Engineering Support Services for:

Rock Island HVdc Project

Midcontinent Independent System Operator

Attention:
Eric Thoms

Report R1299.00.00

Executive Summary: Steady State and Dynamic Analysis

Prepared by:

TransGrid Solutions Inc.
200 – 150 Innovation Dr.
Winnipeg, MB R3T 2E1
CANADA

www.transgridsolutions.com

Jan-27, 2015

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Revisions

Project Name:	Rock Island HVdc Project
Document Title:	Executive Summary: Steady State and Dynamic Analysis
Document Type:	Final report
Document No.:	R1299.00.00
Last Action Date:	Jan-27, 2015

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	ABC	R. Ostash	M. Mohaddes	Jan-27, 2015	Release of final report

Legend of Document Status:

Approved by Client	ABC
Draft for Comments	DFC
Issued for Comments	IFC
Issued for Approval	IFA
Issued for Information	IFI
Returned for Correction	RFC
Approval not Required	ANR

Executive Summary

The Rock Island Clean Line project is an HVdc transmission line that will deliver power from new wind farms connecting to the Rock Island Clean Line 345 kV ac collector transmission system (in northwest Iowa) to a connection in the ComEd system (in PJM).[1][2] It includes an approximately 500 mile +/- 600 kV 3800 MW bipolar HVdc transmission link, capable of delivering 3500 MW to the inverter in the ComEd system (PJM). The 345 kV ac portion of the rectifier substation will connect to the MidAmerican Energy Company (MEC) O'Brien and Highland 345 kV buses (in MISO), and the inverter will connect to the Collins 765 kV bus (in PJM) via 345 kV-765 kV transformation. The Rock Island Clean Line will be designed so that there is only (nominal) near zero power (active or reactive) interchange between the Rock Island Clean Line and the MISO Transmission System.

Steady state and dynamic analyses were performed as part of the MISO System Impact Study (No Harm Test) for the Rock Island-MEC AC interconnection.

Please note that this report is only technical in nature; although it will list how much wind generation crosstripping and how much HVdc runback is required to meet steady state and dynamic performance criteria, this report does not intend to suggest that any steady state power exchange with the AC system will be allowed. Furthermore, this report does not cover the requirements that the Interconnection Agreement with Rock Island HVdc project will need to have to ensure that corrective action plans are implemented and the appropriate transmission service is purchased as needed the Rock Island HVdc project and its subscribers.

The studies were performed based upon the assumption that the Rock Island Clean Line project exchanges near zero MW and Mvar with the ac system at the rectifier in steady state. Violation of this assumption means that Rock Island HVdc line and its subscribers will need to provide additional facilities, special protection schemes, and/or generation run-back, as appropriate, to cure or prevent the violation of this assumption. Further, the Rock Island HVdc link will need to procure sufficient transmission service as necessary for events such as start-up service, ancillary services, back-up service, etc. to cover power exchanges associated with these violations.

The Rock Island wind generation was modeled as 46% Type 3 and 54% Type 4 turbines. The rectifier bus included 2x125 Mvar STATCOMs and the inverter bus included 3x125 Mvar STATCOMs. The rectifier also included 12x126 Mvar of filters and the inverter included 12x216 Mvar of filters. The Mvar levels and number of filters were inputs to this study. During the detailed design studies, the HVdc vendor will further refine these quantities based on more detailed system analysis and, in any event, the customer will be required to meet the steady state and dynamic performance criteria, as well as other performance criteria, and to provide studies and models for review of the impacts by MISO and affected Transmission Owners. In all cases, the Rock Island DC link was set to transfer full rated power.

Clean Line has expressed commitment to a design that will include at least two STATCOMs with redundancy or a third STATCOM. This commitment meets steady state requirements but not dynamic stability requirements.[3][4]

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[1] Rock Island Clean Line will need to designate which RTO the subscriber wind generation and the HVDC facility will be located as part of the Transmission Interconnection Agreement development process.

[2] The determination of which RTO/ISO, if any, to which the Rock Island wind customers will interconnect, will be determined at a later date and will be further discussed between parties during negotiations related to the Interconnection Agreement.

[3] MidAmerican asks Clean line to commit to a design with at least three STATCOMs with redundancy or a fourth STATCOM to meet dynamic stability requirements.

[4] Rock Island will be required to prove, through system simulations, that the final design of the reactive power scheme will allow the Project to meet the MidAmerican Energy stability criteria inclusive of any Special Protection System that is implemented and approved by MISO and MidAmerican Energy.

