Operations Planning Study Report

Motor Starting Assessment and SCP Consolidation

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Executive Summary

Existing SCP 5-TXMN-20 Marlboro Motors Start and Load Limitation and SCP 5-TXMN-03 Empress Area Operation manage the large motors start requests in the Marlboro substation and the Empress area respectively. In the Marlboro substation, there are five 5000 HP motors. Four motors start through auto transformer and one motor starts across the line. The Transcanada's operating procedures determined that only one motor can be started at a time. In the Empress area, there are eight large synchronous motors. All large motors in the Empress area have soft starters. Some soft starters share the same reactor. The configuration of the soft starters determined that the maximum number of motors start at the same time is four.

Motor start analysis was performed for the large motors in Marlboro substation and the Empress area. The motors were modeled as admittance and switching actions were applied to simulate the motor start. The 138 kV bus voltages post motor starting should be above 0.9 p.u.,(124.2 kV) as per AESO Operations Horizon Voltage Limits Guidelines in Operations Domain.

The study results show that for the motors at Marlboro substation, the load capacity at Marlboro is limited under different system operating conditions, which are summarized as following:

System Operating Condition	Load Capacity
System normal	No limit
854L Bickerdike to Marlboro Tap out of service	Maximum two motor starts, the second motor start cannot be C350 motor
973L and 974L Sundance to Bickerdike out of service and capacitor bank at Edson 58S off line	No motor start allowed
973L and 974L Sundance to Bickerdike out of service and capacitor bank at Edson 58S on line	Maximum three motor starts

The study results also indicate that for the large motors in the Empress area, even four motors start at the same time, the 138 kV bus voltages post motor starting would be above 0.9 p.u.. under either system normal condition (N-0) or one element out of service (N-1) system conditions.

To incorporate the study results into procedures, it is recommended to update the existing SCP 5-TXMN-20 Marlboro Motor Start to include the requirements for 973L and 974L double circuit lines outage. Since there is no voltage violation post motors start in the Empress area, it is suggested to remove the content related to the motor start requests in the existing SCP 5-TXMN-03.

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1. Introduction

Motor starting is an important issue which must be considered when evaluating power system performance. The high current that motor draw when starting causes voltage dips in the system. This could depress the bus voltages to a very low level which may violate the Alberta Reliability Standards.

Normally large motors are started with an assisted method, which includes variable frequency drive (VFD), autotransformer starting system, solid state soft starting system, capacitor assisted starting system, or other starting methods. However, even with the starting methods, under certain emergency conditions, starting large motors still could depress the bus voltages to a very low level. Analysis is required to assess the impact of starting large motors under different system operating conditions and what conditions may apply if large motor starting could cause voltage violations.

Currently, the AESO has three SCPs to manage starting of the large motors in Alberta:

i. SCP 5-TXMN-03 Empress Area Operation

ii. SCP 5-TXMN-19 Shell Limestone Motor Start

iii. SCP 5-TXMN-20 Marlboro Motor Start and Load Limitation.

SCP 5-TXMN-19 Shell Limestone Motor Start was reviewed in the recently finished Central West Region Operations Plan in 2017, the other two SCPs haven't been reviewed since they were established although the transmission infrastructure has been reinforced in the past years. The generation and load have also changed. A thorough study is required to capture the changes and assess the impacts to the motor start.

2. Study Objectives

The study objectives include:

- Review the existing SCP 5-TXMN-03 and SCP 5-TXMN-20 and consolidate with Shell Limestone SCP
- Determine the system operating conditions to allow the motor start
- Determine the minimum operating voltage at related buses if needed before motor start

3. Study Criteria and Guidelines

This study will follow the following study criteria and guidelines:

- AESO System Operating Limit Methodology for the Operations Horizon (Version 4)[1]
- AESO Operations Horizon Voltage Limits Guidelines (Version 1.0)[2]
- SCP 7-SYOP-02 Voltage Control[3]

4. Existing Motor Start SCPs

4.1. 5-TXMN-20 Marlboro Motor Start and Load Limitation

The existing SCP 5-TXMN-20 limits the load capacity at 348S Marlboro to be maximum two motor starts in the event of a permanent outage of 854L between 39S Bickerdike and the T-Tap on 854L.

4.2. 5-TXMN-03 Empress Area Operation

The SCP 5-TXMN-034 Empress Area Operation contains two parts. One part is the Medicine Hat DTS and the second part is the Motor Start Requests. In the section of motor starts request, it states that:

For the Empress area 25,000 HP or larger motors,

a. Ensure no other motors 25,000 HP or larger in the area have requested a start at the same time.
b. A real time study should be performed if there are transmission elements outages in the area before allowing large motor starts.

For Sand Hills 54,000 HP motor,

With two Sheerness units online, ensure the following conditions are met:

a. 944L, 951L, 945L, (either 1002 or 1011L) and Amoco Empress 163S 240/138 kV transformer are in service.
b. McNeil 840S converter station is not ramping an energy schedule.
c. No other motor start requests in the area are active.

With one Sheerness unit online, ensure the following conditions are met:

a. 944L, 951L, 945L, (either 1002 or 1011L) and Amoco Empress 163S 240/138 kV transformer are in service.
b. McNeil 840S converter station is not ramping an energy schedule.
c. No other motor start requests in the area are active.
d. One capacitor bank at Amoco Empress 163S is available.

[1] https://www.aeso.ca/assets/Uploads/AESO-SOL-Methodology-for-the-Operating-Horizon.pdf

[2] file://aeso.ca/Dfs/Technical/te/20/45/Ops_Planning_Process/AESO_Operations_Horizon_Voltage_Limits_Guidelines-V1-Final.pdf

[3] file://aeso.ca/dfs/Rshared/SCPs/SCPs/7-SYOP-02.pdf

5. Study Assumptions

This section outlines the study assumptions for assessing the motor starting.

5.1. Base Cases

Studies for the motor starting will be performed with the system topology and configuration expected to exist in the timeframe between 2017 -2018 winter and 2018 summer. The following seasonal base cases will be utilized for the studies:

- 2017-18 Winter Peak (WP).

5.2. Load Assumption

The load assumptions for the Motor Starting Studies are based on the AESO's 2016 Long-term Outlook (LTO) at Area Peak. The coincidental loads for Winter Peak (WP) conditions are shown in Table 5.2-1.

