STAFF RESPONSES TO
GRAIN BELT EXPRESS CLEAN LINE LLC'S FIRST SET OF
DATA REQUESTS DIRECTED TO STAFF WITNESS LANGE

For its First Set of Data Requests Directed to Staff of the Missouri Public Service Commission ("Staff"), Grain Belt Express Clean Line LLC ("Grain Belt Express" or "Company") states the following:

Definitions

1. The term "documents" includes all of the items listed in Missouri Rule of Civil Procedure 58.01(a)(1).

2. The term "Grain Belt Express Project" or "Project" means the transmission line and associated facilities described in Paragraph 14 of the Application in this proceeding.

Data Requests

1) Mr. Lange discusses conclusions within the PJM SIS report with reference to footnotes 83 and 84 on page 54 of Staff's testimony. On page 15 of this study report there is a one-line diagram. How many autotransformers are identified in the one-line diagram between the 765kV Sullivan and 345kV Breed buses?

STAFF RESPONSE: There are two transformers in the one-line diagram on page 15 of the PJM SIS report.

Provided by Staff Witness Shawn Lange

2) Please explain Mr. Lange's understanding of the withdrawal process and rules of interconnection in PJM.

   a. What are the implication of withdrawal of a queue position in the PJM interconnection queue on queue positions that are behind the withdrawing interconnection queue position?

STAFF RESPONSE: The impact of a withdrawal of a queue position on a project whose queue position is lower is that the analysis of the later queue position projects may include impacts of the withdrawal project.

Provided by Staff Witness Shawn Lange

3) Is Mr. Lange aware of any queue positions identified in the PJM SIS report which are no longer in an active status within the PJM interconnection queue?

<u>STAFF RESPONSE</u>: No, but the only "queue position" identified in the PJM SIS report is for the GrainBelt X3-028 project.

Provided by Staff Witness Shawn Lange

4) Is Mr. Lange aware of the Coleman-Duff-Rockport 345 kV transmission line project?

<u>STAFF RESPONSE</u>: Yes.

Provided by Staff Witness Shawn Lange

5) Based on Staff's review of Dr. Galli's direct testimony, what is Mr. Lange's understanding with respect to the number of autotransformers that will exist between the 345 kV and 765 kV systems at the Breed/Sullivan substation in Indiana?

STAFF RESPONSE: It is unclear in Dr. Galli's direct testimony how many transformers are autotransformers.

"The Sullivan substation includes equipment and buswork at both 345kV and 765kV with three 345/765kV transformers interconnecting the 345kV and 765kV networks." Galli Direct Pg. 23 lines 14-16

"The Sullivan substation in Indiana will provide direct access to the 765kV network in PJM via three 345/765 kV transformers" Galli Direct Pg. 7 lines 1-2

Provided by Staff Witness Shawn Lange

6) Mr. Lange discusses conclusions within the SPP SIS report with reference to footnote 87 on page 56 of Staff's testimony. On page 10 of this study report there is a one-line diagram:

a. How many autotransformers are identified in the one-line diagram between the 765kV Sullivan and 345kV Breed buses?

STAFF RESPONSE: Two.

Provided by Staff Witness Shawn Lange

b. Is there a transmission line depicted between the 765kV Sullivan bus and the Reynolds 765kV bus?

STAFF RESPONSE: No.

Provided by Staff Witness Shawn Lange

c. Would Mr. Lange consider a ~100 mile, 765kV transmission line to be “a major transmission upgrade”?

STAFF RESPONSE: It depends on the network prior to and after the existence or the plan to be in existence of a “~100 mile, 765kV transmission line.”~~.~~ A “~100 mile, 765kV transmission line” does not specify whether it is a general or a specific “~100 mile, 765kV transmission line” or give details of transmission network prior to and after the “~100 mile, 765kV transmission line” existed or planned to be in existence.

Provided by Staff Witness Shawn Lange

7) Please explain Mr. Lange’s understanding of what a transmission system congestion issue represents. Specifically, when there’s congestion in a transmission network:

a. What is the cause of that congestion?

