Comanche Flicker Mitigation Study

Revision 1

Prepared for: Public Service Company of Colorado, dba Xcel Energy

Prepared by: General Electric International, Inc.

Date: May 24, 2018

Rev 1, August 9, 2018

FOREWORD

This report was prepared by General Electric International, Inc. (GEII), acting through its Energy Consulting group, based in Schenectady, New York. Questions and any correspondence concerning this document should be referred to:

Paul Datka

Senior Engagement Manager
GE Energy Consulting
General Electric International, Inc.

1 River Rd., Building 53-300x
Schenectady, NY 12345 USA
Office: 518.385.5004
Mobile: 518.265.9500
paul.datka@ge.com

DOCUMENT REVISIONS

Rev. No.	AUTHOR	DATE	DESRIPTION OF CHANGE
a	Paul Datka	5.24.2018	Initial Report Outline
0	Paul Datka	7.23.2018	Initial Report Issue
1	Paul Datka	8.9.2018	Updated STATCOM and SVC location and STATCOM sizing based on recommendations from GE Power Conversion

LEGAL NOTICES

This report was prepared by General Electric International, Inc. as an account of work sponsored by Public Service Company of Colorado, General Electric International, Inc., nor any person acting on their behalf:

1) Makes any warranty or representation, expressed or implied, with respect to the use of any information contained in this report, or that the use of any information, apparatus, method, or process disclosed in the report may not infringe privately owned rights.

2) Assumes any liabilities with respect to the use of or for damage resulting from the use of any information, apparatus, method, or process disclosed in this report.

PROJECT TEAM

Project Manager	**Paul Datka**
Sales Manager	Reginald Mendis
Sales Manager	Bertrand Depommier
Bid Manager	Tushar Prabhu
Sales Manager	Djafer Djerbal
Sales Manager	Jay Morris

CONTENTS

FIGURES

TABLES

1 EXECUTIVE SUMMARY

This study examined how the existing flicker levels at the Comanche substation will increase under three generation retirement scenarios and evaluated the potential mitigation options to bring the flicker levels within the IEEE 1453 recommended levels. The three potential mitigation options examined were: adding a new SVC at the Evraz 34.5kV bus, adding a new STATCOM at the Evraz 34.5kV bus, and adding synchronous condenser(s) either by converting the retired generators or adding new units. All mitigation options included leaving the existing 0 to 100 Mvar SVC at the Evraz Arc Furnace in place to support furnace operations.

The flicker levels at the Comanche substation will increase from the existing $P_{st95\%}$ of 0.86 to approximately 1.45 under the worst-case generation retirement scenario. The IEEE 1453 recommended flicker level, $P_{st95\%}$, for HV-EHV system at Comanche is 0.80 indicating a need to additional mitigation measures.

The mitigation option of adding a new SVC at the Evraz 34.5kV substation bus in conjunction to the existing SVC at the Evraz site will reduce the expected flicker level slightly but will not bring it within the IEEE recommended limits. This is primarily due to the limited flicker reduction factor of the SVC. Even with greatly increasing the size of the SVC, the flicker reducing performance of the SVC is limited.

The mitigation option of adding a new STATCOM at the Evraz 34.5kV substation bus in conjunction to the existing SVC at the Evraz site will reduce the expected flicker level within the IEEE recommended limits for all generation retirement scenarios. The higher flicker reduction factor of the STATCOM compared to a SVC allows for a relatively small STATCOM to provide effective flicker mitigation.

The mitigation option of adding synchronous condensers at the Comanche 230kV bus, either through conversion of the retiring units or adding new units in conjunction with the existing SVC at the Evraz site, will help to reduce the expected flicker levels. For all retirement scenarios, adding new synchronous condensers in the proper amounts can bring the expected flicker levels within the IEEE recommended limits. The option of converting the available existing generators to synchronous condensers only brings the expect flicker levels within the recommended IEEE limits for the scenario when Units 1 and 2 are retired and converted. For the other scenarios, converting the available generators reduces the expected flicker levels, but remain at similar levels to what exists now, slightly above the recommended IEEE limits.

