SYSTEM IMPACT STUDY FOR THE GRANADA 300 MW WIND FARM

PHASE 1, TASK 1.1.2: STABILITY STUDY

Issued: June 13, 2007

Prepared for Public Service Company of New Mexico

Report Number: 2007-11417-2.2.R03

SUBMITTED BY:

Grid Systems Consulting
ABB Inc.
940 Main Campus Drive, Suite 300
Raleigh, N C 27606

Legal Notice

This document, prepared by ABB Inc., is an account of work sponsored by Public Service Company of New Mexico (PNM). Neither PNM nor ABB Inc., nor any person or persons acting on behalf of either party: (i) makes any warranty or representation, expressed or implied, with respect to the use of any information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or (ii) assumes any liabilities with respect to the use of or for damages resulting from the use of any information, apparatus, method, or process disclosed in this document.

Grid Systems Consulting

Technical Report

ABB Inc.	2007-11417-2.2.R03		
Title: System Impact Study for the Granada 300 MW Wind Farm Phase 1, Task 1.1.2: Stability Study	**Dept.** **Consulting**	Date 6/13/07	Pages 783

Author(s):	Reviewed by:	Approved by:
W. Quaintance D. Dickmander	W. Wong	W. Wong

Executive Summary:

This report describes transient stability studies performed to determine the impacts of interconnecting 300 MW of new wind turbines (Project) at the Guadalupe 345 kV station (Guadalupe). The Project will be built in two phases using GE 1.5 MW DFIG units with the initial phase consisting of 201 MW (134 turbines) and an in-service date of October of 2007, and the second phase consisting of 99 MW (66 turbines) and an in-service date of October of 2008. Studies were performed only at the 300 MW output level to identify all necessary transmission impacts and transmission improvements. With the Project in service, total injections on the BB line were 955 MW.

Prior system impact studies (SIS) for generation interconnection projects on the BB line identified the need to advance the conversion of Rio Puerco 345kV switching station[1] (Rio Puerco) to a breaker-and-a-half switching station with a proposed in service date of 2010. Since the Project's proposed in service date is prior to 2010, stability studies were conducted with and without the Rio Puerco station. Prior to completion of this build out of Rio Puerco, with high load and high BB line transfers, certain N-1, N-2 and breaker failure contingencies on the PNM transmission system require curtailment of the output of the generation facilities interconnected to the BB line through an automated remedial action scheme (RAS). The Powerflow study report contains more details on this subject.

Power flow Analysis Summary

The power flow studies[3] found that, with the Project, the system is not viable without the addition of reactive compensation being placed somewhere on the BB line. The power flow analysis also found dynamic shunt reactive compensation (SVC) is preferable to series compensation, and that the SVC location at B-A is preferable to the Project/Guadalupe[4] location. The power flow studies also determined preliminary reactive compensation sizes for further investigation in the dynamic simulation study analysis. The table below shows the additional reactive power support would be needed. The reactive support required to meet N-0 criteria (all lines in service) can be considered static (capacitor). The difference between the N-0 and N-1 (contingency) reactive support requirement can be regarded as an approximate dynamic SVC range.

Stability Analysis Summary

The stability results described in this report are a continuation of the steady state power flow studies described in the companion report[3]. The stability analysis presented in this report show that all pre-project wind farms, including Argonne Mesa, are stable for the BA 115 kV fault before adding the 300 MW Granada wind farm. After adding Granada, an SVC is needed at the Project/Guadalupe location to allow Argonne Mesa to maintain compliance with PNM's LVRT requirement. The stability study results show that an SVC at BA is not effective at keeping Argonne Mesa in compliance with applicable LVRT standard. The transient stability analysis demonstrated that the Project/Guadalupe location would be better

For an SVC at Project/Guadalupe, and without Rio Puerco, an SVC size of 260 Mvar is sufficient to keep Aragonne Mesa, and all other BB line wind farms, on line for the BA 115 kV transformer fault. A 250 Mvar SVC size at Project/Guadalupe was sufficient in the post-Rio Puerco case, but not in the pre-Rio Puerco case.

SVC Sizing from Power Flow and Dynamic Simulation Results				
Criteria	**Without Rio Puerco**		**With Rio Puerco**	
	SVC GUAD	**SVC BA**	**SVC GUAD**	**SVC BA**
PF N-0	116	123	114	99
PF N-1	230	223	149	176
DYN BA115	260	Not Feasible	250	Not Feasible

The case requested by PNM for sizing of the inductive range of the SVC is the trip of the Guadalupe-Taiban Mesa 345 kV line, with the Aragonne Mesa and Granada wind farms at their full power outputs of 200 and 300 MW, respectively.

This case is included in Appendices B2 and B4 for pre-Rio Puerco and post-Rio Puerco conditions respectively. These cases show the SVC going to post-disturbance output levels varying between 0 and 40 MVAR capacitive, settling to around 10 MVAR capacitive in the pre-Rio Puerco case and to around 5 MVAR in the post-Rio Puerco case. These results imply that the inductive portion of the SVC needs to be sized to be equal to or larger than the fixed (mechanically switched) capacitive portion.

For a conventional SVC with one Thyristor Switched Capacitor (TSC) and one Thyristor Switched Reactor (TCR), the TCR would be sized to be slightly larger than the TSC, for hysteresis. The anticipated TSC size is at most 146 MVAR for a 260 MVAR total capacitive range, and the TCR would thus be slightly larger than 146 MVAR. This size is sufficient to cancel the 114 MVAR mechanically switched portion of the SVC.

Preliminary design information for the SVC is given below.

Definition of Terms:

TSC: Thyristor Switched Capacitor
TCR: Thyristor Controlled Reactor

Application voltage:

Nominal high side voltage:	345 kV
Max continuous high side voltage:	345 x 1.1 = 379.5 kV
Max temporary high side voltage:	345 x 1.2 = 414 kV

Capacitive Ratings (all values at high side bus):

Steady-state (continuous) capacitive rating: 114 MVAR
(Needs to be a combination of switched filters and switched capacitor banks. The intention is to have TSC and TCR off at 114 MVAR output of SVC, thereby minimizing losses.)
Dynamic capacitive rating (TSC size): 146 MVAR
Total capacitive rating: 114 + 146 = 260 MVAR

Inductive Rating:

TCR size: ≥ TSC size, for hysteresis

SVC manufacturer to state the inductive MVARs at the 345 kV bus for the following conditions:
- TCR at full conduction
- TSC off
- Switched caps off
- Filters on

It is anticipated that the SVC will need to be provided with the full capability as a single project; i.e. staging of the SVC for the separate phases of the Granada project may not be practical.

