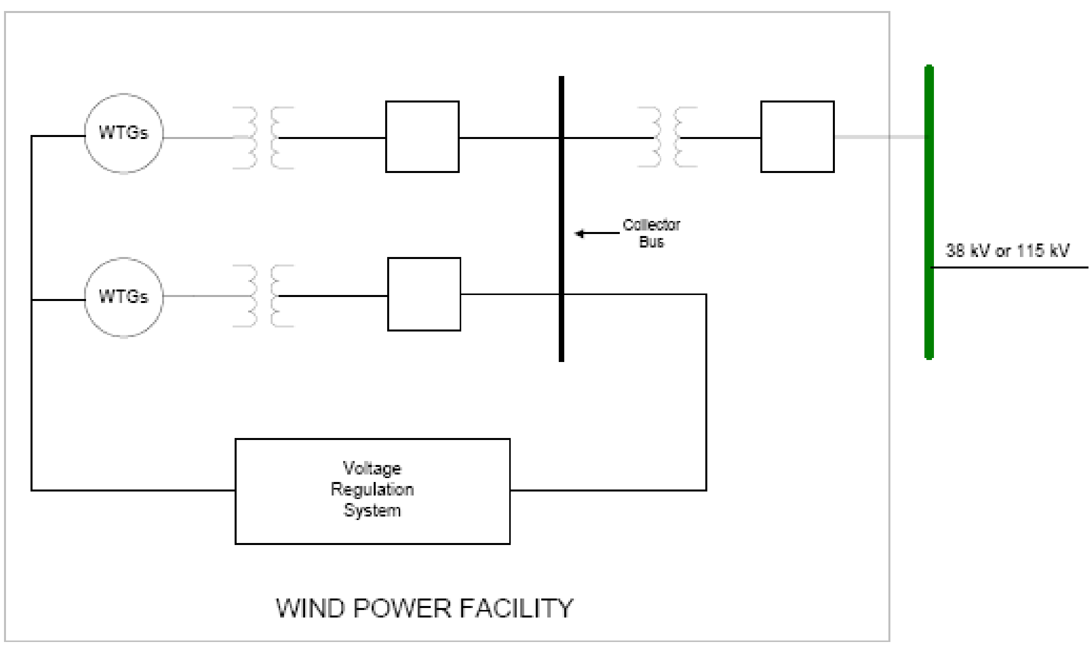

Figure 2 Voltage Regulation at WGF

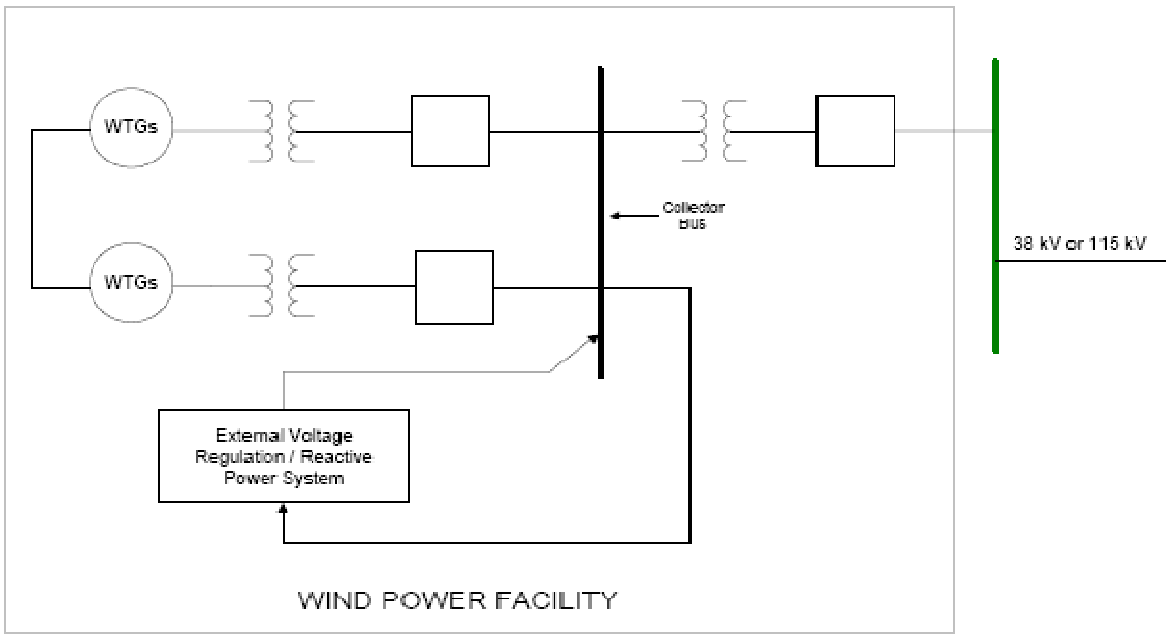

Figure 3 Voltage Regulation at single collector bus

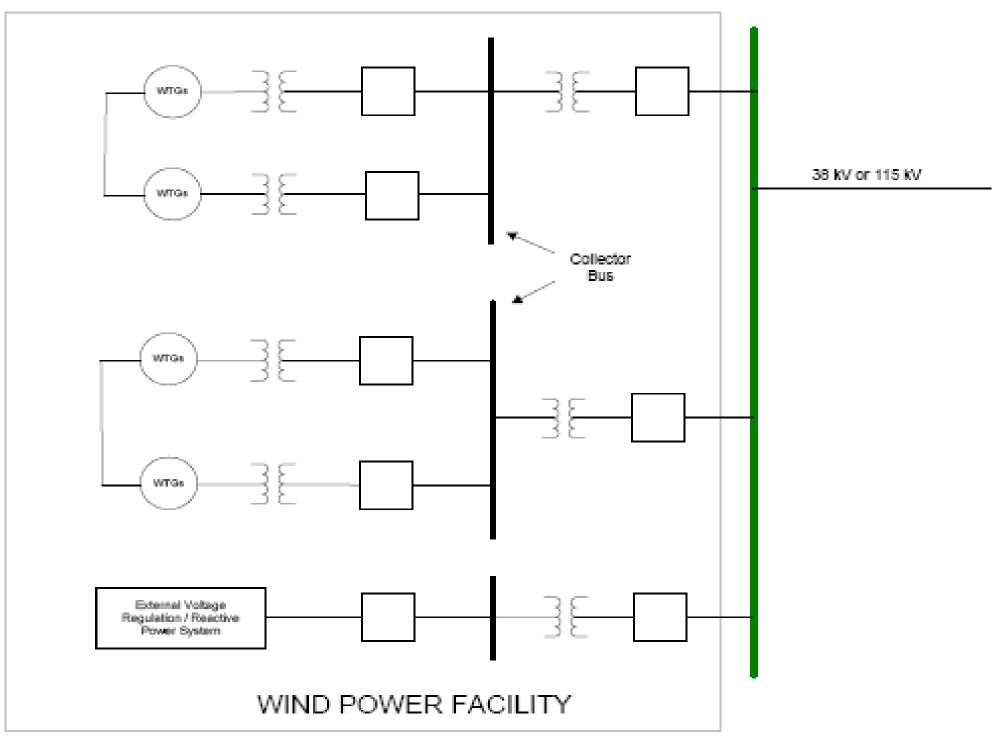

Figure 4 Voltage regulation on a multiple collector bus injection at collector bus

