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Kandahar City Long Term Transmission Plan

Component 1 Subcomponent 2

Kandahar Helmand Power Project (KHPP)

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Project: Kandahar and Helmand Power Project (KHPP)

Component 1 Subcomponent 2 – Refurbish Kandahar City Medium Voltage (MV) Distribution System

Purpose

This report provides a narrative description to support the medium to long term power transmission plan specifically for Kandahar City (Power Sector Master Plan), completed by Fitchner in November 2012.

Black & Veatch performed a Long Term Transmission Planning study leveraging the design basis, substation configurations, and equipment provided by the KHPP and SEPS contracts with the following objectives:

1. Validate the findings of the Power Sector Master Plan with regard to the Kandahar province.
2. Determine the in-service date of the 110 kV Kandahar City loop.
3. Identify system upgrades needed throughout the twenty year planning horizon to maintain system reliability as the system load level increases.
4. Provide a recommendation regarding whether to proceed with a double circuit 110 kV transmission line between Kandahar East – Breshna Kot 110 kV substations.

Background

The Power Section Master Plan (PSMP), completed by Fitchner in November 2012, identified necessary system upgrades required in the provinces to extend the coverage of the country's power supply. The PSMP was broken up into four (4) stages to address near and long-term development 2015, 2020, 2025 and 2032. Several major projects with immediate need for implementation were identified, the following of which were relevant to studies performed by Black & Veatch:

- Finalizing the Salma HPP and Kajaki Expansion HPP (Unit 2, 18.5 MW) (2016)
- NEPS to SEPS interconnector (2017)

In addition, the PSMP calculated the projected load growth for all provinces and identified in-service years for additional transformer capacity. PSMP served as the basis for the Long Term Planning study performed by Black & Veatch which sought to address the following objectives:

1. Validate the findings of the Power Sector Master Plan.
2. Determine the in-service date of the 110 kV Kandahar City loop.
3. Identify system upgrades needed throughout the twenty year planning horizon to maintain system reliability as the system load level increases.
4. Provide a recommendation regarding whether to proceed with a double circuit 110 kV transmission line between Kandahar East – Breshna Kot 110 kV substations.

Approach

Black & Veatch developed four (4) network models of the SEPS, one for each year 2015, 2020, 2025 and 2032 consistent with the PSMP. Each model assumed that the entire SEPS was served by the NEPS-SEPS interconnection; this interconnection was represented by a fictitious generator at the Kandahar East 110 kV substation.

The studies consisted of steady-state power flow analysis using Siemens PTI PSS/E® (Power System Simulator for Engineers) version 32.1.2, a prominent software suite used widely in the field of transmission planning.

The AC Contingency Calculation (ACCC) feature of PSS/E was used to conduct N-1 contingency analysis for each of the four (4) network models. The results were reviewed in pairs (2015-2020, 2020-2025, and 2025-2032). Using linear interpolation of the results, Black & Veatch was able to identify an approximate "problem year" for observed thermal overloads and voltage violations. As needed, Black & Veatch identified system upgrades based on the results of the ACCC simulations.

The conductors used in this study, 120 mm^2 ACSR "Coyote" conductor and 450 mm^2 ACSR "Elk" conductor, are currently in use in the SEPS system. If NEPS-SEPS utilizes a conductor larger than Elk, then the transmission conductor sizing analysis should be revisited.

The following sub-sections discuss the development of the 2015, 2020, 2025 and 2032 base case models.

2015 Network Model Development

The 2015 network model was completed consistent with network data provided by Black & Veatch Special Projects Corp in-country staff, DABS and the PSMP. In consultation with USAID, Black and Veatch confirmed the NEPS-SEPS tie has an expected in-service date of 2017. However, in order to ensure there were no thermal overloads or voltage violations prior to 2017, Black and Veatch used 2015 as the starting year for the analysis to provide greater resolution to the results.

First observations of the network identified unacceptable low voltages throughout SEPS primarily due to the system being radially fed from Kandahar East with long transmission lines between distribution substations.

To mitigate the low voltage conditions, Black & Veatch added two (2) 15 MVAR capacitor banks at Kajaki 110 kV and Durai Junction 110 kV respectively. This addition served two purposes, 1) provides voltage support, 2) reduced the voltage drop on the transmission lines by reducing the amount of reactive power flow at the NEPS-SEPS tie.

In addition, the voltage set point of the fictitious generator used to represent the NEPS-SEPS tie was set to 1.05 per unit with the assumption that the NEPS-SEPS tie would be a strong source.

Figure 1 provides a visual representation of the 2015 network model:

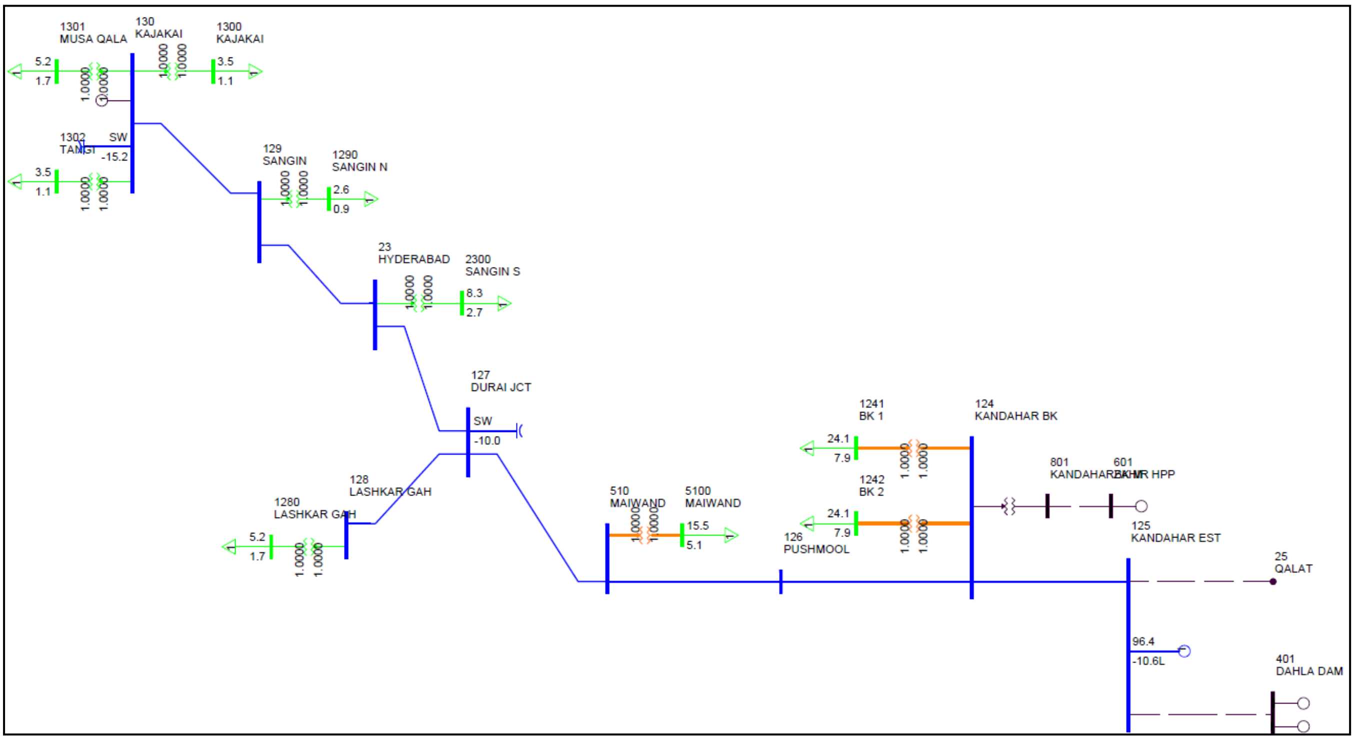

Figure 1 2015 Network Model

2020 Network Model Development

Initial review of the 2015-2020 results indicate that the Kandahar City loop would be required by 2017 to prevent overloading of the Kandahar East – Breshna Kot 110 kV transmission lines.

Consequently a revised 2020 base case was built with the Kandahar City loop in-service. A visual representation of the loop is provided in Figure 2.

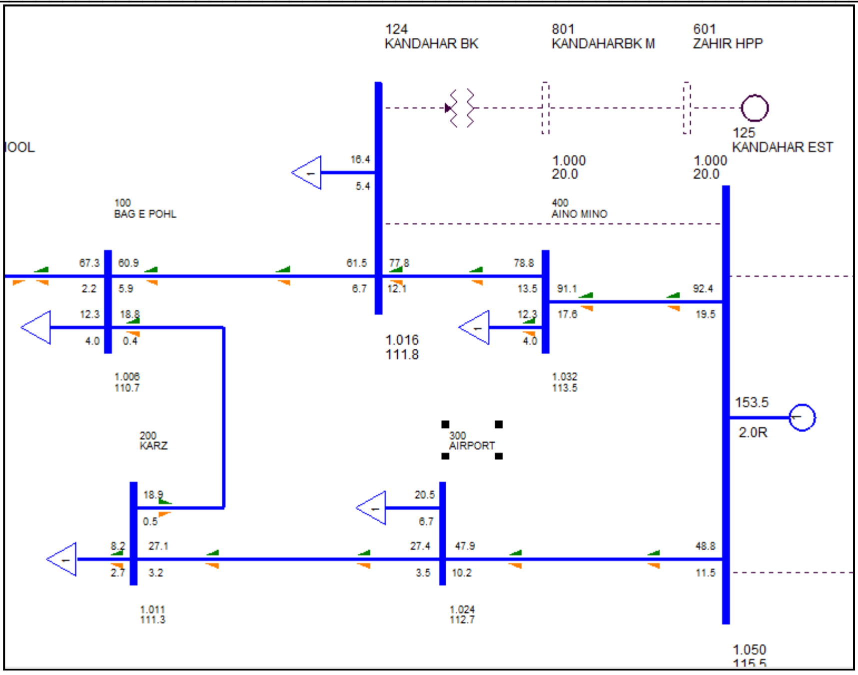

Figure 2 Kandahar City Loop

The loop consists of the following:

- Bag-e-Pohl 110 kV substation located approximately 6.5 km west of Breshna Kot
- Karz 110 kV substation located approximately 12 km southeast of Bag-e-Pohl
- Airport 110 kV substation, located south of the Kandahar International Airport, approximately 18 km east southeast of Karz. The Airport Substation includes a 110 kV radial line to Spin Boldak.
- Aino Mino 110 kV substation located approximately 8 km east of Breshna Kot, between Kandahar East substation and Breshna Kot substation.

All transmission lines were modeled as 120 mm^2 ACSR “Coyote” conductor. The conductor ampacities were calculated per IEEE 738 and are documented in Appendix A.

Using engineering judgment and with agreement from DABS-Kandahar, Black & Veatch divided the total Kandahar load from the PSMP as follows for the Kandahar City loop:

Table 1 Kandahar Loop Load Distribution

Area	% Total Load	Description
Breshna Kot	20%	Serves Kandahar City Center and Argandab to the north. Distribution loads are primarily commercial and residential.
Karz	10%	Serves south Kandahar City and towns south of Kandahar. Distribution loads are primarily residential and agricultural.
Aino Mino	15%	Serves new development and new town of Aino Mino located approximately have way between Breshna Kot and Kandahar East. Distribution loads are primarily commercial and residential.
Airport	25%	Serves southeast area of Kandahar City, including Kandahar International Airport. Distribution loads are primarily industrial and commercial. The substation load will also include a 110 kV radial line to Spin Boldak
Bag-e-Pohl	15%	Serves west area of Kandahar City and is the main tie for the 110 kV line to Helmand Province including Durai Junction and Kajaki. Distribution loads are primarily commercial and residential.
Kandahar East	15%	Serves east area of Kandahar City and towns east and north of this substation. Distribution loads are primarily commercial, residential, and agricultural.
	100%	

These assumptions were made by observing where the current and future load pockets are with respect to proposed locations for these substations. Much of the load pockets outside of Kandahar City proper are too far away for the distribution circuits to reach, necessitating the need for addition substations along the Kandahar City loop. Additional substations also act to reduce transmission line losses by shortening the lines. The estimated reconfigured substation extents are shown in Appendix B. As the new substations are developed, the existing Kandahar City feeders will be reconfigured and loads transferred. A distribution system planning study is recommended to be completed utilizing this long term transmission plan.

The initial review of the base case voltage levels indicate that capacitor banks are needed at Kajaki and Durai Junction, 20 MVAR each, to bring all voltages above 0.92 per unit.