When evaluating the different mitigation options there are many aspects to consider, cost, schedule, long term operational cost, physical size of the solution, and resulting expected flicker level to name a few. While some of the mitigation options do not reduce the expected flicker level within the recommended IEEE planning levels, this may be acceptable as long at the expected flicker level does not increase significantly over the current level. As noted in [2], there are currently no observed effects at the current flicker level of $P_{st95\%}$ equal to 0.86. This may allow for acceptable levels around the current $P_{st95\%}$ level of 0.86.

2 INTRODUCTION

Public Service Company of Colorado anticipates retirements of generating resources at the Comanche coal generation plant. Evraz owns and operates a nearby 140MW Electric Arc Furnace (EAF) with a Ladle Refining Furnace (LRF) that contribute to system wide flicker when operating. The retirement of the Comanche generating units will decrease the available short circuit capacity in the area and cause the system wide flicker due to the nearby arc furnace to increase, potentially to a level that exceeds the IEEE 1453 recommended levels.

The purpose of this study is to evaluate potential flicker mitigation approaches including: a Static Var Compensator (SVC), a Static Synchronous Compensator (STATCOM), and a Synchronous Condenser. Each mitigation approach will be evaluated under the specified scenarios requested by Public Service Company of Colorado, including:

1. Scenario 1 – Retirement of Comanche Unit 1 (325MW)
2. Scenario 2 – Retirement of Comanche Unit 1 (325MW) and Unit 2 (325MW)
3. Scenario 3 – Retirement of Comanche Unit 1 (325MW) and Unit 2 (325MW) with Comanche Unit 3 (860MW) offline

Budgetary estimates and footprint requirements for each of the mitigation approaches are included as a separate document.