STAFF RESPONSE: In general transmission system congestion is caused by transmission limitations imposed on the system, and/or changes in the load or generation at one or more points in the system. These limitations may include, but not limited to, lack of transmission capacity or transmission rating limitations in certain areas due to possible overloading of certain transmission equipment (transformers, substations, etc.).

Provided by Staff Witness Shawn Lange

b. How is it fixed?

STAFF RESPONSE: In general, transmission congestion is resolved by improving the transmission system. This may include, but not limited to, upgrading a transformer, substation, reconductoring a transmission line or possibly adding new transmission capacity in a region or area or a change in load in a region or area.

Provided by Staff Witness Shawn Lange

c. Why would someone want to fix it?

STAFF RESPONSE: In general resolving congestion improves the efficiency of the system overall and may now resolve issues including, but not limited to, dispatching units out of economic order.

Provided by Staff Witness Shawn Lange

8) Is the Audrain SPS, as discussed by Mr. Lange on page 56 of Staff's testimony, still active? If so, when will it no longer be active?

STAFF RESPONSE: It is Staff's understanding that the Multi-Value projects included in MISO's MTEP 11 would resolve the Audrain SPS if and/or when those projects are operational.

Provided by Staff Witness Shawn Lange

9) Is the Audrain SPS currently being modeled/studied in interconnection and other MTEP planning studies by the planning authorities in Missouri? If not, why not? If so, please provide evidence supporting this claim.

STAFF RESPONSE: It is Staff's understanding that the Audrain SPS is not being currently modeled/studied in other MTEP studies. However, the Palmyra substation issue does show up in LOLE modeling done by MISO.

It is Staff's understanding that all prior MTEP approved projects would be included in any studies, performed by MISO or on behalf of MISO, performed after that approved MTEP.

Provided by Staff Witness Shawn Lange

10) If Staff was to discover that for the 500 MW Missouri HVDC Converter Station of the Grain Belt Project, the short circuit ratio at the chosen point-of-interconnection is much higher than 2.0 (which Mr. Lange identified as being an indication of a "weak interconnection point"), would Staff's concerns on this topic be alleviated? If not, why not?

STAFF RESPONSE: Staff's concerns on the short circuit ratio topic would be alleviated if sufficient analysis was provided showing the short circuit ratio for the 500 MW Missouri HVDC converter station at the chosen point of interconnection was 2.0 or higher.

Provided by Staff Witness Shawn Lange

11) Regarding short circuit currents:

a. What is Mr. Lange's understanding of the contributors to short circuit currents in an AC power system?

STAFF RESPONSE: Generally speaking, short circuit currents arise out of the establishment of a low resistance or impedance connection between two points that bypass at least part of a circuit. Since current flows in the direction of least resistance, current will flow between the two points created. The capacity of the system and the duration of the short circuit will determine the consequences of the short circuit will have on the system. Adequate sizing and sequencing of protection devices such as circuit breakers and feeder protection relays, helps to limit damages to the AC system by detecting and removing them from the system as quickly as possible.

Provided by Staff Witness Shawn Lange

b. Does Mr. Lange agree that the short circuit ratio, as discussed on page 58 of Staff's testimony, is calculated as the ratio of the [AC] system short circuit level at the point-of-interconnection to the DC power of the converter station interconnected to that AC system? If not, why not?

STAFF RESPONSE: Yes

Provided by Staff Witness Shawn Lange

c. Does Mr. Lange agree that the denominator of the short circuit ratio for the Missouri Converter Station is the nameplate DC power level of 500 MW? If not, why not?

STAFF RESPONSE: Based on Staff's current understanding of the proposed project, yes.

Provided by Staff Witness Shawn Lange

d. Does the answer to a) suggest that a well-networked transmission system, such as the that near the point-of-interconnection of the Missouri HVDC Converter Station of the Project, would have a higher short circuit ratio, withrespect to the DC power level of the Missouri Converter Station, than a less networked transmission system's (such as southwestern Kansas) short circuit ratio with respect to the DC power level of the Kansas Converter Station? If not, why not?

STAFF RESPONSE: The answer to a) says nothing about the transmission system near the point-of-interconnection of the Missouri HVDC converter Station nor the level of network in southwestern Kansas. In general a well-networked transmission system would suggest a higher short circuit ratio than a less networked transmission system.

