Clean Line Energy Partners, LLC

Western Spirit Clean Line 345 kV

System Impact Study

February, 2017

Prepared by:

Public Service Company of New Mexico

Foreword

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EXECUTIVE SUMMARY

Clean Line Energy Partners, LLC (Transmission Developer) submitted a request to PNM, on April 8, 2016 requesting a wires-to-wires interconnection for a proposed new 345kV transmission line interconnecting to PNM's Rio Puerco 345 kV station. The Transmission Developer is jointly developing the transmission line with the New Mexico Renewable Energy Transmission Authority. This is the Western Spirit Clean Line Project (hitherto referred to as the Project).

The proposed Project will consist of a new, approximately, 140-mile long single circuit 345 kV transmission line from the Torrance, Guadalupe and Lincoln Counties area to PNM's Rio Puerco 345 kV station. The intent is to transmit up to 1000 MW of wind power generation from that area to the Rio Puerco station. This report identifies the interconnection facilities needed at the Rio Puerco station to accommodate the physical interconnection of the Project and also discusses, for informational purposes, the System Impact Study (SIS) results of transferring the Project's 1000 MW across PNM's transmission system. A subsequent SIS will be performed once PNM begins to process the Transmission Service Requests (TSRs) to move power from Rio Puerco station associated with the Project.

Steady-State Performance

The powerflow analysis shows that there is a significant impact by the Project on the PNM transmission system and identifies several minimum system and Project improvements to support the full 1000 MW transfer on an "as available" basis. These requirements are driven by three major impacts: (i) significant requirements for shunt reactive compensation at the Point-Of-Interconnection (POI) and remote end of the Project to ensure steady-state voltage stability and meet interconnection requirements for the exchange of reactive power between PNM and the Project at the POI, (ii) the addition of shunt compensation at the San Juan 345 kV station to maintain acceptable system performance, and (iii) to mitigate observed thermal overloading of certain PNM transmission elements under select contingency scenarios. The details are presented below and in the main report.

In addition, transferring the maximum 1000 MW of wind power from the Project at the POI, through PNM and into Arizona and California will likely have significant impacts on the Arizona transmission system that may require significant system upgrades for additional transmission capacity. This needs to be further studied with affected Arizona entities when transmissions service is requested by the Project.

Dynamic Stability Performance

Dynamic stability analysis shows that a proper amount and mixture of dynamic and mechanically switched shunt reactive compensation is required at the Project POI and remote end of the Project, to ensure stable transient response to various contingency scenarios.

Short Circuit Analysis

Short circuit studies were conducted to determine if the existing circuit breakers, particularly at the Rio Puerco Station, can handle the increased fault currents associated with the Project. Based on these results, the existing circuit breakers are adequate.

Rio Puerco Station Facilities

The interconnection of the Project will require the expansion of the Rio Puerco station. Figure 1 is a breaker level drawing of the proposed expected Rio Puerco station expansion to accommodate the Project interconnection.

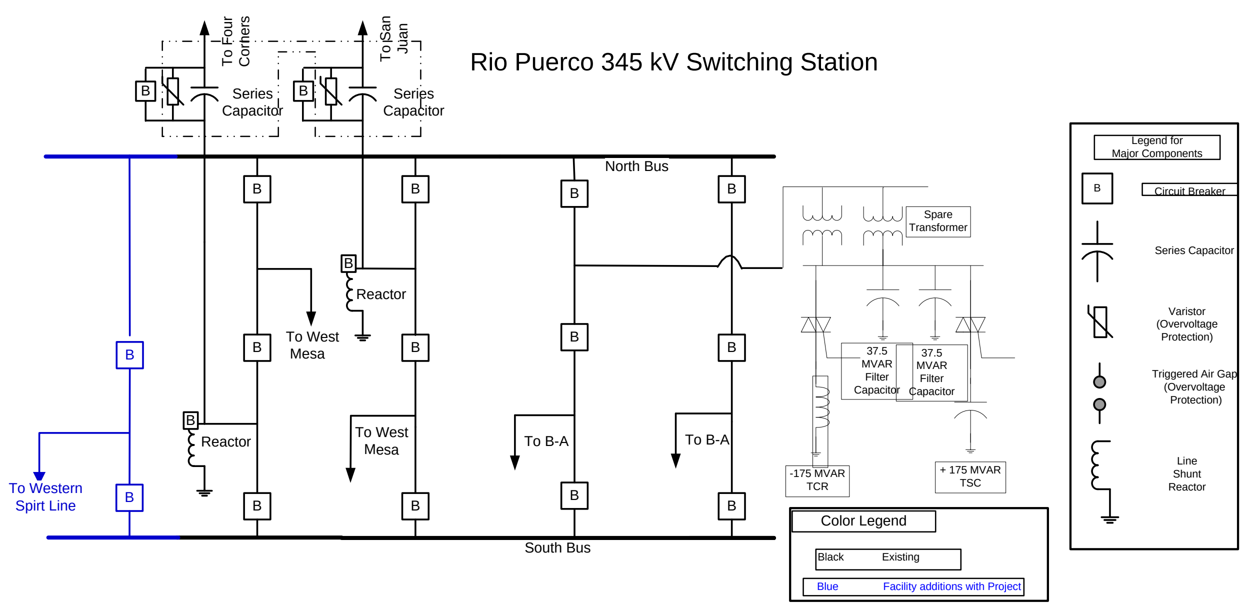

Figure 1: Proposed Rio Puerco station Expansion.

Results Summary

Project Design Considerations

The results presented in this SIS report identified additional Project facilities in order to operate and meet interconnection requirements at the POI. These facilities are assumed at the Rio Puerco end of the project line and include:

- 4 x 100 MVAr shunt capacitor banks at Rio Puerco (with associated switch-gear) end of the Project line. This is for supplying the reactive requirements of the Project at the Rio Puerco end of Project line.
- 1 x 50 MVAr line connected shunt reactor at the Rio Puerco end of the Project line. This is to absorb the 50 MVAr of line charging during minimal load conditions on the Project.

At the time of this study, the final design of the remote end of the Project line as well as the specific wind generator model were not know; thus the following equipment were added on the remote end of the Project to achieve acceptable dynamic behavior for the Type 3 and Type 4 inverter based generation models assumed in the study. For low short-circuit ratio conditions, typically lower than 2 to 3[1], potential issues will need to be addressed to insure reliable operation of inverter based generation. In this analysis, the following items were identified:

- A 200 MVA synchronous condenser at the Point-of-Common-Couple (PCC) (remote end of the 345 kV Project line). This is to provide both reactive support and improved short-circuit levels at the PCC. In addition, another 240 MVAr of shunt compensation was required to support 1000 MW. This might take the form of 3 x 80 MVAr shunt capacitors to be coordinated with the synchronous condenser.
- 1 x 150 MVAr line connected shunt reactor at the remote end of the Project line – i.e. at the PCC end. This is to absorb the 150 MVAr of line charging during minimal load conditions on the Project.

The stability analysis included in the SIS identified some additional considerations in order to achieve stable transient performance. These considerations are discussed in the report and include observations on the inertia of the recommended Project synchronous condenser, coordination of Project shunt devices at the POI and need for dynamic shunt voltage support at the remote end of the Project line that is coordinated with the synchronous condenser.

[1] WECC White Paper: Value and Limitations of the Positive Sequence Generic Models of Renewable Energy Systems https://www.wecc.biz/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/White%20Paper%20Generic%20Model%20Limitations%20December%202015.docx&action=default&DefaultItemOpen=1

The scope of this study does not cover the design, schedule or cost estimates of the Project facilities. The conclusions drawn from this study should only be viewed as an indication of the possible need of both static and dynamic reactive support at the PCC and POI. In order to properly assess the need for these reactive requirements additional studies will need to be performed by the Transmission Developer. The Transmission Developer would be responsible for assuring that the additional reactive requirements stated above meet the requirements for exchange of reactive power between PNM and the Project at the POI. Therefore, the Transmission Developer would need to develop this additional shunt reactive compensation near the Rio Puerco station with appropriate schemes for coordinating with voltage control at Rio Puerco.

Interconnection Facilities

The study identified the following modification in order to interconnect the Project to the PNM transmission system:

- Expanding the Rio Puerco Station.

System Improvements

The study further identified that transferring the full 1000 MW received from the Project at the POI to the Four Corners area will require several system improvements for the "as available" transmission service scenario assumed in the study. The minimum improvements on PNM's system to support the full 1000 MW transfer includes:

- 2 x 150 MVAr shunt capacitor banks at the San Juan 345 kV station (with associated switch gear). This is to restore the reactive margin at San Juan and prevent the San Juan generation from hitting its reactive limits during steady-state conditions.
- Adding a second BA 345/115 kV transformer to resolve thermal overloads of the existing BA 345/115 kV transformer.
- Adding a Phase-Shifting Transformer (PST) at Belen 115 kV to resolve thermal overloads of the 115 kV line to Bernardo due to multiple contingencies.
- Remedial action scheme (RAS) for transfer tripping the Project line (and wind generation) in addition to the existing PNM RAS, for the extreme contingency event of the loss of both Rio Puerco – West Mesa 345 kV lines.

There may be a need for addressing the transmission limitations observed on the Arizona transmission system. A detailed evaluation of needed solutions is outside of the scope of the present study, since these facilities are outside of PNM territory.

Interconnection Facility Costs

The cost estimates developed as part of the SIS are limited to expansion of the Rio Puerco station. The cost estimate and schedule are summarized below:

Interconnection item	Cost	Estimated Time for construction
Expand the Rio Puerco Station	$7.5 M	18 months

Qualifications

Until actual detailed models for the Project including as well as the specific wind generators are available, it is not possible to precisely specify the needed equipment and configuration. Therefore, results of this analysis are preliminary and may be modified based on more detailed technical study to analyze the control interactions between devices, temporary over-voltages, coordination of control and protection, low order harmonic resonance, and dynamic over voltages.

Future studies will be required to identify the necessary transmission facilities once the firm point-to-point transmission delivery service requests are processed. Nothing in this study is intended to imply any right to receive transmission service from PNM until such upgrades are defined and in-service.

1 INTRODUCTION

Clean Line Energy Partners, LLC (Transmission Developer) submitted a request to PNM, on April 8, 2016 requesting a wires-to-wires interconnection for a proposed new 345kV transmission line interconnecting to PNM's Rio Puerco 345 kV station. The Transmission Developer is jointly developing the transmission line with the New Mexico Renewable Energy Transmission Authority. This is the Western Spirit Clean Line Project (Project).

The proposed Project will consist of a new approximately 140-mile long single circuit 345 kV transmission line from the Torrance, Guadalupe and Lincoln Counties area to PNM's Rio Puerco 345 kV station. The intent is to transmit up to 1000 MW of wind power generation from that area to the Rio Puerco station. Figure 2 shows the proposed Project.