Steady State Study: Methodology

Ten power flow cases were used to perform the steady state analysis, including six 2018 and four 2023 cases representing various system topologies and seasons, as summarized in Table E-1.

Table E-1. Steady state study power flow cases

Study Case ID	Year		Season			MVP Transmission		Generation	
	2018	2023	Summer Peak	Summer Shoulder	Light Load	2018 In Service Only	All MVP	Signed GIA	Remaining MVP Generation
1A	X		X			X		X	
1B	X		X					X	
2A	X			X		X		X	
2B	X			X				X	
3A	X				X	X		X	
3B	X				X			X	
4		X	X				X	X	
5		X		X			X	X	
6		X	X				X	X	X
7		X		X			X	X	X

The Rock Island HVdc link was studied at full power transfer of 3800 MW and at 0 MW, depending on the type of steady state analysis being performed, as summarized in Table E-2.

Table E-2. Rock Island HVdc and wind configurations

Rock Island DC Transfer (MW)	Rock Island Wind Generation (MW)	Case	Purpose
3800	3845	All ten cases	Steady state contingency analysis (thermal loading/ steady state voltage)
0 up to 1000 MW	0 up to 1000 MW	2A, 2B	HVDC start-up conditions (step change in voltage)
0 MW	0 MW, with collector system in service	2A, 2B, 3A, 3B	No wind, Light load conditions (high voltages)

For the steady state contingency analysis, a set of areas in the surrounding MISO and PJM systems were monitored for thermal overloads and voltage violations. A large set of system-wide contingencies were applied to the ten power flow scenarios for the system prior to the interconnection of the Rock Island HVdc project and for the system after the interconnection of the Rock Island HVdc project. The purpose was to find any contingencies that result in a new thermal overload or voltage violation or that result in an increase to an existing thermal overload or voltage violation after the interconnection of the Rock Island HVdc project. Impacts to existing thermal overloads were recorded if the impact was greater than 1 MW. Impacts to existing voltage violations were recorded if the impact was greater than 0.01 p.u.

Dynamics Study: Methodology

The MTEP 2013 dynamics package was used for the dynamic study. It included four 2018 power flow cases as listed in Table E-3. In all cases, the Rock Island DC link was set to transfer full rated[5] power.

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[5] Rated DC power in the dynamics study was considered to be 3681 MW and in the steady state study it was 3800 MW. The 3800 MW rating was considered to be the initial approximate maximum value used for the steady state analysis. The 3681 MW rectifier rating was calculated by Siemens as the rating required to deliver 3500 MW to the inverter after DC losses. The dynamic study used a DC model provided by Siemens, hence the more accurate DC rating.

Table E-3. Dynamic Study Cases

Case	Year	Season	Topology	Rock Island DC Transfer (MW)	Rock Island Wind Generation (MW)
1	2018	Shoulder Load	With MVP transmission	3681	3754
2	2018	Light Load	With MVP transmission	3681	3754
3	2018	Should Load	Without MVP transmission	3681	3754
4	2018	Light Load	Without MVP transmission	3681	3754

The Rock Island wind generation was modeled as 46% Type 3 and 54% Type 4 turbines. There were 2x125 Mvar STATCOMs at the rectifier and 3x125 Mvar STATCOMs at the inverter. There were also 12x126 Mvar of filters at the rectifier and 12x216 Mvar of filters at the inverter. The Mvar levels and number of filters were inputs to this study. During the detailed design studies, the HVdc vendor will further refine these quantities based on more detailed system analysis and, in any event, the customer will be required to meet the dynamic performance criteria and to provide studies and models for review of the impacts by MISO and affected Transmission Owners.

A large set of disturbances was simulated, including Rock Island DC pole and bipole blocks, loss of Rock Island wind generation, a Rock Island DC line fault, ac faults near the Rock Island terminals, as well as a large set of system-wide ac disturbances. Areas in the surrounding MISO system and at the inverter terminal were monitored for dynamic stability performance. Particular focus was on the MISO ac system near the rectifier terminal.