Provided by Staff Witness Shawn Lange

12) Regarding the topic of control interactions (CI) as it relates to HVDC converter stations impacts on other HVDC facilities, what is Mr. Lange's understanding of the mitigation measures that could be implemented in order to address such identified CI risks?

STAFF RESPONSE: "Commutation failure may occur both at the initiation of the fault and during recovery from fault. A commutation failure may also occur in one converter as a consequence of commutation failure at the other inverter station electrically close connected. Hence, the HVDC system might become more vulnerable to an ac disturbance when the inverters of several dc links are located in the same ac system with close proximity."

https://library.e.abb.com/public/b3b16a30843135a0c1256fda004aeaee/Aspects_Multiple_Infeed_HVDC_1.pdf

Mitigation techniques for dealing with commutation failures are:

"Temporary increase of inverter extinction angle by 10-12^o before AC switching operations or immediately after fault inception.

Temporary increase of rectifier firing angle during disturbances on the rectifier network.

Voltage dependent current order limiter which reduces the DC current order, and hence the reactive power consumption upon reduction of the AC system voltage.

The use of fast acting reactive controllers such as synchronous condensers and static VAR compensators (SVCs) to help alleviate the risk of commutation failure."

Bayliss, Colin and Hardy, Brian (2012). Transmission and Distribution Electrical Engineering pg. 1049

13) Regarding the topic of control interactions (SSTI) as it relates to HVDC converter stations impacts on electrically nearby generator facilities, what is Mr. Lange's understanding of the mitigation measures that could be implemented in order to address such identified SSTI risks?

STAFF RESPONSE:

System Conditions where SSTI Occurs (As per Detailed Studies)	**Mitigation/Protection Options**
N-0	• Mitigation o Re-tune SSDC in HVDC control system o Install filters o Consideration of turbine-generation parameters during the design/procurement stage o Dynamic stabilizer control o Machine excitation system damping • Protection o Generator protection (TSRs), as an optional backup. This protection must be coordinated with the TFO protection scheme to avoid nuisance tripping and adverse system impacts.
N-1, N-2	• Mitigation o Remedial action scheme o Install filters o Re-tune SSDC in HVDC control system o Consideration of turbine-generation parameters during the design/procurement stage o Dynamic stabilizer control o Machine excitation system damping • Protection o Generator protection (TSRs), as optional for consideration. This protection must be coordinated with the TFO protection scheme to avoid nuisance tripping and adverse system impacts.
N-1-1, N-1-2, N-2-1, N-2-2 Above N-4	• Mitigation o Operational measures/awareness o Remedial action scheme o Install filters o Re-tune SSDC in HVDC control system o Consideration of turbine-generation parameters during design/procurement

	stage o Dynamic stabilizer control o Machine excitation system damping • <u>Protection</u> o Generator protection (TSRs), as optional for consideration. This protection must be coordinated with the TFO protection scheme to avoid nuisance tripping and adverse system impacts.

