Rensselaer

CERTS Project
Voltage Stability Applications using Synchrophasor Data

Report 4
Simulation Studies and Sensitivity Functions:
SCE Wind Hub Study

Submitted by
Joe H. Chow and Maximilian Liehr

Rensselaer Polytechnic Institute
110 8th Street
Troy, NY 12180-3590

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Prepared for
Dejan J. Sobajic, Project Manager

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Disclaimer

Introduction

This is a report for Task 4. This report will focus on the Southern California Edison (SCE) Wind Farm Study.

The original work statement for Task 4 is given as follows.

Task 4 Objective: Specify loadflow cases and dynamic simulations for scenarios selected in Task 2, to validate and complement measured historical PMU data.
Approach: The RPI project team will work with WECC member organization engineers to discuss the detail of the simulations. It is assumed that the loadflow and dynamic simulation will be performed by host WECC member engineers who will work closely with the RPI project team.

As discussed in the proposal, the research team felt that the dynamic simulation would be needed to estimate the true voltage collapse point. However, the development of the AQ-bus method, dynamic simulation is no longer needed. In addition, with the focus of the research on the voltage stability of wind hubs in median to lower voltage transmission systems, a large data set is not needed. The best use of the project resource is to propose methods for wind hub voltage stability margin calculation using the AQ-bus method. This report describes a voltage stability study for a wind hub in the SCE system.

SCE Wind Farm Study

The Tehachapi, California, is one of the best wind resource area in the country, as described by an NREL conference paper[1] published about 10 years ago. In this paper, the authors proposed several ways of providing reactive power support for the region, including a 45-MVar switched capacitors at 15 Mvar each installed at Monolith, and reactive power support at each wind farm.

Following the NREL study and based on system data provided by Armando Salazar of SCE, Figure 1 has been developed as a simplified electrical network connection of the Tehachapi wind region. In this system, 10 wind farms are connected to the 66 kV Antelope-Bailey system which Monolith substation is a part of. The wind farms can be separated into three groups; Windparks, Windlands, and Windfarms. Two windfarms Dutchwind and Flowind will also be included in this study. The total ratings for the windfarms are: Windparks (79.9 MW), Windfarms (144.5 MW), Windlands (73.5 MW), and the other two windfarms (54.5 MW). Thus the maximum output of the system is 352.4 MW/MVA. The total reactive power support given by shunt capacitors for the system is 180 MVar. The system base used in this study is 100 MVA.

The Monolith substation is directly connected to the three main groups of windfarms. Monolith is also connected to some smaller loads including the Cummings, Breeze, and Bor-Hav-Lor-Walker buses. The main load that is present in this area is the Windhub bus and will be considered the swing bus. It is also directly connected to every windfarm area.

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[1] H. Romanowitz, E. Muljadi, C. P. Butterfield, and R. Yinger, "Var Support from Distributed Wind Energy Resources," Proceedings of World Renewable Energy Congress VIII, Denver, Colorado, 2004.