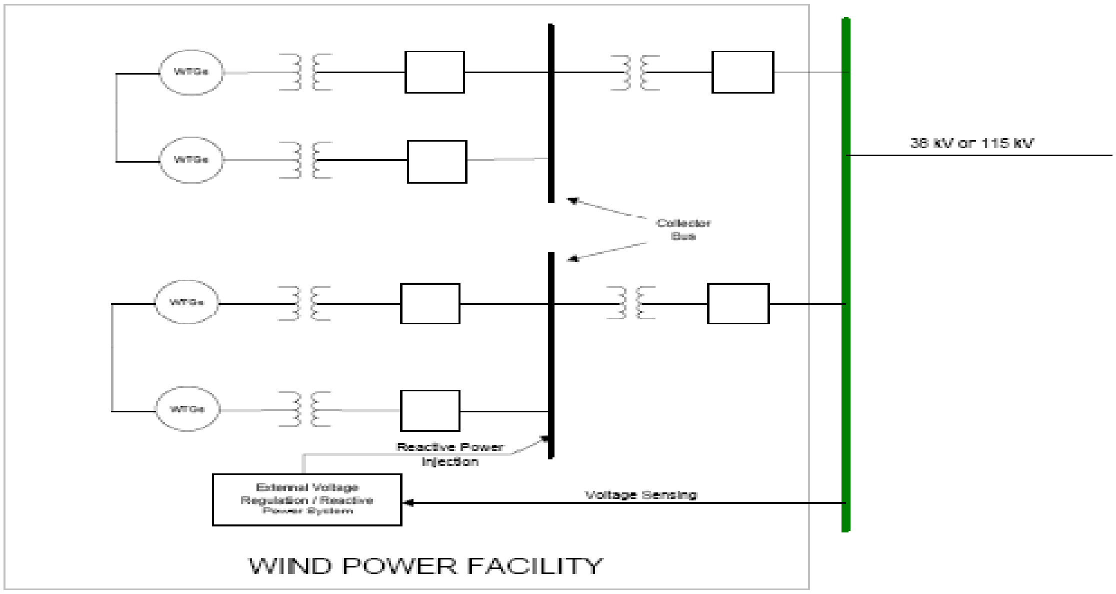

Figure 5 Shared Voltage Regulation for multiple WGF at transmission system bus

3. Reactive Power Capability and Minimum Power Factor Requirements

The total power factor range shall be from 0.85 lagging to 0.85 leading at the point of interconnection (POI). The reactive power requirements provide flexibility for many types of technologies at the Renewable Energy Facility. The intent is that a WGF can ramp the reactive power from 0.85 lagging to 0.85 leading in a smooth continuous fashion at the POI.

The +/- 0.90 power factor range should be dynamic and continuous at the point of interconnection (POI). This means that the WGF has to be able to respond to power system voltage fluctuations by continuously varying the reactive output of the plant within the specified limits. The previously established power factor dynamic range could be expanded if studies indicate that additional continuous, dynamic compensation is required. It is required that the WGF reactive capability meets +/- 0.85 Power Factor (PF) range based on the WGF Aggregated MW Output, which is the maximum MVAr capability corresponding to maximum MW Output. It is understood that positive (+) PF is where the WGF is producing MVAr and negative (-) PF is where the WGF is absorbing MVAr.

This requirement of MVAr capability at maximum output shall be sustained throughout the complete range of operation of the WGF as established by Figure 6.

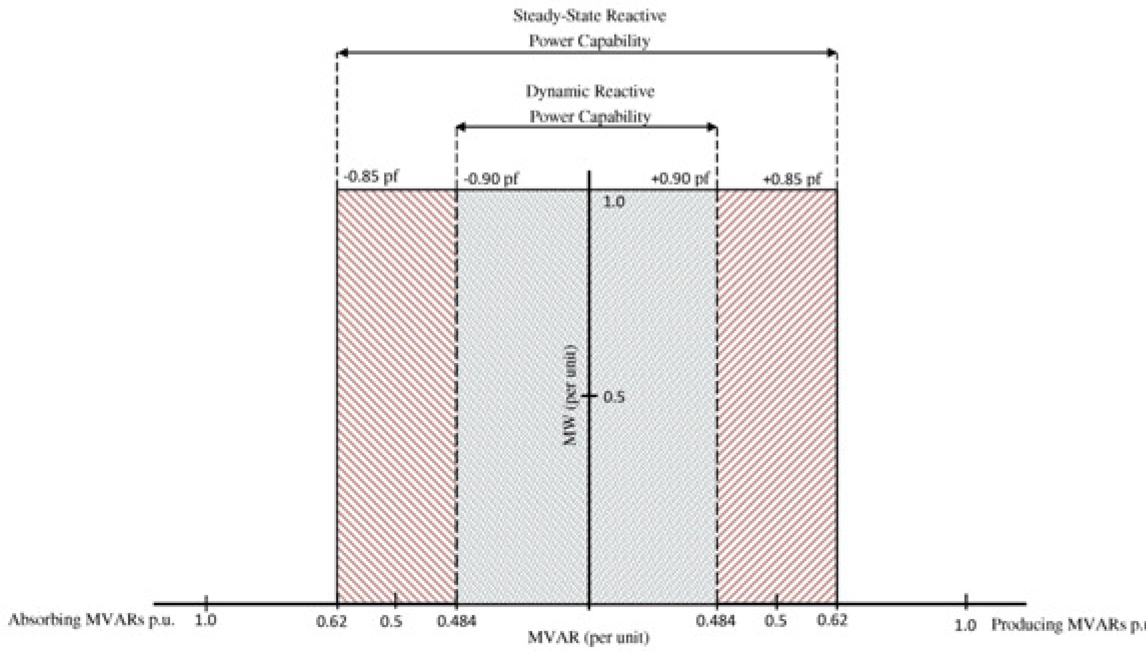

Figure 6 Reactive Power Capability Curve

4. Short Circuit Ratio (SCR) Requirements:

Short Circuit Ratio values (System Short Circuit MVA at POI/WGF MVA Capacity) under 5 shall not be permitted. The constructor shall be responsible for the installation of additional equipment, such as synchronous condensers, and controls necessary to comply with PREPA's minimum short circuit requirements.

5. Frequency Ride Through (FRT):

- 57.5 - 61.5 Hz No tripping (continuous)
- 61.5 - 62.5 Hz 30 sec
- 56.5 - 57.5 Hz 10 sec
- < 56.5 or > 62.5 Hz Instantaneous trip

6. Frequency Response/Regulation and Inertial Response

WTG facility shall provide an immediate real power primary frequency response, proportional to frequency deviations from scheduled frequency, similar to governor response. The rate of real power response to frequency deviations shall be similar to or more responsive than the droop characteristic of 5% used by conventional generators. WTG facility shall have controls that provide both down-regulation and up-regulation. Wind turbine technologies, in combination with energy storage systems such as BESS, flywheels, hybrid systems are acceptable options to comply with PREPA's frequency regulation requirements.

For large frequency deviations (for example in excess of 0.3 Hz), the WGF shall provide an immediate real power primary frequency response of at least 10% of the maximum AC active power capacity (established in the contract) for a time period not less than 10 minutes. The time response (full 10% frequency response) shall be less than 1 second. During disturbances or situations that provoke the system frequency to stay below 59.7 Hz for 10 minutes or more, after the ninth minute the real power primary frequency response shall not decrease at a ramp rate higher than 10% of the maximum AC active power capacity per minute. For smaller frequency deviations (for example less than 0.3 Hz), the WGF response shall be proportional to the frequency deviation, based on the specified 5% droop characteristic. The operational range of the frequency response and regulation system shall be from 10% to 100% of the maximum AC active power capacity (established in the contract). The WGF power output at the POI shall never exceed the maximum AC active power (established in the contract).

The WTG controls shall have the capability to provide inertial response.