The Phase II technical analysis will provide additional confirmation of the findings in this study. Additional reinforcements identified during Phase II, if any, will be documented as outlined in the study proposal.

The input data, study conditions, and results of dynamic simulations are described in the report.

---

[1] Four Corners–West Mesa, San Juan–BA, and West Mesa – BA 345 kV transmission lines that presently run though that site will be looped into and out of the new 345 kV station. The construction schedule is projected to span a three-year period due to very limited windows available for taking the 345 kV line outages.

[2] ABB Technical Report, "System Impact Study for the FPL Energy Taiban Mesa II 51 MW Wind Farm," July 17, 2006.

[3] ABB Technical Report, "System Impact Study for the Granada 300 MW Wind Farm: Phase 1, Task 1.1.1: Power flow Study," May 4, 2007.

[4] Note that a short 345 kV line will connect the Project wind farm substation to the Guadalupe switchyard. Because the line is short and its impedance was not provided to ABB, this radial 345 kV line was not modeled in this study, and instead the Project 345/34.5 kV transformers were connected directly to the Guadalupe 345 kV bus. Thus, no distinction was made in the study between an SVC location at Guadalupe 345 kV bus and an SVC location at the Project 345 kV bus; hence the use of the term "Project/Guadalupe SVC location" in this report.

[5] The applicable LVRT requirement states that generators interconnected to the BA – Blackwater transmission facilities must ride through a 3-phase 5-cycle fault at BA 115 kV with loss of the BA 345/115 kV transformer, and single-line to ground faults on the 345 kV system external to the BA – Blackwater line.

TABLE OF CONTENTS

1 Introduction

In the mid 1980's, Public Service Company of New Mexico ("PNM") constructed a radial 223-mile 345-kV line from the Bernalillo area North of Albuquerque ("BA Station") to Clovis, NM ("Blackwater Station"). A back-to-back 200 MW AC-DC-AC converter was constructed at the Blackwater Station ("HVDC system"). These facilities are known as the Eastern Interconnection Project ("EIP"). In 2003, PNM completed the interconnection of the Taiban Mesa wind generation facility approximately 60 miles west of Blackwater Station. ABB performed extensive studies for PNM and FPL Energy on this initial 204 MW phase of the Taiban Mesa wind project.

Interconnection of the 300 MW Granada wind farm ("Project") is at the Guadalupe 345 kV station (Guadalupe). The Project will be built in two phases using GE 1.5 MW DFIG units. The initial phase consists of 201 MW (134 turbines) and has an in-service date of October of 2007. The second phase consists of 99 MW (66 turbines) and has an in-service date of October of 2008. The Granada 300 MW project is the subject of this study report.

The following interconnection projects on the BB line hold a senior position in the interconnection queue and are assumed to be in service for this study:

a) 200 MW wind power plant in Guadalupe County, NM[1] (Aragonne Mesa).
b) 51 MW wind power plant at the existing Taiban Mesa 345 kV station[2] (Taiban Mesa II).

In response to the request for interconnection of the Project, PNM engaged ABB for the required SIS based on the assumptions, criteria and methodologies described in the Study Scope Agreement [1]. PNM has requested that ABB perform the following studies, using a phased approach:

- Phase I – SIS study and evaluation of reactive power compensation requirements
- Phase II - Identify and evaluate the risk of adverse interactions

This report describes the stability analysis portion of the Phase I task. A companion report describes the power flow analysis portion of Phase I.

The objective of the SIS is to determine, on a preliminary basis, any additional transmission system reinforcements required to accommodate the full output of the Project safely and reliably for system conditions defined by PNM, and to evaluate the reactive power support needed to accommodate the Project.

---

[1] PNM and Aragonne Mesa signed the Large Generation Interconnection Agreement (LGIA) on December 21, 2005, for a total of 200 MW. PNM expanded the Guadalupe station and interconnected the first 90 MW. Aragonne Mesa has advised PNM that it intends to maintain the additional 110 MW reservations pursuant to its three-year entitlement under FERC regulations.
[2] PNM and FPLE signed an LGIA on February 23, 2007 to expand the Taiban Mesa wind farm by 51 MW.

This report is organized as follows. Section 2 summarizes the input data and base cases upon which the study is based. Section 3 discusses the stability study and results. Finally, the conclusions and recommendations of the study are presented in Section 4.

2 Base Cases and Input Data

2.1 Power flow Input Data

Per the study agreement [1], the initial base cases for the Project system impact study (SIS) corresponded to the post-project cases for the Taiban Mesa II 51 MW SIS [2]. These base cases had all Albuquerque area generation off line, including Reeves. An initial power flow screening analysis was conducted by ABB using these base cases, with the project added as described in Section 2.2.

Upon review of the initial screening analysis results as discussed in the companion power flow study report, PNM modified the power flow base cases used in the initial screening analysis to the following cases:

> **abb2007sm_pre_proj_svc_2_fixed_slw.sav**: Peak summer base power flow case without the planned Rio Puerco switching station, pre-project
>
> **abb2007sm_rp_pre_proj_svc_2_fixed_slw.sav**: Peak summer base power flow case with the planned Rio Puerco switching station, pre-project
>
> **abb2007sm_rp_post_proj_svc_2_fixed_slw.sav**: Peak summer base power flow case with the planned Rio Puerco switching station, post-project

The Project was then added by ABB to the "without Rio Puerco" case to complete the set. The changes made by PNM in the above cases, as compared to the post-project cases from the Taiban Mesa 51 MW SIS, were as follows:

- Added Rio Puerco 345/115 kV transformer and 115 kV line to Veranda
- Added Norton - STA 115 kV line
- Increased PNM load by approximately 15% to reflect the latest 2008 peak summer forecast
- Adjusted Albuquerque power factor to 0.987 lagging after load increase
- Added Estancia Basin project (37.5 MW) at Willard 115 kV[3]
- Dispatched Reeves at 69 MW (Reeves #1 and #2 at 22 MW each; Reeves #3 at 25 MW)
- Dispatched Afton generation at 135 MW
- Changed Arroyo PST setting to 60 MW
- Turned on 9 Mvar capacitor at Zia

These corrections brought the study case up to date for a 2008 peak summer condition.