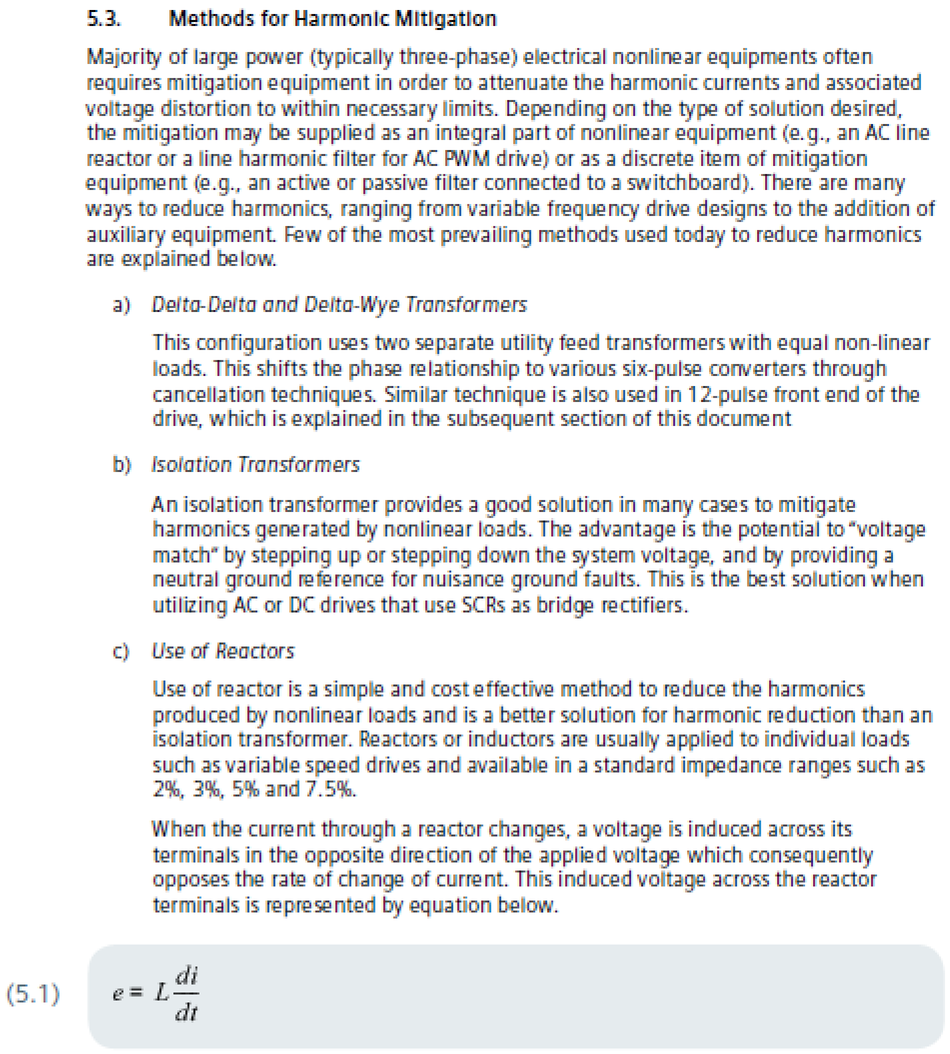
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=0ahUKEwj947eq1fvRAhVnxFQKHXjiBboQFggrMAU&url=https%3A%2F%2Fwww.aeso.ca%2Fassets%2FUploads%2Fprocess-for-SSTI-studies-and-mitigation-protection.docx&usg=AFQjCNET5kRjSzzjhXnbENSbOALEOTZCTQ&bvm=bv.146094739,d.amc

Provided by Staff Witness Shawn Lange

14) Regarding the topic of harmonic currents that are produced by HVDC converter stations, what is Mr. Lange’s understanding of the mitigation measures that could be implemented in order to ensure compliance with harmonic performance requirements?

(SEE NEXT PAGE FOR STAFF RESPONSE)

STAFF RESPONSE:



5.3. Methods for Harmonic Mitigation

Majority of large power (typically three-phase) electrical nonlinear equipments often requires mitigation equipment in order to attenuate the harmonic currents and associated voltage distortion to within necessary limits. Depending on the type of solution desired, the mitigation may be supplied as an integral part of nonlinear equipment (e.g., an AC line reactor or a line harmonic filter for AC PWM drive) or as a discrete item of mitigation equipment (e.g., an active or passive filter connected to a switchboard). There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment. Few of the most prevailing methods used today to reduce harmonics are explained below.

a) *Delta-Delta and Delta-Wye Transformers*

This configuration uses two separate utility feed transformers with equal non-linear loads. This shifts the phase relationship to various six-pulse converters through cancellation techniques. Similar technique is also used in 12-pulse front end of the drive, which is explained in the subsequent section of this document

b) *Isolation Transformers*

An isolation transformer provides a good solution in many cases to mitigate harmonics generated by nonlinear loads. The advantage is the potential to "voltage match" by stepping up or stepping down the system voltage, and by providing a neutral ground reference for nuisance ground faults. This is the best solution when utilizing AC or DC drives that use SCRs as bridge rectifiers.

c) *Use of Reactors*

Use of reactor is a simple and cost effective method to reduce the harmonics produced by nonlinear loads and is a better solution for harmonic reduction than an isolation transformer. Reactors or inductors are usually applied to individual loads such as variable speed drives and available in a standard impedance ranges such as 2%, 3%, 5% and 7.5%.

