Supplement to GI-2007-13 SIS
Review of Cedar Point Reactive Power Compensation System –- Without DSTATCOM

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A. Executive Summary

The GI-2007-13 System Impact Study (SIS) report published by Public Service Company of Colorado (PSCo) on December 11, 2009 indicated that interconnection of the 250 MW Cedar Point wind generation facility using Vestas V-90 VCUS turbines would cause WECC/NERC transient voltage criteria violations for certain contingencies, prior to the 345 kV line from Pawnee to Smoky Hill being in-service. Therefore, the SIS report suggested installing a dynamic reactive power device at Cedar Point to mitigate these criteria violations. Accordingly, a 10 MVAR DSTATCOM has been installed at one of the 34.5 kV substations at the generation facility. This DSTATCOM failed during testing at Cedar Point and will not be quickly repaired. To address this problem, the Vestas V-90 **VCUS** turbines have been modified to V-90 1.8 MW **VCSS** turbines. The main difference between the two types of turbines is that the original VCUS turbines operate under unity power factor, i.e they do not supply or absorb reactive power; while the VCSS units, provide dynamic reactive support between 0.95 power factor (p.f.) lagging to 0.9 p.f. leading. During post-contingency conditions when the system comes back to steady state, the VCSS units provide the same amount of reactive support as under pre-fault conditions. This report details the findings of stability analysis performed by Siemens Energy Inc., Siemens Power Technologies International (Siemens PTI) for certain specific contingencies to determine the impact of replacing the DSTATCOM at the Cedar Point wind generation facility with newer wind turbine controls which enable the wind turbines to provide dynamic reactive support.

The results of this supplemental analysis indicate that the use of the V90 VCSS turbines in place of the VCUS turbines plus dynamic reactive device results in a reliable system with voltages within relevant criteria for the contingencies studied. For the critical outage of the Pawnee to Story 230 kV line to clear a three phase fault by the Pawnee 230 kV bus, the dynamic power capabilities of the VCSS turbines keep the voltage dip at Pawnee within the maximum voltage dip criteria. With the Point of Interconnection (POI) for the facility at Missile Site, faults at that location can be critical. With the tripping of the Pawnee to Missile Site or Missile Site to Daniels Park 230 kV line to clear a fault by Missile Site, when DSTATCOM is out of service and the 50 MVAR capacitor near Missile Site is in-service, the final steady state voltage at the generation facility and at the POI exceeds 1.05 per unit. However, when the overvoltage tripping scheme for the

capacitor banks at the Cedar Point 34.5 kV substation bus are implemented, the post-transient voltage at the POI and the generation facility remain within 5% of the pre-fault voltage.

B. Power Flow Case Setup

For this analysis, the power flow case that was used for the GI-2007-13 SIS was the starting point. In that power flow case, the wind turbines for GI-2007-13 (now referred to as Cedar Point) were modeled as individual Vestas V-90 VCUS 1.8 MW wind turbines connected together with a detailed as-designed 34.5 kV collector system. To meet the need for dynamic reactive support as recommended in the SIS report, a DSTATCOM was being installed at the wind farm, with adjustments to the size of the switched shunt capacitors and reactors. After the DSTATCOM failed during the testing phase which would limit the ability of Cedar Point to deliver power to PSCo, changes to the Vestas turbines were considered to be one option that could allow reactive power capability to be provided during severe PSCo-system disturbances such that relevant reliability criteria to be met. All the generators for Cedar Point generation in the power flow have been modified to represent the capabilities of the VCSS wind turbines being implemented. The total generation at the facility was set to its maximum capacity of 250 MW, unchanged from the GI-2007-13 SIS. For this study, the DSTATCOM has been reflected in the power flow database but set offline. The switched capacitors at the two 34.5 kV substation buses are switched on such that the generators operate at unity power factor. In this case, 13 MVAR of capacitors have been switched on at both the east and west 34.5 kV substations, while the 9 MVAR reactors at those substations would be offline. A 50 MVAR capacitor bank close to the POI has also been set in-service. The sizes of the switched shunt devices are somewhat different than those reflected in the SIS, but prior stability analysis with the DSTATCOM in service indicated that the reliability criteria would be met