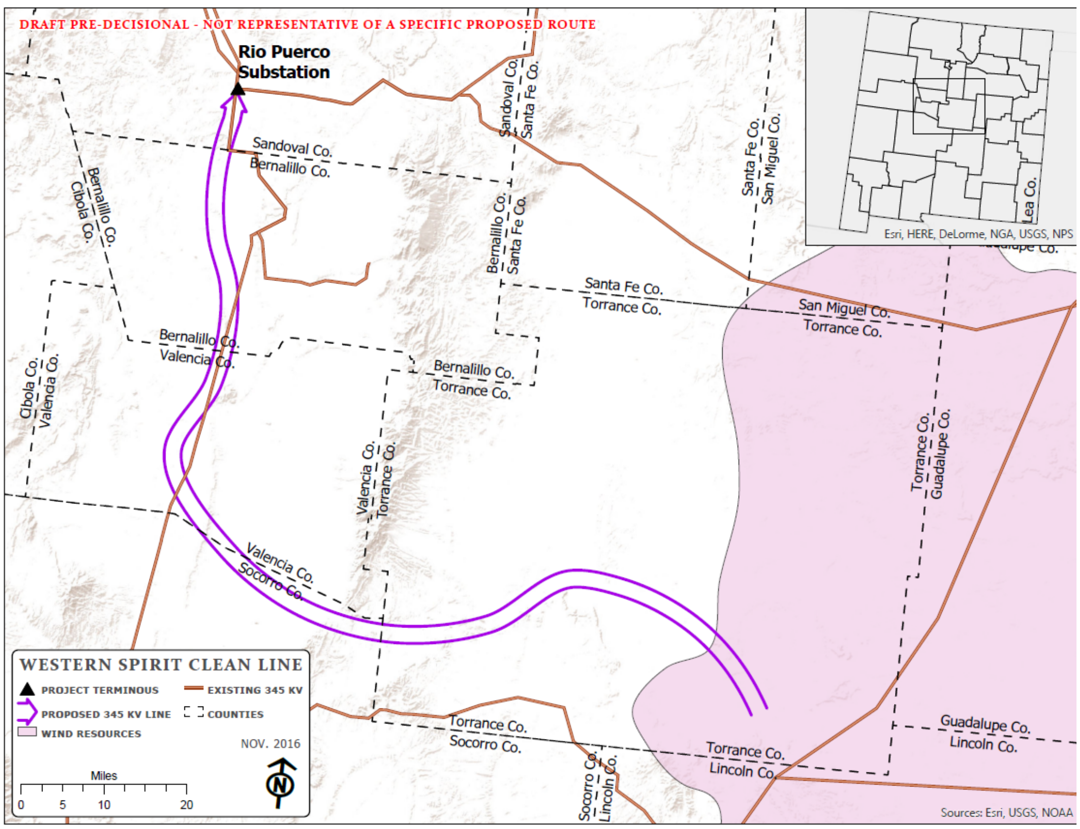

FIGURE 2: PROPOSED WESTERN SPIRIT CLEAN LINES PROJECT.

The goal of this initial system impact study is to identify the potential impact this Project, and the proposed 1000 MW of wind power injection, may have on the PNM transmission system in terms of steady-state power flow (i.e. thermal overloads that may occur on the system), system dynamic performance (i.e. transient stability) and short circuit impact (i.e. exceeding the rating of existing circuit breakers etc.). The results of this study will thus be used to inform the scope of a subsequent and separate Facility Study between PNM and the Transmission Developer which will focus on the required attachment facilities to connect the proposed Project at PNM's Rio Puerco 345 kV station. The Facility Study will be used in the development of the necessary Interconnection Agreement between PNM and Transmission Developer related to the interconnection of the Project.

The system impact study work commenced after all data and necessary information was obtained in mid-July. As specified in the signed scope of work document, the study consists of seven (7) tasks, namely:

Task 1 – Base Case Development

Task 2 – Establishing the Project Model

Task 3 – Steady-State Contingency Analysis

Task 4 – Time-Domain Transient Stability Analysis

Task 5 – Short-Circuit Analysis

Task 6 – Cost of System Upgrades

Task 7 – Final Study Report

"As Available" Transmission Assumption

The study does not assess transmission service from the POI to other points on PNM's system. A subsequent SIS will be performed once PNM begins to process the Transmission Service Requests (TSRs) to transfer power from Rio Puerco station associated with the Project. This analysis assumes transmission utilization on an "as available" basis and does not attempt to identify all limitations associated with transmission service that may require system improvements beyond the POI. The study is performed without assuming curtailment of known existing transmission commitments and does not account for requests pending in the TSRs queue beyond transmission service under study for delivery of additional wind resources out of eastern New Mexico. The study is performed with the assumption of power being delivered to Four Corners and may note certain system deficiencies resulting from the assumed delivery while not identifying deficiencies for other delivery scenarios.

2 TASK 1 –BASE CASE DEVELOPMENT

The first task involved building the peak and light load base cases without the Project to establish the starting point of the study.

Peak summer load conditions were utilized to assess the highest load levels in New Mexico overall and the maximum transfers into Northern New Mexico. High wind exports out of eastern New Mexico occur most frequently during light load conditions and are assessed in appropriate light load cases as well as some assessment of high wind during summer peak conditions.

The following cases were developed to evaluate the proposed Project:

TABLE 1 – STUDY CASES

Starting Case	Case ID	Description
2018HS	18hs	2018 Heavy Summer system for assessing the Project impacts under peak load.
2017LW	17lw	2017 Light Winter case for assessing the Project impacts and possible reactive compensation needs under light load conditions.

Generation dispatch modeled in the New Mexico area is shown in Table 2.

TABLE 2- BASE CASE GENERATION DISPATCH

Unit	Rating	18HS	17LW
Coal			
San Juan Unit 1	329	316	316
San Juan Unit 2 (Retired)			
San Juan Unit 3 (Retired)			
San Juan Unit 4 (Area Swing)	498	457	444
Escalante Generating Station	253	228	139
Four Corners Unit 4	770	770	750
Four Corners Unit 5	770	770	750
Natural Gas/Oil			
Reeves 1 (Natural Gas)	44	44	0
Reeves 2 (Natural Gas)	44	43	0
Reeves 3 (Natural Gas)	67	60	0
Rio Bravo (Natural Gas/Oil)	132	0	0

Unit	Rating	18HS	17LW
Luna Energy Facility (Natural Gas)	600	570	330
Lordsburg (Natural Gas)	80	0	0
Afton (Natural Gas)	259	235	0
Valencia Energy Facility (Natural Gas)	143	143	0
La Luz #1 (Natural Gas)	42.3	0	0
Pyramid Generating Station (Natural Gas)	168	109	0
Wind Resources*			
Taiban Mesa Wind Project	204	204	204
Aragonne Mesa Wind Project	94	94	94
Red Mesa Wind Project	102	5	102
High Lonesome Mesa Wind Project	100	5	100
Broadview/Grady	508	508	508
El Cabo	350	218	218

* Based on total installed turbine capacity. Amount delivered to POI is less.

3 TASK 2 – DEVELOPING THE PROJECT MODEL

As specified in the study scope of work document, and as provided by the Transmission Developer, the following assumptions were made to develop the Project model:

- The Project was added to the base case assuming that all of the wind generation is injected at the remote end of a single 140-mile-long radial 345 kV line terminating at the Rio Puerco 345 kV station. It was assumed that this will thus translate to 1000 MW of injected power at the Rio Puerco 345 kV station.
- The parameters of the new 345 kV line (R, X and B) was provided by the Transmission Developer, that is: R = 0.03645 Ω/mile; X = 0.58536 Ω/mile and B = 7.1665 μS/mile based on H-frame construction using bundled Lapwing conductor with a tower spacing of 27 feet.
- The wind generation (1000 MW delivered to the POI) was dispatched against generation in Arizona.
- For time-domain dynamic simulations all of the wind turbine generators (WTGs) were modeled as a 50/50 split between type 3 and type 4 WTGs, using a GE 1.5 MW model and typical parameters in GE PSLF™ for the type 3 WTGs (without the WindInertia™ and frequency response options) and assuming reasonable parameters with the WECC generic type 4 WTG model (i.e. *regc_a* + *reec_a* + *repc_a*).

While the assumptions above are utilized for the purpose of performing the SIS based on discussions with the Transmission Developer, the actual wind turbine generator models are not currently identified. Therefore, the results of the study may be subject to some future analysis once the actual vendor information/models are available.

3.1 GENERATION DISPATCH

The 1000 MW delivered to the POI was dispatched against gas-turbine and combined-cycle power plants in the Hassayampa area in Arizona. As such, all interface flows in the original base cases are respected, with the exception of flows in and out of Arizona and New Mexico. The export from New Mexico increases by 1000 MW in both cases with the Project, and the export from Arizona decreases by the same amount.

3.2 WESTERN CLEAN LINE PROJECT MODEL

The Project model developed from the assumptions above is shown diagrammatically in Figure 3. A one-line of the Project incorporating the data used in the power flow model is shown in Figure 4 and is based on the following additional assumptions:

- The line parameters were determined based on the R, X and B per mile values provided by the Transmission Developer.
- The substation transformer was assumed to be a single 825 MVA OA transformer with an impedance of 10% on this MVA base and an X/R ratio of 40.
- The equivalent feeder impedance for each of the two wind plants (type 3 and type 4) was assumed to be 0.0026 + j 0.0093 / 0.1471 pu on 100 MVA base. This is based on the typical equivalent feeder impedance of a 200 MW wind power plant, scaled to a 538 MW plant. The typical values come from the WECC modeling guide for wind power plants[2].
- The generator step-up (GSU) transformers have been scaled up in MVA to represent the typical ratio of GSU MVA to generator MW output. Also, the impedance and X/R ratio assumed for the GSU is typical of wind turbine generators.
- The voltage ratings assumed are also typical, i.e. 34.5 kV collector system and 0.7 kV at the generator terminals. Since all the calculations in positive sequence simulation programs such as GE PSLF™ are in the per unit system, the assume kV level of the collector system and generator terminals have no bearing on the results. The significant values are the impedances of the collector system and transformers.
- Each of the two aggregated wind turbine generator (WTG) models (for the type 3 and type 4 WTGs) have been assumed to be generating a maximum of 538 MW in order to achieve a total of 1000 MW of injection at the injection point at the Rio Puerco 345 kV station.