7. Ramp Rate Control

Ramp Rate Control is required to smoothly transition from one output level to another. The WTG facility shall be able to control the rate of change of power output during some circumstances, including but not limited to: (1) rate of increase of power (2) rate of decrease of power, (3) rate of increase of power when a curtailment of power output is released; (4) rate of decrease in power when curtailment limit is engaged. A 10 % per minute rate (based on nameplate capacity) limitation shall be enforced. This limit applies both to the increase and decrease of power output and is independent of meteorological conditions.

8. Power Quality

The developer shall address, in the design of their facilities potential sources and mitigation of power quality degradation prior to interconnection. Design considerations should include applicable standards including, but not limited to

IEEE Standards 142, 519, 1100, 1159, ANSI C84.1, IEC 61400-21, IEC 61000-3-7 and IEC 61000-3-6. Typical forms of power quality degradation include, but are not limited to voltage regulation, voltage unbalance, harmonic distortion, flicker, voltage sags/interruptions and transients.

The developer shall submit the Power Quality Tests Result Report of the wind turbines as described in the IEC 61400-21 standard. This report includes: general wind turbine data, wind turbine rated data at terminals, voltage fluctuations coefficients (flicker coefficients), current harmonics components, current interharmonics components, current high frequency components, response to voltage drops, active power data, reactive power data, grid protection data and reconnection time. The wind turbines shall not exceed the flicker emission limits established by the IEC 61000-3-7 standard and the harmonics emission limits of IEC 61000-3-6.

9. Wind Power Management

WTG facility shall provide adequate technology (communicating technology and the corresponding control equipment) and implement wind power management requirements (ramp rate limits, output limits, curtailment) as established by PREPA.

10. Special Protection Schemes

WTG facility shall provide adequate technology and implement special protection schemes as established by PREPA in coordination with wind power management requirements.

11. Wind Generation Forecasting Systems

WTG facility shall provide adequate technology to support wind generation forecasting systems (short term and day-ahead) as established by PREPA. Individual turbine's availability shall be included.

12. General Interconnection Substation Configuration

An interconnecting generation producer must interconnect at an existing PREPA switchyard. The configuration requirements of the interconnection depend on where the physical interconnection is to occur and the performance of the system with the proposed interconnection. The interconnection must conform, at a minimum, to the original designed configuration of the switchyard. PREPA, at its sole discretion, may consider different configurations due to physical limitations at the site.

13. Modeling and Validation

The Contractor shall submit to PREPA a Siemens - PTI certified PSS/E mathematical model and data related to the proposed WTG facility. When referred to the WTG facility model, this shall include but is not limited to wind generator, transformers, collector systems, plant controllers, control systems and any other equipment necessary to properly model the WTG facility for both steady-state and dynamic simulation modules. It is required that the Contractor submits both an aggregate and detailed model of the WTG facility model. At a later stage in the process, it is also required that the Contractor submits as-built PSS/E mathematical models of the WTG facility.

The Contractor shall be required to submit user manuals for both the Wind Turbine Generator and WTG Facility models including a complete and detailed description of the voltage regulation system (VRS) and frequency regulation system model implementation. The mathematical models shall be fully compatible with the latest and future versions of PSS/E. It is preferred that the models are PSS/E standard models. In the case that the Contractor submits user written models, the Contractor shall be required to keep these models, as well as its corresponding user manual, current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. The Contractor shall submit to PREPA an official report from Siemens - PTI that validates and certifies the required mathematical models, including subsequent revisions. The data and PSS/E model shall also be updated and officially certified according to PREPA requirements when final field adjustments and parameters measurements and field tests are performed to the facility by the contractor. The mathematical model (either PSS/E standard or user written model) of the WTG facility shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete WTG facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical model shall not be considered valid.

The Contractor shall be responsible to submit Siemens – PTI certified PSSE mathematical models of any kind of compensation devices (ie. SVC, STATCOMs, DSTATCOMs, BESS, etc.) used on the WTG facility. It is preferred that the models are standard models provided with PSS/E. In the case that the Contractor submits user written models, the WTG facility Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. In its final form, the mathematical model shall be able to simulate each of the required control and operational modes available for the compensation device and shall be compatible with the latest and future versions of PSSE. Final adjustments and parameters settings related with the control system commissioning process shall be incorporated to the PSSE mathematical model and tested accordingly by the WTG facility Contractor and PREPA system study groups. The Contractor shall also perform on-site field tests for the identification, development, and validation of the dynamic mathematical models and parameters required by PREPA for any kind of compensation devices used at the WTG facility. The mathematical models of the WTG facility and its required compensation devices shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete WTG facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical models shall not be considered valid.

WTG facility Owners that provide user written model(s) shall provide compiled code of the model and are responsible to maintain the user written model compatible with current and new releases of PSS/E until such time a standard model is provided. PREPA must be permitted by the WGF Owner to make available WGF models if required to external consultants with an NDA in place.

14. Transient Mathematical Model

The contractor shall be responsible of providing a detailed transient model of the WTG facility and to show that it is capable of complying with PREPA's transient Minimum Technical Requirements.

15. Dynamic System Monitoring Equipment

The developer of the Renewable Energy Facility shall be required to provide and install a dynamic system monitoring equipment that conforms to PREPA's specifications.

Appendix C: Minimum Technical Requirements of Interconnection of PV Facilities (ver. Aug. 15, 2012)

Minimum Technical Requirements for Interconnection of Photovoltaic (PV) Facilities

The proponent shall comply with the following minimum technical requirements:

1. Voltage Ride-Through:

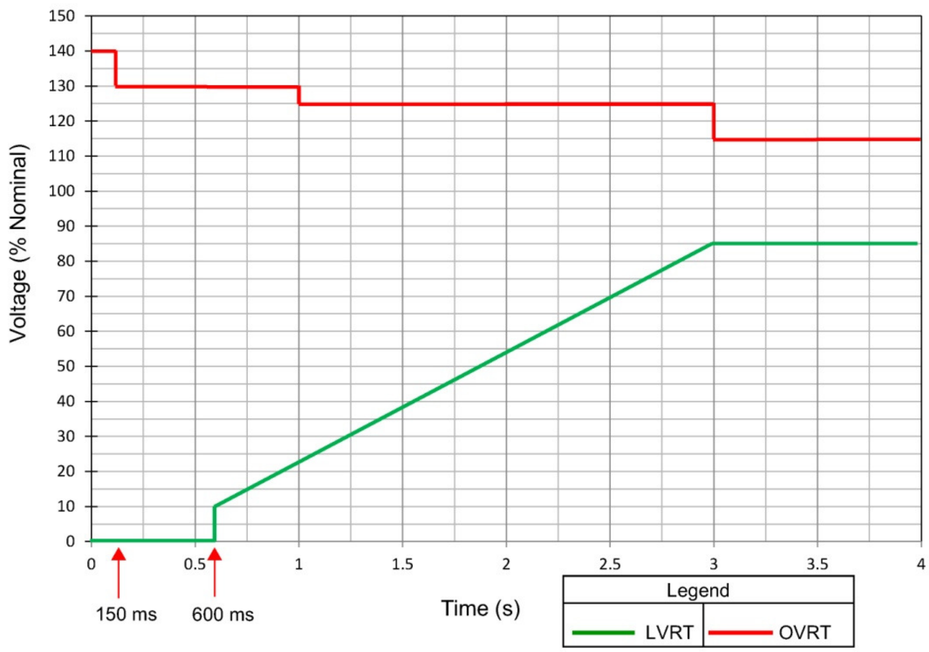

Figure 1 Voltage Ride-Through Requirements

a. PREPA's Low Voltage Ride-Through (LVRT) Requirements:

i. From Figure 1, PREPA requires all generation to remain online and be able to ride-through three phase and single phase faults down to 0.0 per-unit (measured at the point of interconnection), for up to 600 ms.