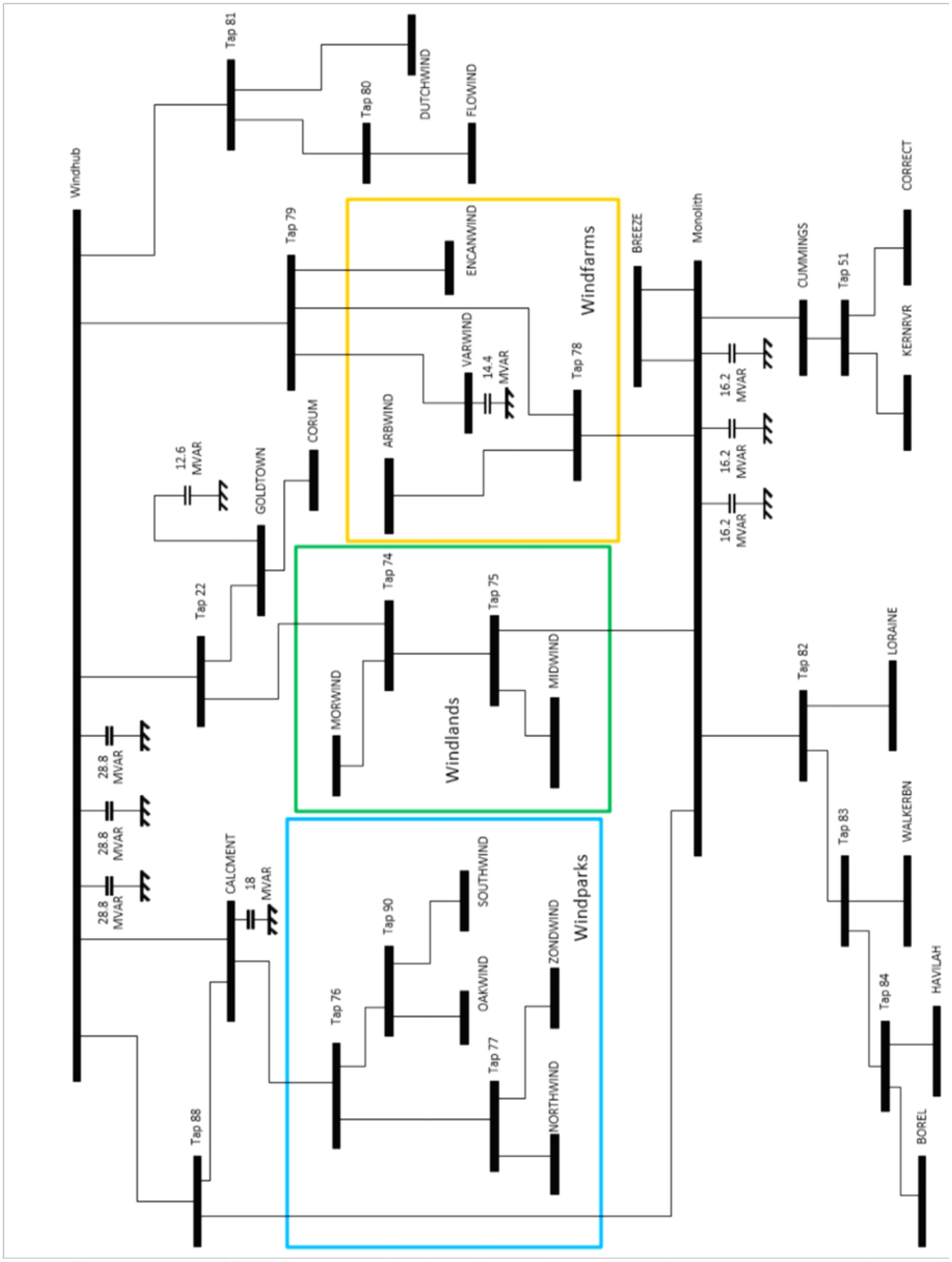


Figure 1: Monolith System Overview

This study will perform a voltage stability analysis for active power is flowing from the windfarms to the areas of load. The maximum real and reactive power outputs and requirements will also be looked at. The data requirements for voltage stability analysis are:

1. Voltage and (P,Q) flow measurements of the individual wind farms and the Monolith and Windhub Buses. The measurements at the Monolith substation are down-sampled PMU data from the PMU located at Monolith. No measurements beyond the Windhub bus were used.
2. Line parameters of the network shown in Figure 1.

Because the main load that is present in this area is the Windhub bus, the largest amount of power will be flowing to this bus. In fact around 90% of the generation flows in this direction. The AQ-bus method is applied to the Windhub connection lines to determine the voltage stability limits for the wind farm outputs. The increase in power will be proportional to the maximum output of each windfarm.