[2] https://www.wecc.biz/Reliability/WECCWindPlantPowerFlowModelingGuide.pdf

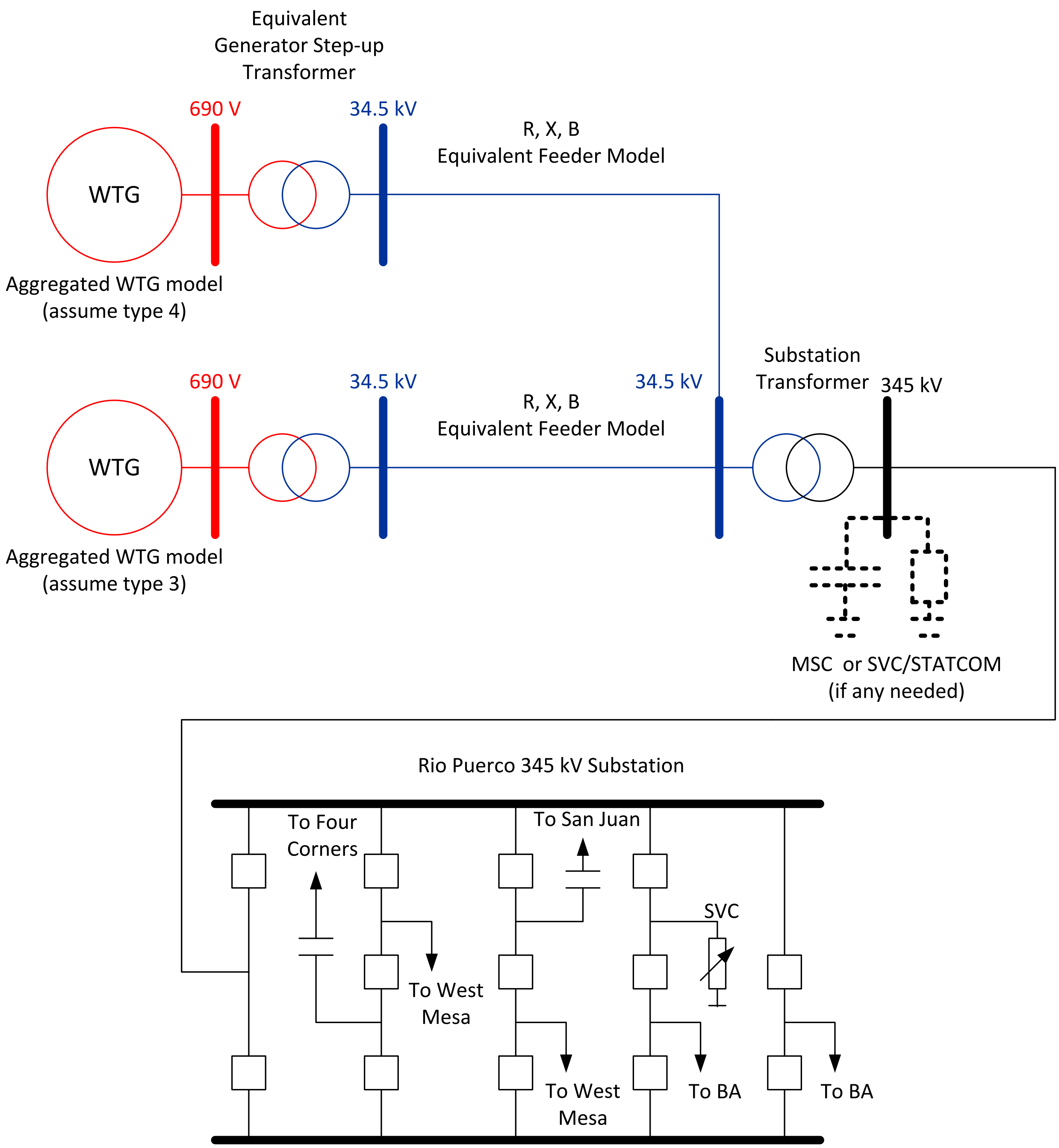

FIGURE 3: PROPOSED MODEL OF THE PROJECT

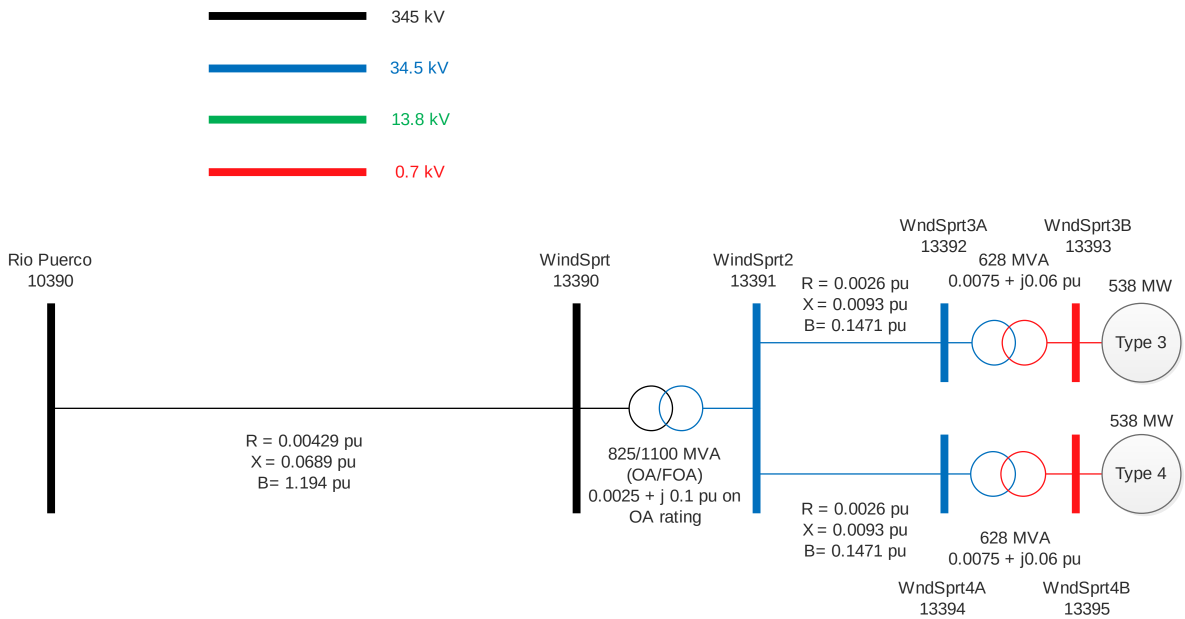

FIGURE 4: MODEL OF THE PROJECT DEVELOPED IN GE PSLF™.

As a first step, this model for the Project was added to both base cases and QV analysis was performed for the all-lines in-service condition at the remote end of the Project 345 kV line – i.e. at bus number 13390 in Figure 4. The results are shown in Figure 5. Both cases have a reactive margin that is deficient by 110 MVAr. This means that in both cases a minimum of 110 MVAr is need at the remote end of the 345 kV line (bus 13390), hitherto referred to as the PCC in order for the power flow case to solve. Per PNM and WECC planning standards it is not sufficient to have the case just barely solving and stable. There must be sufficient reactive margin to ensure stability and a reasonable range of voltage during both all-lines in-service and contingency scenarios. In order to keep the voltage at the PCC in the range of 0.95 to 1.05 pu, as much as 500 MVAr of reactive support at the PCC is required based on the QV plot. Based on this analysis several hundred MVArs of shunt reactive support at the PCC is required.

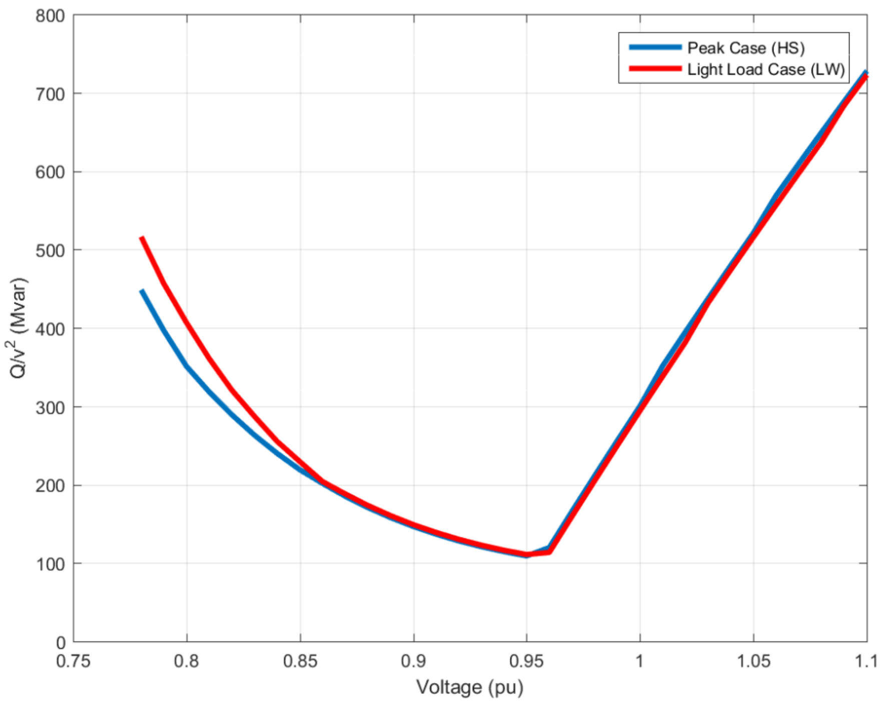

FIGURE 5: QV PLOTS AT WESTERN SPIRIT 345 KV BUS (BUS13390)

Based on calculations from PNM, the maximum and minimum short circuit level at the Rio Puerco 345 kV station is:

Maximum = 7247MVA

Minimum = 5708MVA

Temporarily neglecting the resistive component of fault impedance, these values correspond respectively to a Thevenin impedance of j0.0138 pu and j0.0175 pu on a 100 MVA base, respectively. The Project 345 kV line has an impedance of j0.0689 pu (again neglecting resistance). Thus, the estimated short circuit level at the PCC is:

Maximum = 1210 MVA

Minimum = 1157 MVA

Using the peak load case, a calculation of the short circuit level at the PCC in GE PSLF™ yields a short circuit level of 1229 MVA. This is in good agreement with the calculations above. Now consider that the total generation being connected at the PCC is 1000 MW, thus the short-circuit ratio is in the range of 1.1 to 1.2. It is a well-known fact that positive-sequence programs have limitations in properly representing the dynamic behavior of inverter based generation for low short-circuit ratio conditions that are much lower than 2 to 3[3]. Furthermore, there are actual issues that arise for inverter based generation connected at nodes with a short-circuit ratio much less than 2 to 3, namely, both the phase-lock-loop and the inner current control loops may experience oscillatory behavior, if their gains are too high. Also, with such low short-circuit levels it may also prove difficult to properly protect the transmission line with typical distance relays. As such, for the purposes of the present study it is advisable to model a synchronous condenser at the PCC to raise the short-circuit level.

With both these facts in mind, i.e. that the case is unstable without the addition of shunt compensation at the PCC, and the system may suffer from other difficulties with the low short circuit levels at the PCC, the following actions were taken:

- A synchronous condenser was added at the PCC with a rating of 200 MVA. It is modeled with typical parameters and a typical static exciter (*esst1a*). The data is shown in Appendix A.
- An SVD with a rating of +350 / -150 MVAr is also added at the PCC.

The justification again is as follows:

1. To achieve a stable response, shunt compensation is needed at the PCC. In order to allow for adequate voltage control at the PCC, based on the QV analysis, up to 500 MVAr of shunt compensation may be needed to accommodate 1000 MW of injection.
2. To increase the short-circuit level at the PCC to approximately 2000 MVA, the synchronous condenser was added.