Table 5.2-1: Forecast Area Load (2016 at Area Peak)

Area Name and Season		Forecast Peak Load (MW)
		2017
Area 24 (Fox Creek)	WP	91.05
Area 29 (Hinton/Edson)	WP	158.80
Area 48 (Empress)	WP	265.32

5.3. Power Factors

The historical metering data were used to calculate the average power factor on the load buses around the studied motors. Table 4.3-1 shows the average power factors on the load buses in the studies areas when the loads are at their 95% peak.

Table 4.3-1: Power Factors on the Load Bus in the Study Area

Substation	Power Factor
Marlboro 384S	0.9511
Benbow 397S	0.9223
Chevron Knight 355S	0.9166
Kaybob 346S	0.9029
Deer Hill 1012S	0.9397
Edson 58S	0.9083
Cold Creek 602S	0.9777
Dalhurst 975S	0.9776
Mountain Coal Obed 411S	0.9046
Fickle Lake 406S	0.9679

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Substation	Power Factor
Empress 394S Bus 1	0.9572
Empress 394S Bus 2	0.9998
Sand Hills 341S	0.9931
Empress Liquids 164S	0.9971
Sandy Point 204S	0.9534
Amoco Empress 163S Bus 1	0.9972
Amoco Empress 163S Bus 2	0.8552
Bindloss 914S	0.9384

5.4. Voltage Profile

The AESO SCP 7-SYOP-02 Voltage Control will be used to establish normal system (pre-contingency) voltage profiles for key busses in the Hinton/Edson area and Empress area prior to commencing any studies, as shown in Table 5.4-1.

Table 5.4-1 Summary of Voltage at Key Nodes in the Study Area

Bus Name	Nominal Voltage (kV)	Minimum Operating Limit (kV)	Desired Range (kV)	Maximum Operating Limit (kV)
Bickerdike 39S	240	255	258-263	264
	138	135	140-144	145
Edson 58S	138	138	138-144	145
Medicine Hat 41S	138	135	138-144	145
Amoco Empress 163S	240	247	247-260	264
	138	140	140-144	145

6. Study Methodology

The steady state switching study will be conducted to find the voltage response when starting the large motors. System conditions will be identified if the post starting bus voltages violate the criteria of the Alberta Reliability Standards.

7. Motor Start Models

7.1. Marlboro Motors

At the Marlboro substation, there are five 5000 HP compressor motors which are fed from the AIES 138 kV system through a pair of 138/4.16 kV transformers. All compressor motors have an auto-transformer for reduced voltage starting. However, the auto-transformer for compressor C-350 is not in service. For the remaining four compressors, although the starting mode can be selected to start across the line if desired, it is not a site operating practice. Figure 7.1-1 shows the configuration of the motor connection in substation Marlboro 348S.

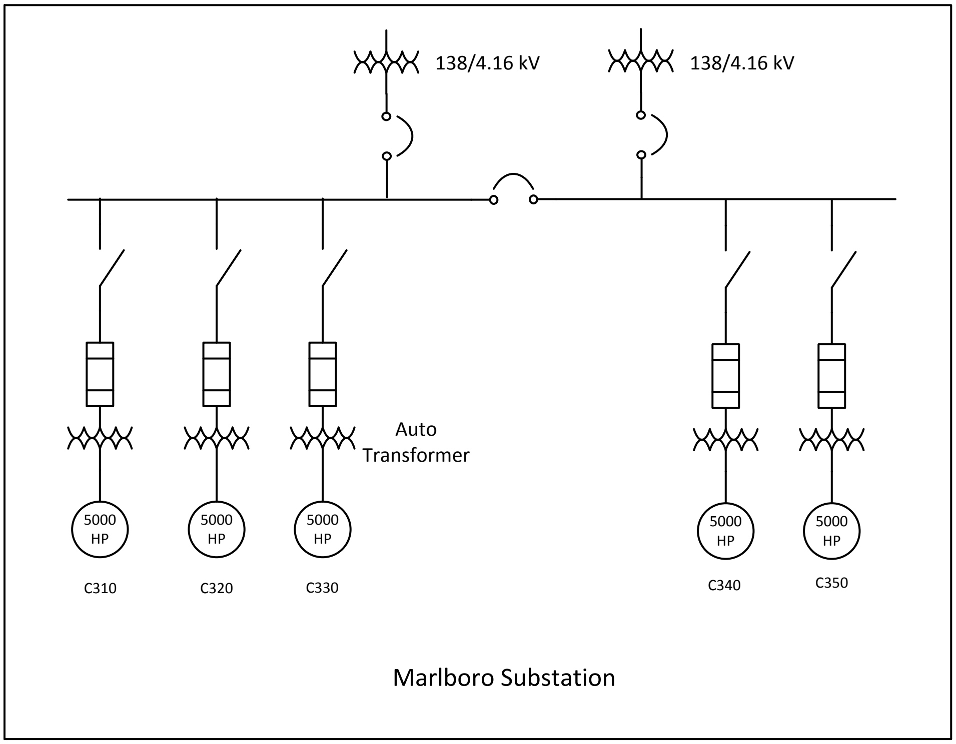

Figure 7.1-1: Configuration of Large Motors in Marlboro Substation

The following motor parameters are provided by the TransCanada Pipeline.

Table 7.1-1: Parameters of the motors in Marlboro Substation

	Starting Current	Full load Current	Starting PF	Full Load PF
Units with auto-transformer	1799	592	0.2 (4 to 5 sec)	0.87
Across the line starting	2728	609	0.2 (2 sec)	0.87

The motors are modeled as equivalent admittance G+jB, where

$G+jB = I_{ST}/I_{FL}*P(\text{in p.u.})/P_{FL}*(\cos\varphi_{ST}-\sin\varphi_{ST})$

Base MVA is 100 MVA.

5000HP = 3.73 MW

$\cos\varphi_{ST} = 0.2$

$\varphi_{ST} = 78.463$

$\sin\varphi_{ST} = 0.9798$

For the motors with auto transformer, G+jB = 1799/592*(3.73/100)/0.87*(0.2-j0.9798)

= 0.02606-j0.12766

For the motor start across the line, G+jB = 2728/609*(3.73/100)/0.87*(0.2-j0.9798)

= 0.03841-j0.18817

7.2. Empress Motors

In the Empress area, there are eight large synchronous motors in total, connected at Amoco Empress 163S, Empress 394S and Sand Hills 341S respectively. All the motors start with the assistance of a soft starter. Table 7.2-1 shows the parameters of the large motors and the soft starters in the Empress area. The soft starters for motors at the Empress substation share one capacitor bank. The soft starters for the motors 1-CM1C and 1-CM1D in Amoco Empress 163S share one capacitor bank and the soft starters for the motors 2-CM1A, 2-CM1B and 2-CM1C in Amoco Empress 163S share another capacitor bank. Figure 7.2-1 to Figure 7.2-3 show the configuration of the motors in the three substations respectively.