When the current through a reactor changes, a voltage is induced across its terminals in the opposite direction of the applied voltage which consequently opposes the rate of change of current. This induced voltage across the reactor terminals is represented by equation below.

$$e = L\frac{di}{dt} \tag{5.1}$$

where:

e = Induced voltage across the reactor terminals

L = Inductance of the reactor, in Henrys

di/dt = Rate of change of current through reactor in Ampere/Second

This characteristic of a reactor is useful in limiting the harmonic currents produced by electrical variable speed drives and other nonlinear loads. In addition, the AC line reactor reduces the total harmonic voltage distortion (THD_v) on its line side as compared to that at the terminals of the drive or other nonlinear load.

In electrical variable speed drives, the reactors are frequently used in addition to the other harmonic mitigation methods. On AC drives, reactor can be used either on the AC line side (called AC line reactors) or in the DC link circuit (called DC link or DC bus reactor) or both, depending on the type of the drive design and/or necessary performance of the supply.

AC line reactor is used more commonly in the drive than the DC bus reactor, and in addition to reducing harmonic currents, it also provides surge suppression for the drive input rectifier. The disadvantage of use of reactor is a voltage drop at the terminals of the drive, approximately in proportion to the percentage reactance at the terminals of the drive.

In large drives, both AC line and DC bus reactors may be used especially when the short circuit capacity of a dedicated supply is relatively low compared to the drive kVA or if the supply susceptible to disturbances. Typical values of individual frequency and total harmonic distortion of the current waveform of a 6-pulse front end without & with integral line reactor are given in Table 5.1.

d) *Passive Harmonic Filters (or Line Harmonic Filters)*

Passive or Line harmonic filters (LHF) are also known as harmonic trap filters and are used to eliminate or control more dominant lower order harmonics specifically 5th, 7th, 11th and 13th. It can be either used as a standalone part integral to a large nonlinear load (such as a 6-pulse drive) or can be used for a multiple small single-phase nonlinear loads by connecting it to a switch board. LHF is comprised of a passive L-C circuit (and also frequently resistor R for damping) which is tuned to a specific harmonic frequency which needs to be mitigated (for example, 5th, 7th, 11th, 13th etc). Their operation relies on the "resonance phenomenon" which occurs due to variations in frequency in inductors and capacitors.

The resonant frequency for a series resonant circuit, and (in theory) for a parallel resonant circuit, can be given as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{5.3}$$

where:

f_r = Resonant frequency, Hz

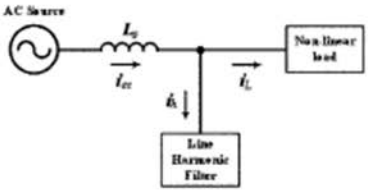
L = Filter inductance, Henrys,

C = Filter capacitance, Farads

The passive filters are usually connected in parallel with nonlinear load(s) as shown in Figure 5.1, and are "tuned" to offer very low impedance to the harmonic frequency to be mitigated. In practical application, above the 13th harmonic, their performance is poor, and therefore, they are rarely applied on higher-order harmonics.

Passive filters are susceptible to changes in source and load impedances. They attract harmonics from other sources (i.e. from downstream of the PCC), and therefore, this must be taken into account in their design. Harmonic and power system studies are usually undertaken to calculate their effectiveness and to explore possibility of resonance in a power system due to their proposed use. Typical values of individual frequency and total harmonic distortion of the current waveform of a 6-pulse front end with integral LHF are given in Table 5.1.

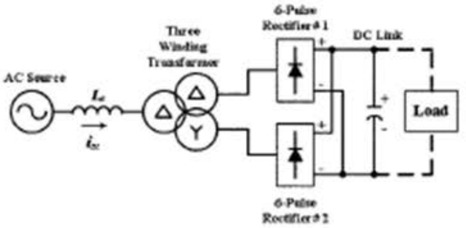
Figure 5.1
Typical connection of a passive harmonic filter



e) *12-pulse converter front end*

In this configuration, the front end of the bridge rectifier circuit uses twelve diodes instead of six. The advantages are the reduction of the 5th and 7th harmonics to a higher order where the 11th and 13th become the predominant harmonics. This will minimize the magnitude of these harmonics, but will not eliminate them.