Figure 3 provides a visual representation of the 2020 network model:

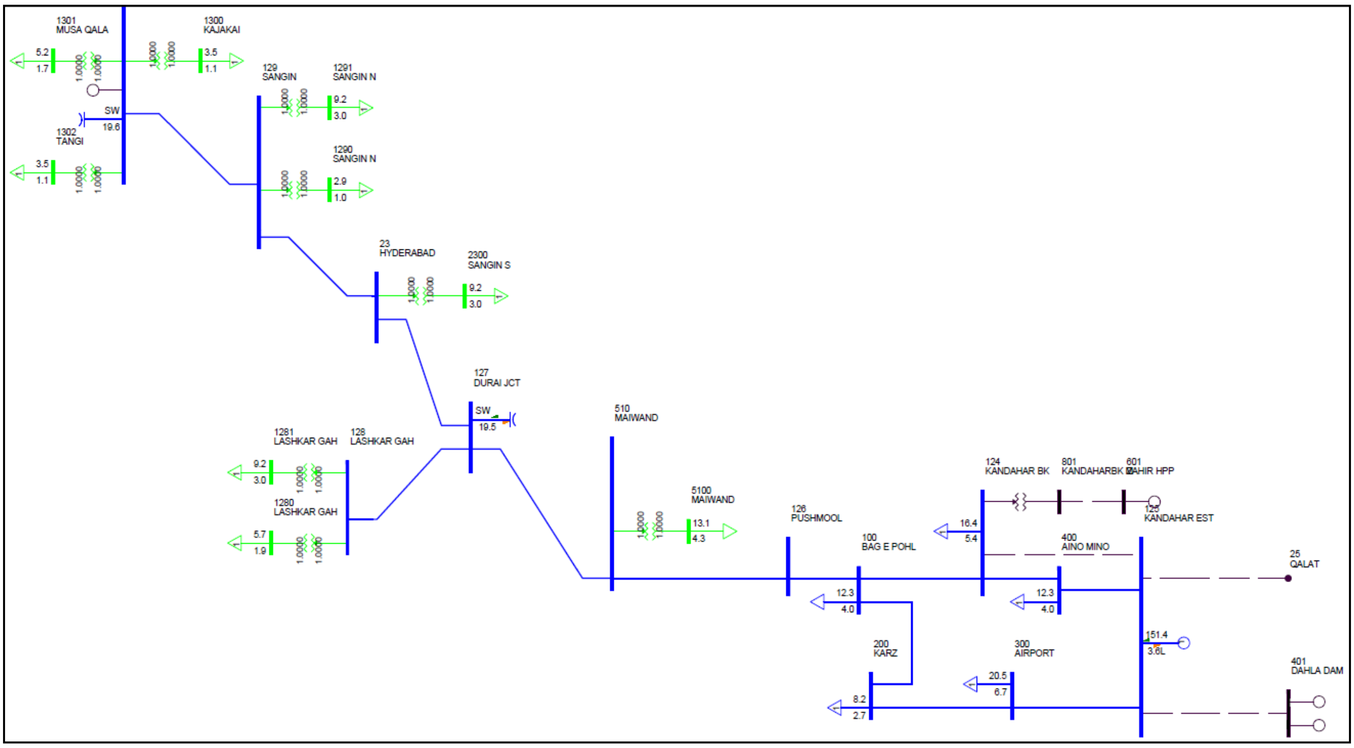

Figure 3 2020 Network Model

2025 Network Model Development

Initial review of the 2025 base case indicated thermal overloads of the Maiwand – Pushmool – Bag-e-Pohl – Breshna Kot 110 kV transmission lines. In addition, the network had unacceptable low voltages throughout.

To mitigate these base case violations, Black & Veatch replaced the following lines with ACSR “Elk” conductor. Elk is the conductor utilized for the transmission line sections associated with Durai Junction substation and Breshna Kot substation.

- Pushmool – Maiwand 110 kV
- Bag-e-Pohl – Pushmool 110 kV
- Bag-e-Pohl – Breshna Kot 110 kV
- Breshna Kot – Aino Mino 110 kV
- Aino Mino – Kandahar East 110 kV

Reconductoring the aforementioned transmission lines with lower impedance conductor greatly reduce the voltage drop along the lines.

In addition, a 20 MVAR capacitor bank was added at Sangin North 110 kV substation to eliminate all base case voltage violations.

Figure 4 provides a visual representation of the 2025 network model:

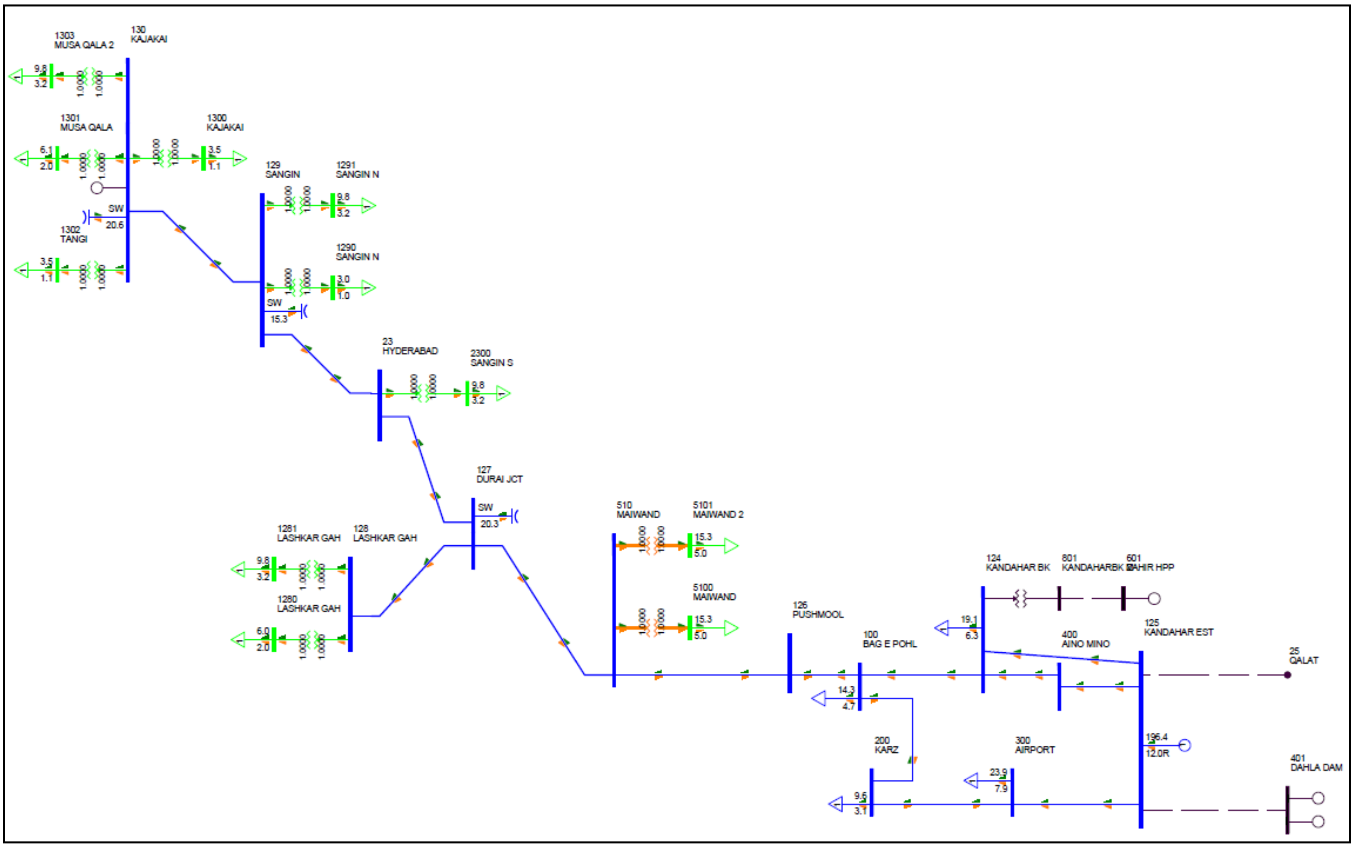

Figure 4 2025 Network Model

2032 Network Model Development

Initial review of the 2032 base case indicated that the network had unacceptably low voltages at several substations.

To mitigate these base case violations, Black & Veatch added an additional 20 MVAR capacitor bank at Maiwand 110 kV substation.

In addition, the Kajaki, Tangi and Sangin North 110/20 kV transformers were overloaded in the base case. These units were upgraded from 4 MVA units to 10 MVA units.

Figure 5 provides a visual representation of the 2032 network model:

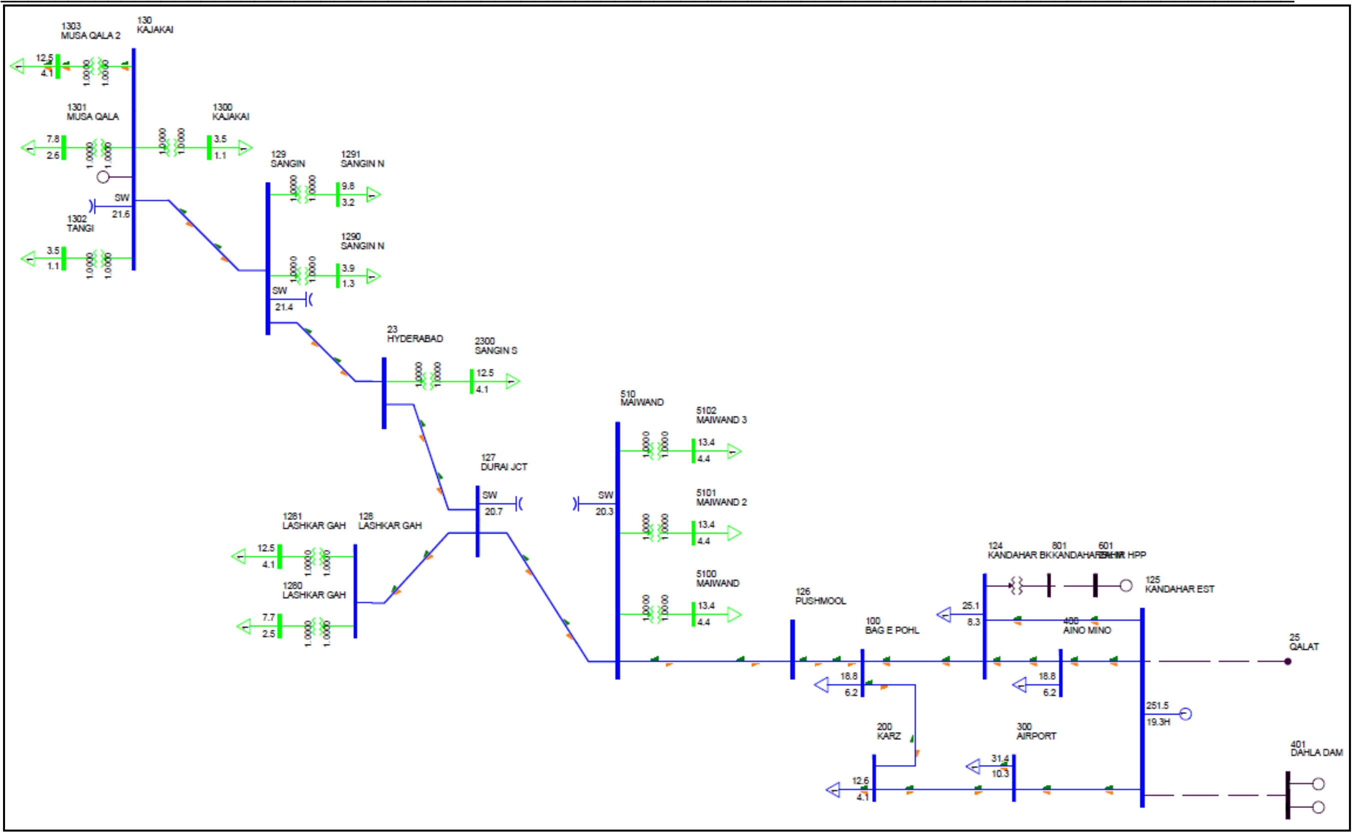

Figure 5 2032 Network Model

Methodology and Assumptions

For this study, the entire SEPS was assumed to be served by the NEPS-SEPS interconnection; this assumption was represented by a fictitious generator at the Kandahar East 110 kV substation.

The Kandahar province system peak has been alternating between summer and winter as more customers get access to appliances for heating and cooling. Throughout the studies, the assumption was implemented that the system will consistently peak during the winter months which are also at a time where Kajaki HPP is not likely to be available as a generation source. In other words, dispatching Kajaki HPP was not considered as an option to mitigate thermal overloads or voltage violations.

Due to the fact that the studies assumed all generation was to be supplied via the NEPS-SEPS tie, the system is very sensitive to changes in load and connectivity. Therefore, for all ACCC simulations the power flow was calculated using the Fixed-Slope Newton Raphson method as this method is more robust for systems with voltage sensitivities.

All loads were modeled with a 0.95 (lagging) power factor.

This study assumes that planned rehabilitation of the Kajaki – Durai Junction - Kandahar 110 kV transmission line has been completed, returning the line to its design basis capacity of 111.5 MVA per Appendix A.

The studies were conducted with and without the double circuit Kandahar East – Breshna Kot 110 kV transmission lines to determine whether the line is needed or not.

Transmission line loadings were calculated based on the ampacity of the line, while transformers loadings were based on their MVA rating.

The voltage was monitored at all SEPS buses, with a minimum threshold of 0.92 per unit and a maximum threshold of 1.05 per unit.