Table 7.2-1: Parameters of Large Motors in Empress Area

Substation	Motor						Soft Starter	
	Motor Name	HP	Voltage (kV)	Full Load Current	Full Load Power Factor	Locked Rotor KVA/HP code	Reactor (mh)	Cap Bank (MVAR)
Amoco Empress 163S	1-CM1-C	30000	13.8	952	1	B	1	40
	1-CM1-D	30000	13.8	952	1	B	1	
	2-CM1-A	30000	13.8	954	1	C	2.52	44
	2-CM1-B	30000	13.8	954	1	C	2.52	
	2-CM1-C	30000	13.8	954	1	C	2.52	
Empress 394S	KM-104	27000	13.8	856	1	B	6.4	28.8
	KM-107	34867	13.2	1153	1	A	1.3	
Sand Hills 341S	5-CM1-1	54000	13.8	1709	1	E	1.62	30 per phase

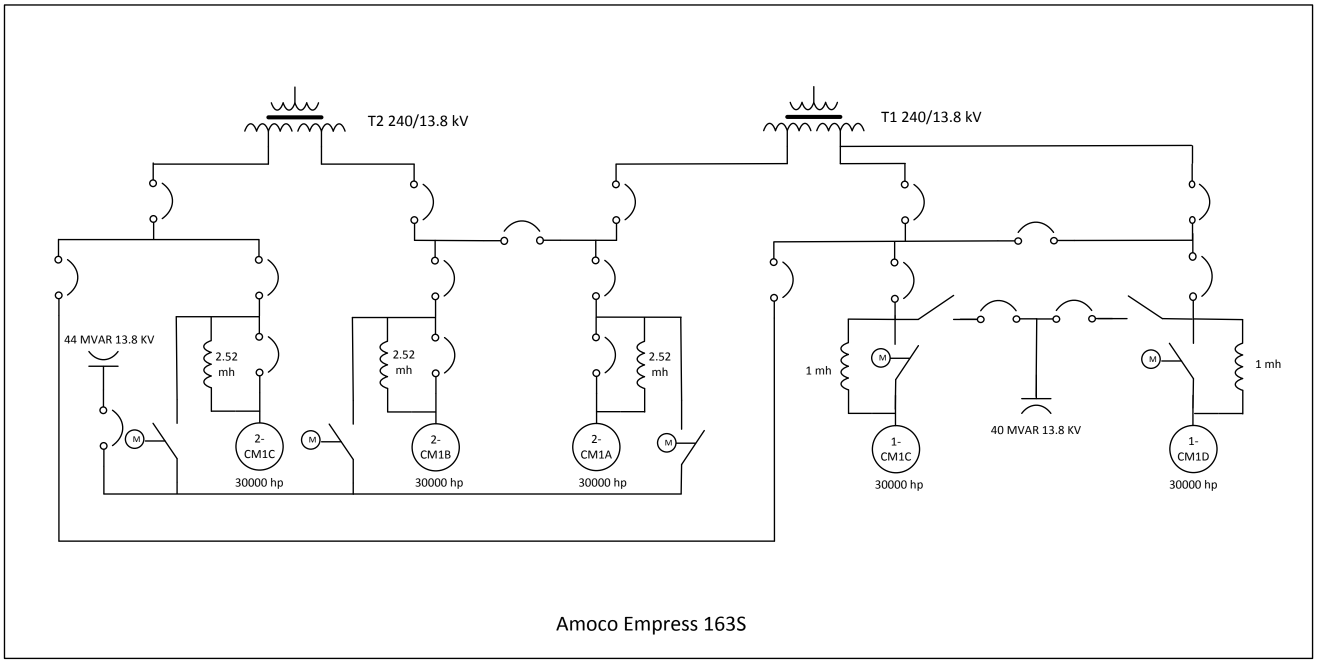

Figure 7.2-1: Configuration of Large Motors in Amoco Empress 163S

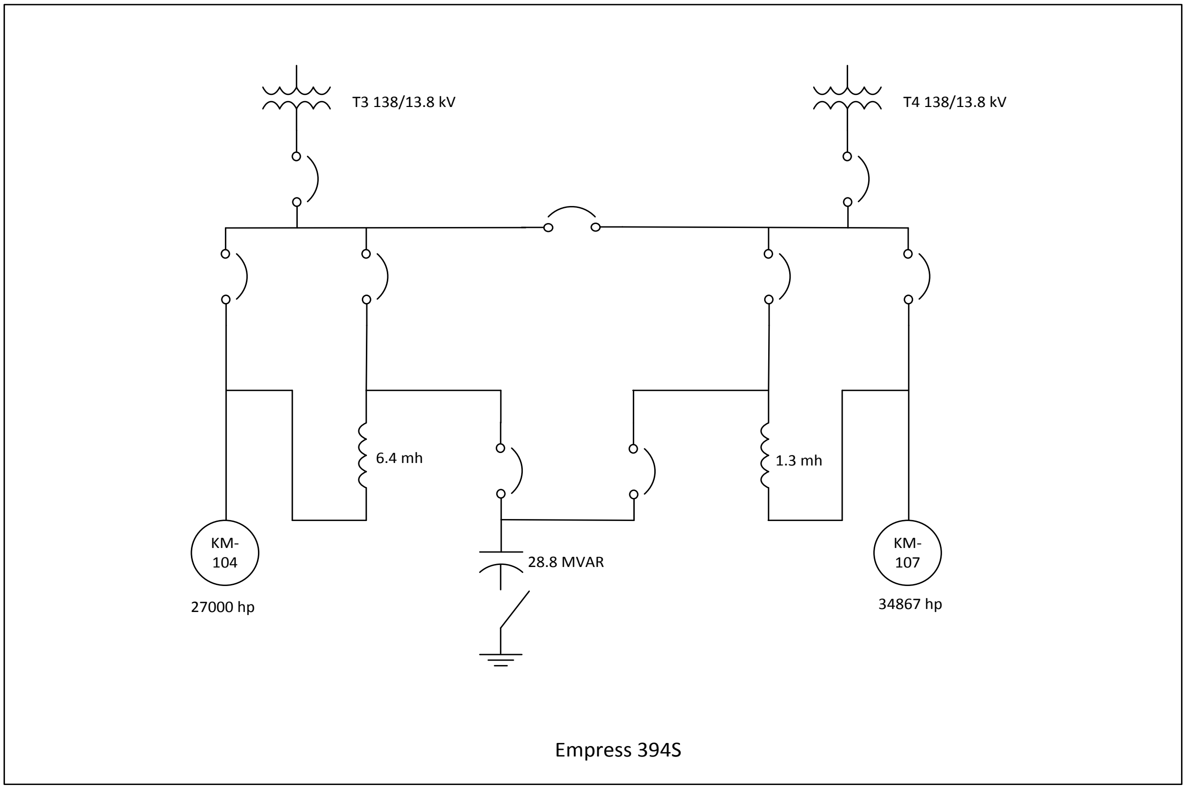

Figure 7.2-2: Configuration of Large Motors in Empress 394S

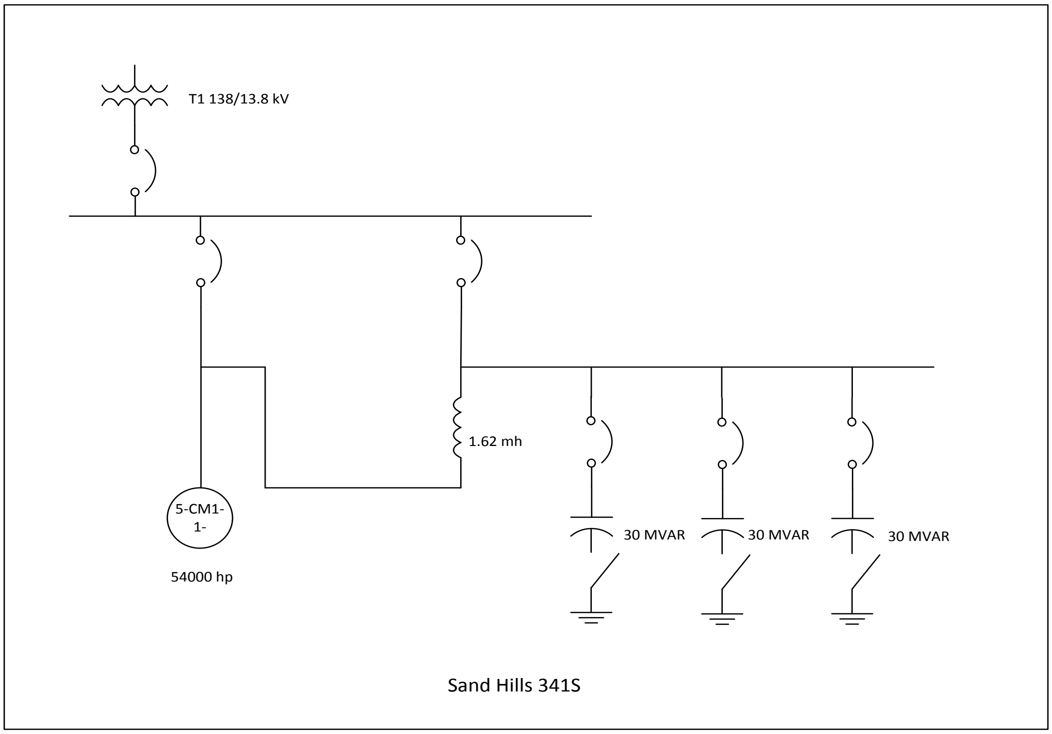

Figure 7.2-3: Configuration of Large Motors in Sand Hills 341S

The motors are modeled as equivalent admittance G+jB, where

$G+jB = I_{ST}/I_{FL}*P(\text{in p.u.})/P_{FL}*(\cos\varphi_{ST}-\sin\varphi_{ST})$

The starting current I_{ST} can be calculated through the Locked Rotor KVA / HP code.

KVA = (Rated Volts X Inrush Current X 1.732 (Square root of 3) / 1000

HP = Name Plate HP

The Lock Rotor KVA /HP Code can be found in Table 7.2-2.

Table 7.2-2 Lock Rotor KVA / HP Code