Figure 5.2
Typical 12 pulse converter front end



The disadvantages are higher cost and special construction, as it requires either a Delta-Delta and Delta-Wye transformer, "Zig-Zag" transformer or an autotransformer to accomplish the 30° phase shifting necessary for the proper operation of 12-pulse configuration. This configuration also affects the overall drive system efficiency rating because of the voltage drop associated with the transformer/s. Figure 5.2 illustrates the typical elementary diagram for a 12-pulse converter front end. The DC sides of both 6-pulse bridge rectifiers are connected in parallel for higher current (Figure 5.2) and connected in series for higher voltage. Typical values of harmonic distortion of the current drawn by 12-pulse converter are given in Table 5.1.

f) *18-pulse converter front end*

An 18-pulse converter front end topology is comprised of either a three phase to nine phase isolation transformer or a lower cost patented design of three phase to nine phase autotransformer, to create a phase shift of ±20° necessary for the 18-pulse operation, and a nine phase diode rectifier containing 18 diodes (two per leg) to convert nine phase AC to DC. Figure 5.3 shows the block diagram of 18-pulse system. Similar to 12-pulse configuration, 18-pulse also has a disadvantages of higher cost & special construction.

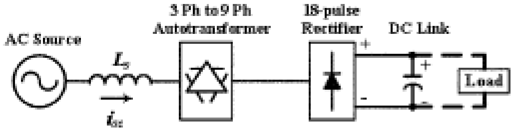


Figure 5.3
18 pulse converter front end

Nine-phase, 18-pulse converters not only have low harmonic distortion in the ac input current, but they also provide a smoother, higher average value of dc output. In addition, since the characteristic harmonics for 18-pulse configuration are $18n \pm 1$ (where n is an integer 1, 2, 3,...), it virtually eliminates the lower order non-characteristic harmonics (5th, 7th, 11th and 13th). A typical harmonic performance of 18-pulse configuration is shown in Table 5.1.

g) *Active filters*

Active filters are now relatively common in industrial applications for both harmonic mitigation and reactive power compensation (i.e., electronic power factor correction). Unlike passive L-C filters, active filters do not present potential resonance to the network and are unaffected to changes in source impedance. Shunt-connected active filters (i.e. parallel with the nonlinear load) as shown in Figure 5.4 below are the common configuration of the active filter. The active filter is comprised of the IGBT bridge and DC bus architecture similar to that seen in AC PWM drives. The DC bus is used as an energy storage unit.

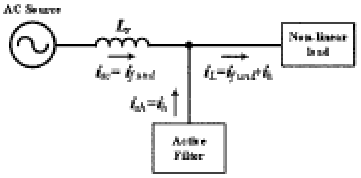


Figure 5.4
Typical connection of active filter

The active filter measures the “distortion current” wave shape by filtering out the fundamental current from the nonlinear load current waveform, which then fed to the controller to generate the corresponding IGBT firing patterns to replicate and amplify the “distortion current” and generate the “compensation current”, which is injected into the load in anti-phase (i.e. 180° displayed) to compensate for the harmonic current. When rated correctly in terms of “harmonic compensation current”, the active filter provides the nonlinear load with the harmonic current it needs to function while the source provides only the fundamental current.

Active filters are complex and expensive products. Also, careful commissioning of active filter is very important to obtain optimum performance, although “self tuning” models are now available. However, active filters do offer good performance in the reduction of harmonics and the control of power factor. Their use should be examined on a project-by-project basis, depending on the application criteria.

h) *Active front end*

"Active front ends" (AFE), also known as "sinusoidal input rectifiers", are offered by a number of AC drive and UPS system companies in order to offer a low input harmonic footprint. A typical configuration of the AC PWM drive with active front end is shown below in Figure 5.5.