Results

2015-2020 Results

Table 2 Summary of Worst Case 2015-2020 Thermal Overload Results (No Kandahar City Loop, No Double Circuit)

TO BUS			FROM BUS			CONTINGENCY	RATING (MVA)	2015 FLOW (MVA)	2015 % LOADING	2020 FLOW (MVA)	2020 % LOADING	PROBLEM YEAR
#	NAME	VOLTAGE (kV)	#	NAME	VOLTAGE (kV)							
124	KANDAHAR BK	110	125	KANDAHAR EST	110	BASE CASE	111.5	96.7	84.6	157.9	141.9	2017
124	KANDAHAR BK	110	1241	BK 1	20	BASE CASE	25	26.2	105	22.2	88.9	2015
124	KANDAHAR BK	110	1242	BK 2	20	BASE CASE	25	26.2	105	22.2	88.9	2015
510	MAIWAND	110	5100	MAIWAND	20	BASE CASE	16	16.9	105.4	14.3	89.1	2015

The results indicate, based on the assumptions documented above, the Kandahar – Breshna Kot 110 kV line will overload close to 2017. This implies that the Kandahar City loop should be built by 2017 to unload the Kandahar – Breshna Kot 110 kV line.

The results assuming the Kandahar City loop will be built by 2017 are shown in Table 3:

Table 3 Summary of Worst Case 2015-2020 Thermal Overload Results (With Kandahar City Loop, No Double Circuit)

TO BUS			FROM BUS			CONTINGENCY	RATING (MVA)	2015 FLOW (MVA)	2015 % LOADING	2020 FLOW (MVA)	2020 % LOADING	PROBLEM YEAR
#	NAME	VOLTAGE (kV)	#	NAME	VOLTAGE (kV)							
124	KANDAHAR BK	110	1241	BK 1	20	BASE CASE	25	26.2	105	----	----	2015
124	KANDAHAR BK	110	1242	BK 2	20	BASE CASE	25	26.2	105	----	----	2015
510	MAIWAND	110	5100	MAIWAND	20	BASE CASE	16	16.9	105.4	14.2	88.7	2015
100	BAG E POHL	110	200	KARZ	110	7	94.94	----	----	103.2	140.9	2019
125	KANDAHAR EST	110	300	AIRPORT	110	7	94.94	----	----	155	174.8	2018
200	KARZ	110	300	AIRPORT	110	7	94.94	----	----	119.8	151.3	2019
100	BAG E POHL	110	124	KANDAHAR BK	110	8	94.94	----	----	112.7	123.1	2020
124	KANDAHAR BK	110	400	AINO MINO	110	8	94.94	----	----	132.6	141.4	2019
125	KANDAHAR EST	110	400	AINO MINO	110	8	94.94	----	----	149.4	154.7	2019

The system was initially studied without the double circuit from Kandahar East – Breshna Kot 110 kV. The system cannot sustain the loss of Kandahar – Aino Mino 110 kV as this will result in a violation of the steady-state stability limit (i.e. non-convergence of the power flow calculations) as the power system can only force a finite amount of power through a single point without the risk of causing a voltage collapse. Consequently transmission lines are rated well below their steady-state stability limit. In this case, all of the power from the NEPS-SEPS tie would forced through the remaining southern half of the Kandahar City loop. The severe loading of the lines result in significant voltage drops.

The Kandahar East – Breshna Kot 110 kV double circuit would mitigate this provided that the double circuit is not on the same tower as this would be a common point of failure.

The results with the Kandahar East – Breshna Kot 110 kV double circuit are shown in Table 4 and Table 5:

Table 4 Summary of Worst Case 2020 Thermal Overload Results (With Kandahar City Loop and Double Circuit)

TO BUS #	TO BUS NAME	TO BUS VOLTAGE (kV)	FROM BUS #	FROM BUS NAME	FROM BUS VOLTAGE (kV)	CONTINGENCY	RATING (MVA)	FLOW (MVA)	% LOADING
100	BAG E POHL	110	124	KANDAHAR BK	110	8	94.9	110	**114.9**
100	BAG E POHL	110	200	KARZ	110	27	94.9	90.8	**117.3**
125	KANDAHAR EST	110	300	AIRPORT	110	27	94.9	135.4	**149.9**
200	KARZ	110	300	AIRPORT	110	27	94.9	104.6	**127.1**

No voltage violations were observed in the 2015 case.

Table 5 Voltage Violations, 2020 (With Kandahar City Loop and Double Circuit)

CONTINGENCY	BUS #	BUS NAME	VOLTAGE (kV)	V-CONT	V-INIT
6	1280	LASHKAR GAH	20	**0.920**	0.950
6	1290	SANGIN N	20	**0.909**	0.942
6	1300	KAJAKAI	20	**0.911**	0.946
6	1302	TANGI	20	**0.911**	0.946
8	1290	SANGIN N	20	**0.913**	0.942
8	1300	KAJAKAI	20	**0.916**	0.946
8	1302	TANGI	20	**0.916**	0.946
15	1290	SANGIN N	20	**0.893**	0.942
15	1291	SANGIN N	20	**0.912**	0.960
15	2300	SANGIN S	20	**0.915**	0.960
27	23	HYDERABAD	110	**0.537**	0.978
27	100	BAG E POHL	110	**0.816**	1.024
27	126	PUSHMOOL	110	**0.729**	1.004
27	127	DURAI JCT	110	**0.594**	0.988
27	128	LASHKAR GAH	110	**0.564**	0.971
27	129	SANGIN	110	**0.531**	0.979
27	130	KAJAKAI	110	**0.524**	0.990
27	200	KARZ	110	**0.867**	1.025
27	510	MAIWAND	110	**0.649**	0.988
27	1280	LASHKAR GAH	20	**0.529**	0.950
27	1281	LASHKAR GAH	20	**0.533**	0.952
27	1290	SANGIN N	20	**0.468**	0.942
27	1291	SANGIN N	20	**0.499**	0.960
27	1300	KAJAKAI	20	**0.446**	0.946
27	1301	MUSA QALA	20	**0.492**	0.972
27	1302	TANGI	20	**0.446**	0.946
27	2300	SANGIN S	20	**0.506**	0.960
27	5100	MAIWAND	20	**0.604**	0.962

No voltage violations were observed in the 2015 case.

The loss of a single circuit of the Kandahar-Breshna Kot 110 kV double circuit (Contingency 6) results in minor voltage sags on the distribution system. These conditions can be mitigated locally with distribution capacitor banks.