Letter Designation	KVA per Horsepower	Letter Designation	KVA per Horsepower
A	0-3.15	L	9-10
B	3.15-3.55	M	10-11.2
C	3.55-4.0	N	11.2-12.5
D	4-4.5	P	12.5-14
E	4.5-5	R	14-16
F	5-5.6	S	16-18
G	5.6-6.3	T	18-20
H	6.3-7.1	U	20-22.4

Letter Designation	KVA per Horsepower	Letter Designation	KVA per Horsepower
J	7.1-8	V	22.4 and up
K	8-9		

Note:

- Locked KVA per horsepower range includes the lower figure up to, but not including, the higher figure.

For the motors 1-CM1-C and 1-CM1-D, their Locked Rotor KVA / HP code is B, for worst case, B means KVA/HP =3.54. Thus

KVA / HP = (13800 x I_{ST} X 1.732) / 1000 / 30000 = 3.54

I_{ST} = 3.54 X 30000 / (13.8 X 1.732) = 4443 Amp

30000 HP = 22.371 MW

Base MVA is 100 MVA

Assume the starting power factor is 0.25 (typical data 0.2-0.3)

$\cos\varphi_{ST} = 0.25$

$\varphi_{ST} = 75.52$

$\sin\varphi_{ST} = 0.96825$

The equivalent admittance G + jB for motors 1-CM1-C and 1-CM1-D is

G+ jB = 4443 / 952 * (22.371/100) / 1.0 x (0.25 – j0.96825) = 0.261 - j1.011

For the reactor shared by motor1-CM1-C and 1-CM1-D,

X_L= 2πωL=2 X 3.14 X 60 X 1.002/1000 = 0.37755 Ohm

$Z_{base} = \sqrt{3}\, U^2/S$ = 1.732 X 13.8^2/ 100 = 3.29842 Ohm

$X_{L\ P.U.} = X_L/Z_{base}$ =0.377 / 3.29842 = 0.1145 Ohm p.u.