Siemens PTI became aware of potentially higher voltage levels at the Missile Site than reflected in the heavy summer power flow case. Therefore, additional analysis was performed to establish if there would be the potential to trip generation at Cedar Point due to high voltages under contingency conditions. To simulate higher voltage levels at Missile Site, generation at Manchief and Peetz Logan was placed offline with generation reduced in southeastern Colorado. This raised the voltage at Pawnee and Missile Site to greater than 1.04 per unit under a normal system configuration.

C. GI-2007-7 SIS Stability Analysis Results

The 2009 SIS report indicated that interconnecting the full 250 MW (with Vestas VCUS turbines) from Cedar Point at Missile Site was stable with no WECC voltage or frequency criteria violations on the PSCo system for most contingencies. However, certain voltage criteria are violated for contingencies 8, 16, 17, 18 and 19 as shown in Table 1. The recommendation that some form of

dynamic reactive power support be added at GI-2007-13 was in part due to the criteria violation noted for contingency 8.

Table 1: Results of Transient Stability Analysis Performed for the GI-2007-7 SIS

Num	Fault Location	Action	Benchmark Cases 2010 and 2013	With Generation at Cedar Point 2010 Case	With Generation at Cedar Point 2013 Case
1	Pawnee 230	Trip Pawnee - Daniel Park 230 KV	stable, no viol	-	-
2	Pawnee 230	Trip Pawnee - Ft. Lupton 230 KV	stable, no viol	stable, no viol	stable, no viol
3	Pawnee 230	Trip Pawnee – Brick Ctr 230 KV	stable, no viol	stable, no viol	stable, no viol
4	Daniel Park 230	Trip Pawnee - Daniel Park 230 KV	stable, no viol	-	
5	Ft.Lupton 230	Trip Pawnee - Ft. Lupton 230 KV	stable, no viol	stable, no viol	stable, no viol
6	Pawnee 230	Trip Pawnee 22/230 KV Transformer Drop Pawnee Unit G1	stable, no viol	stable, no viol	stable, no viol
7	Daniel Park 230	Trip Daniel Park 230/345 KV ckt 1	stable, no viol	stable, no viol	stable, no viol
8	Pawnee 230	Trip Pawnee - Story 230 KV	stable, no viol	max voltage dip > 25% Vpre-fault	stable, no viol
9	-	Drop Pawnee Unit G1	stable, no viol	stable, no viol	stable, no viol
10	Pawnee 230	Trip Pawnee – Pawnee-cap 230 KV Trip Pawnee-cap -Peetz Logan 230 kV	stable, no viol	stable, no viol	stable, no viol
11	-	Trip Pawnee - Ptzcap 230 KV Trip Ptzcap - Peetz Logan 230 KV	stable, no viol	stable, no viol	stable, no viol
12	Story 230	Trip Pawnee - Story 230 KV	stable, no viol	stable, no viol	stable, no viol
13	CP 34KV 1 34.5	Trip Cedar Point 34.5/230kV Transformer	-	stable, no viol	stable, no viol
14	CP_SUB2_230	Trip CP230SUB1- CP230SUB2 230 KV	-	stable, no viol	stable, no viol
15	Missile Site	Trip Missile Site - CP230SUB2 230 KV	-	stable, no viol	stable, no viol
16	Missile Site	Trip Missile Site - Daniel Park 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
17	Missile Site	Trip Missile Site - Pawnee 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
18	Pawnee 230	Trip Pawnee - Missile Site 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
19	Daniel Park 230	Trip Missile Site- Daniel Park 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
20	Pawnee 345	Trip Pawnee-Smoky Hill 345 kV	-	-	stable, no viol
21	Smoky Hill 345	Trip Pawnee-Smoky Hill 345 kV	-	-	stable, no viol

D. Updated Stability Analysis Results

The focus of this supplemental study was to determine if the modification of the wind turbine characteristics, from V-90 VCUS to V-90 VCSS, in place of the DSTATCOM would allow the Cedar Point facility to operate during severe system disturbances and not have an adverse impact on PSCo. Specifically, this study focused only on the contingencies with criteria violations in the 2009 SIS.