The loss of the Kandahar East – Airport 110 kV line (Contingency 8) results overloads the Bag-e-Pohl – Breshna Kot 110 kV line as well as minor voltage sags on the distribution system. The Kandahar City loop was initially studied assuming the conductors would be 120 mm^2 ACSR “Coyote”. This conductor size is adequate for system intact conditions, but not under N-1 contingency conditions. Therefore, a larger conductor will need to be selected for the Kandahar City loop such as “Elk” ACSR. Elk is the conductor utilized for the transmission line sections associated with Durai Junction substation and Breshna Kot substation.

The loss of the Bag-e-Pohl – Breshna Kot 110 kV line (Contingency 27) results in a system voltage collapse and severe thermal overloads on the southern half of the Kandahar City loop similar to the loss of the Kandahar East – Aino Mino 110 kV line described previously. This overload condition indicates that the SEPS cannot be served solely by the NEPS-SEPS tie with only a single transmission line corridor available. Therefore, another transmission line from Breshna Kot – Bag-e-Pohl which is geographically diverse from the currently proposed line will be required to keep the loop intact.

2020-2025 Results

Table 6 Summary of Worst Case 2020-2025 Thermal Overload Results (With Kandahar City Loop and Double Circuit)

TO BUS			FROM BUS			CONTINGENCY	RATING (MVA) 2020	RATING (MVA) 2025	2020 FLOW (MVA)	2020 % LOADING	2025 FLOW (MVA)	2025 % LOADING	PROBLEM YEAR
#	NAME	VOLTAGE (kV)	#	NAME	VOLTAGE (kV)								
510	MAIWAND	110	5100	MAIWAND	20	BASE CASE	16	16	14.2	88.6	16.6	104	2025
510	MAIWAND	110	5101	MAIWAND 2	20	BASE CASE		16			16.6	104	2025
100	BAG E POHL	110	124	KANDAHAR BK	110	8	94.9	216.6	110	114.9	149.4	67.4	2020

Due to the increased load growth from 2020-2025, the Maiwand 110/20 kV transformers are required to be upgraded from 16 MVA units.

The results also reinforce the findings of the 2015-2020 results, identifying the need to have an alternate transmission path from Breshna Kot – Bag-e-Pohl. Reconductoring the Kandahar City loop will not be sufficient.

Table 7 2025-2032 Voltage Violations, Worst Case Results

CONTINGENCY	BUS #	NAME	VOLTAGE (kV)	2020 V-CONT	2020 V-INIT	2025 V-CONT	2025 V-INIT	PROBLEM YEAR
6	1280	LASHKAR GAH	20	0.91988	0.95001	0.94195	0.96896	2021
6	1290	SANGIN N	20	0.90897	0.9423	0.9433	0.97457	2022
6	1300	KAJAKAI	20	0.91128	0.9462	0.93889	0.9718	2022
6	1302	TANGI	20	0.91128	0.9462	0.93889	0.9718	2022
8	1290	SANGIN N	20	0.91337	0.9423	0.96156	0.97457	2021
8	1300	KAJAKAI	20	0.9159	0.9462	0.95809	0.9718	2021
8	1302	TANGI	20	0.9159	0.9462	0.95809	0.9718	2021
15	1290	SANGIN N	20	0.89265	0.9423	0.96344	0.97457	2022
15	1291	SANGIN N	20	0.9117	0.96014	0.98089	0.99175	2021
15	2300	SANGIN S	20	0.91472	0.95975	0.97913	0.989	2021

The increased load causes several voltage violations throughout the network as early as 2021. These are mitigated by the upgrades identified for the 2025 base case during model development. Specifically, the results indicate the need for the Sangin North 20 MVAR capacitor bank to be installed as early as 2021.

2025-2032 Results

No thermal overloads were observed between 2025 and 2032 with the upgrades identified from the 2020-2025 results and the base case upgrades identified during the development of the 2032 case.

The voltage results are shown in Table 8:

Table 8 2025-2032 Voltage Violations, Worst Case Results

CONTINGENCY	BUS #	NAME	VOLTAGE (kV)	2025 V-CONT	2025 V-INIT	2032 V-CONT	2032 V-INIT	PROBLEM YEAR
6	1280	LASHKAR GAH	20	0.94195	0.96896	**0.91615**	0.96634	2031
6	1281	LASHKAR GAH	20	0.94384	0.9708	**0.91895**	0.96897	2032
9	1280	LASHKAR GAH	20	0.9384	0.96896	**0.90412**	0.96634	2029
9	1281	LASHKAR GAH	20	0.94031	0.9708	**0.90697**	0.96897	2030

Very minimal voltage sags were detected at Lashkar Gah for the loss of either the Kandahar East – Aino Mino 110 kV line or the Kandahar East – Airport 110 kV line. This voltage drop could be mitigated by installing distribution capacitor banks as previously identified in the 2020-2025 results.

Additional Considerations

The aforementioned results promote the following recommendations:

1. Build the Kandahar City Loop by 2017 with “Elk” ACSR.
2. Build a second Kandahar East-Breshna Kot 110 kV transmission line ideally on a separate transmission path from the initial line.
3. Build a second Breshna Kot-Bag-e-Pohl 110 kV transmission line ideally on a separate transmission path from the initial line.

Building the Kandahar City loop 2017 (1) must be done regardless. The Breshna Kot 110/20 kV substation is located in the center of Kandahar City; therefore, transmission line access is severely limited. Two additional transmission line terminations into Breshna Kot may not be feasible due to the limited routing space into the substation and within the complex itself. Additional analysis was undertaken to identify alternate options to (2) and (3) above.

As previously discussed, the system cannot sustain the loss of the any transmission from Breshna Kot-Kandahar East 110 kV. Additional transmission is clearly needed to keep the Kandahar City loop intact during an N-1 contingency.

Per Appendix B, the Karz substation is located in a rural region to the south of Kandahar City. As an alternative to the Breshna Kot-Kandahar City 110 kV line, additional analysis was conducted assuming a 12 km 110 kV line from Karz-Kandahar East was built by 2020. The results are shown in Table 9 and Table 10:

No thermal overloads or voltage violations were observed in the 2020 and 2025 case.