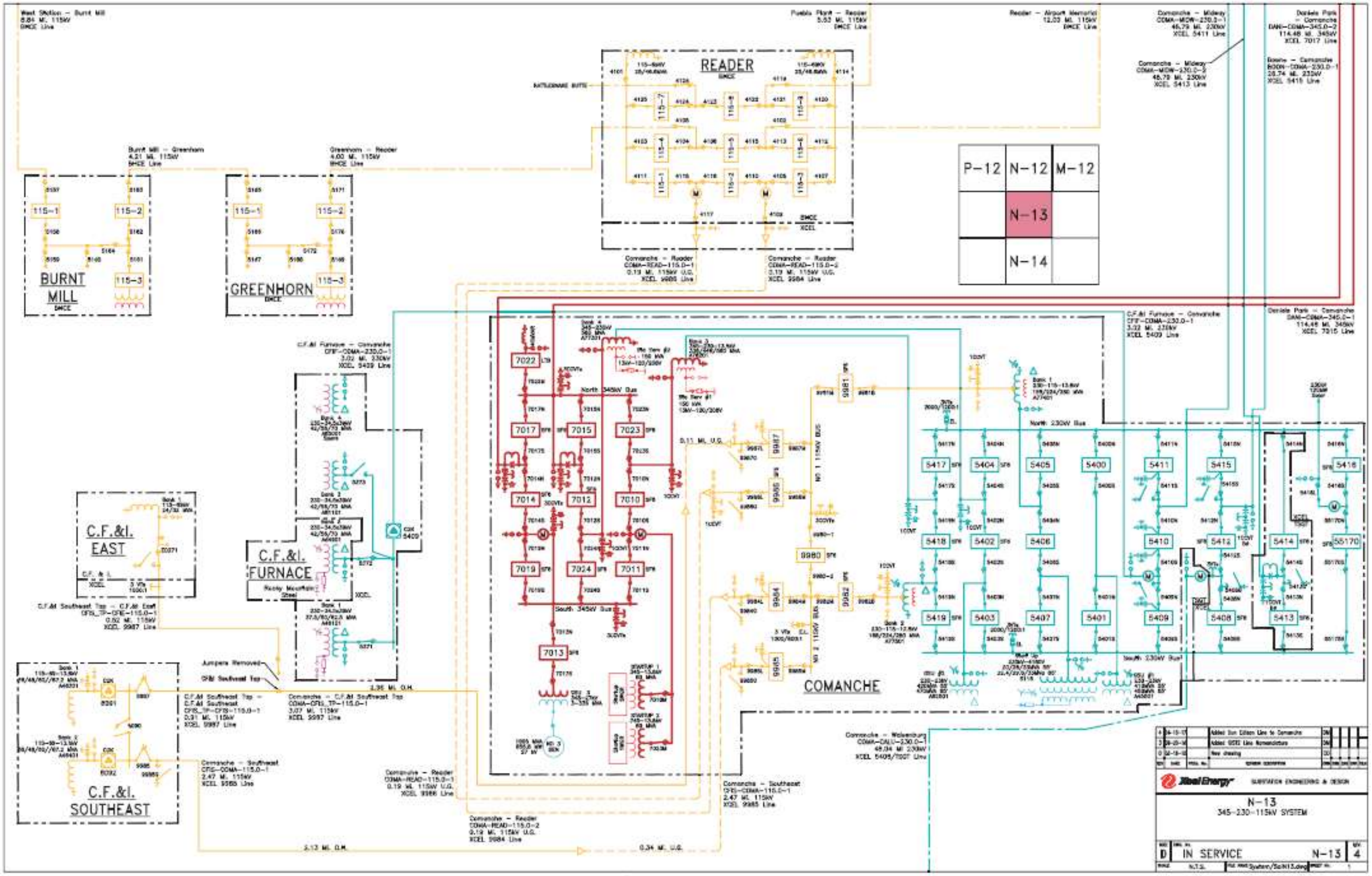
3 SYSTEM CHARACTERISTICS, DATA, AND SINGLE LINES

3.1 Surrounding Power System Characteristics

The following power system data and one-line were received from the Public Service Company of Colorado and used throughout this analysis. Note, the point of common coupling (PCC) reference of the EAF is the 230kV bus at the Comanche Substation. The EAF is connected to the Comanche Substation via a 230kV overhead transmission line, line 5409 in Figure 3-1.

Table 3-1 Public Service Company of Colorado Area System Parameters

Description	Value
3-Phase Fault Level at Comanche 230kV North [1]	
- Base Case	25,181kA, X/R 49.99, **10,031.4 MVA_{SC}**
- Scenario 1	22,440kA, X/R 50.62, **8,939.5 MVA_{SC}**
- Scenario 2	19,723kA, X/R 50.89, **7,857.1 MVA_{SC}**
- Scenario 3	15,607kA, X/R 11.17, **6,217.4 MVA_{SC}**
System Voltage at the PCC	230kV
Length of 230kV overhead transmission line connecting the EAF to the PCC	3.02 miles (4.86km)
Typical Reactance (X_L) of a 230kV overhead transmission line	0.785 Ω/mile (0.488 Ω/km)



Do Not Copy, Distribute To Others, Or Use To Make Drawings/Designs Without Express Written Consent From Public Service Company of Colorado

Figure 3-1 Public Service Company of Colorado Area Single Line

3.2 Evraz Electric Arc Furnace (EAF) and Ladle Refining Furnace (LRF)

The following data and one-line for the Evraz Electric Arc Furnace (EAF) and Ladle Refining Furnace (LRF) were received from the Public Service Company of Colorado and used throughout this analysis. The 230kV connection from the Comanche Substation connects to the Evraz EAF via three, 230-34.5kV step down transformers. The EAF is typically operated with any 2 of 3 step-down transformers in service. The common 34.5kV bus at the facility serves both the EAF and the LRF via their own step-down transformers. The EAF also has a series reactor on the 34.5kV side of the transformer for current limiting, refer to the EAF one-line in Figure 3-2.

Table 3-2 Evraz Electric Arc Furnace Parameters

Description	Value
Step Down Transformer #1	230kV - 34.5/39kV 37.5/50.0/62.5 MVA 7.16% at 37.5 MVA
Step Down Transformer #2	230kV - 34.5/39kV 37.5/50.0/62.5 MVA 7.00% at 37.5 MVA
Step Down Transformer #3	230kV - 34.5/39kV 37.5/50.0/62.5 MVA 7.16% at 37.5 MVA
EAF Series Reactor - Tapped	34.5kV, 2000A 0, 2.0, 2.5, 3.0, 3.5, 4.0 Ω[1]
EAF Transformer	34.5kV - 750V to 1175V 85 MVA 1.68% at 85 MVA and 1175V
EAF Secondary Impedance	2.77 mΩ
LRF Transformer	34.5kV - 300V 15 MVA 4.90% at 15 MVA
LRF Transformer	5.00 mΩ[2]

[1] The series reactor is normally operated on the 2.0Ω tap

[2] Estimated/Assumed Values

There is an existing 0 to 100 Mvar Static Var Compensator (SVC) operated by Evraz connected to the EAF's 34.5kV bus. The SVC includes the TCR and a harmonic filter bank with the stages tuned for the 2nd-7th harmonics.

