transmission lines will increase in equal proportions. Due to this relationship equation 6.4 can be applied to get the loss factor. This development comes from the standard loss formula 6.2.

Equation 6.2 Power Loss Formula: $Losses = I^2 R$

Equation 6.3 Correlation between load and current: $Load \propto I$

Equation 6.4 Loss Factor (LF_2) development: $LF_2 = \sqrt{LF_1}$

The loss factor was calculated to 0.298. This relates the amount of losses in the peak case to the expect amount of losses at an average level throughout the year. These values were used to calculate energy use. Marginal energy cost was supplied by Xcel Energy's resource planning department. Capacity cost was also supplied at $20,000 per MW.

The total yearly savings was calculated by equation 6.5. This equation includes the cost of energy and capacity. For the economic analysis, this formula was applied each year.

$$\$Savings = MWreduction_{peak} * 8760 * (\$ / MWH) + MWreduction_{peak} * \$20{,}000$$

Equation 6.5 Savings calculation

Option 2 (Hiawatha @ 345 kV) in this study shows significant amounts of loss savings. In 2012 there were 1.7 MW of savings and 3 MW of savings in 2018. For economic analysis the MW savings were scaled at this rate of increase from 2011 through 2023. For a pessimistic view 2024-2030 was held fixed at 5 MW.

7.0: Economic Analysis

7.1: Total Installed Cost

The total installed costs were based off of indicative estimates and may change with estimate refinement. The estimated years are estimates based on a 1.5% load growth for the study area. These are subject to change based on the actual load growth experienced in the area. This will not change the need only the in-service date.

Option 1: 115 kV dbl ckt, dbl bundled Hiawatha Plan –

- 115/13.8 kV stations at Midtown and Hiawatha. Midtown is located at Oakland site
- Staging for costs
    - 2010
        - HIA & MID @ 115 kV - $18,311,000
    - 2013
        - Cleveland substation - $15,187,000
        - Cleveland-Lexington 115 kV (4 mi) - $3,016,000

        - 2 – 672 MVA xfmrs at Red Rock - $13,394,000
    - 2014
        - Crosstown substation - $6,143,000
        - Crosstown-WIL 115 kV dbl ckt (3 mi) - $3,381,000
        - 2 – 672 MVA xfmrs at Parkers Lake - $12,080,000
        - 2 – 672 MVA xfmrs at Eden Prairie - $15,000,000
    - 2016
        - Crosstown 2nd dist xfmr - $3,774,000
        - MID 2nd dist xfmr - $3,774,000
    - 2017
        - HIA 2nd dist xfmr - $4,610,000
    - 2018
        - Reconductor Afton-Red Rock 115 kV ckt (12.8mi) - $3,404,800
    - 2020
        - Cleveland-HIA 115 kV dbl ckt Dbl Bundle (7mi) - $7,889,000

Total Cost - $109,963,000

Option 2: 345 kV Hiawatha Plan -

- 115/13.8 kV stations at Midtown and Hiawatha. Midtown is located at Oakland site
- Staging for costs
    - 2010
        - HIA & MID @ 115 kV - $18,311,000
    - 2013
        - Cleveland substation - $15,187,000
        - Cleveland-Lexington 115 kV (4 mi) - $3,016,000
        - 2 – 672 MVA xfmrs at Red Rock - $13,394,000
    - 2014
        - Crosstown substation - $6,143,000
        - Crosstown-WIL 115 kV dbl ckt (3 mi) - $3,381,000
        - 2 – 672 MVA xfmrs at Parkers Lake - $12,080,000
        - 2 – 672 MVA xfmrs at Eden Prairie - $15,000,000
    - 2016
        - Crosstown 2nd dist xfmr - $3,774,000
        - MID 2nd dist xfmr - $3,774,000
    - 2017
        - HIA 2nd dist xfmr - $4,566,000
    - 2018
        - Reconductor Afton-Red Rock 115 kV ckt (12.8mi) - $3,404,800
    - 2018
        - Cleveland-HIA 345 kV (7mi) - $6,552,000
        - HIA 345 kV sub work - $7,140,000