For modelling simplicity, four (4) shunt capacitor banks were also modelled, each of 100 MVAr, at Rio Puerco, and assumed to be controlled by the Rio Puerco SVC such that they are automatically switched in if the SVC exceeds 80 MVAr, and switched out (if already in-service) if the SVC absorbs more than -50 MVAr. Such coordinated control is easily achievable and has been installed in many other similar SVC installations[4]. This is done to facilitate enough

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[3] WECC White Paper: Value and Limitations of the Positive Sequence Generic Models of Renewable Energy Systems https://www.wecc.biz/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/White%20Paper%20Generic%20Model%20Limitations%20December%202015.docx&action=default&DefaultItemOpen=1

[4] P. Pourbeik, A. Bostrom and B. Ray, “Modeling and application studies for a modern static VAr system installation”, IEEE Transactions on Power Delivery (Volume:21, Issue: 1), Page(s): 368 – 377, Jan. 2006.

additional shunt compensation at the Rio Puerco station to meet voltage control and reactive requirements between the Project and the PNM transmission system. This is needed to compensate for more than 400 MVAr (see Table 3) of reactive power flowing into the Project line at Rio Puerco with full wind generation which completely exhausts the Rio Puerco SVC and renders it incapable of support the system for contingency conditions.

The Transmission Developer would be responsible for assuring that the additional reactive requirements stated above meet the requirements for exchange of reactive power between PNM and the Project at the POI. Therefore, the Transmission Developer would need to develop this additional shunt reactive compensation near the Rio Puerco station with appropriate schemes for coordinating with voltage control at Rio Puerco. Such detailed modeling and analysis is beyond the scope of the current system impact study.

It is imperative to realize that all the analysis presented here does not consider the impact of the Project on the PNM transmission system, this is considered in the next two tasks, namely the steady-state contingency analysis and the time-domain stability simulations.

Until actual detailed models for the final Project conditions are available, it is not possible to precisely specify the needed equipment and configuration. Therefore, what has been developed here is a reasonable approach based on the present limited information available. It is a sound basis for performing the system impact study. Thus, the final proposed Project model is shown in Figure 6.

The dynamic models used for the type 3 WTGs is the default GE turbine models in GE PSLF™ (without the WindInertia™ and frequency response options). For the type 4 WTGs a typical generic model has been used. The synchronous condenser at the PCC is modeled as shown in Figure 6. The SVD at the PCC was modeled simply as a shunt and not as an SVC in dynamics.

To summarize, the following should be emphasized:

- Reactive support will be needed both at the Rio Puerco end and the remote end of the Project line.
- The most likely approach for the final design will be to utilize additional switched shunt capacitors near Rio Puerco. The Transmission Developer would need to develop this additional shunt reactive compensation near the Rio Puerco station. For the remote end, a similar approach can be taken with a synchronous condenser plus coordinated switched shunt capacitors, which are controlled by a PLC to coordinate with the reactive power output of a synchronous condenser. For the conditions where the line is lightly loaded and thus generating reactive power that needs to be absorbed, 345 kV line reactors will likely need to be installed at both ends of the line.
- The details of the control strategies and exact sizing of the switched shunt capacitors/reactors will require detailed analysis outside of the present scope of work

and to be done once more detail is known about the actual Project configuration, wind turbine equipment, collector system design etc.

- Note that the scheduled voltage at the PCC (bus 13390) is set to 1 pu throughout the simulations in order to achieve a reasonable voltage and simplify the simulations. Also, increasing the voltage schedule when injecting 1000 MW will mean a need for additional shunt compensation at the PCC. The actual final choice of voltage schedule at this location will need to be more carefully considered in the final design to try to optimize the balance between required shunt reactive support and system design. As shown in Table 3, the range of the shunt reactive support at the PCC is from -150 MVAr to 230 MVAr from 0 to 1000 MW of injection. The choice of voltage schedule and line surge impedance loading results in the reactive output of the SVD at bus 13390 to absorbing 230 MVAr capacitive for a change in power injection from 800 to 1000 MW. This is because of the assumption of keeping the voltage schedule at the PCC at 1 pu. In the final design a more careful consideration will need to be given to the voltage schedule at the PCC to minimize switching of the reactive devices – for example, introducing a voltage schedule with a deadband of 1 to 2 %.

TABLE 3: POWER FLOW SIMULATIONS FOR VARIOUS OUTPUT LEVELS OF THE PROJECT – ALL-LINES IN-SERVICE.

Case	MW		Injections at Rio Pureco (MW/Mvar)	Voltages							SVC Rio Puerco (Mvar)	Shunts Rio Puerco (Mvar)	SC Wind Spirit (Mvar)	SVD at Wind Spirit (Mvar)	Wnd Sprt3B (Mvar)	Wnd Sprt4B (Mvar)
	Wnd Sprt3B	Wnd Sprt4B		Rio Puerco 345 kV	Wind Sprt 345 kV	Wind Sprt2 34.5 kV	Wnd Sprt3A 34.5 kV	Wnd Sprt4A 34.5 kV	BA 345kV	Rio Puerco 115 kV						
HS	0	0	0 / 52	1.03	1.017	1.026	1.027	1.031	1.026	1.042	3	0	0	-150	0	45
HS	100	100	197 / 23	1.031	1.021	1.028	1.033	1.033	1.027	1.043	-13	0	29	-150	15	15
HS	0	200	197 / 19	1.031	1.018	1.024	1.031	1.031	1.027	1.043	-9	0	35	-150	21	21
HS	200	200	294 / -3	1.031	1.018	1.026	1.032	1.032	1.026	1.043	-10	0	35	-150	19	19
HS	250	250	484 / -81	1.029	1.008	1.019	1.029	1.029	1.025	1.042	21	0	55	-150	41	41
HS	300	300	577 / -137	1.031	1.002	1.015	1.027	1.027	1.027	1.044	-24	100	68	-150	56	56
HS	400	400	759 / -250	1.032	1	1.01	1.025	1.025	1.027	1.05	-28	200	72	-34	65	65
HS	538	538	1000 / -457	1.029	1	1.005	1.023	1.023	1.025	1.048	22	300	72	230	78	78
LW	0	0	0 / 45	1.037	1.024	1.03	1.031	1.033	1.031	1.042	-29	0	23	-150	0	22
LW	100	100	197 / 17	1.036	1.022	1.029	1.033	1.033	1.031	1.042	-22	0	27	-150	12	12
LW	0	200	197 / 13	1.036	1.019	1.024	1.031	1.031	1.031	1.041	-19	0	33	-150	18	18
LW	200	200	390 / - 43	1.034	1.015	1.023	1.03	1.03	1.029	1.04	12	0	42	-150	26	26
LW	250	250	484 / -89	1.037	1.01	1.019	1.029	1.029	1.031	1.042	-32	100	52	-150	37	37
LW	300	300	577 / -140	1.035	1.003	1.015	1.027	1.027	1.03	1.04	8	100	67	-150	54	54
LW	400	400	759 / -252	1.034	1	1.01	1.025	1.025	1.029	1.039	24	200	72	-37	65	65
LW	538	538	1000 / -460	1.032	1	1.005	1.023	1.023	1.027	1.044	50	400	73	224	78	78

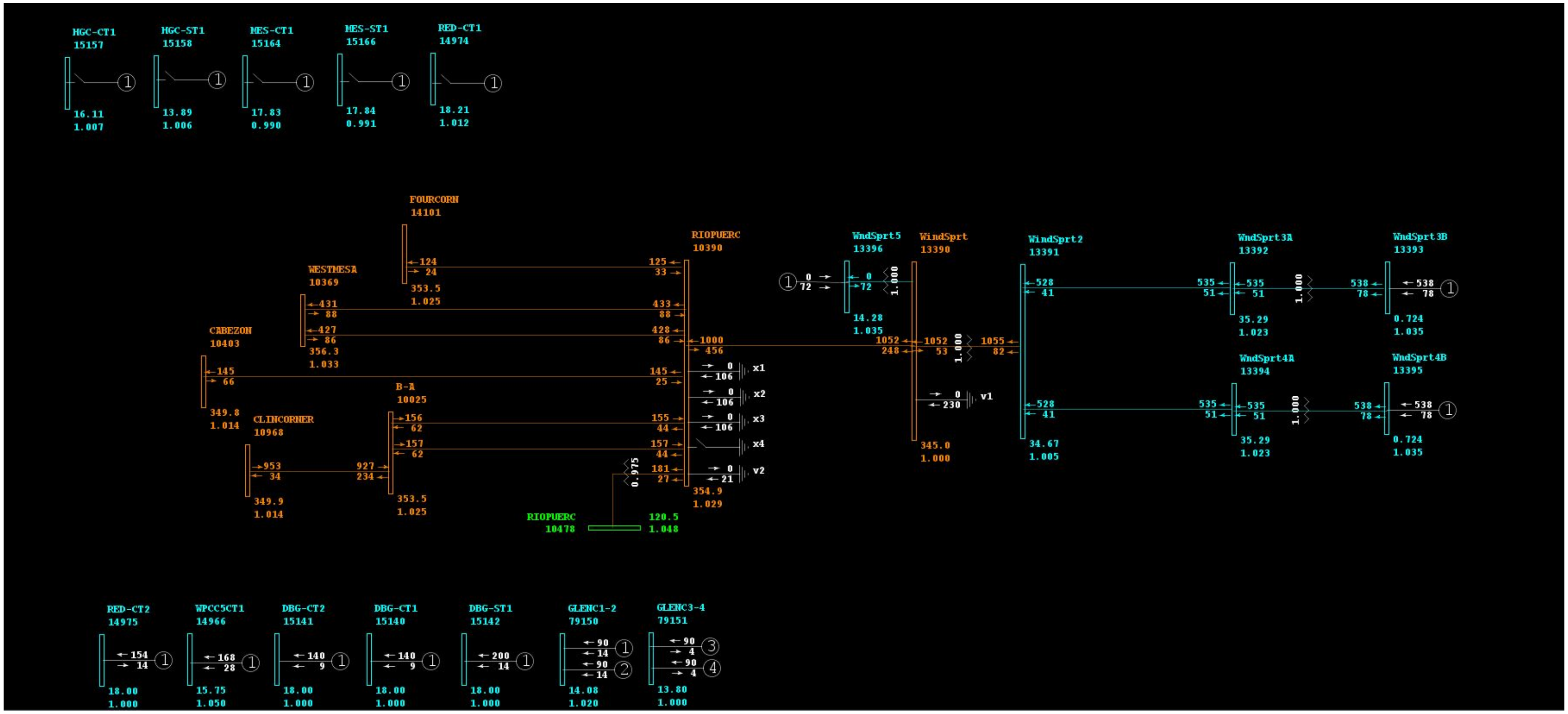

FIGURE 6: PROJECT MODEL IN THE PEAK BASE CASE.