Study Conclusions

The following conclusions and recommendations are made based on the results of the steady state and dynamic stability analyses:

1) Special Protection Systems (SPS)

Use of the SPS's described in a), b) and c) is required to mitigate violations of TO planning criteria caused by the Rock Island Clean Line project. In addition, these SPS's satisfy the requirements of the System Impact Study Agreement specification that the Rock Island Clean Line be designed so that there is only (nominal) near zero power (active or reactive) interchange between the Rock Island Clean Line and the MISO Transmission System.

a) Loss of the Rock Island Bipole

It is recommended to use an SPS to crosstrip all of the Rock Island wind generation following the loss of the Rock Island bipole. Loss of the bipole is considered to be a permanent event from which the bipole does not automatically recover. There were significant thermal overloads that resulted from the loss of a bipole (some > 200%). Due to the magnitude of the overloads, manual adjustment of the wind generation following the contingency would not be an acceptable method with which to mitigate these overloads. Therefore, the SPS is required to avoid significant thermal overloading in the ac system near the rectifier[6]. It is also required to meet dynamic performance criteria and to avoid cascade tripping of the Manitoba-Ontario delta-P relays, and to avoid voltage collapse near the rectifier during prior outage conditions.

b) Loss of the Rock Island Pole

It is recommended to use an SPS to crosstrip the Rock Island wind generation that the pole was carrying and which cannot be transferred to the healthy pole following the loss of a Rock Island pole, in order to quickly minimize the power exchange with the ac system at the rectifier after the pole is lost. Although the SPS is not required for stability reasons, it is required to prevent thermal overloading in the ac system near the rectifier. Many of the MidAmerican emergency conductor ratings equal normal conductor ratings. These emergency ratings must be met within 0.5 seconds and normal ratings must be met within 5 seconds. Loss of the pole in this case is considered to be a permanent event from which the pole does not automatically recover (i.e. it is not a temporary DC line fault from which the DC recovers).

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[6] PRC standards require that relay settings be at least 150% of 345 kV line ratings. The study shows overloads of >200%, so the opportunity exists for overloads to exceed relay trip settings. As the design for the HVdc link proceeds, relay settings for existing relays near the Rock Island project will need to be reviewed and revised, as appropriate, to minimize negative impacts from the Rock Island operation.

c) Loss of Rock Island Wind Generation

It is recommended to use an SPS to perform a fast HVdc power order runback if Rock Island wind generation is suddenly lost. If the loss of wind generation is large enough (1730 MW in the dynamic simulation), this SPS is required to meet dynamic performance criteria. In addition, there were significant thermal overloads (some > 150%) that resulted from the loss of Rock Island wind generation (2000 MW in the steady state simulation), which also require this SPS for mitigation. The SPS could reduce the HVdc power order within 100-200 ms.

Another alternative is to rely on the Rock Island's HVdc power exchange controller. This controller is designed to follow normal variations in the power output of the wind generation in order to minimize the steady state power exchange with the ac system by controlling the HVdc power order using a large time constant. If the HVdc power order is not quickly runback using an SPS after wind generation is lost, this slow power exchange controller will eventually reduce the HVdc power order so that minimal power is being exchanged with the ac system. However, it would take more time, likely in the range of 15 seconds, which is too long to meet the dynamic performance criteria. The 15 second time constant is adjustable and it could be reduced to a lower value of 5 seconds, for example. Use of a smaller time constant would need to be studied in order to verify if this would satisfy the dynamic performance criteria, and if the emergency thermal ratings would be met in 0.5 seconds. It should be noted that the use of the power exchanger with 5 to 15 second constant to ramp back generation in 0.5 seconds to meet an emergency thermal rating constraint is a difficult proposition at best.

2) Thermal Overloads and Voltage Violations

The list of new and impacted thermal overloads and voltage violations must be reviewed by the Transmission Owners of the affected systems in order to determine if any mitigation is required.

3) High Voltage during No Wind, Light Load Conditions

In situations of no wind and light load, the 2x125 Mvar STATCOMs at the rectifier must be in service if the Rock Island wind collector system is in service in order to prevent high voltages and to keep the voltage within acceptable limits (i.e. < 1.05 p.u.) due to charging from the wind collector system.[7,8]

4) HVdc Start-up Conditions

It is required to have at least 1x125 Mvar STATCOM in service when starting up the HVdc link in order to prevent potentially large step changes in steady state ac voltage, which can result from switching filters in to service and when switching a pole on to minimum power (around 190 MW). The STATCOM is able to quickly control the voltage back to steady state values. The STATCOM also helps to maintain a steadier ac voltage when the DC power and wind generation are being ramped up.