[3] PNM and Western Water & Power on March 7, 2007signed the LGIA to expand the Tri-State's Willard 115 kV to interconnection of 36.7 MW of renewable biomass-fired steam generation.

All cases used in the study, including the above cases, were in GE-PSLF 15.2 format. The studies were run using PSLF 16.0.

Miscellaneous files used in power flow studies:

BW_LF.p: EPCL to set correct conditions for Blackwater
qlimits.p: Pre- and post-contingency EPCL for Albuquerque area generator reactive power limits
nh-series-reactor.p: Post-contingency EPCL for control of NH series reactor

2.2 Development of Power flow Base Cases for SIS

The following assumptions were made by ABB in developing the post-project base cases:

1. Total BB line injections of 955 MW as follows:

- 200 MW from the Blackwater HVDC station
- 204 MW from the existing Taiban Mesa wind farm
- 51 MW from the proposed Taiban Mesa expansion project
- 200 MW from the proposed Aragonne Mesa wind farm (Mitsubishi 1000A wind turbines, with associated reactive compensation equipment)
- 300 MW from the Project (GE 1.5 MW turbines)

2. The Aragonne Mesa wind farm project and reactive support equipment were modeled as documented in reference [3].

The power flow cases developed by ABB included a detailed model of the Blackwater HVDC station, a model for the original Taiban Mesa 204 MW project, and the Taiban Mesa 51 MW expansion project, and a model for the Aragonne Mesa 200 MW project.

The following four power flow base cases were developed:

1. System + Aragonne Mesa (at 200 MW) + Blackwater at 200 MW (east to west) + Taiban Mesa (at 255 MW), **without Rio Puerco**

2. System + Aragonne Mesa (at 200 MW) + Blackwater at 200 MW (east to west) + Taiban Mesa (at 255 MW), **+ 300 MW Granada Project, without Rio Puerco**

3. System + Aragonne Mesa (at 200 MW) + Blackwater at 200 MW (east to west) + Taiban Mesa (at 255 MW), **with Rio Puerco**

4. System + Aragonne Mesa (at 200 MW) + Blackwater at 200 MW (east to west) + Taiban Mesa (at 255 MW), **+ 300 MW Granada Project, with Rio Puerco**

The Project was accommodated by redispatching (reducing) generation at the San Juan plant.

Power flow diagrams corresponding to the above conditions are given in Appendix A of the companion power flow study report.

The powerflow base cases resulting from the above development efforts and used in the subsequent dynamics analysis were as follows:

Without Rio Puerco:

abb2007sm_pre_proj_fixed_slw.sav
abb2007sm_post_proj_svc_1_fixed_slw.sav
abb2007sm_post_proj_svc_2_fixed_slw.sav

With Rio Puerco:

abb2007sm-rp_pre_proj_fixed_slw.sav
abb2007sm-rp_post_proj_svc_1_fixed_slw.sav
abb2007sm-rp_post_proj_svc_2_fixed_slw.sav

The post-Pajarito sensitivity case investigated in the power flow study was not used in the dynamics study.

2.3 Dynamics data

The dynamics data used for the study were obtained from the Taiban Mesa 51 MW SIS and are described below.

WECC system dynamics data file:

2007hs-bcs.dyd: dynamics data for the full WECC system

Controls for line reactor switching:

The files for control of the line reactors ("**reactor-inrun-epcl.p**" and "**reactor.dat**") were provided by PNM. To facilitate automated execution in PSAS, the above epcl was converted by ABB to epcmod models "**mssr.p**" (for conditions without Rio Puerco) and "**mssr_rp.p**" (for conditions with Rio Puerco). These models were then invoked in the dynamics data file for the present study.

Data for simulation of Aragonne Mesa 200 MW wind farm:

Data from the following files supplied by S&C in April 2006 were used:

add-sandc-200mw.dyd: Dynamics data for the wind turbines and statcoms

The above dynamics data file invokes the following EPCLs:

shaft2m.p
wndtrb-2.p
scdstcom_AB.p
scdstcom_AB_B.p

File **scdstcom_AB.p** is for the Statcom located at the 34.5 kV bus at Aragonne Mesa, while file **scdstcom_AB_B.p** is for the Statcom located at the 138 kV bus.

Switching controls for the mechanically switched capacitors at Aragonne Mesa were disabled in the DYD file as received from S&C. As no updated control logic for Aragonne Mesa was available from S&C at the time of the present studies, the switching controls for these capacitors were left disabled in this study, meaning that the capacitors remain connected through the duration of the dynamic simulations.

For the dynamics simulations in the Granada SIS, all of the Aragonne Mesa cap banks were connected except one 13 MVAR cap bank at the Aragonne 34.5 kV bus. The reason for disconnecting the 13 MVAR bank for the Granada SIS was to maintain power factor at the Aragonne 345 kV POC as close to unity as possible, with consideration of the final design of the shunt compensation at the Aragonne wind turbines.

The present control logic for Aragonne Mesa is understood to connect switched capacitor bank(s) with the ac voltage is detected to be below 0.9 pu, as would occur for a nearby ac fault. It is possible that connection of the remaining Aragonne Mesa 13 MVAR cap bank during the fault could slightly reduce the requirements for dynamic vars in conjunction with addition of the Granada Project. However, there will be detection delays and mechanical delays between the fault instant and the instant that the 13 MVAR cap bank is connected. The conservative approach used for the present study is therefore to leave the remaining 13 MVAR Aragonne capacitor bank off for the dynamics cases. This covers the possibility that connection of the 13 MVAR cap bank could be delayed by several cycles.