For the motors 2-CM1-A, 2-CM1-B and 2-CM1-C, their Locked Rotor KVA / HP code is C, for worst case, C means KVA/HP =3.99. Thus

KVA / HP = (13800 x I_{ST} X 1.732) / 1000 / 30000 = 3.99

I_{ST} = 3.99 X 30000 / (13.8 X 1.732) = 5008 Amp

30000 HP = 22.371 MW

Base MVA is 100 MVA

Assume the starting power factor is 0.25 (typical data 0.2-0.3)

$\cos\varphi_{ST}$ = 0.25

φ_{ST} = 75.52

$\sin\varphi_{ST}$ = 0.96825

The equivalent admittance G + jB for motors 2-CM1-A, 2-CM1-B and 2-CM1-C is

G+ jB = 5008 / 954 * (22.371/100) / 1.0 x (0.25 – j0.96825) = 0.29359 - j1.13708

For the reactor shared by motor 2-CM1-A, 2-CM1-B, and 2-CM1-C

X_L= 2πωL=2 X 3.14 X 60 X 2.52/1000 = 0.95 Ohm

$Z_{base} = \sqrt{3}\, U^2/S$ = 1.732 X 13.8^2/ 100 = 3.29842 Ohm

$X_{L\ P.U.} = X_L/Z_{base}$ =0.95 / 3.29842 = 0.28802 Ohm p.u.

For the motor KM-104, the Locked Rotor KVA / HP code is B, for worst case, B means KVA/HP =3.54. Thus

KVA / HP = (13800 x I_{ST} X 1.732) / 1000 / 27000 = 3.54

I_{ST} = 3.54 X 27000 / (13.8 X 1.732) = 3999 Amp

27000 HP = 20.134 MW

Base MVA is 100 MVA

Assume the starting power factor is 0.25 (typical data 0.2-0.3)

$\cos\varphi_{ST}$ = 0.25

φ_{ST} = 75.52

$\sin\varphi_{ST}$ = 0.96825

The equivalent admittance G + jB for motor KM-104 is

G+ jB = 3999 / 856 * (20.134/100) / 1.0 x (0.25 – j0.96825) = 0.23506 – j0.9104

For the reactor of KM-104,

X_L= 2πωL=2 X 3.14 X 60 X 6.4/1000 = 2.41 Ohm

$Z_{base} = \sqrt{3}\, U^2/S$ = 1.732 X 13.8^2/ 100 = 3.29842 Ohm

$X_{L\ P.U.} = X_L/Z_{base}$ =2.41 / 3.29842 = 0.73065 Ohm p.u.

For the motor KM-107, the Locked Rotor KVA / HP code is A, for worst case, A means KVA/HP =3.14. Thus

KVA / HP = (13800 x I_{ST} X 1.732) / 1000 / 34867 = 3.14

I_{ST} = 3.14 X 34867 / (13.8 X 1.732) = 4803 Amp

34867 HP = 26 MW

Base MVA is 100 MVA

Assume the starting power factor is 0.25 (typical data 0.2-0.3)

$\cos\varphi_{ST} = 0.25$

$\varphi_{ST} = 75.52$

$\sin\varphi_{ST} = 0.96825$

The equivalent admittance G + jB for motor KM-107 is

G+ jB = 4803 / 1153 * (26/100) / 1.0 x (0.25 – j0.96825) = 0.26975 – j1.04474

For the reactor of KM-107,

X_L= 2πωL=2 X 3.14 X 60 X 1.3/1000 = 0.49 Ohm

$Z_{base} = \sqrt{3}\, U^2/S$ = 1.732 X 13.8^2/ 100 = 3.29842 Ohm

$X_{L\ P.U.} = X_L/Z_{base}$ =0.49 / 3.29842 = 0.14856 Ohm p.u.

For the motor 5-CM1-1, the Locked Rotor KVA / HP code is E, for worst case, E means KVA/HP =4.99. Thus

KVA / HP = (13800 x I_{ST} X 1.732) / 1000 / 54000 = 4.99

I_{ST} = 4.99 X 54000 / (13.8 X 1.732) = 11274 Amp

54000 HP = 40.268 MW

Base MVA is 100 MVA

Assume the starting power factor is 0.25 (typical data 0.2-0.3)

$\cos\varphi_{ST} = 0.25$

$\varphi_{ST} = 75.52$

$\sin\varphi_{ST} = 0.96825$

The equivalent admittance G + jB for motor 5-CM1-1 is

G+ jB = 11274 / 1709 * (40.268/100) / 1.0 x (0.25 – j0.96825) = 0.66409 – j2.572

For the reactor of 5-CM1-1,

X_L= 2πωL=2 X 3.14 X 60 X 1.62/1000 = 0.61 Ohm

$Z_{base} = \sqrt{3}\, U^2/S = 1.732 \times 13.8^2/100 = 3.29842$ Ohm

$X_{L\ P.U.} = X_L/Z_{base} = 0.61 / 3.29842 = 0.18516$ Ohm p.u.

8. Model Validation

In August 8-10, 2000, Amoco Canada Petroleum Company (BP Amoco) commissioned their new gas processing unit at their Empress, Alberta facility that includes a single 54,000 HP synchronous motor among other electrical loads. This involved frequent starting of the 54,000 HP coupled motor and coincident operation of the gas re-compression process. (Coupled means that the motor is mechanically connected to the gearbox and compressor.) The 138 kV bus voltages at Empress 394S and Amoco Empress 163S were monitored. Customer and system conditions that prevailed from August 8-10, 2000 follows:

- All major loads in the Empress area were operating.
- Conoco's harmonic filter bank was on-line.
- Sheerness Units One and Two were operating.
- McNeil Converter station was at full import (Approx. 150 MW)
- Both 240 kV and 138 kV circuits into Amoco Empress 163S was in service.

From the power system data collected, the voltage change during the motor starts ranged from 3.9-4.6% and averaged 4.2% amongst all data collected. Information is summarized in Table 8-1 below. The percentage of voltage change is calculated based on following equation:

Percentage of voltage change = 100* (pre-start "steady state"- post start "steady state" voltages) / pre-start "steady state" voltage). The detail of the report is in the attachment A.

Table 8-1: Summary of Voltage Change Aug. 8-10, 2000

Location	Date/Time	Phase A Voltage Change	Phase B Voltage Change	Phase C Voltage Change
Empress 394S	Aug. 8/11:17	3.9%	No Data	3.9%
Empress 394S	Aug. 8/14:11	4.2%	4.35%	4.6%
Amoco Empress 163S	Aug. 8/14:11	4.3%	4.3%	4.3%
Empress 394S	Aug. 8/16:27	4.0%	4.3%	4.4%
Amoco Empress 163S	Aug. 8/16:27	4.3%	4.2%	4.3%
Amoco Empress 163S	Aug. 8/19:36	4.3%	4.2%	4.3%
Empress 394S	Aug. 9/19:15	4.0%	3.9%	4.2%
Empress 394S	Aug. 9/20:44	4.0%	4.0%	4.2%
Empress 394S	Aug. 10/09:28	4.0%	No Data	4.6%

Using the motor model developed in previous section, the 54,000 HP motor starting at Sand Hills 341S was simulated. The system conditions were the same as what in the report. The voltage change on the 138 kV buses at Empress and Amoco Empress were collected and presented in Table 8-2 below.