Table 9 2025-2032 Thermal Overloads with Karz-Kandahar East 110 kV

TO BUS			FROM BUS			CONTINGENCY	2025	2025	2032	2032	Problem Year
#	NAME	VOLTAGE (kV)	#	NAME	VOLTAGE (kV)		FLOW (MVA)	% LOADING	FLOW (MVA)	% LOADING	
100	BAG E POHL	110	200	KARZ	110	7	137.2	**68**	193.7	**111**	2031

The Karz-Bag-e-Pohl 110 kV transmission line will become overloaded by 2031 for the loss of either Breshna Kot-Aino Mino or Aino Mino-Kandahar East 110 kV lines. This can be remedied by building an additional 110 kV transmission line from Karz-Bag-e-Pohl. It would be ideal if this line was on a separate structure and right of way from the original line as this geographic diversity will promote increased reliability. Figure 6 provides a visual representation:

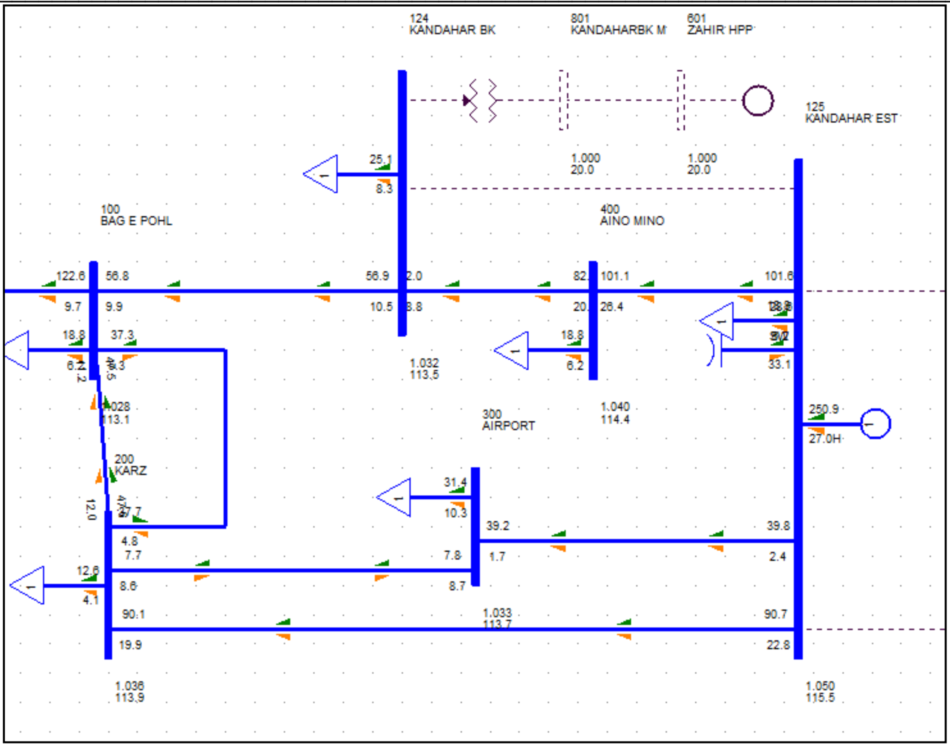

Figure 6 Kandahar City Loop with Kandahar East – Karz and Karz – Bag-e-Pohl 110 kV Additions

Table 10 2025-2032 Voltage Results with Karz-Kandahar East 110 kV

Contingency	Bus			2025	2025	2032	2032	Problem Year
	#	Name	Voltage (kV)	V-CONT	V-INIT	V-CONT	V-INIT	
7	1280	LASHKAR GAH	20	0.93518	0.94726	**0.89115**	0.94108	2028
7	1281	LASHKAR GAH	20	0.93709	0.94915	**0.89406**	0.9438	2028
7	5100	MAIWAND	20	0.9343	0.95014	**0.91811**	0.96413	2032
7	5101	MAIWAND 2	20	0.9343	0.95014	**0.91811**	0.96413	2032
7	5102	MAIWAND 3	20	----	----	**0.91811**	0.96413	2032

For the loss of Breshna Kot-Aino Mino 110 kV, several voltage sags on the 20 kV system were detected. However, the previously recommended distribution capacitors at Lashkar Gah accompanied by new distribution capacitors at Maiwand would remedy these violations.

Recommendations

The results of the 2015-2020, 2020-2025 and 2025-2032 contingency analyses identified several system upgrades required to support the SEPS throughout the 20 year planning horizon:

- Install 15 MVAR capacitor bank at Kajaki 110 kV by 2015.
- Install 15 MVAR capacitor bank at Durai Junction 110 kV by 2015.
- Build the Kandahar City 110 kV loop by 2017.
  - Conductor type is Elk 30/4.5 ACSR.
  - Bag-e-Pohl 110 kV substation located approximately 6.5 km west of Breshna Kot
  - Karz 110 kV substation located approximately 12 km southeast of Bag-e-Pohl
  - Airport 110 kV substation, located south of the Kandahar International Airport, approximately 18 km east southeast of Karz. The Airport Substation includes a 110 kV radial line to Spin Boldak.
  - Aino Mino 110 kV substation located approximately 8 km east of Breshna Kot, between Kandahar East substation and Breshna Kot substation
- Build Kandahar East – Karz 110 kV transmission line by 2017.
  - Assuming only the NEPS-SEP tie is serving the entire SEPS.
- Build Karz-Bag-e-Pohl 110 kV #2 transmission line ideally on a separate transmission path from Karz-Bag-e-Pohl #1 110 kV transmission line by 2031.
  - Assuming only the NEPS-SEP tie is serving the entire SEPS.
- Increase the size of the Kajaki and Durai Junction capacitor banks by 2020.
- Install distribution capacitor banks at Kajaki, Lashkar Gah and Sangin North by 2020.
- Install a 20 MVAR capacitor bank at Sangin North by 2021.
- Replace the Maiwand 110/20 kV, 16 MVA transformers by 2025.
- Install 20 MVAR capacitor bank at Maiwand 110 kV by 2032.
- Replace the Tangi and Sangin North 110/20 kV transformers by 2032.
- Install distribution capacitor banks at Maiwand by 2032.

A potential increase in the capacity of the Kajaki HPP, from 51 MW to 200 MW (i.e. an additional 150 MW) has been studied provided the dam level is raised. To support the additional export of power to Kandahar City, one proposal is for a 92 km 110 kV transmission line to be built from Kajaki to Kandahar East. To assess the impact of such a line, Black & Veatch performed additional N-1 contingency analysis on the 2032 case with Kajaki HPP dispatched at 200 MW with the following two options:

1. Kajaki – Kandahar East 110 kV
2. Kajaki – Bag-e-Pohl 110 kV

The N-1 contingency analysis revealed no thermal overloads or voltage violations. As previously discussed, physical barriers (population density) are preventing another transmission line being brought into Breshna Kot. Building the new line to one of the southern loop substations would require a line crossing which is detrimental to system reliability.

The Kajaki – Kandahar East 110 kV option would require a mountain crossing which will add considerable cost to the line as well as a maintenance challenge. The Kajaki – Bag-e-Pohl 110 kV option is also feasible, provided right-of-way can be acquired as the substation is located in a more densely populated region. Both options are electrically feasible, the final decision will most likely come down to cost.