Estancia Generation Data:

PNM provided dynamics data for the new Estancia generator in a file called “**Estancia.dyd**”.

2.4 Data for Granada 300 MW Project

The data given below are as received from PNM for the SIS.

Collector System Data:

Phase I (201 MW, 134 units, 1.5 MW each):

Padmount equivalent:	X= 0.00324 + j 0.02431 (0.575 kV generator side voltage); 100 MVA base
Collector system only:	X= 0.00666 + j 0.02538; B = 0.03067 (34.5 kV); 100 MVA base
Station Transformer:	Two parallel units, 10% impedance on ONAN rating of 80 MVA, X/R = 60

Phase 2 (99 MW, 66 units, 1.5 MW each):

Padmount equivalent:	X= 0.00658 + j 0.04935 (0.575 kV generator side voltage); 100 MVA base
Collector system only:	X= 0.01795 + j 0.07866; B = 0.02998 (34.5 kV); 100 MVA base
Station Transformer:	One unit, 10% impedance on ONAN rating of 80 MVA, X/R = 60

Note that a short 345 kV line will connect the wind farm substation to the Guadalupe switchyard. Because the line is short and the impedance was not known, this radial 345 kV line was not modeled in this study. The wind farm 345/34.5 kV transformers were connected directly to the Guadalupe 345 kV bus.

Wind Turbine Data:

Nameplate rating:	1.5 MW
Rated Power Factor:	Adjustable from 0.95 lagging (overexcited) to 0.90 leading (underexcited) at generator terminals
Terminal Voltage:	575 V at the wind turbine generator terminals

Generator Model:

The GE 1.5 MW wind turbine generator model per version 16.0 of the GE PSLF® program was used for the study. A single-machine equivalent system (equivalent generator, pad-mounted transformer and collector system) was used to represent each Phase of the Project. Station transformers were modeled explicitly. The simulations assumed that the voltage control points for the wind farms were as shown in Table 1 below.

Table 1. Voltage Control Points		
Wind Farm	**Powerflow**	**Dynamics**
Taiban Mesa I	Taiban Mesa 345 kV	Taiban Mesa 345 kV
Taiban Mesa II	Wind Turbine Bus	Wind Turbine Bus
Aragonne Mesa	Aragonne 34.5 kV Aragonne 138 kV	scdstcom_AM.p* scdstcom_AM_B.p*
Granada (Project)	Wind Turbine Bus	Wind Turbine Bus

*For dynamics, the Aragonne Mesa Statcoms are modeled by S&C using a voltage control with a deadband. The voltage control is disabled (Statcom output fixed) if the ac voltage is above 0.9 pu. The voltage control is enabled if the ac voltage falls below 0.9 pu, as would occur for an ac fault.

For the Granada (Project) wind farm, the aggregate wind turbine models control their own bus voltage to 1.05 pu in the powerflow and dynamics cases.

Single Line Diagram:

A single line diagram of the Project, with its anticipated layout and interconnection at Guadalupe, is given as Figure 1.

SVC Model:

The power flow study showed that an SVC is required for the Granada wind farm to connect to the Guadalupe 345 kV station. Two SVC locations are considered in this stability study: the Project/Guadalupe 345 kV location and BA 345 kV. The power flow cases have the SVCs starting with a precontingency (N-0) output to maintain the pre-project voltage levels. These N-0 Mvars could be mechanically switched capacitors or part of the SVC capacity. Either way, the N-0 Mvars are already on-line before the disturbance happens.

For this study, dynamic models of the "**svcwsc**" type were added with typical parameters. The maximum capacitive admittance of the SVC dynamic models was set to the N-1 SVC sizes found in the power flow study, as shown in Table 2.

Table 2. Preliminary SVC Sizes from Power flow Results				
Criteria	**Without Rio Puerco**		**With Rio Puerco**	
	SVC GUAD	**SVC BA**	**SVC GUAD**	**SVC BA**
PF N-0	116	123	114	99
PF N-1	230	223	149	176