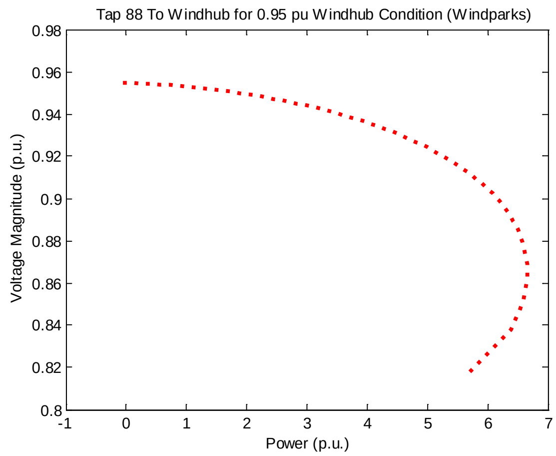
Results

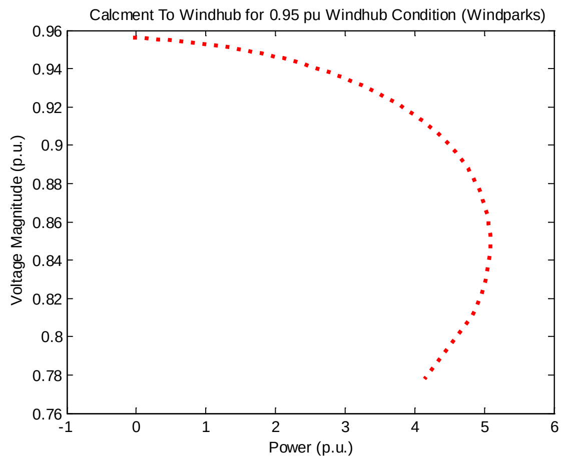
In order to utilize the AQ bus method we must push the power output out as far as possible. Thus, we will plot until and past the voltage collapse point. Two separate cases were performed for voltage stability analysis. Each case focused on the power flow through the lines directly connected to the Windhub bus. Case 1 represented a starting voltage of 0.95 pu for the Windhub bus whereas case 2 at a starting voltage of 1.0 pu for the Windhub bus. The results obtained from running the AQ bus method are plotted in Figure 2.

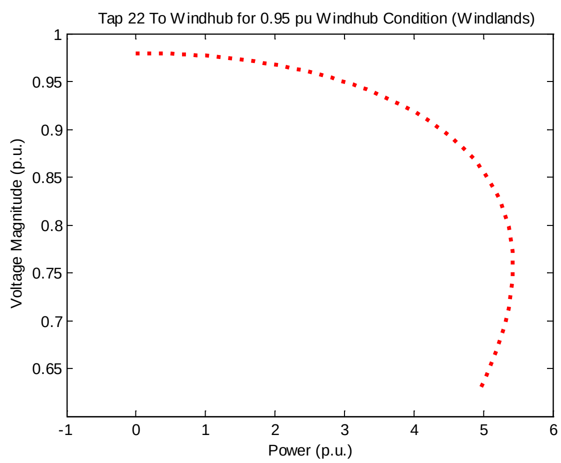
These results show a clear indication for voltage stability within the system. When looking at the maximum power output of the installed windfarms, of 3.524 pu, we see that the maximum power output will be reached well before the voltage collapse point. In fact, if the maximum output from the windfarms were to double, the system would still be considered within a stable region of operation. Furthermore, the most constraining paths are Tap 88, Cal Cement, and Tap 22, whereas Tap 79 and Tap 81 still have more transfer margin (as they have yet to show a voltage collapse point).

Using these plots, it seems that the system can handle more wind farms, in addition to those already installed. To illustrate, the PQ curve for the Windhub bus is plotted in Figure 3. This plot shows clearly the reactive power support needed to accommodate the increase in power generation.