ii. All generation remains online and operating during and after normally cleared faults on the point of interconnection.

iii. All generation remains online and operating during backup-cleared faults on the point of interconnection.

iv. During the low voltage fault conditions, the PV facility shall operate on reactive current injection mode. This mode of operation shall be implemented with a reactive current droop characteristic which shall have an adjustable slope from 1 to 5%. A dead band of 15 % is required.

b. PREPA's Overvoltage Ride-Through (OVRT) Requirements:

i. PREPA requires all generation to remain online and able to ride-through symmetrical and asymmetrical overvoltage conditions specified by the following values illustrated in Figure 1:

Overvoltage (pu)	Minimum time to remain online
1.4 – 1.3	150 ms
1.3 – 1.25	1 s
1.25 – 1.15	3 s
1.15 or lower	indefinitely

2. Voltage Regulation System (VRS)

Constant voltage control shall be required. Photovoltaic System technologies in combination with Static Var Controls, such as Static Var Compensators (SVCs), STATCOMs and DSTATCOMs are acceptable options to comply with this requirement. A complete and detailed description of the VRS control strategy shall be submitted for evaluation.

a) Photovoltaic Facilities (PVF) must have a continuously-variable, continuously-acting, closed loop control VRS; i.e. an equivalent to the Automatic Voltage Regulator in conventional machines.

b) The VRS set-point shall be adjustable between 95% to 105% of rated voltage at the POI. The VRS set-point must also be adjustable by PREPA's Energy Control Center via SCADA.

c) The VRS shall operate only in a voltage set point control mode. Controllers such as Power Factor or constant VAR are not permitted.

d) The VRS controller regulation strategy shall be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop shall be adjustable from 0 to 10%.

e) At zero percent (0%) droop, the VRS shall achieve a steady-state voltage regulation accuracy of +/- 0.5% of the controlled voltage at the POI.

f) The VRS shall be calibrated such that a change in reactive power will achieve 95% of its final value no later than 1 second following a step change in voltage. The change in reactive power should not cause excessive voltage excursions or overshoot.

g) The generator facility VRS must be in service at any time the PVF is electrically connected to the grid regardless of MW output from the PVF.

h) The VRS dead band shall not exceed 0.1%.

3. Reactive Power Capability and Minimum Power Factor Requirements

The total power factor range shall be from 0.85 lagging to 0.85 leading at the point of interconnection (POI). The reactive power requirements provide flexibility for many types of technologies at the Renewable Energy Facility. The intent is that a PVF can ramp the reactive power from 0.85 lagging to 0.85 leading in a smooth continuous fashion at the POI.

The +/- 0.90 power factor range should be dynamic and continuous at the point of interconnection (POI). This means that the PVF has to be able to respond to power system voltage fluctuations by continuously varying the reactive output of the plant within the specified limits. The previously established power factor dynamic range could be expanded if studies indicate that additional continuous, dynamic compensation is required. It is required that the PVF reactive capability meets +/- 0.85 Power Factor (PF) range based on the PVF Aggregated MW Output, which is the maximum MVAr capability corresponding to maximum MW Output. It is understood that positive (+) PF is where the PVF is producing MVAr and negative (-) PF is where the PVF is absorbing MVAr.

This requirement of MVAr capability at maximum output shall be sustained throughout the complete range of operation of the PVF as established by Figure 2.

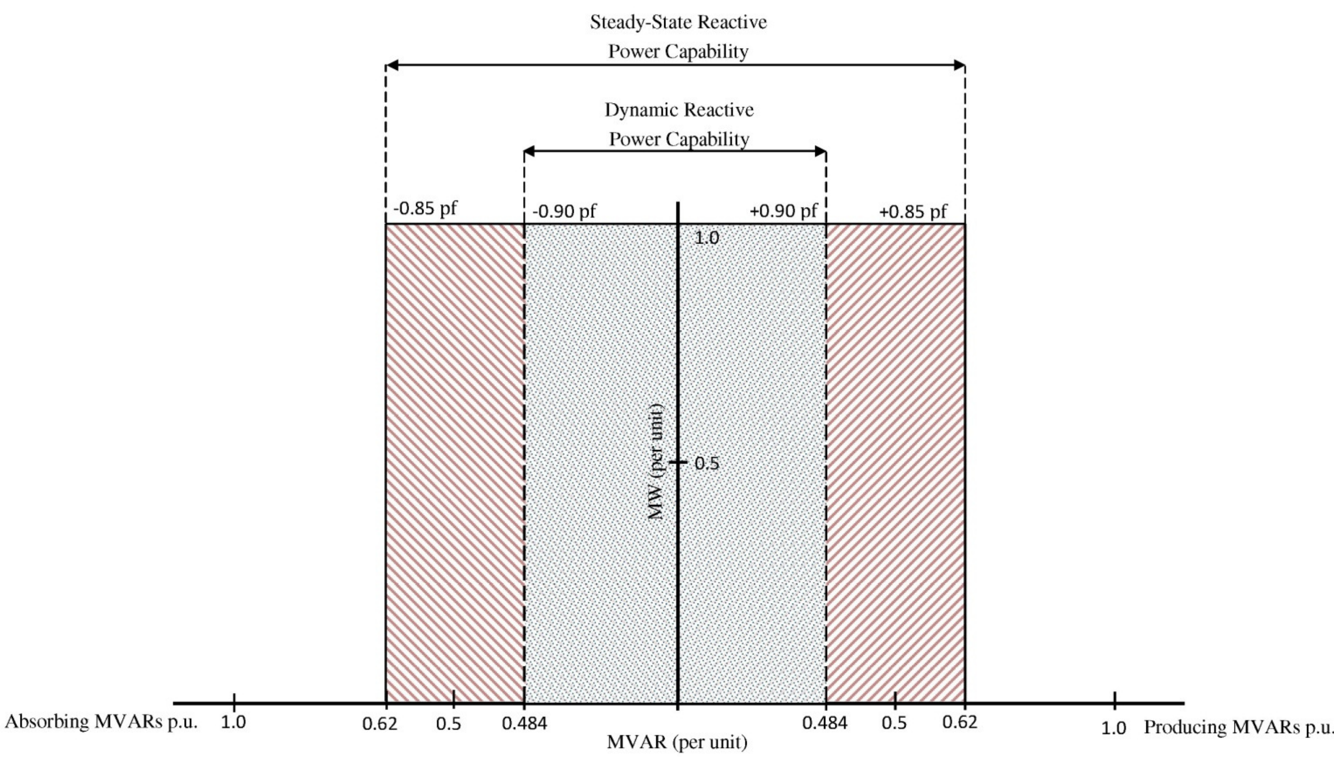

Figure 2 Reactive Power Capability Curve

4. Short Circuit Ratio (SCR) Requirements:

Short Circuit Ratio values (System Short Circuit MVA at POI/PV Facility MVA Capacity) under 5 shall not be permitted. The constructor shall be responsible for the installation of additional equipment, such as synchronous condensers, and controls necessary to comply with PREPA's minimum short circuit requirements.

5. Frequency Ride Through (FRT):

- 57.5 - 61.5 Hz No tripping (continuous)
- 61.5 - 62.5 Hz 30 sec
- 56.5 - 57.5 Hz 10 sec
- < 56.5 or > 62.5 Hz Instantaneous trip

6. Frequency Response/Regulation:

PV facility shall provide an immediate real power primary frequency response, proportional to frequency deviations from scheduled frequency, similar to governor response. The rate of real power response to frequency deviations shall be similar to or more responsive than the droop characteristic of 5% used by conventional generators. PV facility shall have controls that provide both for down-regulation and up-regulation. PV technologies, in combination with energy storage systems such as, but not limited to BESS, flywheels and hybrid systems are acceptable options to comply with PREPA's frequency response and regulation requirements.