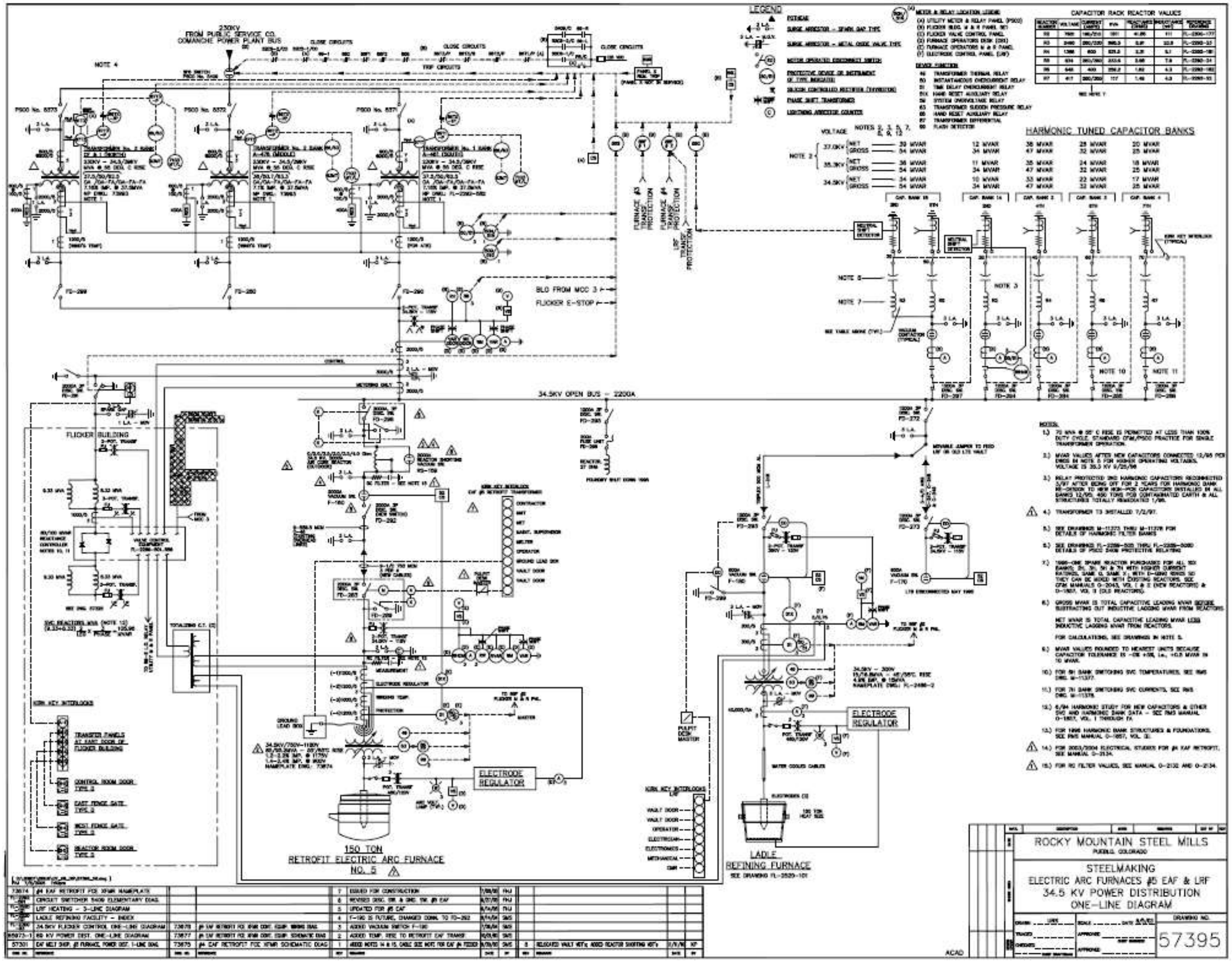


Figure 3-2 Evraz Electric Arc Furnace Single Line

The measure of a given EAF to contribute to flicker is dependent on the network it is connected to and is characterized by the furnace's K_{st} value. From IEEE 1453, K_{st} is defined by the equation:

$$K_{st} = \frac{P_{st95\%}}{S_{cc_f}/S_{cc_n}}$$

Where:

- $P_{st95\%}$: Short-term flicker severity measured over a period of ten minutes with a 95% probability of not being exceeded
- Scc_f: Short-circuit capacity of the furnace at the PCC (electrodes shorted)
- Scc_n: Short-circuit capacity of the system at the PCC (short circuit at the PCC)

For the Evraz EAF, the K_{st} of the furnace was not known. However, from the equation above and the information provided by the Public Service Company of Colorado, K_{st} can be estimated. From Study 1 of reference [1], the Scc_n under the base or current system configuration at Comanche's 230kV North bus can be calculated as **10,031.3 MVA$_{SC}$**. Using the data in Table 3-1 and Table 3-2 above, the Scc_f of the EAF can be calculated as **215.5 MVA**. From Table 1 of reference [2], the $P_{st95\%}$ at the Comanche 230kV line 5409 that is the PCC of the Evraz EAF is given as **0.86**. However, this $P_{st95\%}$ value includes the existing SVC and the K_{st} of the EAF should be calculated without the existing SVC. To do this the flicker reduction factor of the current SVC must be estimated. From Case 10 of reference [3], which shows the P_{st} in 2007 at Comanche with and without the SVC active, the reduction factor can be estimated to be approximately 1.72. Using this factor and the formula above, the K_{st} of the EAF can be calculated to be approximately **69**.

4 PERFORMANCE OBJECTIVES

IEEE Standard 1453-2015 defines the recommended short term and long-term flicker planning levels (denoted L_{Pst} and L_{Plt}) for both medium voltage (MV), 1kV to 35kV, and high voltage (HV) / extra high voltage (EHV), 35kV and above, system. Table 2 of IEEE 1453 is copied below for reference:

Table 4-1 IEEE 1453 Recommended Flicker Planning Levels

	MV	HV-EHV
L_{Pst}	0.9	0.8
L_{Plt}	0.7	0.6

The PCC for the Evraz EAF is at the 230kV Comanche bus. A level of P_{st} equal to 0.8 will be used as the acceptable limit when evaluating the flicker mitigation options in the following sections.

5 VOLTAGE FLICKER CALCULATIONS

This section will analyze the change in flicker at the Comanche PCC under the three scenarios listed in Section 2. The analysis will focus around the resulting flicker levels assuming no mitigation is present, including the existing SVC. This will ensure the mitigation options presented in Section 6 address the actual flicker level of the system.

The short-term flicker severity factor ($P_{st95\%}$) will be calculated for each scenario using the K_{st} formula in Section 3.2 solved for $P_{st95\%}$.

$$P_{st95\%} = K_{st}\left({S_{cc_f}}/{S_{cc_n}}\right)$$

For each scenario Scc_f is the same as calculated in Section 3.2, 215.5 MVA, as this is a function of the design of the EAF and will not change. For K_{st}, an additional factor will be added to the value calculated in Section 3.2 to account for any changes run to run and to add a level of conservatism to the analysis. A K_{st} value of 72.0 will be used throughout the analysis.

5.1 Scenario 1 – Retirement of Comanche Unit 1 (325MW)

Scenario 1 addresses the retirement of Comanche Unit 1. The retirement of Unit 1 will lower the available short circuit strength of the system making it more susceptible to flicker. From reference [1], the available short circuit strength of the system in this condition is 8,939.5 MVA_{SC}. Using the equation above, the values for K_{st} and Scc_f from Section 5, and assuming the existing SVC is off, the resulting $P_{st95\%}$ under this condition is 1.74.

5.2 Scenario 2 – Retirement of Comanche Unit 1 (325MW) and Unit 2 (325MW)

Scenario 2 addresses the retirement of Comanche Units 1 and 2. The retirement of Unit 1 and Unit 2 will further lower the available short circuit strength of the system making it more susceptible to flicker. From reference [1], the available short circuit strength of the system in this condition is 7,857.1 MVA_{SC}. Using the equation above, the values for K_{st} and Scc_f from Section 5, and assuming the existing SVC is off, the resulting $P_{st95\%}$ under this condition is 1.97.