3.3 SUMMARY OF PROJECT MODEL

As outlined above, the four (4) base cases used in the remainder of the system impact study are listed below:

- bhs18_np.sav – peak base case without the Project
- bhs18_wp.sav – peak base case with the Project
- blw17_np.sav – light load base case without the Project
- blw17_wp.sav – light load base case with the Project

Until actual detailed models for the final Project conditions are available, it is not possible to precisely specify the needed equipment, configuration and control strategies. What has been developed here is a reasonable approach based on the present limited information available. It is a sound basis for performing the system impact study. The final proposed Project model is shown in Figure 7.

The dynamic models used for the type 3 WTGs is the default GE turbine models in GE PSLFTM. For the type 4 WTGs a typical generic model has been used. The synchronous condenser at the PCC is modeled using standard generator and exciter models. The SVD at the PCC was modeled simply as a shunt and not as an SVC in dynamics, since it is assumed that in the end it may be possible to installed controlled switch shunt capacitor banks at the PCC that are with the synchronous condenser.

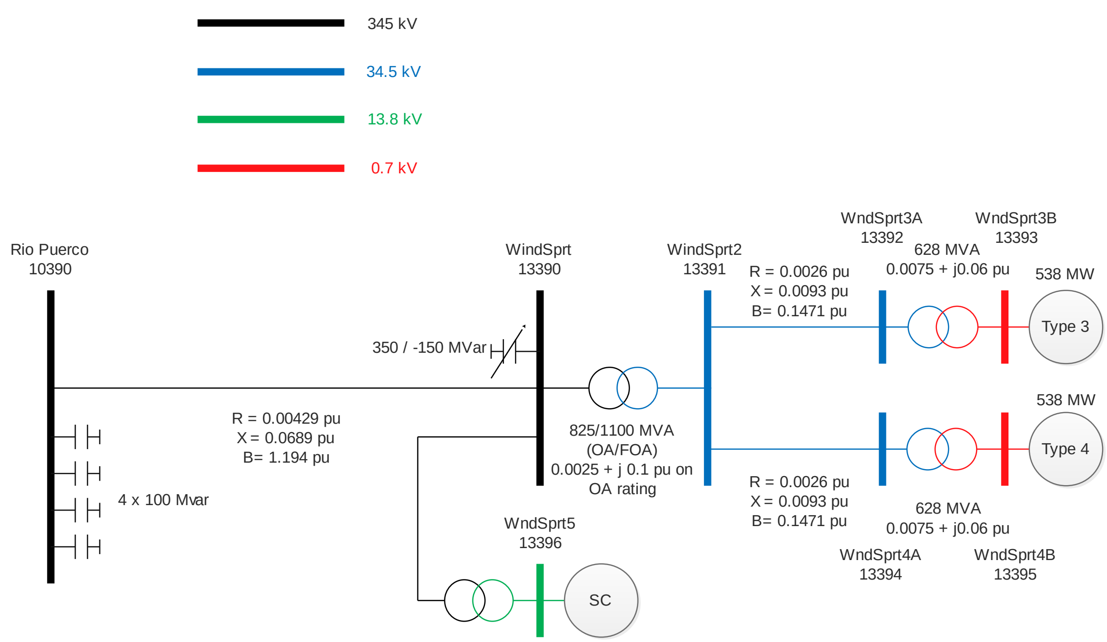

FIGURE 7: THE PROPOSED PROJECT MODEL.

4 TASK 3 – CONTINGENCY ANALYSIS

Contingency analysis was performed on the four (4) base cases developed in order to observe the potential impact of the Project on the transmission system. The steady-state criteria applied were as follows:

Table 4 – Steady State Criteria

Area	Conditions	Loading Limits	Voltage (per unit)	Voltage Drop	Application
El Paso Electric	Normal (P0)	< Normal Rating	0.95 - 1.05		69kV and above
			0.95 - 1.07		Artesia 345 kV
			0.95 - 1.08		Arroyo 345 kV PST source side
			0.90 - 1.05		Alamo, Sierra Blanca and Van Horn 69kV
	Contingency (P1-P7)	< Emergency Rating	0.925 - 1.05	7%	60 kV to 115 kV
			0.95 - 1.07	7%	Artesia 345kV
			0.95 - 1.08	7%	Arroyo 345kV PST source side
			0.90 - 1.05		Alamo, Sierra Blanca and Van Horn 69kV
			0.95 - 1.05	7%	Hidalgo, Luna, or other 345 kV buses
PNM	Normal (P0)	< Normal Rating	0.95-1.05		46 kV and above
			0.95-1.1		Taiban Mesa, Guadalupe 345 kV and Jicarilla 345 kV buses
	Single Contingency (P1)	< Emergency Rating	0.925-1.08[5]	6 %	46 kV to 115 kV
			0.95-1.1	6 %	Taiban Mesa and Guadalupe 345 kV buses
			0.925-1.08[5]	7%	69 kV to 115 kV buses in southern New Mexico
			0.90 – 1.08[5]	6 %	230 kV and above

[5] PROVIDED OPERATOR ACTION CAN BE UTILIZED TO ADJUST VOLTAGES BACK DOWN TO 1.05 PER UNIT

Area	Conditions	Loading Limits	Voltage (per unit)	Voltage Drop	Application
			0.90 – 1.08[5]	7%	230 kV and above buses in southern New Mexico
	Double Contingency (P2-P7)	< Emergency Rating	0.90-1.08[5]	10 %	46 kV and above
			0.95-1.1	10 %	Taiban Mesa and Guadalupe 345 kV buses
Tri- State	Normal (P0)	< Normal Rating	0.95-1.05		All buses
	Single Contingency (P1)	< Emergency Rating	0.90-1.1	8 %	69 kV and above except Northeastern NM and Southern NM
			0.90-1.1	8%	69 kV and above in Northeastern NM and Southern NM
	Double Contingency (P2-P7)	< Emergency Rating	0.90-1.1	10%	All buses

All equipment loadings must be below their normal ratings under normal conditions. All line loadings must be below their emergency ratings for both single and double contingencies. All transformers and equipment with emergency rating should be below their emergency rating for single and double contingencies.

The list of contingencies studied is as follows:

Table 5 - List of Steady State Contingencies

	Contingencies	Category	Pre-Project	Post-Project
0	All Lines in Service	P0	X	X
1	Ojo-Taos 345 kV Line	P1	X	X
2	San Juan-Jicarilla 345 kV Line	P1	X	X
3	Jicarilla-Ojo 345 kV Line	P1	X	X
4	San Juan-McKinley 345 kV Line 1	P1	X	X
6	San Juan-Shiprock 345 kV Line	P1	X	X

	Contingencies	Category	Pre-Project	Post-Project
7	San Juan-Cabezon-Rio Puerco 345 kV Line	P1	X	X
8	San Juan-Hesperus 345 kV Line	P1	X	X
9	San Juan-Four Corners 345 kV Line	P1	X	X
10	Four Corners-Rio Puerco 345 kV Line	P1	X	X
11	Rio Puerco-West Mesa 345 kV Line ckt 1	P1	X	X
12	BA-Rio Puerco 345 kV Line ckt 1	P1	X	X
13	BA-Norton 345 kV Line	P1	X	X
14	BA-Cline Corner-Guadalupe 345 kV Line	P1	X	X
15	West Mesa-Sandia 345 kV Line	P1	X	X
16	Norton 345/115 kV Transformer	P1	X	X
17	Rio Puerco 345/115 kV Transformer	P1	X	X
18	BA 345/115 kV Transformer	P1	X	X
19	San Juan 345/230 kV Transformer	P1	X	X
20	West Mesa 345/115 kV Transformer 1	P1	X	X
21	Ojo 345/115 kV Transformer	P1	X	X
22	Taos 345/115 kV Transformer 1	P1	X	X
23	Gladstone-Walsenburg 230 kV Line	P1	X	X
24	Comanche-Walsenburg 230 kV Line	P1	X	X
25	West Mesa-Ambrosia 230 kV Line	P1	X	X
27	Gladstone 230/115 kV Transformer 1	P1	X	X
28	Walsenburg 230/115 kV Transformer T2	P1	X	X
29	West Mesa 230/115 kV Transformer 1	P1	X	X
30	Springer-Storrie Lake 115 kV Line	P1	X	X
31	Gladstone-Springer 115 kV Line	P1	X	X
32	Valencia-Zia 115 kV Line (Zia-Eldorado-Colinas-Rowe Tap-Valencia)	P1	X	X
33	Norton-Hernandez 115 kV Line	P1	X	X
34	Ojo-Hernandez 115 kV Line	P1	X	X
35	Norton-Zia 115 kV Line	P1	X	X

	Contingencies	Category	Pre-Project	Post-Project
36	Norton-Zia-Algodones 3 terminal 115 kV Line	P1	X	X
37	Zia – BA 115 kV line	P1	X	X
38	Blue Water- Ambrosia 115 kV Line	P1	X	X
39	BA-STA Station 115 kV Line	P1	X	X
40	Four Corners-Moenkopi 500 kV line	P1	X	X
41	Four Corners-Cholla 1 345 kV	P1	X	X
42	Shiprock-Four Corners 345 kV line	P1	X	X
43	Rio Puerco – BA 1&2 345kV ckts 1 & 2	P7	X	X
44	Rio Puerco-West Mesa 345 kV ckts 1 & 2	Extreme Event	X	X
45	San Juan –Jicarilla– Ojo 345 kV line	P4	X	X
46	Ojo 345/115 kV Transformer and Ojo-Taos 345 kV Line	P4	X	X
47	Ojo-Jicarilla and Ojo-Taos 345 kV lines	P4	X	X
50	PEGS Generation and Four Corners-Rio Puerco 345 kV line	P3	X	X
51	PEGS Generation and San Juan-Rio Puerco 345 kV line	P3	X	X
52	West Mesa – Arroyo 345 kV line	P1	X	X
54	San Juan – McKinley 345 kV circuits 1 and 2	P7	X	X
58	Western Spirit Clean Line 345 kV	P1		X

4.1 RESULTS OF THE CONTINGENCY ANALYSIS

Prior to performing any contingencies, with all-lines in-service, it was noticed that a few transformers, at lower voltages and some generator step-up transformers, in the peak and light load cases were already overloaded. None of these overloads were affected by the Project, nor materially affected by any contingency. Thus, they were neglected for the rest of the analysis.

For the light load case, the Project causes an overload in the base case with all-lines in-service. The overload is on the Belen-Bernardo-Socorro 115 kV line. This overload is further aggravated by several of the contingencies, as reported below. These are shown in Table 6.

Table 6 - List of Steady State Thermal Over-Loads in the Light Load Base Cases with All-Lines In-Service

Branch	Area	Rating	Loading (pu)	
			Without Western Spirits	With Western Spirits
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	74 MVA	0.893	**1.072**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	75 MVA	0.862	**1.041**

Next the full battery of contingencies was simulated on all four (4) cases. The results are summarized below.