For small frequency deviations (for example less than 0.3 Hz), the PV facility response shall be proportional to the frequency deviation, based on the specified 5% droop characteristic. The frequency response dead band shall not exceed 0.02%. For large frequency deviations (for example in excess of 0.3 Hz), the PV facility shall provide an immediate real power primary frequency response of at least 10% of the maximum AC active power capacity (established in the contract). The time response (full 10% frequency response) shall be less than 1 second.

If energy storage systems are utilized to comply with the frequency regulation requirements, and during a disturbance the system frequency stays below 59.7 Hz, the facility frequency response shall be maintained for at least 9 minutes. After the ninth minute the real power primary frequency response shall not decrease at a ramp rate higher than 10% of the maximum AC active power capacity per minute.

The operational range of the frequency response and regulation system shall be from 10% to 100% of the maximum AC active power capacity (established in the contract). The PV facility power output at the POI shall never exceed the maximum AC active power (established in the contract).

7. Ramp Rate Control:

Ramp Rate Control is required to smoothly transition from one output level to another. The PV facility shall be able to control the rate of change of power output during some circumstances, including but not limited to: (1) rate of increase of power, (2) rate of decrease of power, (3) rate of increase of power when a curtailment of power output is released; (4) rate of decrease in power when curtailment limit is engaged. A 10 % per minute rate (based on AC contracted capacity) limitation shall be enforced. This ramp rate limit applies both to the increase and decrease of power output and is independent of meteorological conditions. The ramp rate control tolerance shall be +10%.

8. Power Quality Requirements:

The developer shall address, in the design of their facilities potential sources and mitigation of power quality degradation prior to interconnection. Design considerations should include applicable standards including, but not limited to IEEE Standards 142, 519, 1100, 1159, and ANSI C84.1. Typical forms of power quality degradation include, but are not limited to voltage regulation, voltage unbalance, harmonic distortion, flicker, voltage sags/interruptions and transients.

9. Special Protection Schemes:

PV facility shall provide adequate technology and implement special protection schemes as established by PREPA in coordination with power management requirements.

10. General Interconnection Substation Configuration:

An interconnecting generation producer must interconnect at an existing PREPA switchyard. The configuration requirements of the interconnection depend on where the physical interconnection is to occur and the performance of the system with the proposed interconnection. The interconnection must conform, at a minimum, to the original designed configuration of the switchyard. PREPA, at its sole discretion, may consider different configurations due to physical limitations at the site.

11. MODELING AND VALIDATION

The Contractor shall submit to PREPA a Siemens - PTI certified PSS/E mathematical model and data related to the proposed PV facility. When referred to the PV facility model, this shall include but is not limited to PV inverters, transformers, collector systems, plant controllers, control systems and any other equipment necessary to properly model the PV facility for both steady-state and dynamic simulation modules. It is required that the Contractor submits both an aggregate and detailed version of the PV facility model. At a later stage in the process, it is also required that the Contractor submits as-built PSS/E mathematical models of the PV Facility.

The Contractor shall be required to submit user manuals for both the PV inverter and the PV facility models including a complete and detailed description of the voltage regulation system (VRS) and frequency regulation system model implementation. The mathematical models shall be fully compatible with the latest and future versions of PSS/E. It is preferred that the models are PSS/E standard models. In the case that the Contractor submits user written models, the Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. The Contractor shall submit to PREPA an official report from Siemens - PTI that validates and certifies the required mathematical models, including subsequent revisions. The data and PSS/E model shall also be updated and officially certified according to PREPA requirements when final field adjustments and parameters measurements and field tests are performed to the facility by the contractor. The mathematical model (either PSS/E standard or user written model) of the PV facility shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete PV facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical model shall not be considered valid.

The Contractor shall be responsible to submit Siemens – PTI certified PSSE mathematical models of any kind of compensation devices (ie. SVC, STATCOMs, DSTATCOMs, BESS, etc.) used on the PV facility. It is preferred that the models are standard models provided with PSS/E. In the case that the Contractor submits user written models, the PV facility Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. In its final form, the mathematical model shall be able to simulate each of the required control and operational modes available for the compensation device and shall be compatible with the latest and future versions of PSSE. Final adjustments and parameters settings related with the control system commissioning process shall be incorporated to the PSSE mathematical model and tested accordingly by the PV facility Contractor and PREPA system study groups. The Contractor shall also perform on-site field tests for the identification, development, and validation of the dynamic mathematical models and parameters required by PREPA for any kind of compensation devices used at the PV facility. The mathematical models of the PV facility and its required compensation devices shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete PV facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical models shall not be considered valid.

PV facility Owners that provide user written model(s) shall provide compiled code of the model and are responsible to maintain the user written model compatible with current and new releases of PSS/E until such time a standard model is provided. PREPA must be permitted by the PV facility Owner to make available PV Facility models if required to external consultants with an NDA in place.

12. TRANSIENT MATHEMATICAL MODEL

The Contractor shall be responsible of providing a detailed transient model of the PV facility and to show that it is capable of complying with PREPA's transient Minimum Technical Requirements.

13. DYNAMIC SYSTEM MONITORING EQUIPMENT

The developer of the PV facility shall be required to provide and install a dynamic system monitoring equipment that conforms to PREPA's specifications.

Appendix D: Minimum Technical Requirements of Interconnection of Wind Facilities (ver. Aug. 15, 2012)

Minimum Technical Requirements for Interconnection of Wind Turbine Generation (WTG) Projects

The proponent shall comply with the following minimum technical requirements:

1. Voltage Ride-Through

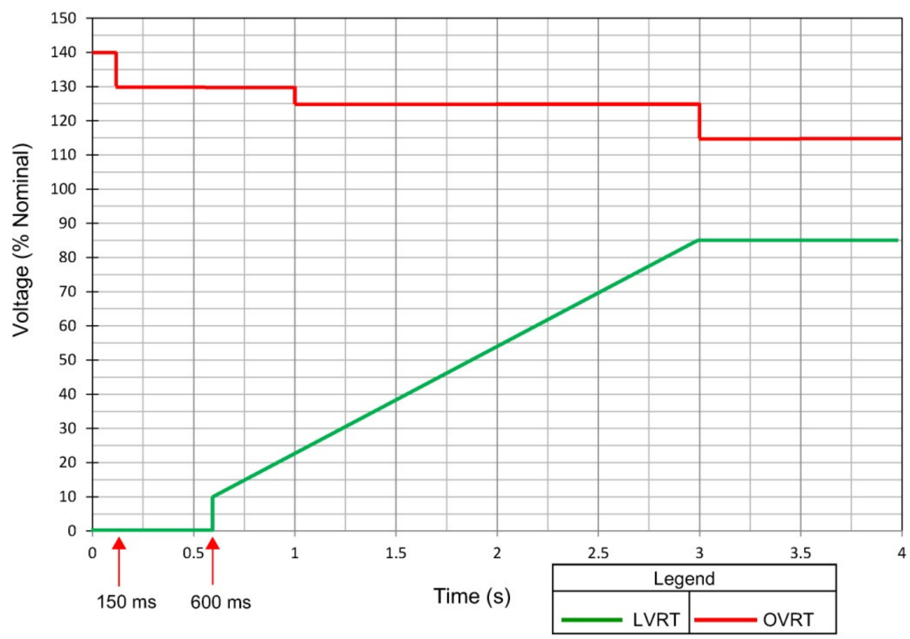

Figure 1 Voltage Ride-Through Requirements

a. PREPA's Low Voltage Ride-Through (LVRT) Requirements:

   i. From Figure 1, PREPA requires all generation to remain online and be able to ride-through three phase and single phase faults down to 0.0 per-unit (measured on the point of interconnection), for up to 600 ms.