5) Consideration of STATCOM Outages

These studies were performed under the assumption that the 2x125 Mvar STATCOMs at the rectifier and the 3x125 Mvar STATCOMs at the inverter were always in-service, i.e. prior outage of a STATCOM was not considered. This assumes that the STATCOMs will be designed with redundancy. If redundancy is not intended, further analysis is required to study the prior outage of a STATCOM, and the HVdc power transfer may need to be de-rated under such conditions. Clean Line has committed to a design that will include at least two STATCOMs with redundancy or a third STATCOM. This commitment meets steady state requirements but not dynamic stability requirements.[910]

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[7] The STATCOMs should be fully redundant, otherwise an additional STATCOM (a third STATCOM at the rectifier) would need to be added to ensure that loss of a STATCOM will still provide sufficient dynamic reactive to meet steady state voltage criteria during no wind, light load conditions.

[8] The 34.5 kV wind collector cable system was not modeled in this study. Once the 34.5 kV collector system layout is designed, a study will be required to assess the impact of the 34.5 kV cables on the high voltages that result from the no wind, light load conditions.

[9] MidAmerican asks Clean line to commit to a design with at least three STATCOMs with redundancy or a fourth STATCOM to meet dynamic stability requirements.

[10] Rock Island will be required to prove, through system simulations, that the final design of the reactive power scheme will allow the Project to meet the MidAmerican Energy stability criteria inclusive of any Special Protection System that is implemented and approved by MISO and MidAmerican Energy.

6) Temporary Overvoltages (TOV) at the Rectifier

Due to the very low short circuit ratio (SCR) at the rectifier (i.e. size of the HVdc link and wind farms relative to the short circuit strength of the AC system), this study concluded that excessive TOVs at the rectifier are an issue that the HVdc vendor will need to carefully consider in their design. Ultimately it is up to the vendor to design the HVdc system to ensure that all dynamic performance criteria are met. TOVs at the rectifier were observed to violate criteria (> 1.2 p.u. for more than 40 ms) after a fault at the inverter was cleared. In addition, some of the TOVs observed in this study were difficult to make conclusions on because they jumped instantaneously to very high values after clearing a three-phase fault (3PF) near the rectifier (up to 1.76 p.u. in prior outage conditions, which exceeds the TOV criteria). PSSE is not a suitable tool for studying fast transient voltages; rather an EMT study tool (e.g. PSCAD) should be used. The HVdc design studies performed by the vendor will need to include EMT-type studies to further investigate the transient overvoltages. Tuning/design of the STATCOM controls, the HVdc controls, the number of filters in-service, the rating of dynamic reactive support and the response of the Rock Island wind farms will all play a role in the ac system voltage response. All of these items can be modeled with more detail and accuracy in an EMT study tool. In addition, transformer saturation was modeled at the Rock Island converter transformers in this study, but not on other nearby transformers. Transformer saturation can aid in reducing TOVs, which will also be taken into account in the vendor's EMT design phase studies.

Further EMT-type studies will also be needed to assess equipment in the area, including but not limited to, breaker TRV, capacitor switching and arrester energy studies (insulation coordination). Studies such as insulation coordination are performed by the vendor and can only be done once the HVdc design is complete. Such a study will need to look one bus back from the Rock Island 345 kV ac substation to ensure that existing equipment is well-protected and within rating. If not well-protected, this equipment will need to be replaced with appropriately rated equipment.

7) AC System Frequency at the Rectifier

The ac system frequency response met the overfrequency criteria used in this study; i.e. it remained below 61.8 Hz and did not go above 60.5 Hz for more than 20 cycles. The frequency also did not drop below 59.5 Hz for more than 20 cycles, which is one requirement of the underfrequency criteria.
There is, however, the potential for frequency to dip below the 59.3 Hz underfrequency load shedding (UFLS) point when the DC and wind farms are recovering their power after a fault is cleared. It is required to keep the frequency above 59.3 Hz at buses where load is present, as this is the setting for the first block of UFLS. It was found that if the Rock Island DC power recovery was slowed down slightly (i.e. to better coordinate with the power recovery response of the wind farms), the underfrequency improved from 59.2 Hz to 59.4 Hz at Lakefield, where load is present.

8) Response of Rock Island Wind Farms

The response of the Rock Island wind farms plays an important role in the dynamic response of the ac system. Given that details of the wind farms (types, sizes, locations, etc.) and collector system are not yet known, it will be important for future studies to be performed using a more accurate representation of the wind farms once these details are known. For example, the Type 4 wind farms used in the study were seen to initiate their "fault ride-through" response in times when there was no fault because the voltage briefly dipped below the 0.9 p.u. threshold. Given the weakness of the ac system, the ac voltage setpoint of the wind farm fault ride-through logic should be carefully considered so that it does not operate when it is not needed. Entering fault ride-through mode results in the wind farms reducing their power output, then ramping it back up after the voltage recovers. This is acceptable during faults, but causes unnecessary disturbance to the ac system if it is initiated when it is not needed.