For contingency 8, the results of the stability analysis indicated that the VCSS turbines provide sufficient reactive power dynamically to keep the transient voltage deviation at Pawnee within 25% of the initial voltage, the most critical contingency. However for contingencies 16 through 19, the final voltage deviation at the Missile Site POI and at all buses at the generation facility

exceeds 5% of the initial voltage. The final voltage also exceeds 1.05 per unit at these buses with voltages as high as 1.091 per unit at the generator buses.

The switched shunts at the 34.5 kV substation buses at Cedar Point have a protection scheme which prevents extremely high voltages on the wind farm. At the west substation, the protection relay is set to block capacitors/reactor switching when the voltage at the 230 kV substation bus reaches 1.05 per unit. When the voltage reaches 1.08 per unit all capacitors are switched out instantaneously while the reactor is switched in. Similarly at the east substation, when the voltage at the 230 kV substation bus reaches 1.10 per unit, all capacitors are switched out instantaneously while the reactor is switched in.

Once the overvoltage protection scheme for the capacitor banks at the east and west substations was implemented in PSS®E; the post-contingency overvoltages for contingencies 16 through 19 were mitigated. The overvoltage protection scheme tripped the capacitors at both the east and west substations and switched in the 9 MVAR reactor at the west substation. This kept the post-contingency voltage at the POI to be within 5% the pre-fault value and the voltages at the buses on the west substation are lower than their pre-fault values. The reactor can be prevented from switching in by adding a delay to its operation when the voltage rises to 1.08 per unit.

Since the voltage levels at the POI have been observed to be near 1.05 per unit at times, additional analysis was also performed with the POI voltage raised to about 1.04 per unit. In order to achieve this voltage profile, the generation at Peetz Logan and Manchief was switched off. This decreased the loading on the 230 kV circuit from Pawnee to Daniels Park and raised the voltage at Missile Site. The capacitor bank at the POI was online to assist in raising the voltage at the POI. The capacitors at the Cedar Point generator 34.5 kV substation buses were left online and the wind turbines were providing 250 MW in this case. With this setup, no voltage or frequency criteria violations were observed for contingency 8. For contingencies 16 through 19, the post-contingency voltage at the POI and the generation facility is around 1.063 per unit; but the voltage deviation is less than 5%. However, if the overvoltage protection scheme for the switched shunts is implemented, no voltage violations are observed.

Table 2: Results of Transient Stability Analysis Performed for Cedar Point VCSS Turbines

Num	Fault Location	Action	With VCSS at Cedar Point 2010 Case	With VCSS at Cedar Point and High Voltage Capacitor Tripping
8	Pawnee 230	Trip Pawnee - Story 230 KV	stable, no viol	stable, no viol
16	Missile Site	Trip Missile Site - Daniel Park 230 KV	final ΔV>5% at POI,	stable, no viol
17	Missile Site	Trip Missile Site - Pawnee 230 KV	final ΔV>5% at POI,	stable, no viol
18	Pawnee 230	Trip Pawnee - Missile Site 230 KV	final ΔV>5% at POI,	stable, no viol
19	Daniel Park 230	Trip Missile Site- Daniel Park 230 KV	final ΔV>5% at POI,	stable, no viol

E. Conclusion

The results of stability analysis show that the newer Vestas V-90 1.8 MW VCSS turbines supply an adequate amount of dynamic reactive power, thus minimizing the need for the DSTATCOM. However, the outage of either the Pawnee to Missile Site or Missile Site to Daniels Park 230 kV line causes high post-contingency steady state voltages at the POI and generation facility when the 50 MVAR capacitor close to the POI is in-service. This issue is mitigated by the by the overvoltage protection mechanism which trips the capacitors at the 34.5 kV generation facility substation and switches in the reactor at high voltage.