   ii. All generation remains online and operating during and after normally cleared faults on the point of interconnection.

   iii. All generation remains online and operating during backup-cleared faults on the point of interconnection.

iv. During the low voltage fault conditions, the wind generation facility shall operate on reactive current injection mode. This mode of operation shall be implemented with a reactive current droop characteristic which shall have an adjustable slope from 1 to 5%. A dead band of 15 % is required.

b. PREPA's Overvoltage Ride-Through (OVRT) Requirements:

i. PREPA requires all generation to remain online and able to ride-through symmetrical and asymmetrical overvoltage conditions specified by the following values illustrated in Figure 1:

Overvoltage (pu)	**Minimum time to remain online**
1.4 – 1.3	150 ms
1.3– 1.25	1 s
1.25 – 1.15	3 s
1.15 or lower	Indefinitely

2. Voltage Regulation System (VRS)

Constant voltage control shall be required. Wind Turbine Generation (WTG) technologies in combination with Static Var Controls, such as Static Var Compensators (SVC), STATCOMs and DSTATCOMs are acceptable options to comply with this requirement. A complete description of the VRS control strategy shall be submitted for evaluation.

a) Wind Generation Facilities (WGF) must have a continuously-variable, continuously-acting, closed loop control VRS; i.e. an equivalent to the Automatic Voltage Regulator in conventional machines.

b) The VRS set-point shall be adjustable between 95% to 105% of rated voltage at the POI. The VRS set-point must also be adjustable by PREPA's Energy Control Center via SCADA.

c) The VRS shall operate only in a voltage set point control mode. Controllers such as Power Factor or constant VAR are not permitted.

d) The VRS controller regulation strategy shall be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop shall be adjustable from 0 to 10%.

e) At zero percent (0%) droop, the VRS shall achieve a steady-state voltage regulation accuracy of +/- 0.5% of the controlled voltage at the POI.

f) The VRS shall be calibrated such that a change in reactive power will achieve 95% of its final value no later than 1 second following a step change in voltage. The change in reactive power should not cause excessive voltage excursions or overshoot.

g) The generator facility VRS must be in service at any time the WGF is electrically connected to the grid regardless of MW output from the WGF.

h) The VRS dead band shall not exceed 0.1%.

Examples of possible VRS configurations:

The following examples serve as possible solutions for REF voltage regulation and reactive power compensation.