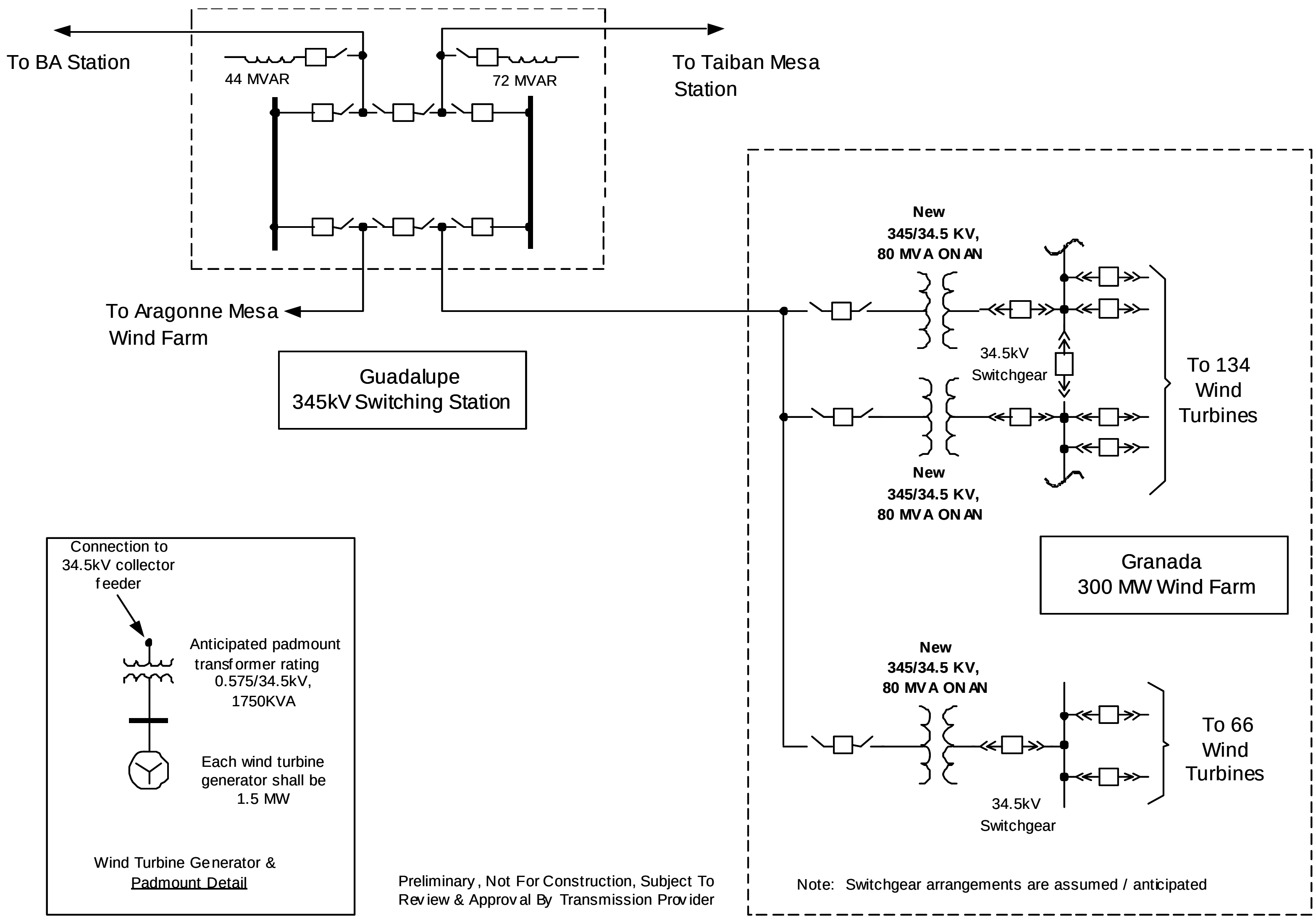

Figure 1. Granada 300 MW Project Interconnection - Preliminary One-Line Diagram

3 Stability Simulations and Results

Stability conditions were studied for N-0, N-1, N-2, and breaker failure contingencies, with investigations of static var compensator (SVC) options to accommodate the increased BB line power from the Project. The contingencies studied and the results of the stability study are given in the following sections.

3.1 Contingency Case List

The case list for the dynamic simulations is identical to that for power flow simulations as shown in Table 3. Table 3 also shows the initiating events for the contingencies.

Table 3. Case List (Dynamics Cases)

	No Rio Puerco		With Rio Puerco	
N-1 Contingencies	**Without Project**	**With Project**	**Without Project**	**With Project**
San Juan – BA 345 kV (3ph 4 cycle fault at BA)	✓	✓		
San Juan – Rio Puerco 345 kV (3ph 4 cycle fault at Rio Puerco)			✓	✓
Four Corners – West Mesa 345 kV (3ph 4 cycle fault at W.M.)	✓	✓		
Four Corners – Rio Puerco 345 kV (3ph 4 cycle fault at Rio Puerco)			✓	✓
BA – West Mesa 345 kV (3ph 4 cycle fault at BA)	✓	✓		
BA – Rio Puerco 345 kV (3ph 4 cycle fault at BA)			✓	✓
Rio Puerco – West Mesa 345 kV (3ph 4 cycle fault at R.P.)			✓	✓
Blackwater – Taiban Mesa 345 kV (3ph 4 cycle fault at T.M.)	✓	✓	✓	✓
BA – Norton 345 kV (3ph 4 cycle fault at Norton)	✓	✓	✓	✓
San Juan – Ojo 345 kV (3ph 4 cycle fault at Ojo)	✓	✓	✓	✓
West Mesa – Arroyo 345 kV (3ph 4 cycle fault at W.M.)	✓	✓	✓	✓
BA - Guadalupe 345 kV (3ph 4 cycle fault at BA)	✓	✓	✓	✓
Taiban Mesa – Guadalupe 345 kV (3ph 4 cycle fault at Guad)	✓	✓	✓	✓
BA 345/115 kV transformer (3ph 5 cycle fault at BA 115)	✓	✓	✓	✓
Norton 345/115 kV trans. (3ph 5 cycle fault at Norton 115)	✓	✓	✓	✓
Ojo 345/115 kV transformer (3ph 5 cycle fault at Ojo 115)	✓	✓	✓	✓
Sandia 345/115 kV trans. (3ph 5 cycle fault at Sandia 115)	✓	✓	✓	✓
West Mesa 345/115 kV T1 (3ph 5 cycle fault at W.M.1 115)	✓	✓	✓	✓
West Mesa 345/115 kV T2 (3ph 5 cycle fault at W.M.2 115)	✓	✓	✓	✓
N-2 Contingencies				
San Juan – BA & BA – West Mesa 345 kV (1 ph 12 cycle fault at BA)	✓	✓		
BA – Rio Puerco 345 kV (both lines) kV (1 ph 12 cycle fault at BA 345)			✓	✓
Breaker Failure Contingencies				
BA – Taiban Mesa & BA – Norton 345 kV (1 ph 12 cycle fault at BA 345)	✓	✓	✓	✓
BA – West Mesa & BA 345/115 kV transformer (1 ph 12 cycle fault at BA 345)	✓	✓		
BA – Rio Puerco & BA 345/115 kV transformer kV (1 ph 12 cycle fault at BA 345)			✓	✓

For 3 phase fault cases, zero-impedance (bolted) faults were simulated. For single-phase fault cases, the fault impedance (zero and negative sequence impedance) was modeled using impedance values provided previously by PNM.

3.2 Study Approach for Dynamics Cases

In previous analyses of wind farms on the 345 kV BB line, the critical dynamic requirement was for the wind farms to ride through (i.e. stay on line) for a three-phase fault with normal clearing at the BA 115 kV bus resulting in loss of the BA 345/115 kV transformer. This fault was simulated on the two pre-project base cases (with and without Rio Puerco) as well as the 4 post-project base cases (added Granada wind farm and two SVC locations – Project/Guadalupe or BA).

Existing and previously proposed wind farms on the BB line have doubly-fed asynchronous generators (also known as doubly-fed induction generators) wind turbines except for the 200 MW Aragonne Mesa wind farm which has conventional induction generators. The Aragonne Mesa project also has a relatively high-impedance connection to the transmission system. Aragonne Mesa's combination of conventional induction generators and high impedance in the collector system results in somewhat greater sensitivity to disturbances in the dynamics cases studied.