Table 8-2: Simulation Results of Sand Hills Motor Start

Location	Pre-start Voltage	Post Start Voltage	Voltage Change
Amoco Empress 163S	140.3	134.3	4.28%
Empress 394S	140.2	134.3	4.21%

The simulation results indicate that the motor models developed based on the parameters obtained from the customer and the assumptions based on engineering judgement are reliable.

9. Study Results

9.1. Marlboro Motors Starting

The Marlboro substation is tapped on line 854L. The flow on line 854L has great impact on the voltage response when starting the Marlboro motors. The historical flow on 854L is shown in Figure 9.1-1. It shows that the flow is always from south to north. 95% peak flow and 95% of light flow were used to study the impact of 854L flow on the Marlboro motor starting, which are 90 MW and 47 MW respectively.

Though there is nothing physically preventing the operators from starting the motors in quick succession, TransCanada Pipeline has operating protocols in place so that they leave 15 minutes between starts. Therefore, starting multiple motors at the same time is not possible and one motor start at a time is studied.

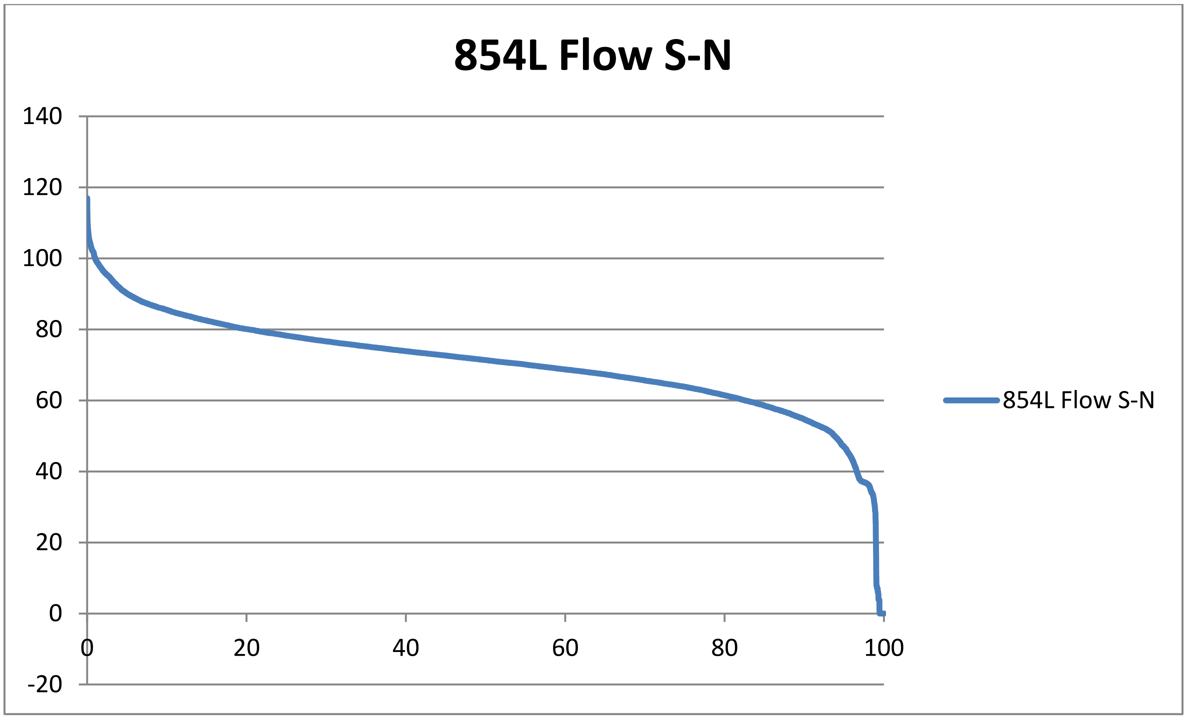

Figure 9.1-1: Historical Power Flow on 854L South to North

Motor starting under system normal condition and with one element outage close to the Marlboro substation were assessed. The study always starts from the assumption of four motors already in service and start the fifth motor to test the voltage respond on the nearby buses. If there is any bus voltage violation, i.e., 138 kV bus voltage lower than 0.9 p.u. (124.2 kV), then move to the assumption of three motors in service and start the fourth motor, and so on.

There are two capacitor banks in the area to support the local voltage. The capacitor bank at Cold Creek has never been switched on since it' built. This is because switching on this capacitor bank may cause high voltage violation on the 25 kV buses at the Cold Creek substation. Details can be found in the Central West Region Operation Study Report. This problem will not be solved in short term. So only the capacitor bank at the Edson 58S substation is considered to evaluate the impact of capacitor bank to the motor starting at Marlboror 384S.

The study results are shown in Table 9.1-1 and Table 9.1-2 for the flow on 854L with 90MW and 47 MW south to north respectively.

Table 9.1-1: Bus Voltage Respond to Marlboro Motor Start – 854L Flow 90 MW S-N

Contingency	# of Motors in service	Motor start method	Pre-motor start bus voltage at Marlboro (kV)	Bus voltage at Marlboro (kV)	Pre-motor start bus voltage at Cheviot (kV)	Post motor start bus voltage at Cheviot (kV)
N-0	4	Auto Transformer	138.1	136.6	137.2	136.6
		Across-the-Line	138.1	136	137.2	136.4
854L Deerhill to Marlboro Tap	4	Auto Transformer	140	137.7	138.1	137.4
		Across-the-Line	140	137	138.1	137.1