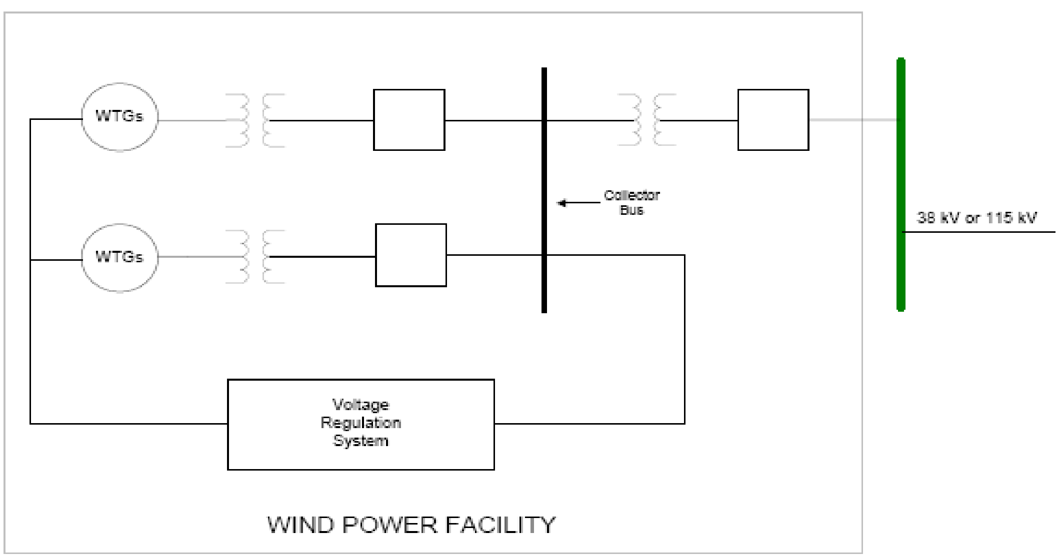

Figure 2 Voltage Regulation at WGF

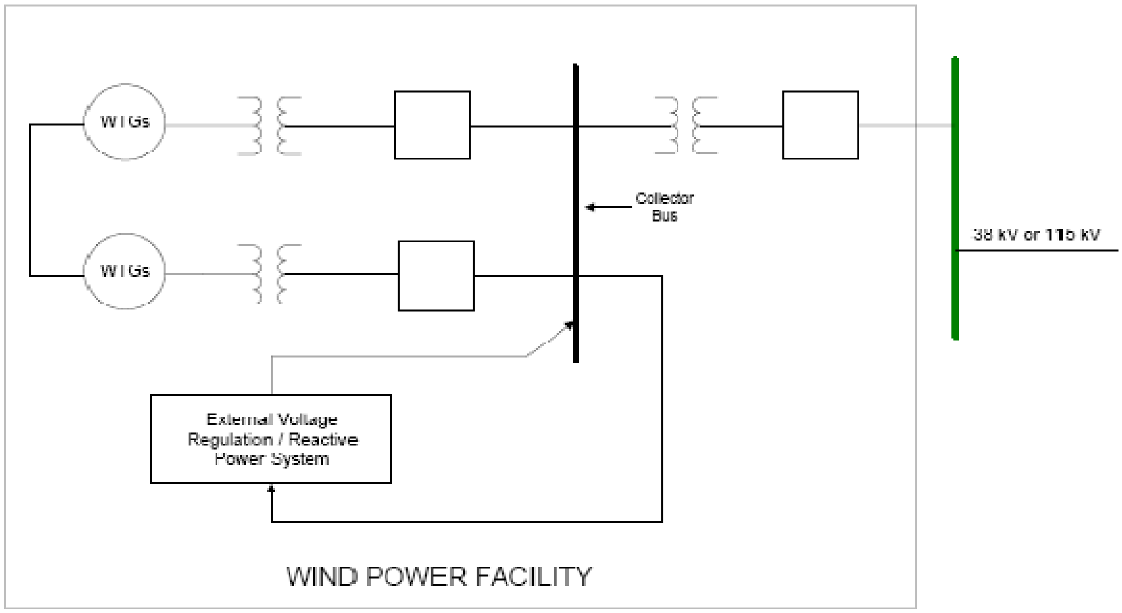

Figure 3 Voltage Regulation at single collector bus

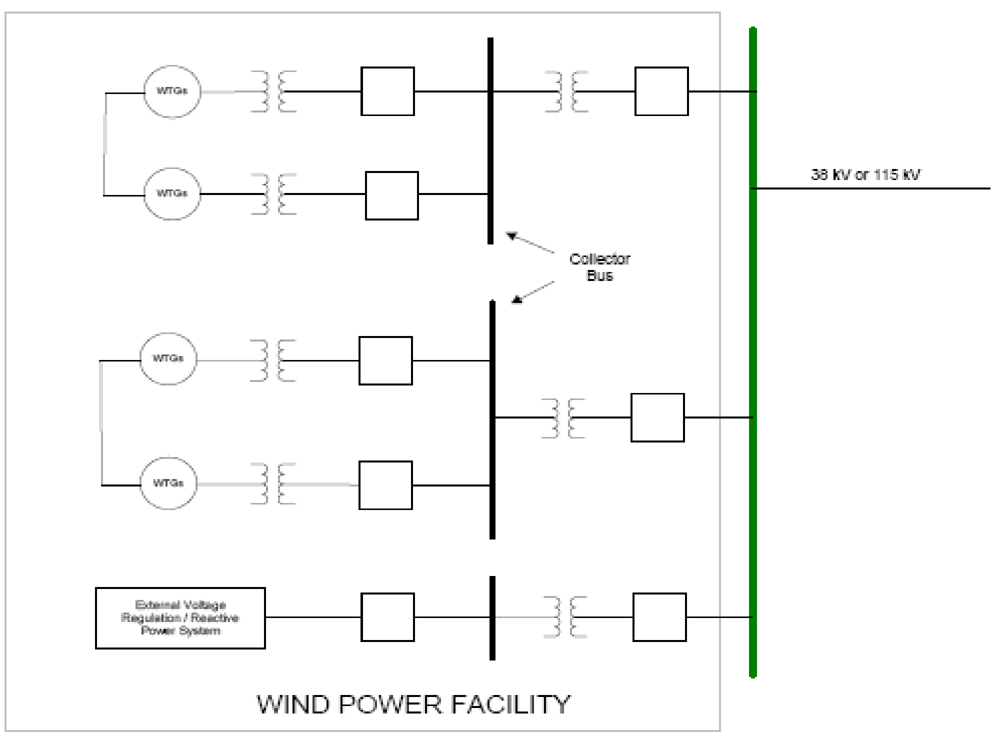

Figure 4 Voltage Regulation on a multiple collector bus injection at collector bus

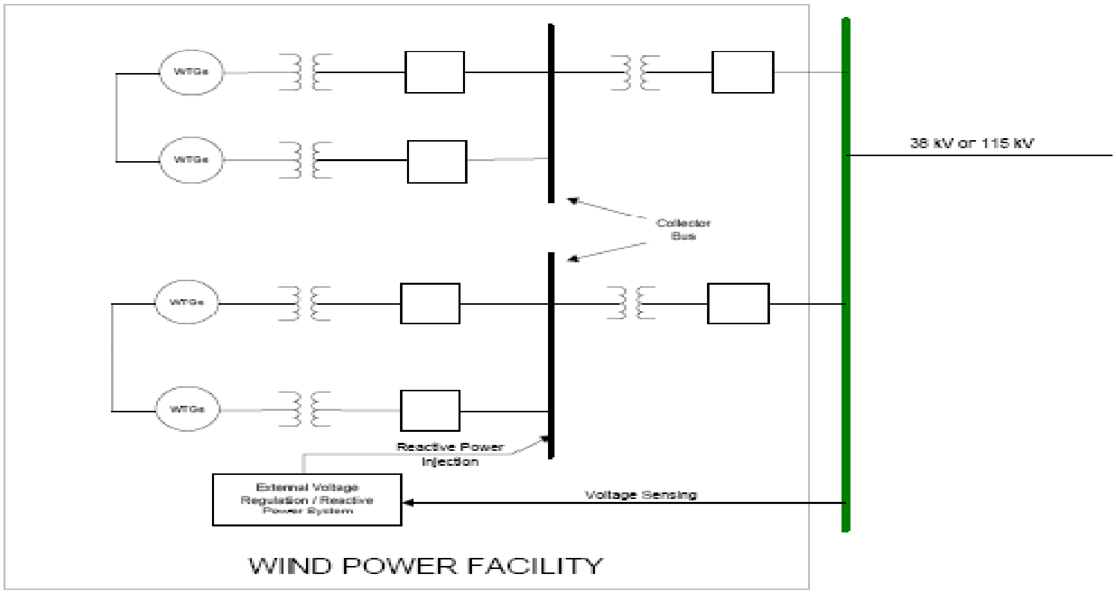

Figure 5 Shared Voltage Regulation for multiple WGF at transmission system bus

3. Reactive Power Capability and Minimum Power Factor Requirements

The total power factor range shall be from 0.85 lagging to 0.85 leading at the point of interconnection (POI). The reactive power requirements provide flexibility for many types of technologies at the Renewable Energy Facility. The intent is that a WGF can ramp the reactive power from 0.85 lagging to 0.85 leading in a smooth continuous fashion at the POI.

The +/- 0.90 power factor range should be dynamic and continuous at the point of interconnection (POI). This means that the WGF has to be able to respond to power system voltage fluctuations by continuously varying the reactive output of the plant within the specified limits. The previously established power factor dynamic range could be expanded if studies indicate that additional continuous, dynamic compensation is required. It is required that the WGF reactive capability meets +/- 0.85 Power Factor (PF) range based on the WGF Aggregated MW Output, which is the maximum MVAr capability corresponding to maximum MW Output. It is understood that positive (+) PF is where the WGF is producing MVAr and negative (-) PF is where the WGF is absorbing MVAr.

This requirement of MVAr capability at maximum output shall be sustained throughout the complete range of operation of the WGF as established by figure 6.

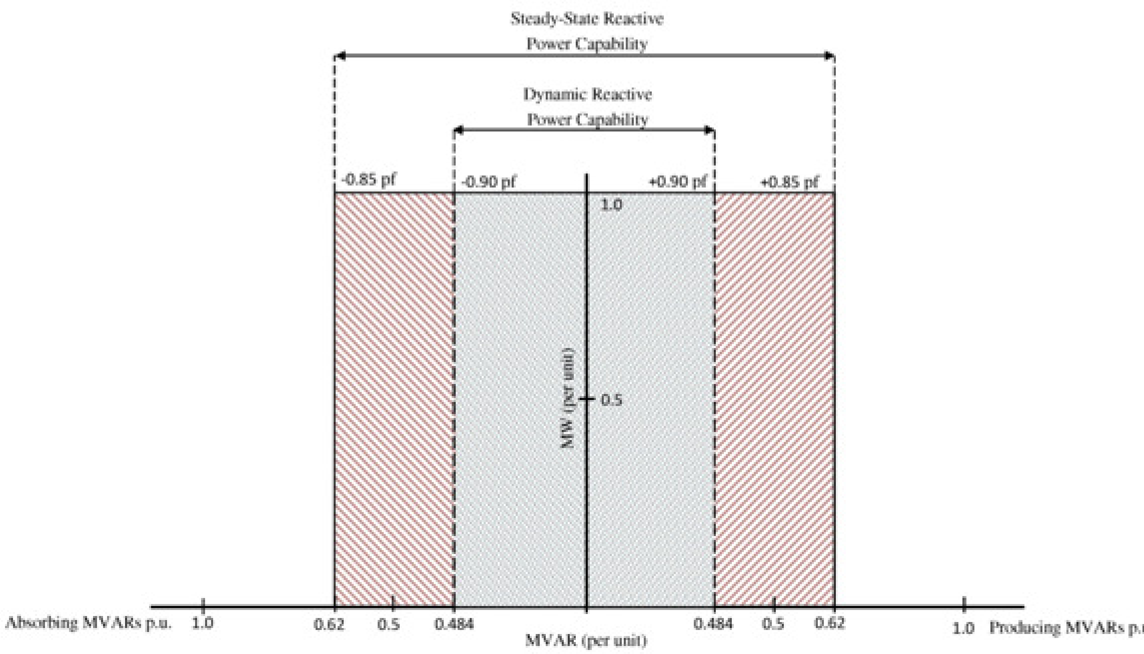

Figure 6 Reactive Power Capability Curve

4. Short Circuit Ratio (SCR) Requirements:

Short Circuit Ratio values (System Short Circuit MVA at POI/WGF MVA Capacity) under 5 shall not be permitted. The constructor shall be responsible for the installation of additional equipment, such as synchronous condensers, and controls necessary to comply with PREPA's minimum short circuit requirements.