9) Coordination between Rock Island HVdc System and Wind Farms

Coordination between HVdc recovery and wind farm recovery after faults should be considered in the design of the Rock Island project in order to optimize the response of the ac system. As discussed in point 7), better coordination of the HVdc power recovery rate with the recovery of the wind farms improved the system frequency response and mitigated a violation of the 59.3 Hz UFLS criteria. Slowing down the DC recovery has other implications, however. For example, it may prolong the ac system overvoltage or it may not be desirable at the inverter end. These issues will need to be balanced out in the final design of the HVdc system in order to optimize the ac system response at both the rectifier and inverter, and to meet all dynamic performance criteria.

10) Power on Interconnecting AC Transmission lines – Protection Study

The 345 kV ac lines that connect the Rock Island 345 kV ac bus to the MidAmerican ac system experience large sudden changes in real and reactive power during various disturbances, including loss of the bipole, loss of a pole, when recovering from a three-phase fault, etc. It is recommended to perform a detailed study to verify that these sudden changes in power will not cause protection to trip facilities in the area. The study should use system protection data provided by MidAmerican.

11) Neal and Lakefield Generator Delta-P

The study found the potential for the Neal and Lakefield generators to experience sudden step changes in power greater than 0.5 p.u. This step change occurred following the loss of the Rock Island bipole, when all wind generation was crosstripped simultaneously. If the wind generation was crosstripped in smaller groups with small time delays in between, the individual delta-P values were reduced below 0.5 p.u. Since generator delta-P analysis is only a screening tool and since the potential for high delta-P values was found, further detailed investigation of the Neal and Lakefield generators will be required to ensure that these disturbances will not result in damage to these generating units.

12) Temporary Overvoltages at the Inverter (PJM)

The 345 kV Rock Island inverter ac bus experienced large TOVs during various disturbances. Table E-4 lists the TOVs observed at the 345 kV inverter ac bus and at the Collins 765 kV bus, as well as the duration that the TOV at the 345 kV bus was above 1.2 p.u. In all cases, the 3x125 Mvar STATCOMs at the inverter were absorbing their maximum reactive power during the TOV.

Table E-4. TOVs at the inverter

Disturbance	Peak Overvoltage at Rock Island 345 kV ac inverter bus (p.u.)	Peak Overvoltage at Collins 765 kV ac bus (p.u.)	Duration that the 345 kV TOV is greater than 1.2 p.u. (ms)
Loss of Rock Island bipole	1.38	1.20	100*
Loss of Rock Island pole	1.19	1.09	0
On recovery from 3PF at inverter	1.40	1.21	100
During 3PF at rectifier	1.35	1.16	90

*Duration of TOV will be the time delay between bipole block and tripping of ac filters. 100 ms was assumed in this study.

The 345 kV inverter ac bus is connected to the Collins 765 kV bus via two autotransformers, each having a fairly high impedance (15%). The high impedances of these transformers weaken the 345 kV inverter bus, and also drive the need for a large amount of reactive power compensation (filters) to overcome the Mvar losses in the transformers. Both of these factors play a role in the high TOVs observed at the 345 kV bus.

As required under PJM manual 14E[11], the interconnection customer is required to perform additional EMT analyses that are typically performed during the detailed design phase of the project. These EMT studies will further refine the TOV impacts and will also include transformer saturation models that could impact the level of TOV due to the project and any required mitigation thereof.

13) Operation at Reduced DC Voltage

Sometimes, if the DC line insulation is compromised, it is not possible to start back up to full DC voltage after a DC line fault. In this case, several unsuccessful restarts may be attempted at full DC voltage prior to restarting at reduced DC voltage. When the DC link recovers to reduced voltage, the tap changers are still sitting at the same tap position as they were prior to the DC line fault. Because of the reduced DC voltage, the firing angles of the converters will increase significantly until the tap changers have had a chance to move to a new operating point to bring the firing angles back to lower values. During this time, the reactive power consumed by the converter is higher due to the higher firing angles. This extra reactive power will be drawn from the ac systems and/or the Rock Island wind farms and the STATCOMs until the tap changers reach their final new operating point, which could take several minutes.

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[11] http://www.pjm.com/~/media/documents/manuals/m14e.ashx

The Siemens PSSE DC model used in this study is not set up for the user to be able model a DC line fault with restart to reduced DC voltage on one pole. However, the vendor will be responsible to consider this scenario in their design studies to ensure that all system performance criteria are met.