Voltage and Reactive Power Issues:

There were no significant voltage violations or delta-voltage violations in either the peak load or light load case. However, a significant observation is that the San Juan generation is either at or very close to its reactive limit in the base case with the Project in-service for both the peak and light load conditions. This means that in operations, the generation would be riding either on or very close to its over-excitation limit with all-lines in-service. This is not normal for an all-lines in-service condition, and not acceptable. This may put the units at risk of potentially tripping if a nearby fault or disturbance transiently pushes the unit's field voltage/current temporarily over protective limits. Figure 8 shows QV plots at the San Juan 345 kV station for both the peak and light load conditions, with all-lines in-service, with the Project and without the Project. It is clear from this QV analysis that the Project diminishes the reactive margin at San Juan by between 200 to 300 MVAr over the typical planning voltage range of 0.95 to 1.05. This is what leads to the additional 200 to 300 MVAr of reactive output from the San Juan generators to maintain the voltage at the San Juan 345 kV station as the 1000 MW of wind generation is exported from PNM system. An addition 300 MVAr of shunt compensation may be needed at the San Juan 345 kV station to accommodate the Project depending where the power is delivered. This might take the form of two 150 MVAr switched shunt capacitor banks that are manually controlled by the operator to coordinate with the reactive output of the San Juan generation. The exact sizing and amount of shunt compensation will need to be defined by more detailed transmission study.

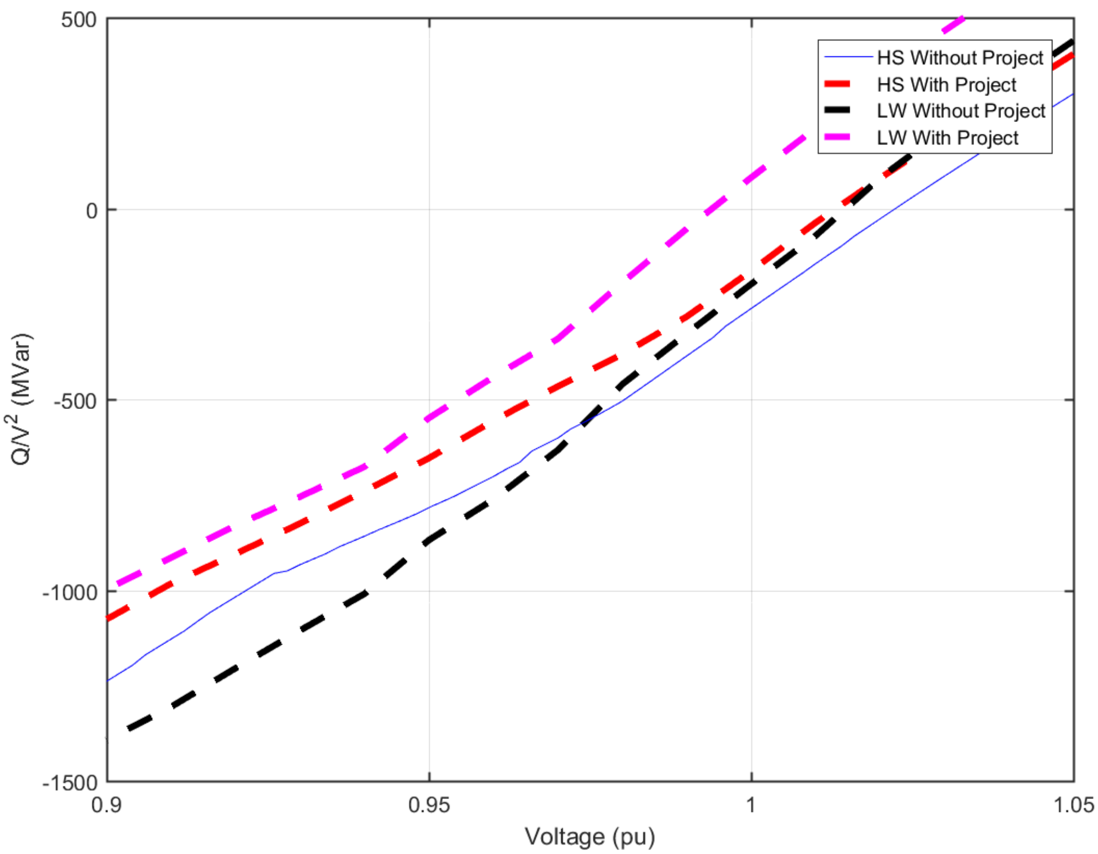

FIGURE 8: QV PLOTS FOR ALL-LINES IN-SERVICE AT THE SAN JUAN 345 BUS FOR THE PEAK AND LIGHT LOAD CASES, WITH AND WITHOUT THE WESTERN SPIRIT PROJECT

Thermal Issues:

For the peak load condition, the results of the contingency analysis are shown in Table 7. The following observations are pertinent:

- For the loss of both Rio Puerco – West Mesa 345 kV lines, there are numerous overloads on the underlying 115 kV system. All of these overloads are significantly aggravated by the Project and some half-dozen other new thermal overloads also occur on the 115 kV system. There is an existing RAS used by PNM to address the overloads seen in the base case without the Project. However, when implemented, this RAS scheme did not resolve any of the new overloads. To do so, the Project had to also be tripped. The resulting case is on the verge of a diverging power flow solution, which indicates and very severe case. Thus, although the RAS and tripping of the Project appears to resolve the thermal issues, this is a very severe case and may need more focused analysis during the facility studies for the Project.

- For the loss of either the BA–Norton 345 kV line or the Norton 345/115 kV transformer, then BA 345/115 kV transformer is overloaded. The additional of a second BA 345/115 kV transformer resolves these overloads.

For the light load case the contingency analysis results are shown in Table 8. The following observations are pertinent:

- Table 6 showed that for the light load scenario, the Belen-Bernardo-Socorro 115 kV line is overloaded with all-lines in-service. This 115 kV line is significantly overloaded for numerous contingency scenarios. This suggests that curtailment of the Project is not a viable solution when such thermal overloads occur for numerous outages. A solution identified for this problem, which resolved all these cases when simulated, is to introduce a Phase-shifting Transformer at Belen 115 kV.
- The loss of both Rio Puerco–West Mesa 345 kV lines results in the overload, with the Project, of three underlying 115 kV transmission lines. This is similar to the issues, though less aggravated, seen in the peak load case. In this case, the existing PNM RAS scheme did resolve the problem, without the need to curtail or trip the Project.
- Either one of the Four Corners–Cholla 345 kV lines is overloaded by more than 13% for the loss of the other line. Both lines are simultaneously overloaded by more than 25% for the loss of the Four Corner–Moenkopi 500 kV line. These lines are in Arizona Public Service (APS) transmission system and so no further analysis was performed here. However, it is important to note that this observation suggests that the 1000 MW of wind power being dispatch from the Project, through PNM and into Arizona and California will likely have very significant impacts on the Arizona transmission system that may require significant system upgrades for additional transmission capacity. This needs to be further studied with APS when transmissions service is requested by the Project.

TABLE 7 - LIST OF STEADY STATE THERMAL OVER-LOADS FOR CONTINGENCY ANALYSIS IN THE PEAK LOAD CASE

Branch	Area	Owner	Contingency	No.	Rating (MVA)	Loading (pu)	
						Without Project	With Project
B-A 115.00-NO_BERN 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	1.599	1.794
B-A 115.00-SIGNET_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	1.028	1.149
CORRALB 115.00-COTTONWT 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	156	1.275	1.501
COTTONWT 115.00-IRVING 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	156	1.043	1.271
NO_BERN 115.00-AVILA_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	1.549	1.743
REEVES_2 115.00-ROY 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	1.415	1.607
RIOHONDO 115.00-IRIS 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	156	1.022	1.123
ROY 115.00-AVILA_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	1.48	1.673
PACHMANN 115.00-IRIS 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	156	1.138	1.243
PALM_T 115.00-PACHMANN 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	120	1.213	1.43
RR_TAP 115.00-BLCKRA_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	120	1.078	1.292
RR_TAP 115.00-PALM_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	120	1.079	1.294
B-A 345.00-B-A 115.00 ck=1	NEW MEXICO	PN1 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	472	1.354	1.48
BLCKRA_T 115.00-SCENICNM 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	120	<0.95	1.11
PANORAMT 115.00-VERANDAT 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	156	<0.95	1.013
RIOPUERC 115.00-PRGRSS 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	200	<0.95	1.011
RIOPUERC 115.00-VERANDAT 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	200	<0.95	0.991
WESTMS_3 115.00-SCENICNM 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	120	<0.95	1.025
BROADVWW1 34.50-BROADVWW11 34.50 ck=1	NEW MEXICO	OWNER0	RIOPUERC345-WESTMESA 345 1 and 2	44	120	<0.95	1.064
TORRANCE 34.50-TORRANCE 115.00 ck=1	NEW MEXICO	TSGT New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	6	<0.95	1.439
BROADVWW 345.00-BROADVWW 34.50 ck=1	NEW MEXICO	OWNER0	RIOPUERC345-WESTMESA 345 1 and 2	44	120	<0.95	1.122
ARGONNE2 34.50-ARGN_DST 0.48 ck=1	NEW MEXICO	US Bur Reclam - N Pac Regn	RIOPUERC345-WESTMESA 345 1 and 2	44	12	<0.95	1.349
B-A 345.00-B-A 115.00 ck=1	NEW MEXICO	PN1 New Mexico	B-A 345.00-NORTON 345 ck=1	13	472	<0.95	1.01
B-A 345.00-B-A 115.00 ck=1	NEW MEXICO	PN1 New Mexico	NORTON 345.00-NORTON_1 115 ck=1	16	472	<0.95	1.01