5.3 Scenario 3 – Retirement of Comanche Unit 1 (325MW) and Unit 2 (325MW) with Comanche Unit 3 (860MW) offline

Scenario 3 addresses the retirement of Comanche Units 1 and 2 and assumes Unit 3 is offline. With Unit 3 offline and the retirement of Unit 1 and Unit 2, the available short circuit strength of the system will again be further reduced making it more susceptible to flicker. From reference [1], the available short circuit strength of the system in this condition is 6,217.4 MVA_{SC}. Using the equation above, the values for K_{st} and Scc_f from Section 5, and assuming the existing SVC is off, the resulting $P_{st95\%}$ under this condition is 2.50.

5.4 Summary of Flicker Calculations

The following table summarizes the results of each scenario described above. These calculations assume no mitigation from the existing 0 to 100 Mvar SVC at the Evraz EAF. As can be seen below, with no mitigation, all scenarios greatly exceed the IEEE recommended flicker levels.

Table 5-1 Summary of Flicker Calculations without Mitigation

	System Short Circuit Strength, Scc_n	Short-Term Flicker Severity Factor, $P_{st95\%}$, no mitigation
Scenario 1	8,939.5 MVA_{SC}	1.74
Scenario 2	7,857.1 MVA_{SC}	1.97
Scenario 3	6,217.4 MVA_{SC}	2.50

6 FLICKER MITGATION SOLUTIONS - RECOMMENDED RATINGS

This section will analyze the estimated reduction in flicker at the Comanche PCC under the three scenarios listed in Section 2 with additional new mitigation. Four mitigation options will be examined, a new SVC, a new STATCOM, conversion of the retired Comanche generation units to synchronous condensers, and new synchronous condensers. All four approaches assume the existing 0 to 100 Mvar SVC at the Evraz EAF remains in operation to support furnace operation.

6.1 Approach 1 – Static Var Compensator (SVC)

An SVC mitigates flicker by reducing the magnitude of the of voltage dips caused by operation of the EAF. To be effective, the SVC should be sized to match the short circuit capacity (Scc_f) of the EAF and be at least 1.5 times as big as the EAF. From the calculations in Section 3.2, the short circuit capacity (Scc_f) of the EAF is 215.5 MVA. This dictates the total size of the new and existing SVC should be approximately 215 Mvar. A total SVC of 215 Mvar is 1.54 times larger than the size of the EAF, meeting the 1.5 times requirement. The new SVC being considered in this section has a rating of 0 to +115 Mvar, this along with the existing 0 to +100 Mvar SVC total the 215 Mvar desired above.

The expected flicker reduction factor (R_f) of a properly sized SVC is in the range of 1.5-2.0 based on Table 5 of IEEE Standard 1453-2015. From GE's experience and for this analysis, a reduction factor of 1.8 will be used for the new SVC and a reduction factor of 1.724, as calculated in Section 3.2, will be used for the existing SVC. To calculate the resulting flicker level at the PCC the following formula will be used:

$$P_{st95\%-Comp} = \frac{P_{st95\%-noComp}}{R_f}$$

Where:

- $P_{st95\%\text{-}Comp}$: Short-term flicker severity measured over a period of ten minutes with a 95% probability of not being exceeded with the compensating or mitigation device
- $P_{st95\%\text{-}unComp}$: Short-term flicker severity measured over a period of ten minutes with a 95% probability of not being exceeded without any compensation or mitigation device, from Section 5
- R_f: Combined Flicker Reduction Factor of the new and existing mitigation device calculated by weighting the individual reduction factors by the relative size of each mitigation option out of the total combined size

Using the approach described above, Table 6-1 shows the expected flicker levels using a new 0 to +115 Mvar SVC located at the Evraz 34.5kV bus along with the existing 0 to +100 Mvar SVC at the Evraz site.

The combined flicker reduction factor (R_f) for the two SVCs used in this calculation is 1.729. Having two SVCs operating in close proximity has the potential for control interactions requiring the control systems of each device to be properly designed, tuned, and coordinated.

Table 6-1 Expected Flicker Levels at the PCC – Approach 1

Scenario	Expected Flicker Level
Scenario 1, retirement of Comanche Unit 1	1.00
Scenario 2, retirement of Comanche Unit 1 and 2	1.14
Scenario 3, retirement of Comanche Unit 1 and 2 with Unit 3 offline	1.44

What can be seen from Table 6-1 is that for each scenario, the resulting flicker levels are outside of the IEEE 1453 guidelines.