Contingency	# of Motors in service	Motor start method	Pre-motor start bus voltage at Marlboro (kV)	Bus voltage at Marlboro (kV)	Pre-motor start bus voltage at Cheviot (kV)	Post motor start bus voltage at Cheviot (kV)
685L Deerhill to Benbow	4	Auto Transformer	138.7	137.1	137.8	137
		Across-the-Line	138.7	136	137.8	136.7
720L Benbow to Fox Creek	4	Auto Transformer	135.9	134.3	136	135.4
		Across-the-Line	135.9	133.6	136	135.1
854L Bickerdike to Marlboro Tap	4		122.2		138.8	
	3	Auto Transformer	124.9	121.3	138.8	138.7
		Across-the-Line	124.9	119.8	138.8	138.7
	2	Auto Transformer	127.3	123.5	138.8	138.7
		Across-the-Line	127.3	121.9	138.8	138.7
	1	Auto Transformer	129.4	125.2	138.8	138.7
		Across-the-Line	129.4	123.5	138.8	138.7
	0	Auto Transformer	131.3	126.2	138.8	138.7
		Across-the-Line	131.3	125	138.8	138.7
973L and 974L Sundance to Bickerdike (Capacitor bank at Edson 58S offline)	4	N/A	123.3	-	120.9	-
	3	Auto Transformer	124.5	-	121.8	-
		Across-the-Line	124.5	-	121.8	-
	2	Auto Transformer	125.6	-	122.6	-
		Across-the-Line	125.6	-	122.6	-
	1	Auto Transformer	126.6	-	123.3	-
		Across-the-Line	126.6	-	123.3	-
	0	Auto Transformer	127.5	-	124	-
		Across-the-Line	127.5	-	124	-
973L /974L (Capacitor bank at Edson 58S online)	4	Auto Transformer	126.5	124.6	124.5	123.3
		Across-the-Line	126.5	123.8	124.5	122.8
	3	Auto Transformer	127.7	125.7	125.4	124.1
		Across-the-Line	127.7	124.9	125.4	123.6
	2	Auto Transformer	128.7	126.7	126.2	124.9
		Across-the-Line	128.7	125.9	126.2	124.3

Table 9.1-2: Bus Voltage Respond to Marlboro Motor Start – 854L Flow 47 MW S-N

Contingency	# of Motors in service	Motor start method	Pre-motor start bus voltage at Marlboro (kV)	Bus voltage at Marlboro (kV)	Pre-motor start bus voltage at Cheviot (kV)	Post motor start bus voltage at Cheviot (kV)
N-0	4	Auto Transformer	139.1	137.7	137.7	137.2
		Across-the-Line	139.1	137.1	137.7	136.9
854L Deerhill to	4	Auto Transformer	140.1	138.4	138.4	137.7

Contingency	# of Motors in service	Motor start method	Pre-motor start bus voltage at Marlboro (kV)	Bus voltage at Marlboro (kV)	Pre-motor start bus voltage at Cheviot (kV)	Post motor start bus voltage at Cheviot (kV)
Marlboro Tap		Across-the-Line	140.1	137.7	138.4	137.4
685L Deerhill to Benbow	4	Auto Transformer	139.6	137.9	138.1	137.4
		Across-the-Line	139.6	137.2	138.1	137.1
720L Benbow to Fox Creek	4	Auto Transformer	136.8	135.2	136.4	135.7
		Across-the-Line	136.8	134.6	136.4	135.4
854L Bickerdike to Marlboro Tap	4	Auto Transformer	127.8	124.2	138.7	138.7
		Across-the-Line	127.8	122.8	138.7	138.7
	3	Auto Transformer	129.5	125.7	138.7	138.7
		Across-the-Line	129.5	124.2	138.7	138.7
973L and 974L Sundance to Bickerdike (Capacitor bank at Edson 58S offline)	4	Auto Transformer	125.5	-	123	-
		Across-the-Line	125.5	-	123	-
	3	Auto Transformer	126.3	-	123.6	-
		Across-the-Line	126.3	-	123.6	-
	2	Auto Transformer	127	-	124.1	-
		Across-the-Line	127	-	124.1	-
	1	Auto Transformer	127.6	125.6	124.6	123.3
		Across-the-Line	127.6	124.7	124.6	122.7
	0	Auto Transformer	128.2	125.9	125	123.6
		Across-the-Line	128.2	125	125	123
973L /974L (Capacitor bank at Edson 58S online)	4	Auto Transformer	128.7	126.8	126.6	125.3
		Across-the-Line	128.7	126	126.6	124.8

The results show that under system normal condition, there is no problem to start the motor.

When 854L from Bickerdike to Marlboro Tap is out of service, the load capacity at Marlboro 384S would be limited to maximum two motor starts. The second motor start cannot be C350 motor which is across the line starting.

When 973L and 974L from Sundance to Bickerdike double circuit lines are out of service, if the capacitor bank at Edson 58 S is not available, no motor start is allowed. If the capacitor bank at Edson is on, the load capacity at Marlboro 384S would be limited to maximum three motor starts.

The above results are summarized in Table 9.1-3.

Table 9.1-3: Limits of Marlboro Motor Starts

System Operating Condition	Load Capacity
System normal	No limit
854L Bickerdike to Marlboro Tap	Maximum two motor starts, the second motor start cannot be C350 motor
973L and 974L Sundance to Bickerdike, Capacitor bank at Edson 58S off line	No motor start allowed
973L and 974L Sundance to Bickerdike, Capacitor bank at Edson 58S on line	Maximum three motor starts

9.2. Empress Area Motor Starting

Figure 7.2-1 to 7.2-3 show that some motors in the Empress area share the same capacitor bank. This configuration determined that the motors which share the same capacitor bank cannot start at the same time. The maximum possible number of the motors starting at the same time is four, which is the motor at Sand Hills, one of the motors at Empress, one of the motors of 2-CM1-A, 2-CM1-B and 2-CM1-C and one of the motors of 1-CM1-C and 1-CM1-D at Amoco Empress.

Four motors start at the same time under system normal condition and one element outage in the empress area were assessed. Two scenarios were considered. One scenario is that the AB-SK intertie is 0 MW. The other scenario is that the AB-SK intertie is at 150 MW export. All other motors were online. The capacitor bank at the Amoco Empress was switched off in the study. The capacitor bank at McNeil was switched off for the scenario of 0 MW AB-SK intertie and was switched on for the scenario of AB-SK intertie export 150 MW. The 138 kV buses close to the large motors in the Empress area were monitored. Table 9.2-1 and Table 9.2-2 show the study results.