Total Cost - $115,722,800

Option 3: Parkers Lake-Aldrich 345 kV Plan -

- 115/13.8 kV stations at Midtown and Hiawatha. Midtown is located at Oakland site
- Staging for costs
  - 2010
    - HIA & MID @ 115 kV - $18,311,000
  - 2013
    - Cleveland substation - $15,187,000
    - Cleveland-Lexington 115 kV (4 mi) - $3,016,000
    - 2 – 672 MVA xfmrs at Red Rock - $13,394,000
  - 2014
    - ALD sub work - $13,540,000
    - ALD-PKL 345 kV (7 mi) - $6,552,000
    - Crosstown addition - $6,143,000
    - Crosstown-WIL 115 kV dbl ckt (3 mi) - $3,381,000
    - 2 – 672 MVA xfmrs at Eden Prairie - $15,000,000
  - 2016
    - Crosstown 2nd dist xfmr - $3,774,000
    - MID 2nd dist xfmr - $3,774,000
  - 2017
    - HIA 2nd dist xfmr - $4,610,000
  - 2018
    - Reconductor Afton-Red Rock 115 kV ckt (12.8mi) - $3,404,800
  - 2019
    - ALD-MID 115 kV (2 mi) - $1,576,000

Total Cost - $111,662,800

Option 4: Quad 345 kV Plan -

- 115/13.8 kV stations at Midtown and Hiawatha. Midtown is located at Oakland site
- Staging for costs
  - 2010
    - HIA & MID @ 115 kV - $18,311,000
  - 2013
    - Red Rock upgrade - $13,540,000
    - Rogers Lake upgrade - $13,540,000
    - RRK-RLK 345 kV (6 mi) - $5,616,000
    - Cleveland substation - $15,187,000
    - Cleveland-Lexington 115 kV (4 mi) - $3,016,000
  - 2014
    - Cleveland-HIA 345 kV (7mi) - $6,552,000
    - HIA 345 kV sub work - $7,140,000
    - BDS 345 kV sub addition - $15,187,000
    - Crosstown Substation - $6,143,000
    - Crosstown-WIL 115 kV dbl ckt (3 mi) - $3,381,000
  - 2015

- ALD sub work - $15,187,000
- ALD-PKL 345 kV (7 mi) - $6,552,000

o 2016

- Crosstown 2nd dist xfmr - $3,774,000
- MID 2nd dist xfmr - $3,774,000

o 2017

- HIA 2nd dist xfmr - $4,610,000

Total Cost - $141,510,000

7.2: Evaluated Costs (with losses)

Evaluated costs take into account present worth value and overall system loss savings. An economic analysis of the cost savings associated with transmission system loss reduction is discussed in section 6.1. The detailed Present Worth Analysis spreadsheets are listed in Appendix D.

115 kV dbl ckt, dbl bundled Hiawatha Plan –

Total Installed Cost - $109,963,000
Present Worth Cost - $94,797,345

345 kV Hiawatha Plan -

Total Installed Cost - $115,722,800
Present Worth Cost - $95,574,140

Parkers Lake-Aldrich 345 kV Plan -

Total Installed Cost - $111,662,800
Present Worth Cost - $93,785,538

Quad 345 kV Plan -

Total Installed Cost - $141,510,000
Present Worth Cost - $96,104,596

8.0: Relevant Concerns

8.1: Load Serving Issues

Several load-serving issues exist or are imminent in southern Minneapolis and in the greater Twin Cities metro areas. These are summarized below and described in the following paragraphs.

Load center	Critical Contingencies
Southtown Substation	Loss of any of the 115/13.8 kV distribution transformers
Distribution Feeders	System intact overloads, several N-1 overloads
Minneapolis Metro Transformers (Parkers Lake, Eden Prairie, Red Rock)	Loss of one of the 345/115 kV transformers currently feeding the inner 115 kV system

The Southtown substation located in south Minneapolis as is currently served at the 115 kV level. There are currently a total of 54 MW of load at risk for loss of one of the 3 existing 115/13.8 kV distribution transformers. Adding another distribution transformer to relieve this risk at the existing Southtown substation is not possible due to the site would have to be expanded to accommodate a new transformer. The current Southtown site is in a heavily populated and congested area making expansion difficult.

Currently, there are 16 distribution feeders within the south Minneapolis area that are experiencing normal (base case) overloads totaling about 24 MVA. There are an additional 39 feeders that have contingency overloads (N-1) totaling about 225 MVA. These feeders currently do not have adequate N-1 backup to serve the entire load. Load would have to be curtailed in some cases to prevent sever loading on the existing distribution system.

The Minneapolis/St. Paul metro 115 kV area is primarily fed through the double circuited 345 kV loop that feeds the 115 kV system through large 345/115 kV transformers. Continued load growth on the 115 kV system will push the bulk 345/115 kV transformers beyond their acceptable 115% emergency under certain contingencies. This will cause the need for replacing the existing transformers to larger transformers or to add additional transformer capacity on the 345 kV system. Several of these sites have site limitations on the substation making expansion unlikely. In the case of the Red Rock 345/115 kV transformers, even when the existing pair of 448 MVA transformers is replaced with a pair of 672 MVA transformers, load growth will outstrip capacity in 2016 forcing another solution.