References

[1] "TA 7637 (AFG) Power Sector Master Plan", Fichtner, Nov. 2012.

[2] "Kandahar Energy Assessment – South Afghanistan Energy Assessment (SAEA)", Black & Veatch, 2012.

[3] "Substation Extents", Black & Veatch, 2013.

Appendix A – Conductor Ampacities

USER INPUT DATA AND LOOKUP VALUES:

CONDUCTOR SPECIFICS:	
Conductor:	ACSR ELK
Rated Temperature (°C):	75
Latitude (° North):	31.37
Conductor Runs:	East-West

CONDUCTOR TABLE LOOKUP:	
R_{high} (Ω/m):	6.06E-05
R_{low} (Ω/m):	7.60E-05
T_{high} (°C):	80
T_{low} (°C):	20
Conductor Diameter (in):	1.240157

ENVIRONMENTAL CONDITIONS:	
Ambient Temperature (°C):	20
Elevation (m):	1010
Wind Speed (ft/s):	2
Wind Direction Relative to Conductor:	Perpendicular
Sun Time:	10:00 AM
Atmospheric Conditions:	Clear
ε, Solar Emissivity (0.23 to 0.91):	0.5
α, Solar Absorptivity (0.23 to 0.91):	0.5

FINAL RESULTS:	
Ampacity (A):	1136.93
Thermal Rating @ 75C (MVA):	216.61

CONVECTION HEAT LOSS (qc):

CALCULATION CONSTANTS:	
T_{film} (°C):	60
ρ_f (kg/m³):	0.93891
μ_f (Pa·s):	0.00002
k_f (W/(m·°C)):	0.0287

CALCULATED HEAT LOSS (qc):	
qc1	74.94
qc2	70.27

RADIATED HEAT LOSS (qr):

CALCULATION CONSTANTS:	
Conductor Diameter (in):	1.240157
ε, Solar Emissivity (0.23 to 0.91):	0.5
Ambient Temperature (°C):	20
Rated Temperature (°C):	75

CALCULATED HEAT LOSS (qr):	
qr	20.45

SOLAR HEAT GAIN (qs):

CALCULATION CONSTANTS:	
δ, Solar Declination (°):	170.00
Hc:	61.726
Zc:	99.329
Z_l:	90
θ:	62.13
Qs:	1005.576364
Ksolar:	1.1
A':	0.103346417

CALCULATED SOLAR HEAT GAIN (qs):	
qs:	15.40

USER INPUT DATA AND LOOKUP VALUES:

CONDUCTOR SPECIFICS:	
Conductor:	ACSR Coyote
Rated Temperature (°C):	75
Latitude (° North):	31.37
Conductor Runs:	East-West

CONDUCTOR TABLE LOOKUP:	
R_{high} (Ω/m):	2.19E-04
R_{low} (Ω/m):	2.73E-04
T_{high} (°C):	80
T_{low} (°C):	20
Conductor Diameter (in):	0.625984

ENVIRONMENTAL CONDITIONS:	
Ambient Temperature (°C):	20
Elevation (m):	1010
Wind Speed (ft/s):	2
Wind Direction Relative to Conductor:	Perpendicular
Sun Time:	10:00 AM
Atmospheric Conditions:	Clear
ε, Solar Emissivity (0.23 to 0.91):	0.5
α, Solar Absorptivity (0.23 to 0.91):	0.5

FINAL RESULTS:	
Ampacity (A):	498.30
Thermal Rating @ 75C (MVA):	94.94

CONVECTION HEAT LOSS (qc):

CALCULATION CONSTANTS:	
T_{film} (°C):	60
ρ_f (kg/m³):	0.93891
μ_f (Pa·s):	0.00002
k_f (W/(m·°C)):	0.0287

CALCULATED HEAT LOSS (qc):	
qc1	52.99
qc2	46.62

RADIATED HEAT LOSS (qr):

CALCULATION CONSTANTS:	
Conductor Diameter (in):	0.625984
ε, Solar Emissivity (0.23 to 0.91):	0.5
Ambient Temperature (°C):	20
Rated Temperature (°C):	75

CALCULATED HEAT LOSS (qr):	
qr	10.32

SOLAR HEAT GAIN (qs):

CALCULATION CONSTANTS:	
δ, Solar Declination (°):	170.00
Hc:	61.726
Zc:	99.329
Z_l:	90
θ:	62.13
Qs:	1005.576364
Ksolar:	1.1
A':	0.052165333

CALCULATED SOLAR HEAT GAIN (qs):	
qs:	7.77

USER INPUT DATA AND LOOKUP VALUES:

CONDUCTOR SPECIFICS:	
Conductor:	AAC Canna
Rated Temperature (°C):	75
Latitude (° North):	31.37
Conductor Runs:	East-West

CONDUCTOR TABLE LOOKUP VALUES:	
R_{high} (Ω/m):	1.75E-04
R_{low} (Ω/m):	1.46E-04
T_{high} (°C):	75
T_{low} (°C):	25
Conductor Diameter (in):	0.724

ENVIRONMENTAL CONDITIONS:	
Ambient Temperature (°C):	20
Elevation (m):	1010
Wind Speed (ft/s):	2
Wind Direction Relative to Conductor:	Perpendicular
Sun Time:	10:00 AM
Atmospheric Conditions:	Clear
ε, Solar Emissivity (0.23 to 0.91):	0.5
α, Solar Absorptivity (0.23 to 0.91):	0.5

FINAL RESULTS:	
Ampacity (A):	585.39
Thermal Rating @ 75C (MVA):	111.53

CONVECTION HEAT LOSS (qc):

CALCULATION CONSTANTS:	
T_{film} (°C):	60
ρ_f (kg/m³):	0.93891
μ_f (Pa·s):	0.00002
k_f (W/(m·°C)):	0.0287

CALCULATED HEAT LOSS (qc):	
qc1	57.03
qc2	50.88

RADIATED HEAT LOSS (qr):

CALCULATION CONSTANTS:	
Conductor Diameter (in):	0.724
ε, Solar Emissivity (0.23 to 0.91):	0.5
Ambient Temperature (°C):	20
Rated Temperature (°C):	75

CALCULATED HEAT LOSS (qr):	
qr	11.94

SOLAR HEAT GAIN (qs):

CALCULATION CONSTANTS:	
δ, Solar Declination (°):	170.00
Hc:	61.726
Zc:	99.329
Z_l:	90
θ:	62.13
Qs:	1005.576364
Ksolar:	1.1
A':	0.060333333

CALCULATED SOLAR HEAT GAIN (qs):	
qs:	8.99

Appendix B – Substation Extents