Table 9.2-1 Bus Voltage Respond to Empress Motor Start – AB - SK intertie 0 MW

Contingency	Status	138 kV Bus Voltage				
		Amoco Empress	Empress	Sand Hills	Sandy Point	McNeil
System Normal (N-0)	Pre Start	143.1	143.1	143.1	143.1	143.2
	Post Start	131	131	130.9	131	131.5
1002L Jenner to Amoco Empress	Pre Start	141.3	141.3	141.3	141.3	141.4
	Post Start	128.2	128.2	128.1	128.2	128.7
1011L Cypress to Amoco Empress	Pre Start	143.1	143.1	143.1	143	143.2
	Post Start	131.1	131.2	131	131.1	131.7
945L Jenner to Cypress	Pre Start	141.3	141.3	141.3	141.3	141.4
	Post Start	128.1	128.1	127.9	128.1	128.6
944L /951L Ware Junction to Jenner	Pre Start	141.9	141.9	141.9	141.9	141.9
	Post Start	128.7	128.7	128.5	128.7	129.2
Amoco Empress	Pre Start	143	143	143	143	143.1

Contingency	Status	138 kV Bus Voltage				
		Amoco Empress	Empress	Sand Hills	Sandy Point	McNeil
240/138 kV Transformer	Post Start	130.3	130.4	130.1	130.3	130.9
658L Chappic Lake to Cypress	Pre Start	143.1	143.1	143.1	143.1	143.2
	Post Start	129.3	129.3	129.1	129.3	129.7
One Sheerness unit offline	Pre Start	143.3	143.3	143.3	143.3	143.4
	Post Start	130.6	130.6	130.4	130.6	131.1
Two Sheerness unit offline	Pre Start	144	144	144	144	144
	Post Start	130.6	130.6	130.4	130.5	131
7L760 Oyen to KSP Tap	Pre Start	142.4	142.4	142.4	142.4	142.5
	Post Start	129.1	129.2	129	129.1	129.7
668L Cypress to Empress	Pre Start	143.1	143	143.1	143	143.2
	Post Start	130.7	130.4	130.6	130.7	131.7
668L Cypress to Amoco Empress	Pre Start	143.1	143.1	143.1	143	143.2
	Post Start	130.8	130.9	130.6	130.7	131.7
760L Empress to Amoco Empress	Pre Start	143.2	143	143.2	143.1	143.2
	Post Start	130.9	131.2	130.8	130.9	131.5

Table 9.2-2 Bus Voltage Respond to Empress Motor Start – AB - SK intertie 150 MW

Contingency	Status	138 kV Bus Voltage				
		Amoco Empress	Empress	Sand Hills	Sandy Point	McNeil
System Normal (N-0)	Pre Start	141.3	141.3	141.3	141.3	140.9
	Post Start	129.1	129.1	129	129.1	129
1002L Jenner to Amoco Empress	Pre Start	138.5	138.4	138.5	138.4	138
	Post Start	125.3	125.3	125.2	125.3	125.1
1011L Cypress to Amoco Empress	Pre Start	141.3	141.2	141.3	141.3	140.9
	Post Start	129.2	129.3	129.1	129.2	129.2
945L Jenner to Cypress	Pre Start	138.4	138.3	138.4	138.3	137.8
	Post Start	125.1	125.1	125	125.1	124.9
944L /951L Ware Junction to Jenner	Pre Start	138.9	138.9	138.9	138.9	138.4
	Post Start	125.7	125.7	125.4	125.7	125.5
Amoco Empress 240/138 kV Transformer	Pre Start	141	141	141	141	140.6
	Post Start	128.2	128.2	128	128.2	128.3
658L Chappic Lake to Cypress	Pre Start	141.2	141.1	141.2	141.2	140.7
	Post Start	127.1	127.1	127	127.1	126.9
One Sheerness unit offline	Pre Start	141.3	141.3	141.3	141.3	140.9
	Post Start	128.6	128.6	128.4	128.6	128.5

Contingency	Status	138 kV Bus Voltage				
		Amoco Empress	Empress	Sand Hills	Sandy Point	McNeil
Two Sheerness unit offline	Pre Start	140.6	140.6	140.6	140.6	140.2
	Post Start	127.2	127.2	127	127.2	127
7L760 Oyen to KSP Tap	Pre Start	140.2	140.2	140.2	140.2	139.8
	Post Start	126.8	126.9	126.7	126.8	126.8
668L Cypress to Empress	Pre Start	141.3	141.2	141.3	141.2	140.9
	Post Start	128.8	128.7	128.7	128.8	129.2
668L Cypress to Amoco Empress	Pre Start	141.3	141.3	141.3	141.3	140.8
	Post Start	128.9	129	128.7	128.9	129.1
760L Empress to Amoco Empress	Pre Start	141.3	141.1	141.3	141.3	140.8
	Post Start	129	129.2	128.9	129	129

The results show that even with four motors starting at the same time under N-1 system condition, the 138 kV bus voltage in the Empress area would not be lower than 0.9 p.u..

10. Summary

Existing SCP 5-TXMN-20 Marlboro Motors Start and Load Limitation and SCP 5-TXMN-03 Empress Area Operation manage the large motors start requests in the Marlboro substation and the Empress area respectively. In the Marlboro substation, there are five 5000 HP motors. Four motors start through auto transformer and one motor starts across the line. The Transcanada's operating procedures determined that only one motor can be started at a time. In the Empress area, there are eight large synchronous motors. All large motors in the Empress area have soft starters. Some soft starters share the same reactor. The configuration of the soft starters determined that the maximum number of motors start at the same time is four.

Motor start analysis was performed for the large motors in Marlboro substation and the Empress area. The motors were modeled as admittance and switching actions were applied to simulate the motor start. The 138 kV bus voltages post motor starting should be above 0.9 p.u.,(124.2 kV) as per AESO Operations Horizon Voltage Limits Guidelines in Operations Domain.

The study results show that for the motors at Marlboro substation, the load capacity at Marlboro is limited under different system operating conditions, which are summarized as following:

System Operating Condition	Load Capacity
System normal	No limit
854L Bickerdike to Marlboro Tap out of service	Maximum two motor starts, the second motor start cannot be C350 motor
973L and 974L Sundance to Bickerdike out of service and capacitor bank at Edson 58S off line	No motor start allowed
973L and 974L Sundance to Bickerdike out of service and capacitor bank at Edson 58S on line	Maximum three motor starts

The study results also indicate that for the large motors in the Empress area, even four motors start at the same time, the 138 kV bus voltages post motor starting would be above 0.9 p.u.. under either system normal condition (N-0) or one element out of service (N-1) system conditions.

To incorporate the study results into procedures, it is recommended to update the existing SCP 5-TXMN-20 Marlboro Motor Start to include the requirements for 973L and 974L double circuit lines outage. Since there is no voltage violation post motors start in the Empress area, it is suggested to remove the content related to the motor start requests in the existing SCP 5-TXMN-03.

11. Revision History

Rev. #	Description	Author	Date
V1D1	*Draft for internal comments*	*Eric Wu*	*January 31, 2018*
V1 FINAL	*Final Report*	*Eric Wu*	*March 5, 2018*