8.2: Constructability & Schedule Considerations

The transmission Options under evaluation differ significantly with respect to the number and type of construction activities required. These differences have ramifications with respect to the lead times involved in implementing the series of improvements required. Simpler Options are easier to build.

Options that require large amounts of reconductoring and rebuilding require disproportionately more time. This arises because power system reliability considerations limit the number of circuits within a geographical sub-area that can be simultaneously out of service for upgrade or replacement, since many of the circuits involved are to some degree electrically in parallel. This dictates that construction cannot be undertaken simultaneously on more than a few existing

circuits per season; rather, sequential construction is required. In contrast, Options that rely less heavily on reconductors and rebuilds encounter fewer construction outage constraints.

Table 4 summarizes the types of transmission line work involved and gives an estimated duration of work; based on a January 2010 start date. For this study load growth was assumed at a conservative 1.5% based on the 7-year historical averages for the study area. This is considered low for a major metropolitan area.

Table 4
Constructability & Schedule Considerations
For the South Minneapolis Electric Reliability Project

		miles of transmission					
Option	Description	New	Recond	Rebuild	Total	Capacitors	Years
1	Hiawatha @ 115 kV	27	12.8	0	39.8	0	8
2	Hiawatha @ 345 kV	20	12.8	0	32.8	0	8
3	Aldrich @ 345 kV	22	12.8	0	34.8	0	9
4	Quad 345 kV	33	0	0	33	0	7

The timing of the transmission system improvements for each of these options is highly dependent on the system load growth. So this means that for each of these options some parts could happen sooner or later depending on how fast the load grows.

8.3: Double-Circuit Line Considerations

The 345 kV Hiawatha Plan, which has been identified as the "Preferred Plan", involves addition of a new Hiawatha 345/115 kV substation, a new Midtown 115 kV substation, a new Cleveland 345/115 kV substation, a new Crosstown 115 kV substation, a new double circuit 115 kV line from Hiawatha-Midtown, a new 345 kV line from Cleveland-Hiawatha, and a new double circuit 115 kV line from Wilson-Crosstown. Implementation of these circuits requires consideration of whether it is desirable or acceptable to construct these pairs of circuits on double-circuit structures.

The conclusion is that in the case of the Hiawatha-Midtown 115 kV lines and the Wilson-Crosstown 115 kV lines it is appropriate to put them on the same structures. Loss of these two lines will only affect the distribution load located at the new Midtown and Crosstown substations.

For the new 345 kV line between Hiawatha-Cleveland it is not appropriate to double circuit with existing lines. This new lines will be a major source to the area, double circuiting it with an existing line will mean we have to plan for loss of both lines under one contingency. The existing system can handle the loss of the new 345 kV line with out causing issues on the existing transmission system. Consequently, the 345 kV line from Cleveland-Hiawatha must be constructed in a manner that minimizes exposure to "common-mode" failures, which would simultaneously render both circuits unusable.

Common-mode failure mechanisms for double-circuit lines include

- electrical failure of line insulation due to lightning strike;
- mechanical failure of one or more structures;
- broken shield wire falling into power conductors;
- wind-blown debris causing conductor-conductor short circuits;
- insulator contamination due to road salt, soot, or agricultural chemicals;
- wind/sleet/ice conditions
- contact with aircraft or construction equipment (crane, dump truck)
- protective relaying malfunction ("sympathetic tripping" due to fault on adjacent circuit)

These common-mode failure mechanisms have all been experienced on the Xcel Energy/NSP transmission system, on double-circuit lines at all voltage levels from 69 kV to 345 kV.

In consideration of these common-mode outage mechanisms, the NERC Planning Standards recognize double-circuit line outages as a "single-contingency" type of event ("Category C-5"). Consequently, evaluation of electric transmission system capability is performed considering failure of both circuits of a double-circuit line as being a single-contingency event. Double-circuit lines therefore are not appropriate in situations where two independent circuits are required for reliability purposes.

Double-circuit construction is acceptable if the power system can reliably withstand simultaneous failure of both circuits. Double circuit construction therefore can be appropriate in situations where the two circuits serve different functions, connect different pairs of substations, split away and proceed in different directions, or where high capacity (but not redundancy) is required.

9.0: Detailed Listing of Recommended and System Alternative Plans' Facilities

The Recommended Plan is the "345 kV Hiawatha Plan" configuration.