6.2 Approach 2 – Static Synchronous Compensator (STATCOM)

Similar to an SVC, a STATCOM mitigates flicker by reducing the magnitude of the of voltage dips caused by operation of the EAF. To be effective, the dynamic range of the STATCOM should be sized to match the short circuit capacity (Scc_f) of the EAF. From the calculations in Section 3.2, the short circuit capacity (Scc_f) of the EAF is 215.5 MVA. This dictates the dynamic range of the STATCOM should be ±107.5 Mvar with a capacitive filter bank of +107.5Mvar. However, considering the existing 0 to +100 Mvar SVC at the Evraz site, the effective size of the STATCOM can be reduced based. For this section the size of the STATCOM being considered is ±95 Mvar with a +85 Mvar capacitor filter bank.

The expected flicker reduction factor (R_f) of a properly sized STATCOM is in the range of 3.0-6.0 based on Table 5 of IEEE Standard 1453-2015. From GE's experience and for this analysis, a reduction factor of 3.45 will be used for the new STATCOM and a reduction factor of 1.724, as calculated in Section 3.2, will be used for the existing SVC. To calculate the resulting flicker level at the PCC the same formula from Section 6.1 will be used.

Using the approach described above, Table 6-2 shows the expected flicker levels using a new ±95 Mvar STATCOM with a +85 Mvar capacitor filter bank located at the Evraz 34.5kV bus along with the existing 0 to +100 Mvar SVC at the Evraz site. The combined flicker reduction factor (R_f) for the STATCOM and SVC used in this calculation is 3.1. Having two dynamically controlled reactive devices operating in close proximity has the potential for control interactions requiring the control systems of each device to be properly designed, tuned, and coordinated.

Table 6-2 Expected Flicker Levels at the PCC – Approach 2

Scenario	Expected Flicker Level
Scenario 1, retirement of Comanche Unit 1	0.56
Scenario 2, retirement of Comanche Unit 1 and 2	0.64
Scenario 3, retirement of Comanche Unit 1 and 2 with Unit 3 offline	0.80

What can be seen from Table 6-2 is that for all scenarios, the proposed STATCOM reduces the expected flicker to a within than the IEEE 1453 recommended planning level.

6.3 Approach 3 – Synchronous Condensers with the existing Evraz SVC

Synchronous Condensers help to mitigate flicker by increasing the short circuit capacity of the system, strengthening the system and reducing the magnitude of voltage dips during EAF operations. The fast-acting controls of synchronous condensers also help to mitigate flicker by responding to voltage dips and dynamically adjusting the compensation.

To estimate the additional short circuit capacity provided by the synchronous condenser, the size of the synchronous condenser, its sub-transient reactance, the size of its associated step up transformer, and its rated impedance will be used. The total short circuit capacity of the unit will be combined with the contribution from the system from Table 3-1 to come up with a new total. This total will then be used to estimate the new flicker levels as described in Section 5.

To estimate the added benefit from the synchronous condenser controls response, the recommendations of reference [4] will be followed. From reference [4], the equivalent increase in short circuit capacity resulting from the synchronous condenser controls response is approximately two times the increase in short circuit capacity of the synchronous condenser alone. For this analysis, a factor of 1.75 will be used to add a measure of conservatism over the value from [4].

In this approach, the existing Evraz SVC is assumed to remain in service to support furnace operations while providing additional flicker mitigation. This is acceptable as the time constants of the control schemes of the SVC and the synchronous condenser are different enough that it will not cause interactions between the two. In fact, synchronous condensers can be used near power electronic based equipment as a stabilizing method.

Two different options to using synchronous condensers will be analyzed in this section. Option 1 will examine converting the retired Comanche generators to synchronous condensers. Option 2 will examine adding new synchronous condensers and transformers optimized for the application.

6.3.1 Approach 3 – Option 1: Converting retired Units to Synchronous Condensers

Converting the existing Comanche Unit 1 and Unit 2 generators to synchronous condensers as they are retired allows for reusing exiting equipment including potentially the generator, the step-up transformer, the generator breaker, and the associated connecting cabling; however, it requires using older equipment and may not be as efficient as installing new equipment optimized for the application. Table 6-3 lists the key parameters of the exiting generating units and equipment.