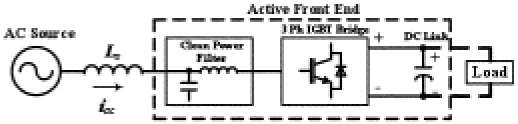


Figure 5.5
Active Front End

As can be seen below, a normal 6-pulse diode front end is replaced by a fully controlled IGBT bridge, an identical configuration to the output inverter bridge. The DC bus and the IGBT output bridge architecture are similar to that in standard 6-pulse AC PWM drives with diode input bridges.

The operation of the input IGBT input bridge rectifier significantly reduces lower order harmonics compared to conventional AC PWM drives with 6-pulse diode bridges (<50th harmonic). However, as an inherent nature it introduces significant higher order harmonics, above the 50th. In addition, the action of IGBT switching introduces a pronounced "ripple" at carrier frequencies (~2-3 kHz) into the voltage waveform which must be attenuated by a combination of AC line reactors (which also serve as an energy store that allows the input IGBT rectifier to act as a boost regulator for the DC bus) and capacitors to form a passive (also known as clean power) filter. As compared to conventional 6-pulse AC PWM drives of same rating, AFE drives have significantly higher conducted and radiated EMI emissions, and therefore, special precautions and installation techniques may be necessary when applying them. AFE drives are inherently "four quadrant" (i.e. they can drive and brake in both directions of rotation with any excess kinetic energy during braking regenerated to the supply), offer high dynamic response and are relatively immune to voltage dips. The true power factor of AFE drive is high (approximately 0.98-1.0). The reactive current is usually controllable via the drive interface keypad.

i) *Power System Design*

Harmonics can be reduced by limiting the non-linear load to 30% of the maximum transformer's capacity. However, with power factor correction capacitors installed, resonating conditions can occur that could potentially limit the percentage of non-linear loads to 15% of the transformer's capacity. Use the following equation to determine if a resonant condition on the distribution could occur:

$$h_r = \sqrt{\frac{kVA_{sc}}{kVAR_c}} \tag{5.1}$$

https://www.industry.usa.siemens.com/drives/us/en/electric-drives/ac-drives/Documents/DRV-WP-drive_harmonics_in_power_systems.pdf

Provided by Staff Witness Shawn Lange

15) Is Mr. Lange aware of any electric generating or transmission facilities which are owned and/or operated by entities regulated by the Electric Reliability Organization (ERO) Enterprise (i.e. NERC and the Regional Entities) which were not designed in accordance with IEEE, NESC, and/or IEC standards? If so, please explain.

STAFF RESPONSE: Staff witness Shawn Lange is not aware "of any electric generating or transmission facilities which are owned and/or operated by entities regulated by the Electric Reliability Organization (ERO) Enterprise (i.e. NERC and the Regional Entities) which were not designed in accordance with IEEE, NESC, and/or IEC standards".

Provided by Staff Witness Shawn Lange

16) Grain Belt Express intends to register with NERC in its various functions within the NERC Reliability Functional Model as outlined on page three (3) of Schedule AWG-4. Please provide an explanation as to why Mr. Lange believes that a NERC Reliability Functional Model entity would design equipment that is considered part of the Bulk Electric System without consideration of IEEE, NERC, and IEC standards.

STAFF RESPONSE: Staff witness Shawn Lange is not alleging that any or all "NERC Reliability Functional Model entity[sic] would design equipment that is considered part of the Bulk Electric System without consideration of IEEE, FERC, and IEC standards." Neither is Staff witness Shawn Lange alleging Grain Belt Express has not followed or taken into consideration IEEE, NERC, and IEC standards with the information that has been provided.

Staff witness Shawn Lange cannot predict all future business considerations that may be taken into account to cause a "NERC Reliability Functional Model entity would[sic] design equipment that is considered part of the Bulk Electric System without consideration of IEEE, FERC, and IEC standards."

Nor can Staff witness Shawn Lange predict all future business considerations that may cause an entity to change its intentions.

Provided by Staff Witness Shawn Lange

/s/ Karl Zobrist

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CERTIFICATE OF SERVICE

I certify that a copy of the foregoing Data Request was served upon the party to which it was directed by email or U.S. Mail, postage prepaid, this ___3rd__ day of February, 2017.

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