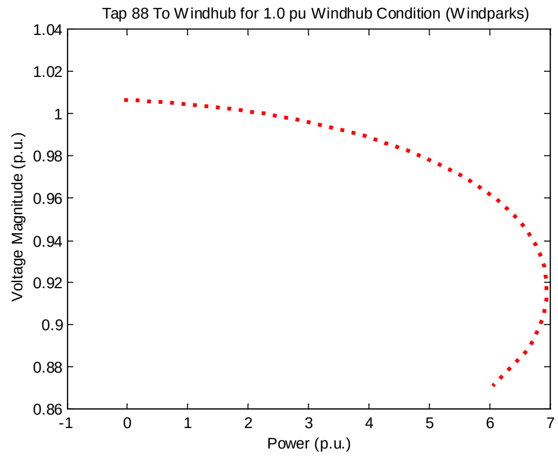
Case 1: 0.95 pu Voltage at Windhub

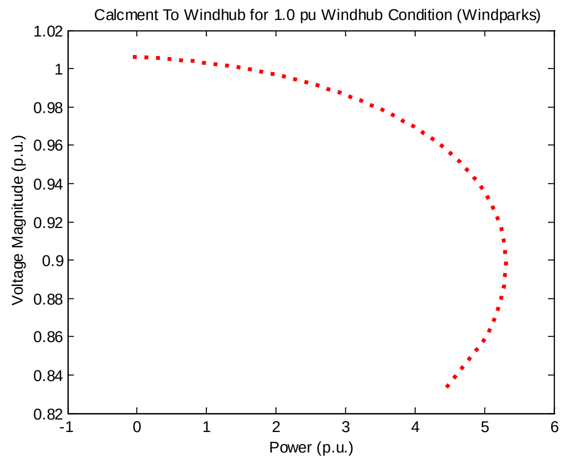


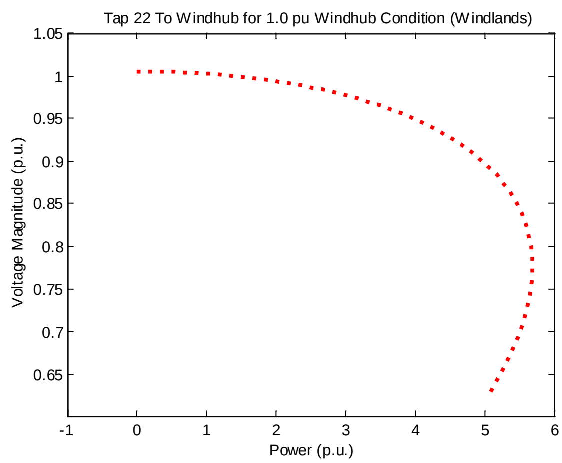




Case 2: 1.0 pu Voltage at Windhub







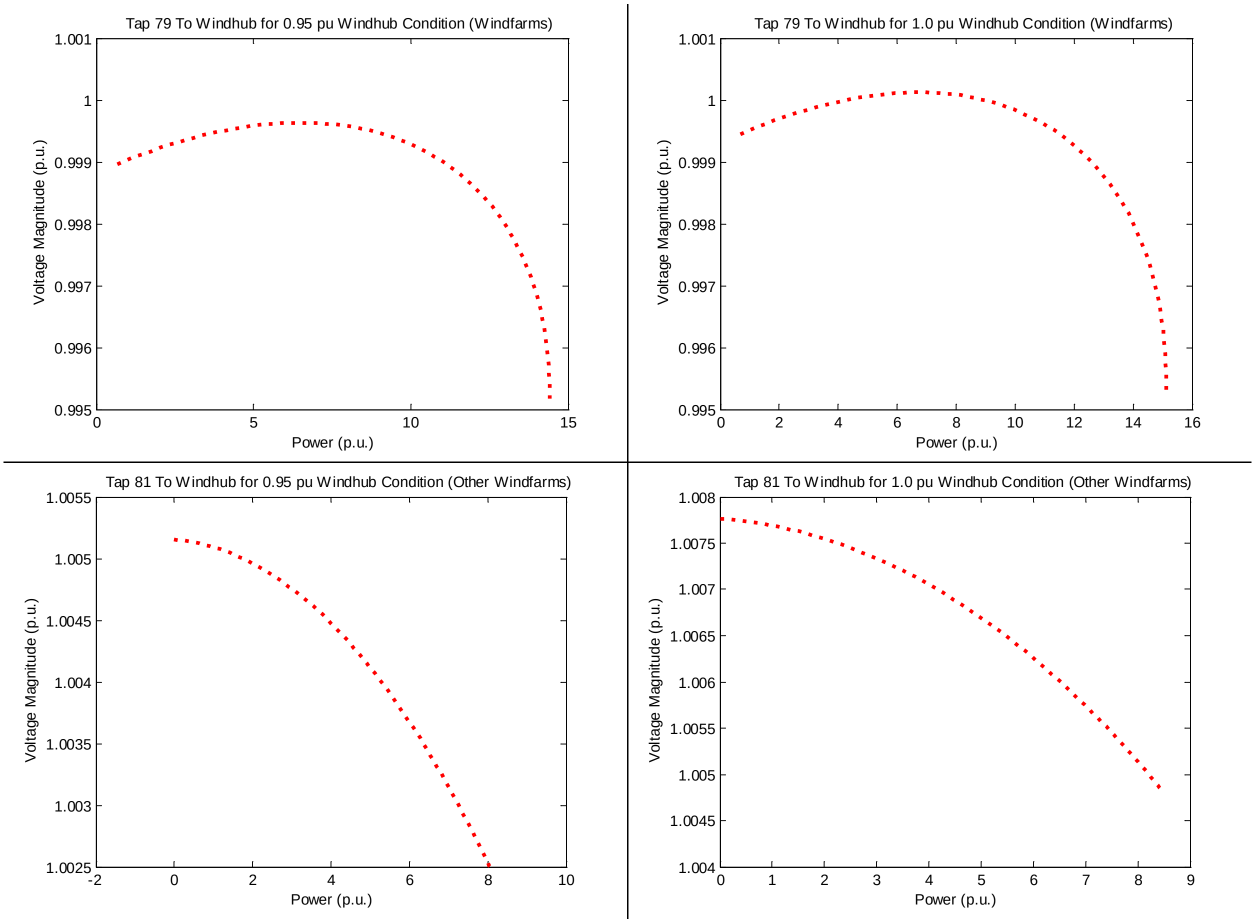


Figure 2: PV Curves for Power Transfer to Windhub Bus – left column: Windhub voltage starts at 0.95 pu, and right column: Windhub voltage starts at 1.0 pu

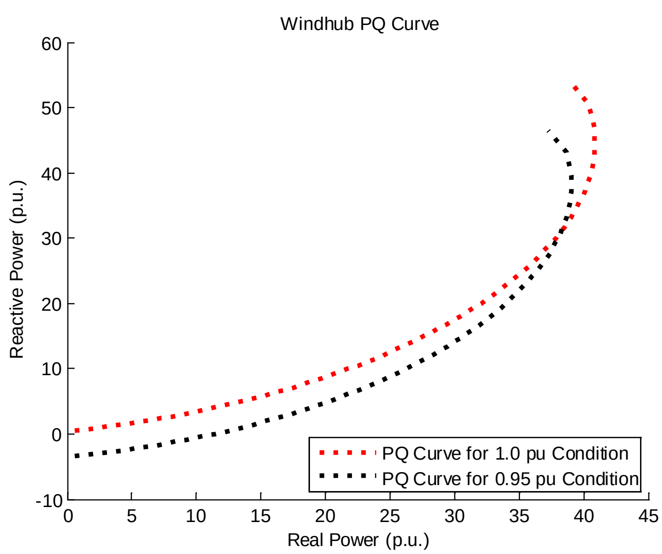


Figure 3: PQ Curves for Windhub Bus

Figure 3 shows that at higher levels of real power output, a large amount of reactive power is needed. At the current maximum power output the system's reactive shunt support is clearly enough to handle the system. When the power is increased some new shunt capacitors will need to be installed as well as use of reactive support from generators within the system. Some key values for the PQ curves are shown below in Table 1. The active power flows on the various lines into the Windhub bus can be found from the PV curves shown in Figure 2.

Table 1: Values for Real and Reactive Power for 1.0 pu Condition

Real Power Flow	Reactive Power Flow Required
3.3514 pu	1.2183 pu
6.9009 pu	2.2743 pu
40.8775 pu	44.7453 pu

These values represent the reactive power support needed for real power flow through the combined lines to the Windhub bus. The first row represents the amount of flow for the current maximum generation of 3.524 pu (as the flow is around 90% of the generation). The second represents double the maximum and the third the maximum output of the PQ curve.

Conclusions

In this report we have shown the results of the AQ bus method voltage stability analysis for the Monolith SCE system. At the current maximum real power output the system is voltage stable. The Monolith area can in fact hold a much larger amount of wind generation while maintaining stability. If the generation limit were to double through more wind farm installations, then the system would go beyond the shunt reactive power support. However, with more shunt installments and increased use of reactive support from generators, the system should remain voltage stable. Further increase of wind farm installation would require substantial reactive power investment, or new transmission/distribution line investment.