Table 6-3 Existing Generator Parameters – Approach 3, Option 1

Parameter	Value
Comanche Unit 1	
Rated Power	450 MVA
Rated Voltage	24.0 kV
Power Factor	0.85
Sub-Transient Reactance (X"d)	0.30 p.u.
Unit 1 Generator Step-up Transformer	
Rated Power	410.0 MVA 55°C
Rated Voltage	230.0 / 23.0 kV
Rated Impedance	11.5% @ 410 MVA
Comanche Unit 2	
Rated Power	440 MVA
Rated Voltage	24.0 kV
Power Factor	0.90
Sub-Transient Reactance (X"d)	0.28 p.u.
Unit 2 Generator Step-up Transformer	
Rated Power	420.0 MVA 55°C
Rated Voltage	230.0 / 23.0 kV
Rated Impedance	12.6% @ 420 MVA

Using the approach described above and the formulas in Sections 5 and 6.1, Table 6-4 shows the expected flicker levels using synchronous condensers based on converting the existing generation units as they are retired along with the existing 100 Mvar Evraz SVC with a reduction factor (R_f) of 1.72.

Table 6-4 Expected Flicker Levels at the PCC – Approach 3, Option 1

Scenario	Expected Flicker Level
Scenario 1, retirement and conversion of Comanche Unit 1 and existing 100 Mvar SVC	0.83
Scenario 2, retirement and conversion of Comanche Unit 1 and 2 and existing 100 Mvar SVC	0.78
Scenario 3, retirement and conversion of Comanche Unit 1 and 2 with Unit 3 offline and existing 100 Mvar SVC	0.91

What can be seen from Table 6-4 is that for all Scenarios, the resulting flicker levels are either below the IEEE 1453 guidelines or very close to the existing 0.86 level. An additional new synchronous condenser for both Option 1 and Option 2 could be considered to further reduce the expected flicker level below IEEE 1453 at an additional cost if desired.

6.3.2 Approach 3 – Option 2: Adding new Synchronous Condensers

Installing new synchronous condensers, transformers, and their respective control system at the Comanche generator station allows for an optimized solution for the application. Table 6-5 lists the key parameters of a typical synchronous condenser unit and transformer that would be suitable for this application. There are other sizes that would also be suitable depending on the available space and redundancy needs.

Table 6-5 Typical Synchronous Condenser Parameters – Approach 3, Option 2

Parameter	Value
Typical Synchronous Condenser Unit	
Rated Power	+278 / -114 MVA
Rated Voltage	19.0 kV
Sub-Transient Reactance (X"d)	0.15 p.u.
Unit 1 Generator Step-up Transformer	
Rated Power	280 MVA 55°C
Rated Voltage	230.0 / 19.0 kV
Rated Impedance	8.0% @ 280 MVA

Using the approach described above and the formulas in Sections 5 and 6.1, Table 6-6 shows the expected flicker levels using new synchronous condensers along with the existing 100 Mvar Evraz SVC with a reduction factor (R_f) of 1.72.

Table 6-6 Expected Flicker Levels at the PCC – Approach 3, Option 2

Scenario	Expected Flicker Level
Scenario 1, retirement of Comanche Unit 1: Two new 278 Mvar synchronous condenser and existing 100 Mvar SVC	0.68
Scenario 2, retirement of Comanche Unit 1 and 2: Two new 278 Mvar synchronous condenser and existing 100 Mvar SVC	0.74
Scenario 3, retirement of Comanche Unit 1 and 2: Three new 278 Mvar synchronous condenser and existing 100 Mvar SVC	0.72

What can be seen from Table 6-6 is that for all Scenarios, the resulting flicker levels are below the IEEE 1453 guidelines.

7 REFERENCES

[1] Fault Studies prepared by Daniel L. Kelley, March 20, 2018

[2] NEI Electric Power Engineering, Inc., “Xcel Energy, Comanche Unit 1 and 2 Shutdown Flicker Impact Study”, February 7, 2018

[3] Manitoba HVDC Research Centre Inc., “Lamar 230kV HVDC Site and City of Lamar Flicker Evaluation, Summary of Report 2005-2007”, March 20, 2007

[4] A. Robert and M. Couvreur, “Arc Furnace Flicker Assessment and Mitigation”, CIGRE 1994