5. Frequency Ride Through (FRT):

- 57.5 - 61.5 Hz No tripping (continuous)
- 61.5 - 62.5 Hz 30 sec
- 56.5 - 57.5 Hz 10 sec
- < 56.5 or > 62.5 Hz Instantaneous trip

6. Frequency Response/Regulation and Inertial Response

WTG facility shall provide an immediate real power primary frequency response, proportional to frequency deviations from scheduled frequency, similar to governor response. The rate of real power response to frequency deviations shall be similar to or more responsive than the droop characteristic of 5% used by conventional generators. WTG facility shall have controls that provide both down-regulation and up-regulation. Wind turbine technologies, in combination with energy storage systems such as BESS, flywheels and hybrid systems are acceptable options to comply with PREPA's frequency regulation requirements.

For small frequency deviations (for example less than 0.3 Hz), the WGF response shall be proportional to the frequency deviation, based on the specified 5% droop characteristic. The frequency response dead band shall not exceed 0.02%. For large frequency deviations (for example in excess of 0.3 Hz), the WGF shall provide an immediate real power primary frequency response of at least 10% of the maximum AC active power capacity (established in the contract). The time response (full 10% frequency response) shall be less than 1 second.

If energy storage systems are utilized to comply with the frequency regulation requirements, and during a disturbance the system frequency stays below 59.7 Hz, the facility frequency response shall be maintained for at least 9 minutes. After the ninth minute the real power primary frequency response shall not decrease at a ramp rate higher than 10% of the maximum AC active power capacity per minute.

The operational range of the frequency response and regulation system shall be from 10% to 100% of the maximum AC active power capacity (established in the contract). The WGF power output at the POI shall never exceed the maximum AC active power (established in the contract).

The WTG controls shall have the capability to provide inertial response.

7. Ramp Rate Control

Ramp Rate Control is required to smoothly transition from one output level to another. The WTG facility shall be able to control the rate of change of power output during some circumstances, including but not limited to: (1) rate of increase of power (2) rate of decrease of power, (3) rate of increase of power when a curtailment of power output is released; (4) rate of decrease in power when curtailment limit is engaged. A 10 % per minute rate (based on nameplate capacity) limitation shall be enforced. This limit applies both to the increase and decrease of power output and is independent of meteorological conditions. The ramp rate control tolerance shall be +10%.

8. Power Quality

The developer shall address, in the design of their facilities potential sources and mitigation of power quality degradation prior to interconnection. Design considerations should include applicable standards including, but not limited to IEEE Standards 142, 519, 1100, 1159, ANSI C84.1, IEC 61400-21, IEC 61000-3-7 and IEC 61000-3-6. Typical forms of power quality degradation include, but are not limited to voltage regulation, voltage unbalance, harmonic distortion, flicker, voltage sags/interruptions and transients.

The developer shall submit the Power Quality Tests Result Report of the wind turbines as described in the IEC 61400-21 standard. This report includes: general wind turbine data, wind turbine rated data at terminals, voltage fluctuations coefficients (flicker coefficients), current harmonics components, current interharmonics components, current high frequency components, response to voltage drops, active power data, reactive power data, grid protection data and reconnection time. The wind turbines shall not exceed the flicker emission limits established by the IEC 61000-3-7 standard and the harmonics emission limits of IEC 61000-3-6.

9. Wind Power Management

WTG facility shall provide adequate technology (communicating technology and the corresponding control equipment) and implement wind power management requirements (ramp rate limits, output limits, curtailment) as established by PREPA.

10. Special Protection Schemes

WTG facility shall provide adequate technology and implement special protection schemes as established by PREPA in coordination with wind power management requirements.

11. Wind Generation Forecasting Systems

WTG facility shall provide adequate technology to support wind generation forecasting systems (short term and day-ahead) as established by PREPA. Individual turbine's availability shall be included.

12. General Interconnection Substation Configuration

An interconnecting generation producer must interconnect at an existing PREPA switchyard. The configuration requirements of the interconnection depend on where the physical interconnection is to occur and the performance of the system with the proposed interconnection. The interconnection must conform, at a minimum, to the original designed configuration of the switchyard. PREPA, at its sole discretion, may consider different configurations due to physical limitations at the site.

13. Modeling and Validation

The Contractor shall submit to PREPA a Siemens - PTI certified PSS/E mathematical model and data related to the proposed WTG facility. When referred to the WTG facility model, this shall include but is not limited to wind generator, transformers, collector systems, plant controllers, control systems and any other equipment necessary to properly model the WTG facility for both steady-state and dynamic simulation modules. It is required that the Contractor submits both an aggregate and detailed model of the WTG facility model. At a later stage in the process, it is also required that the Contractor submits as-built PSS/E mathematical models of the WTG facility.

The Contractor shall be required to submit user manuals for both the Wind Turbine Generator and WTG Facility models including a complete and detailed description of the voltage regulation system (VRS) and frequency regulation system model implementation. The mathematical models shall be fully compatible with the latest and future versions of PSS/E. It is preferred that the models are PSS/E standard models. In the case that the Contractor submits user written models, the Contractor shall be required to keep these models, as well as its corresponding user manual, current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. The Contractor shall submit to PREPA an official report from Siemens - PTI that validates and certifies the required mathematical models, including subsequent revisions. The data and PSS/E model shall also be updated and officially certified according to PREPA requirements when final field adjustments and parameters measurements and field tests are performed to the facility by the contractor. The mathematical model (either PSS/E standard or user written model) of the WTG facility shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete WTG facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical model shall not be considered valid.

The Contractor shall be responsible to submit Siemens – PTI certified PSSE mathematical models of any kind of compensation devices (ie. SVC, STATCOMs, DSTATCOMs, BESS, etc.) used on the WTG facility. It is preferred that the models are standard models provided with PSS/E. In the case that the Contractor submits user written models, the WTG facility Contractor shall be required to keep these models current with the future versions of the PSS/E program until such time that PSS/E has implemented a standard model. In its final form, the mathematical model shall be able to simulate each of the required control and operational modes available for the compensation device and shall be compatible with the latest and future versions of PSSE. Final adjustments and parameters settings related with the control system commissioning process shall be incorporated to the PSSE mathematical model and tested accordingly by the WTG facility Contractor and PREPA system study groups. The Contractor shall also perform on-site field tests for the identification, development, and validation of the dynamic mathematical models and parameters required by PREPA for any kind of compensation devices used at the WTG facility. The mathematical models of the WTG facility and its required compensation devices shall be officially certified by Siemens - PTI before a specific and validated PSS/E mathematical model of the complete WTG facility be submitted to PREPA. The Contractor shall be responsible of submitting the official reports and certifications from Siemens – PTI, otherwise the mathematical models shall not be considered valid.

WTG facility Owners that provide user written model(s) shall provide compiled code of the model and are responsible to maintain the user written model compatible with current and new releases of PSS/E until such time a standard model is provided. PREPA must be permitted by the WGF Owner to make available WGF models if required to external consultants with an NDA in place.

14. Transient Mathematical Model

The contractor shall be responsible of providing a detailed transient model of the WTG facility and to show that it is capable of complying with PREPA's transient Minimum Technical Requirements.

15. Dynamic System Monitoring Equipment

The developer of the Renewable Energy Facility shall be required to provide and install a dynamic system monitoring equipment that conforms to PREPA's specifications.