TABLE 8 - LIST OF STEADY STATE THERMAL OVER-LOADS FOR CONTINGENCY ANALYSIS IN THE LIGHT LOAD CASE

Branch	Area	Owner	Contingency	No.	Rating (MVA)	Loading (pu)	
						Wihtout Project	With Project
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN500.00-MOENKOPI 500 ck=1	40	74	0.993	**1.241**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN500.00-MOENKOPI 500 ck=1	40	74	0.962	**1.209**
FOURCORN 345.00-CHOLLA 345.00 ck=1	ARIZONA	Arizona Public Service	FOURCORN500.00-MOENKOPI 500 ck=1	40	687	0.964	**1.256**
FOURCORN 345.00-CHOLLA 345.00 ck=2	ARIZONA	Arizona Public Service	FOURCORN500.00-MOENKOPI 500 ck=1	40	687	0.967	**1.261**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN345.00-MCKINLEY 345 ck=1	4	74	<0.95	**1.088**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN345.00-MCKINLEY 345 ck=1	4	74	<0.95	**1.057**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN345.00-RIOPUERCO 345 ck=1	7	74	<0.95	**1.147**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN345.00-RIOPUERCO 345 ck=1	7	74	<0.95	**1.115**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN345.00-RIOPUERC 345 ck=1	10	74	<0.95	**1.15**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN345.00-RIOPUERC 345 ck=1	10	74	<0.95	**1.118**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	NORTON_2115.00-HERNANDZ 115 ck=1	33	74	<0.95	**1.083**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	NORTON_2115.00-HERNANDZ 115 ck=1	33	74	<0.95	**1.051**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN345.00-CHOLLA 345 ck=1	41	74	<0.95	**1.119**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN345.00-CHOLLA 345 ck=1	41	74	<0.95	**1.087**
FOURCORN 345.00-CHOLLA 345.00 ck=2	ARIZONA	Arizona Public Service	FOURCORN345.00-CHOLLA 345 ck=1	41	687	<0.95	**1.136**
B-A 115.00-NO_BERN 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	<0.95	**1.037**
NO_BERN 115.00-AVILA_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	<0.95	**1.022**
ROY 115.00-AVILA_T 115.00 ck=1	NEW MEXICO	PN2 New Mexico	RIOPUERC345-WESTMESA 345 1 and 2	44	155	<0.95	**1.007**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN-RIOPUERC 345 and PEGS Gen	50	74	<0.95	**1.127**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	FOURCORN-RIOPUERC 345 and PEGS Gen	50	74	<0.95	**1.096**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN-RIOPUERCO 345 and PEGS Gen	51	74	<0.95	**1.123**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN-RIOPUERCO 345 and PEGS Gen	51	74	<0.95	**1.092**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	WESTMESA345.00-ARR___PS 345 ck=1	52	74	<0.95	**1.254**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	WESTMESA345.00-ARR___PS 345 ck=1	52	74	<0.95	**1.222**
BERNARDO 115.00-BELEN_PG 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN-MCKINLEY 345 ck 1 and 2	54	74	<0.95	**1.143**
BERNARDO 115.00-SOCORROP 115.00 ck=1	NEW MEXICO	TSGT New Mexico	SAN_JUAN-MCKINLEY 345 ck 1 and 2	54	74	<0.95	**1.111**

4.2 SUMMARY OF CONTINGENCY ANALYSIS RESULTS AND PROPOSED SOLUTIONS

The results of the contingency analysis may be summarized as follows:

Voltage and Reactive Power Issues:

No major voltage violations were observed, no doubt owning partly to the reactive compensation deployed at the Project PCC and Rio Puerco for ensuring steady-state voltage stability at the Project site. None-the-less, it was clearly seen that the reactive margin at San Juan is severely reduced due to the large injection of power dispatched towards Arizona. As such, there is a need for shunt compensation at the San Juan 345 kV station to ensure adequate reactive margin to prevent the San Juan generation from being at their maximum reactive limit. Based on the present analysis, this would require two (2) 150 MVAr shunt capacitors at the San Juan 345 kV station.

Thermals Issues:

There were several significant thermal overloads that were due to the Project:

- For the loss of both Rio Puerco–West Mesa 345 kV lines, there are numerous overloads on the underlying 115 kV system that are new overloads caused by the Project, both in the peak and light load case. **Solution:** *An existing RAS that trips many 115 kV radial lines alleviates this issue in the light load case, but is not enough to solve the problem in the peak load case. For the peak load case the Project (and thus all the wind generation) must be tripped.*
- For the loss of either the BA–Norton 345 kV line or the Norton 345/115 kV transformer, in the peak load case, the BA 345/115 kV transformer is overloaded. **Solution:** *A second BA 345/115 kV transformer is required.*
- Table 6 showed that for the light load scenario the Belen- Bernardo-Socorro 115 kV line is overloaded with all-lines in-service. The same elements are significantly overloaded for numerous contingency scenarios in the light load case. **Solution:** *Replace the Belen series reactors with a phase-shifting transformer.*
- The Four Corners–Cholla 345 kV circuit 1 (2) is overloaded by more than 13% for the loss of the circuit 2 (1). Furthermore, Four Corners – Cholla 345 kV circuits 1 and 2 are both overloaded by more than 25% for the loss of the Four Corner – Moenkopi 500 kV line. ***These overloaded elements are in Arizona transmission system so no further analysis will be performed in this study. However, it is important to note that these observations are indicative of potential significant impact by the Project on neighboring systems such as Arizona. This needs to be further studied with affected neighboring transmission owners.***

5 TASK 5 – TIME-DOMAIN STABILITY ANALYSIS

In this task, time-domain stability analysis was performed on all six power flow scenarios. That is:

- bhs18_np.sav – peak base case without the Project
- bhs18_wp.sav – peak base case with the Project
- blw17_np.sav – light load base case without the Project
- blw17_wp.sav – light load base case with the Project

Table 10 is the list of contingencies analyzed in time-domain stability analysis. All these cases were simulated for the six base cases. Some general comments should be made upfront:

Initially the cases were simulated for the with-Project case using the dynamics data at the PCC (bus 13390 – see Figure 6 and Figure 7) presented in the Appendix for the synchronous condenser, and making the static var device modeled into a fixed shunt. This resulted in almost every one of the 345 kV disturbances in the with-Project cases to be unstable. The reason being that (a) the synchronous condenser was too light in inertia and would quickly lose synchronism, and (b) the voltage at the PCC would not be well regulated post disturbance, since the SVD was a fixed shunt. The following changes to the "assumed" Project models were made:

a. Changed the inertia of the synchronous condenser from 1 MWs/MVA to 2.5 MWs/MVA, and the gain of its exciter to 220.
b. Changed the SVD at bus 13390 from a fixed shunt to a +350/-150 MVAr SVC.

With these changes almost all the cases were stable post-Project. Thus, the results below incorporate these changes. Since there are no details available on the design of the Project, the assumed changes are based on engineering judgment. The details of these devices are critical to the Project design and the dynamic performance of the Project and the PNM system. Thus, should this proceed to the next phase of analysis – a facility study – then a more thorough and detailed analysis will be required, with proper equipment models to better determine the actual design and required equipment to be installed. For example, it may be possible to achieve similar dynamic performance by installing a number of switched shunt capacitor banks at the 345 kV level at the PCC and having shunt capacitor banks automatically switched and coordinated through programmable logic control (PLC) with the synchronous condenser. Such detailed modeling and analysis is beyond the scope of the current system impact study.

TABLE 9 - LIST OF CONTINGENCIES FOR STABILITY ANALYSIS

	Disturbance	Category	Fault Location	Fault Type
0	No Disturbance	P0	N/A	N/A
1	Ojo – Taos 345 kV line	P1	Ojo 345 kV	3 Phase
2	San Juan – Rio Puerco 345 kV line	P1	Rio Puerco 345 kV	3 Phase
3	BA – Norton 345 kV line	P1	BA 345 kV	3-Phase
4	Walsenburg – Gladstone 230 kV line	P1	Walsenburg 230 kV	3-Phase
5	BA-Rio Puerco 345kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG
6	Rio Puerco-West Mesa 345 kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG
7	San Juan – Jicarilla – Ojo 345 kV lines	P4	Jicarilla 345 kV	SLG
8	(Not Used)			
9	Western Spirit Clean Line 345 kV	P1	Rio Puerco 345 kV	3-phase
10	B-A-Clines Corners 345 kV line	P1	Rio Puerco 345 kV	3-phase
11	Rio Puerco 345/115 kV Transformer	P1	Rio Puerco 115 kV	3-Phase
12	Rio Puerco – Four Corners 345 kV	P1	Rio Puerco 345 kV	3-phase
13	Rio Puerco – West Mesa 345 kV ckt 1	P1	Rio Puerco 345 kV	3-phase
14	Loss of Rio Puerco SVC	P2	Rio Puerco 345 kV	3-phase
15	Four Corn-Moenkopi 500 kV Line	P1	Four Corn 500 kV	3-phase

5.1 RESULTS OF THE TIME-DOMAIN STABILITY ANALYSIS

Table 11 summarizes the results of the stability analysis. Plots supporting each case are provided in the accompanying PDF files for each of the three scenarios: (i) peak (heavy summer), (ii) light load (light winter), and (iii) light load sensitivity case[6].

[6] All of the plots in the PDF files are for the cases where in the with-Project case the synchronous condenser inertia has been increased to 2.5 and the shunt at the POI is an SVC. For the sake of brevity, plots for the original cases

By perusing the table of results, and the associated plots in the PDF files, the following conclusions may be drawn from the stability analysis:

1. For the peak load case all the results are similar for all the outages with and without the Project. The one exception was disturbance 10. In this case the post disturbance voltage in PNM is oscillatory. This case was re-simulated and this time within 12 cycles after the fault two (2) of the four 100 MVAr shunt capacitor banks at Rio Puerco (introduced per the power flow analysis, for supporting the reactive losses of the Project) were tripped. This resulted in acceptable post-contingency voltages. This reaffirms what was stated in the power flow analysis, that the 4 x 100 MVAr shunt capacitors at Rio Puerco should be coordinated with the existing Rio Puerco SVC and automatically controlled/switched by the SVC for voltage control.
2. For the light load case the system behaves generally the same with and without the Project for all the scenarios simulated. The one exception is disturbance 12, where the with-Project case has greater voltage swings.
3. The loss of the Project, when the wind power plants are at peak load – i.e. 1000 MW of injection, will cause a significant frequency dip throughout the entire WECC system. In the light load case, the system wide frequency settles at around 59.9 Hz. This is not as low as the current largest single contingency on the WECC system (the loss of a Paloverde Unit), but it is quite close to that value. This is something to be noted.

Thus, the general conclusion that can be drawn is, as mentioned previously, that the details of dynamic devices to be incorporated into the Project are critical to the Project dynamic performance and the overall dynamic performance of the PNM system. Namely, the control strategy of the wind power plants, the dynamics of the synchronous condenser, and the nature of the controls and switching of the shunt compensation both at the remote and Rio Puerco end of the Project line. Should this proceed to the next phase of analysis a more thorough and detailed analysis will be required, with proper equipment models to better determine the actual design and required equipment to be installed. For example, it may be possible to achieve similar dynamic performance by installing a number of switched shunt capacitor banks at the 345 kV level at the POI and having shunt capacitor banks automatically switched and coordinated through programmable logic control (PLC) with the synchronous condenser. Such detailed modeling and analysis is beyond the scope of the current system impact study.

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with a fixed shunt at the POI and a light inertia SC (H =1) have not been included, since most of these cases were unstable as mentioned.