For the cases involving tripping of portions of the BB line the Blackwater DC was represented as an equivalent load to avoid numerical integration problems in the simulation when the HVDC is isolated from the system.

In this study, wind farms were represented with approximate positive-sequence models. The collector system was not modeled in detail. While the positive-sequence simulations provide an approximate indication, a more complete assessment of system performance should be undertaken with more complete models and simulation tools, in the context of the Facilities Study.

The Phase II studies will include detailed three-phase models of the systems on the BB line, and will cover the following topics:

- Subsynchronous Torsional Interaction (SSTI)
- Control Interactions and Coordination
- Temporary Overvoltages and Generator Self-Excitation
- Transient Recovery Voltage

The control interaction cases will include fault simulations, and these additional simulations will help to confirm the sizing of the SVC.

3.3 Dynamic Simulation Results

The applicable LVRT requirement states that generators interconnected to the BA – Blackwater transmission facilities must ride through a 3-phase 5-cycle fault at BA 115 kV with loss of the BA 345/115 kV transformer, and single-line to ground faults on the 345 kV system external to the BA – Blackwater line. Based on previous study experience, the BA 115 kV fault is the worst-case scenario with respect to the LVRT requirement. The simulation results show that the LVRT performance of the Aragonne Mesa is most at risk of being affected by the addition of the Project. In the pre-project simulations of the BA 115 kV transformer fault, Aragonne Mesa and all other wind farms stayed on line.

In all four post-project simulations with the SVC sizes listed in Table 2 above, the Aragonne Mesa wind farm tripped on undervoltage.

The Aragonne Mesa LVRT settings as given by Mitsubishi [6] are as shown in Figure 2 below.

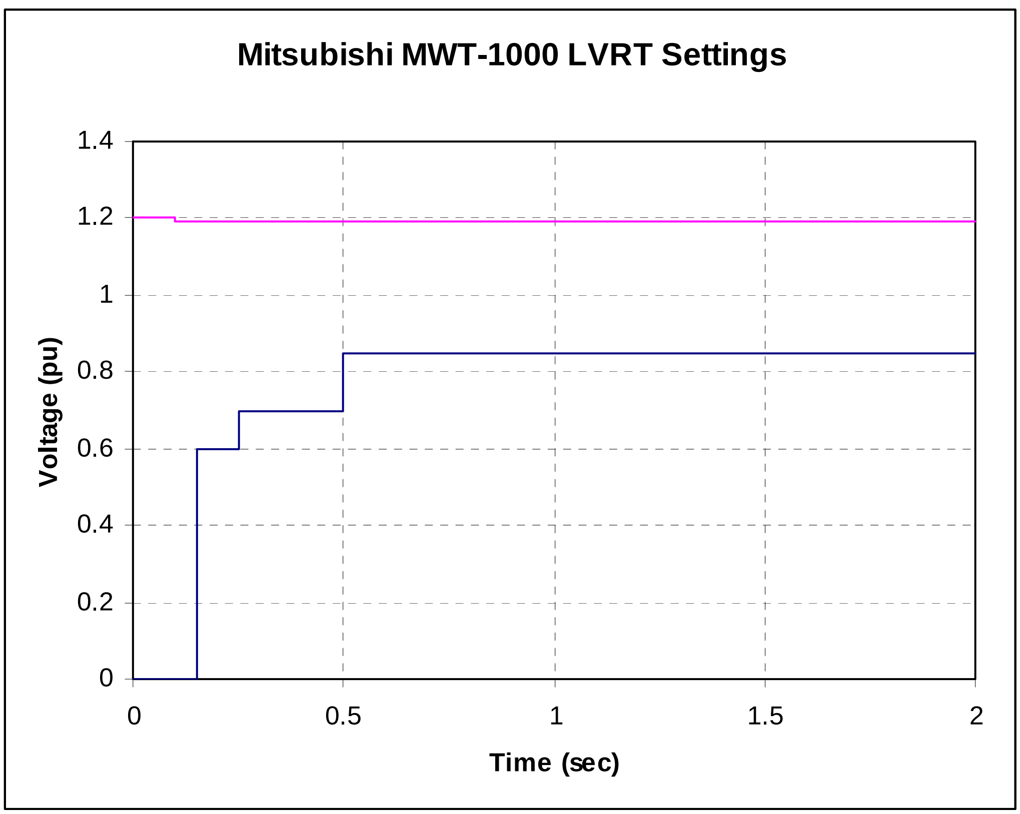

Figure 2. Mitsubishi MWT-1000 Low Voltage Ridethrough (LVRT) Settings

The SVC sizes were then increased to determine how large they need to be to keep Aragonne Mesa on line. For an SVC at Project/Guadalupe, and without Rio Puerco, increasing the size to 260 Mvar is sufficient to keep Aragonne Mesa, and all other BB line wind farms, on line for the BA 115 kV transformer fault. A 250 Mvar SVC size was sufficient in the post-Rio Puerco case, but not in the pre-Rio Puerco case.

An SVC at BA 345 was not able to keep Aragonne Mesa on line. The BA SVC size was increased as high as 600 Mvar, but Aragonne Mesa still tripped due to low voltage. Thus, the BA 345 kV location is determined to be too far from Aragonne Mesa to supply the dynamic reactive power Aragonne Mesa needs to ride through the transient conditions. Particularly after the addition of the 300 MW Granada wind farm, the flow and angle difference on the Guadalupe - BA 345 kV line are found to be too large for reactive power injection at BA 345 to help Aragonne Mesa.

The dynamic SVC sizing results were added to the end of Table 2, giving Table 4 shown below:

Table 4. SVC Sizing from Power Flow and Dynamic Simulation Results

Criteria	Without Rio Puerco		With Rio Puerco	
	SVC GUAD	SVC BA	SVC GUAD	SVC BA
PF N-0	116	123	114	99
PF N-1	230	223	149	176
DYN BA115	260	Not Feasible	250	Not Feasible

The dynamic simulation plots corresponding to the findings in Table 4 are given in Appendix A.