TABLE 10 – STABILITY RESULTS

No.	Disturbance	NERC Category	Fault Location	Fault Type	Extra Actions Taken (e.g. RAS)	Verde Project	Without Project	With Project
1	Ojo - Taos 345 kV	P1	Ojo 345 kV	3-phase	None	No	Stable	Stable
2	San Juan - Rio Puerco 345 kV	P1	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
3	BA - Norton 345 kV	P1	BA 345 kV	3-phase	None	No	Stable	Stable
4	Walsenburg - Gladstone 230 kV	P1	Walsenburg 230 kV	3-phase	Tri-State RAS	No	Stable	Stable
5	BA - Rio Puerco 345 kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG	Trip Taiban Mesa - Blackwater 345 kV	No	Stable	Stable
6	Rio Puerco - West Mesa 345 kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG	None	No	Stable	Stable
7	San Juan - Jicarilla - Ojo 345 kV	P4	Jicarilla 345 kV	SLG	None	No	Stable	Stable
9	Western Spirits Clean Line 345 kV	P1	Western Spirit 345 kV	3-phase	None	No	N/A	Stable
10	BA - Cline Corners 345 kV	P1	BA 345 kV	3-phase	None	No	Stable	Oscilatory Voltages
11	Rio Puerco 345/115 Transformer	P1	Rio Puerco 115 kV	3-phase	None	No	Stable	Stable
12	Rio Puerco - Four Corners 345 kV	P1	Four Corners 345 kV	3-phase	None	No	Stable	Stable
13	Rio Puerco - West Mesa 345 kV ckt 1	P1	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
14	Loss of Rio Puerco SVC	P2	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
15	Four Corners - Moenkopi 500 kV	P1	Four Corners 500 kV	3-phase	None	No	Stable	Stable
1	Ojo - Taos 345 kV	P1	Ojo 345 kV	3-phase	None	No	Stable	Stable
2	San Juan - Rio Puerco 345 kV	P1	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
3	BA - Norton 345 kV	P1	BA 345 kV	3-phase	None	No	Stable	Stable
4	Walsenburg - Gladstone 230 kV	P1	Walsenburg 230 kV	3-phase	Tri-State RAS	No	Stable	Stable
5	BA - Rio Puerco 345 kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG	Trip Taiban Mesa - Blackwater 345 kV	No	Stable (large V swing)	Stable (large V swing)
6	Rio Puerco - West Mesa 345 kV ckts 1 & 2	P7	Rio Puerco 345 kV	SLG	None	No	Stable	Stable
7	San Juan - Jicarilla - Ojo 345 kV	P4	Jicarilla 345 kV	SLG	None	No	Stable	Stable
9	Western Spirits Clean Line 345 kV	P1	Western Spirit 345 kV	3-phase	None	No	N/A	Stable
10	BA - Cline Corners 345 kV	P1	BA 345 kV	3-phase	None	No	Stable	Stable
11	Rio Puerco 345/115 Transformer	P1	Rio Puerco 115 kV	3-phase	None	No	Stable	Stable
12	Rio Puerco - Four Corners 345 kV	P1	Four Corners 345 kV	3-phase	None	No	Stable	Stable (large V swing)
13	Rio Puerco - West Mesa 345 kV ckt 1	P1	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
14	Loss of Rio Puerco SVC	P2	Rio Puerco 345 kV	3-phase	None	No	Stable	Stable
15	Four Corners - Moenkopi 500 kV	P1	Four Corners 500 kV	3-phase	None	No	Stable	Stable

6 TASK 5 – SHORT-CIRCUIT ANALYSIS

A short circuit analysis was performed[7] to determine if there is an increase in fault duty that results from the addition of the Project. It was assumed the Project consisted of 50/50 split between Type 3 and Type 4 WTGs. The results did not identify a significant increase in fault duty or breakers that would exceed the interrupt rating as a result of the Project addition. The table below shows the fault duty identified at Rio Puerco before and after addition of the Project.

TABLE 11 - FAULT DUTY IMPACTS

	Pre-Project Short Circuit MVA		Post-Project Short Circuit MVA	
Bus	3-Phase	L-G	3-Phase	L-G
Rio Puerco 345	8122	8478	8936	9151

[7] The short circuit study assumed the generation projects in PNM's generation queue.

7 TASK 6 – COST ESTIMATES FOR SYSTEM UPGRADES

The conclusions drawn from this study should only be viewed as an indication of the possible need of both static and dynamic reactive support at the PCC and POI. In order to properly assess the need for these reactive requirements additional studies will need to be performed by the Transmission Developer. The Transmission Developer is responsible for assuring that the additional reactive requirements stated above are sufficient to meet interconnection requirements for exchange of reactive power between PNM and the Project at the POI. Therefore, the Transmission Developer would need to develop this additional shunt reactive compensation near the Rio Puerco station while coordinating with PNM on the overall control of the compensation.

For now, the cost estimate is limited to expansion of the Rio Puerco station. The cost estimate and schedule are summarized below:

Interconnection item	Cost	Estimated Time for construction
Expand the Rio Puerco Station	$7.5 M	18 months

8 SUMMARY

Based on the analysis performed in this system impact study, the introduction of the Project into the PNM system will have a significant impact on the PNM transmission system, and may also have a significant impact on the neighboring Arizona transmission system.

<u>Project Design Considerations</u>
The results presented in this report identified additional Project facilities in order to operate and meet interconnection requirements at the POI. These facilities are assumed at the Rio Puerco end of the Project line and include:

- 4 x 100 MVAr shunt capacitor banks at Rio Puerco (with associated switch-gear) end of the Project line. This is for supplying the reactive requirements of the Project at the Rio Puerco end of Project line.
- 1 x 50 MVAr line connected shunt reactor at the Rio Puerco end of the Project line. This is to absorb the 50 MVAr of line charging during minimal load conditions on the Project.

At the time of this study, the final design of the remote end of the Project line as well as the specific wind generator model were not know; thus the following equipment were added on the remote end of the Project to achieve acceptable dynamic behavior for the Type 3 and Type 4 inverter based generation models assumed in the study. For low short-circuit ratio conditions, typically lower than 2 to 3[8], potential issues will need to be addressed to insure reliable operation of inverter based generation. In this analysis, the following items were identified:

- A 200 MVA synchronous condenser at the PCC (remote end of the 345 kV Project line). This is to provide both reactive support and improved short-circuit levels at the PCC. In addition, another 240 MVAr of shunt compensation was required to support 1000 MW. This might take the form of 3 x 80 MVAr shunt capacitors to be coordinated with the synchronous condenser.
- 1 x 150 MVAr line connected shunt reactor at the remote end of the Project line – i.e. at the PCC end. This is to absorb the 150 MVAr of line charging during minimal load conditions on the Project.

From a stability analysis perspective, it was found that for the system response to be stable with the addition of the Project, the following assumptions had to be made at a minimum:

[8] WECC White Paper: Value and Limitations of the Positive Sequence Generic Models of Renewable Energy Systems https://www.wecc.biz/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/White%20Paper%20Generic%20Model%20Limitations%20December%202015.docx&action=default&DefaultItemOpen=1

1. That the synchronous condenser has inertia of at least 2.5 MWs/MVA, and a fast-acting static exciter.
2. That control of the shunt compensation at the Rio Puerco end of the Project line is coordinated with voltage control at the Rio Puerco station.
3. That the shunt compensation at the remote end of the Project line is in the form of an SVC. A more detailed analysis during the facility studies stage may reveal that PLC controlled switch shunt capacitors that are coordinated with the synchronous condenser and automatically switched may also yield a similar dynamic performance, but such determinations will require more detailed analysis at the facility studies stage.

The scope of this study does not cover the design, schedule or cost estimates of the Project facilities at the POI and PCC. The conclusions drawn from this study should only be viewed as an indication of the possible need of both static and dynamic reactive support at the PCC and POI. In order to properly assess the need for these reactive requirements additional studies will need to be performed by the Transmission Developer. The Transmission Developer would be responsible for assuring that the additional reactive requirements stated above meet the requirements for exchange of reactive power between PNM and the Project at the POI. Therefore, the Transmission Developer would need to develop this additional shunt reactive compensation near the Rio Puerco station with appropriate schemes for coordinating with voltage control at Rio Puerco.

Interconnection Facilities

The study identified the following modification in order to interconnect the Project to the PNM transmission system:

- Expanding the Rio Puerco Station at a cost of $7.5 M.

System Improvements

The study further identified that transferring the full 1000 MW received from the Project at the POI to the Four Corners area will require several system improvements for the "as available" transmission service scenario assumed in the study. The minimum improvements on PNM's system to support the full 1000 MW transfer includes:

- 2 x 150 MVAr shunt capacitor banks at the San Juan 345 kV station (with associated switch gear). This is to restore the reactive margin at San Juan and prevent the San Juan generation from hitting its reactive limits during steady-state conditions.
- Adding a second BA 345/115 kV transformer to resolve thermal overloads of the existing BA 345/115 kV transformer.
- Adding a Phase-Shifting Transformer (PST) at Belen 115 kV to resolve thermal overloads of the 115 kV line to Bernardo due to multiple contingencies.

* Remedial action scheme (RAS) for transfer tripping the Project line (and wind generation) in addition to the existing PNM RAS, for the extreme contingency event of the loss of both Rio Puerco – West Mesa 345 kV lines.

There may be a need for addressing the transmission limitations observed on the Arizona transmission system. A detailed evaluation of needed solutions is outside of the scope of the present study, since these facilities are outside of PNM territory.

Frequency Response Impacts

Finally, as shown in the stability analysis, when the Project is at a transfer level of 1000 MW (which may only occur rarely), the loss of the Project line will cause a significant WECC wide system frequency decline, which can be as much as 100 mHz. This makes the Project one of the largest contingencies in the whole of WECC in terms of system wide frequency events.

Qualifications

Until actual detailed models for the Project including as well as the specific wind generators are available, it is not possible to precisely specify the needed equipment and configuration. Therefore, results of this analysis are preliminary and may be modified based on more detailed technical study to analyze the control interactions between devices, temporary over-voltages, coordination of control and protection, low order harmonic resonance, and dynamic over voltages.

Future studies will be required to identify the necessary transmission facilities once the firm point-to-point transmission delivery service requests are process. Nothing in this study is intended to imply any right to receive transmission service from PNM until such upgrades are defined and in-service.

APPENDIX A WESTERN SPIRIT STABILITY MODEL

TABLE 11: MODEL PARAMETERS FOR THE SYNCHRONOUS CONDENSER

```
gentpj                13396 "WindSprt5    " 13.80   "1 "   : #9
mva=200.0000  "tpdo" 5.0000 "tppdo" 0.0300 "tpqo" 0.5000 "tppqo"
0.0400 "h" 1.0000 "d" 0.0000 "ld" 1.7000 /

"lq"  1.6000  "lpd"  0.2000  "lpq"  0.3500  "lppd"  0.1600  "lppq"
0.1700 "ll" 0.1400 "s1" 0.1500 "s12" 0.4500 "ra" 0.0001 "rcomp"
0.0000 "xcomp" 0.0000 "accel" 0.5000 "kis" 0.0000

esst1a             13396 "WndSprt5    "  13.80   "1 "   : #9 "tr"
0.0  "vimax"     999.00  "vimin"    -999.00  "tc"  1.000000  "tb"
10.0000 "ka"   190.00 "ta" 0.020000 "vrmax"   7.8000 "vrmin"   -
6.7000 "kc" 0.050000 /

"kf"  0.0  "tf"  1.000000  "tc1"  0.0  "tb1"  0.0  "vamax"    999.00
"vamin"  -999.00 "ilr" 0.0 "klr" 0.0 "uelin" 0.0 "pssin" 0.0
```

APPENDIX B STABILITY PLOTS

Heavy Summer Results

Appendix B Stability Plots - HS.pdf

Light Winter Results

Appendix B Stability Plots - LW.pdf