All dynamic faults from Table 3 were tested with a 250 Mvar SVC at Project/Guadalupe (the lower of the two values above), although 260 MVAR will be needed if the Rio Puerco project is not built. The results of these simulations are given in Appendix B.

As found in the Aragonne Mesa SIS, the Aragonne Mesa wind farm will trip for three-phase 345 kV faults at BA, West Mesa, or Rio Puerco. This is not surprising since the SVC was sized for the BA 115 kV fault, and 345 kV faults are electrically closer to Aragonne Mesa and cause more severe acceleration of the Aragonne Mesa turbines. Tolerance to 345 kV 3-phase faults is not required per PNM's LVRT requirement.

In cases where Aragonne Mesa trips, the simulations show very high voltage (> 1.2 pu) in the Aragonne Mesa area as the Aragonne Statcoms ramp from full inductive to their steady state limits after 2 seconds. The reason for this is that the S&C Statcom models as received by ABB have the capacitor switching logic disabled. If enabled and modeled as in the actual system, the Aragonne capacitor banks would switch off to remove the overvoltage after tripping of the wind turbines.

3.4 Sizing of Inductive Range of SVC

For the inductive sizing of the SVC, criteria were stated by PNM as given in Table 5 below.

Table 5. Voltage Limits	
Station	Criteria
Guadalupe 345 kV	1.2 pu temporary 1.1 pu continuous
BA 345 kV	1.06 pu

The case requested by PNM for sizing of the inductive range is the trip of the Guadalupe-Taiban Mesa 345 kV line, with the Aragonne Mesa and Granada wind farms at their full power outputs of 200 and 300 MW, respectively.

This case is included in Appendices B2 and B4 for pre-Rio Puerco and post-Rio Puerco conditions respectively, as case “3p-GT-hs-rp0-gr300-svc1” (pre-Rio Puerco) and case “3p-GT-hs-rp1-gr300-svc1” (post-Rio Puerco). These cases show the SVC going to post-disturbance output levels varying between 0 and 40 MVAR capacitive, settling to around 10 MVAR capacitive in the pre-Rio Puerco case and to around 5 MVAR in the post-Rio Puerco case. These results imply that the inductive portion of the SVC needs to be sized to be equal to or larger than the fixed (mechanically switched) capacitive portion.

For a conventional SVC with one TSC and one TCR, the TCR would be sized to be slightly larger than the TSC, for hysteresis. The anticipated TSC size is at most 146 MVAR for a 260 MVAR total capacitive range, and the TCR would thus be slightly larger than 146 MVAR. This size is sufficient to cancel the 114 MVAR mechanically switched portion of the SVC.

3.5 Compliance with Applicable WECC Over/Under Frequency Standards

WECC under/overfrequency requirements are shown in Table 6 below. These requirements should be reviewed with the manufacturer of the wind turbines for the Granada project to confirm that the turbines meet the standard.

Table 6: WECC Off-Nominal Frequency Requirements

Under-frequency Limit	Over-frequency Limit	WECC Minimum Time
> 59.4 Hz	60 Hz to < 60.6 Hz	N/A (continuous operation)
≤ 59.4 Hz	≥60.6 Hz	3 minutes
≤ 58.4 Hz	≥61.6 Hz	30 seconds
≤ 57.8 Hz		7.5 seconds
≤ 57.3 Hz		45 cycles
≤ 57 Hz	>61.7 Hz	Instantaneous trip

3.6 Voltage Coordination and Control Interaction Requirements

Day to day operation of wind farms often require some means of dynamic regulation of voltage, since both megawatt injection and megavar consumption of the wind farm change minute to minute and hour to hour (due to wind fluctuations). In the case of Granada, voltage regulation at the point of common connection is accomplished by the var absorption and var production capabilities of the wind turbines in conjunction with the dynamic vars provided by the SVC.

Benefits of sources of dynamic vars such as those provided by the DFIG wind turbines at Granada include:

1. Regulation of voltage at the point of interconnection.
2. Maintain stable operation of the wind farm for the various fault scenarios studied.
3. Prevent overvoltage conditions on the wind farm collector system (and at the point of interconnection) for cases when turbines shutdown quickly (due to high winds) or trip off (due to nearby 345 kV transmission faults).
4. Help to maintain a flat voltage profile on the collector system – this helps to keep real power losses on the collector system as low as possible. If the collector system voltage is allowed to fall with increasing power output from the wind turbines, this would also result in increased losses on the collector system.

4 Short Circuit Analysis

A short circuit analysis was performed by PNM and is included in this report. The detailed results are presented in Appendices C-1 and C-2, with the main findings summarized below.

The effects on fault duty of the Project are summarized in Table 7. The table reflects both the "before project" and "after project" cases. Based on the projected system configurations at the time of this project, there appears to be no issues with respect to fault interrupting capacity.

Table 7. Short Circuit Analysis

Station Name	Before Project	After Project
Blackwater 345kV	1040 MVA	1272 MVA
Taiban Mesa 345kV	1513 MVA	2061 MVA
Guadalupe 345kV	2118 MVA	3108 MVA
B-A 345kV	5530 MVA	6008 MVA
B-A 115kV	3719 MVA	3826 MVA

5 Cost and Construction Schedule Estimates

The table below gives estimates of the cost and construction time required to interconnect the Project and system reinforcements identified in this report. The cost and construction schedule estimates are non-binding.

<table>
<tr><th colspan="3">Table 8. For Project Output at 300 MW</th></tr>
<tr><th>System Upgrade</th><th>Estimated Cost</th><th>Time[1]</th></tr>
<tr><td>Install two breakers at Guadalupe 345 kV switching station for the Project 345 kV line and SVC</td><td>4.0 MUSD[2]</td><td>18 months[2]</td></tr>
<tr><td>SVC, including mechanically switched capacitors (MSC):</td><td></td><td></td></tr>
<tr><td>Define technical specification; contract negotiations</td><td>--</td><td>6 months</td></tr>
<tr><td>SVC Equipment</td><td rowspan="2">15.6 MUSD[3]</td><td rowspan="2">24 months</td></tr>
<tr><td>Civil works and installation (turnkey)</td></tr>
<tr><td>RAS</td><td>0.1 MUSD[2]</td><td>6 months[2]</td></tr>
</table>

[1] Includes time for permitting and construction.
[2] As estimated by PNM
[3] Includes design, engineering, manufacturing, testing at factories, transportation to site (DDP site, Incoterms 2000), installation supervision, commissioning, spares and special tools. One three-phase power transformer is included. Any permitting and sales/use taxes have been excluded.

The Phase II technical analysis will provide additional confirmation of the findings in this study. Additional reinforcements identified during Phase II, if any, will be documented as outlined in the study proposal.

6 Conclusions and Recommendations

The dynamic analysis presented in this report showed that all pre-project wind farms, including Argonne Mesa, are stable for the BA 115 kV fault before adding the 300 MW Granada wind farm. After adding Granada, a 250 Mvar SVC is needed at Project/Guadalupe to keep Argonne Mesa on line. An SVC at BA is not effective at keeping Argonne Mesa on line.

The power flow results showed a preference for the BA SVC location because the post-contingency steady-state reactive needs for the PNM system as a whole are closer to BA than Project/Guadalupe, and a Project/Guadalupe SVC would be out of service for loss of the Guadalupe – BA 345 kV line. The Project/Guadalupe SVC location also had an unsolvable breaker failure contingency in the power flow study.

The stability results described in this report are a continuation of the steady state power flow studies described in the companion report[3]. The stability analysis presented in this report show that all pre-project wind farms, including Argonne Mesa, are stable for the BA 115 kV fault before adding the 300 MW Granada wind farm. After adding Granada, an SVC is needed at the Project/Guadalupe location to allow Argonne Mesa to maintain compliance with PNM's LVRT requirement. The stability study results show that an SVC at BA is not effective at keeping Argonne Mesa in compliance with applicable LVRT standard. The transient stability analysis demonstrated that the Project/Guadalupe location would be better

For an SVC at Project/Guadalupe, and without Rio Puerco, an SVC size of 260 Mvar is sufficient to keep Aragonne Mesa, and all other BB line wind farms, on line for the BA 115 kV transformer fault. A 250 Mvar SVC size at Project/Guadalupe was sufficient in the post-Rio Puerco case, but not in the pre-Rio Puerco case.

SVC Sizing from Power Flow and Dynamic Simulation Results

Criteria	Without Rio Puerco		With Rio Puerco	
	SVC GUAD	SVC BA	SVC GUAD	SVC BA
PF N-0	116	123	114	99
PF N-1	230	223	149	176
DYN BA115	260	Not Feasible	250	Not Feasible

The case requested by PNM for sizing of the inductive range of the SVC is the trip of the Guadalupe-Taiban Mesa 345 kV line, with the Aragonne Mesa and Granada wind farms at their full power outputs of 200 and 300 MW, respectively.

This case is included in Appendices B2 and B4 for pre-Rio Puerco and post-Rio Puerco conditions respectively. These cases show the SVC going to post-disturbance output levels varying between 0 and 40 MVAR capacitive, settling to around 10 MVAR capacitive in the pre-Rio Puerco case and to around 5 MVAR in the post-Rio Puerco case. These results imply that the inductive portion of the SVC needs to be sized to be equal to or larger than the fixed (mechanically switched) capacitive portion.

For a conventional SVC with one Thyristor Switched Capacitor (TSC) and one Thyristor Switched Reactor (TCR), the TCR would be sized to be slightly larger than the TSC, for hysteresis. The anticipated TSC size is at most 146 MVAR for a 260 MVAR total capacitive range, and the TCR would thus be slightly larger than 146 MVAR. This size is sufficient to cancel the 114 MVAR mechanically switched portion of the SVC.

Preliminary design information for the SVC is given below.

Definition of Terms:

TSC: Thyristor Switched Capacitor
TCR: Thyristor Controlled Reactor

Application voltage:

Nominal high side voltage:	345 kV
Max continuous high side voltage:	345 x 1.1 = 379.5 kV
Max temporary high side voltage:	345 x 1.2 = 414 kV

Capacitive Ratings (all values at high side bus):

Steady-state (continuous) capacitive rating: 114 MVAR
(Needs to be a combination of switched filters and switched capacitor banks. The intention is to have TSC and TCR off at 114 MVAR output of SVC, thereby minimizing losses.)
Dynamic capacitive rating (TSC size): 146 MVAR
Total capacitive rating: 114 + 146 = 260 MVAR

Inductive Rating:

TCR size: $\geq$ TSC size, for hysteresis

SVC manufacturer to state the inductive MVARs at the 345 kV bus for the following conditions:

- TCR at full conduction
- TSC off
- Switched caps off
- Filters on

It is anticipated that the SVC will need to be provided with the full capability as a single project; i.e. staging of the SVC for the separate phases of the Granada project may not be practical.

Note that a short 345 kV line will connect the Project wind farm substation to the Guadalupe switchyard. Because the line is short and its impedance was not provided to ABB, this radial 345 kV line was not modeled in this study, and instead the Project

345/34.5 kV transformers were connected directly to the Guadalupe 345 kV bus. Thus, no distinction was made in the study between an SVC location at Guadalupe 345 kV bus and an SVC location at the Project 345 kV bus; hence the use of the term "Project/Guadalupe SVC location" in the report.

The Phase II technical analysis will provide additional confirmation of the findings in this study. Additional reinforcements identified during Phase II, if any, will be documented as outlined in the study proposal.

References

[1] ABB Study Proposal, "System Impact Study for the Granada 300 MW Wind Generation Project," October 16, 2006.

[2] ABB Technical Report, "System Impact Study for the Granada 300 MW Wind Farm: Phase 1, Task 1.1.1: Power flow Study," May 4, 2007.

[3] ABB Technical Report, "System Impact Study for the FPL Energy Taiban Mesa II 51 MW Wind Farm," July 17, 2006.

[4] ABB Technical Report, "Reactive Compensation System Study for the 200 MW Generation Project at Aragonne Mesa," March 22, 2006.

[5] Western Electric Coordinating Council Reliability Criteria, December 2004.

[6] Mitsubishi drawing "Mitsubishi MWT-1000A Grid Connection Technology"