Lines--new		miles	conductor kcm
Cleveland-Hiawatha 345 kV		7	2 x 795 ACSR
Cleveland-Lexington 115 kV		4	1 x 795 ACSS
Hiawatha-Midtown 115 kV dbl ckt		2 x 1.5	1 x 795 ACSS
Wilson-Crosstown 115 kV dbl ckt		2 x 3	1 x 795 ACSS
	Total	20	

Lines--reconductor or rebuild			
Afton-Red Rock 115 kV	reconductor	12.8	1 x 795 ACSS
	Total	12.8	

Transformers	MVA
Cleveland 345/115 kV	1 x 672
Hiawatha 345/115 kV	1 x 448

Red Rock #9 & #10 replacement	2 x 448 →	2 x 672
Parkers Lake #9 & #10 replacement	2 x 448 →	2 x 672
Eden Prairie #9 & #10 replacement	2 x 448 →	2 x 672
	Total Increase	2016

Reactive (voltage control) facilities

Shunt Capacitors		MVAR
None identified		
	Total Increase	0

Shunt Reactors		MVAR
None identified		
	Total Increase	0

Substations--new

Cleveland 345/115 kV Substation (by Cleveland Ave and Hwy 280)
Hiawatha 345/115 kV Substation (~1 mi North of Southtown substation)
Midtown 115 kV Substation (~2 mi South of downtown Minneapolis)
Crosstown 115 kV Substation (by 35 W and Hwy 62 interchange)

Substations--modified

Eden Prairie add 345 kV ring bus

Alternative 1 is the "115 kV Hiawatha Plan" configuration.

Lines--new		miles	conductor kcm
Cleveland-Hiawatha 115 kV dbl ckt, dbl bundled		2 x 7	2 x 795 ACSS
Cleveland-Lexington 115 kV		4	1 x 795 ACSS
Hiawatha-Midtown 115 kV dbl ckt		2 x 1.5	1 x 795 ACSS
Wilson-Crosstown 115 kV dbl ckt		2 x 3	1 x 795 ACSS
	Total	27	

Lines--reconductor or rebuild			
Afton-Red Rock 115 kV	reconductor	12.8	1 x 795 ACSS
	Total	12.8	

Transformers		MVA
Cleveland 345/115 kV		1 x 672
Hiawatha 345/115 kV		1 x 448
Red Rock #9 & #10 replacement	2 x 448 →	2 x 672
Parkers Lake #9 & #10 replacement	2 x 448 →	2 x 672
Eden Prairie #9 & #10 replacement	2 x 448 →	2 x 672
	Total Increase	2016

Reactive (voltage control) facilities

Shunt Capacitors		MVAR
None identified		
	Total Increase	0

Shunt Reactors		MVAR
None identified		
	Total Increase	0

Substations--new

Cleveland 345/115 kV Substation (by Cleveland Ave and Hwy 280)
Hiawatha 115 kV Substation (~1 mi North of Southtown substation)
Midtown 115 kV Substation (~2 mi South of downtown Minneapolis)
Crosstown 115 kV Substation (by 35 W and Hwy 62 interchange)

Substations--modified

Eden Prairie add 345 kV ring bus

Alternative 2 is the " Parkers Lake-Aldrich 345 kV Plan " configuration.

Lines--new		miles	conductor kcm
Parkers Lake-Aldrich 345 kV		7	2 x 795 ACSR
Cleveland-Lexington 115 kV		4	1 x 795 ACSS
Aldirch-Midtown 115 kV		2	1 x 795 ACSS
Hiawatha-Midtown 115 kV dbl ckt		2 x 1.5	1 x 795 ACSS
Wilson-Crosstown 115 kV dbl ckt		2 x 3	1 x 795 ACSS
	Total	22	

Lines--reconductor or rebuild			
Afton-Red Rock 115 kV	reconductor	12.8	1 x 795 ACSS
	Total	12.8	

Transformers		MVA
Cleveland 345/115 kV		1 x 672
Hiawatha 345/115 kV		1 x 448
Red Rock #9 & #10 replacement	2 x 448 →	2 x 672
Eden Prairie #9 & #10 replacement	2 x 448 →	2 x 672
	Total Increase	1568

Reactive (voltage control) facilities

Shunt Capacitors		MVAR
None identified		
	Total Increase	0

Shunt Reactors		MVAR
None identified		
	Total Increase	0

Substations--new

Cleveland 345/115 kV Substation (by Cleveland Ave and Hwy 280)
Hiawatha 115 kV Substation (~1 mi North of Southtown substation)
Midtown 115 kV Substation (~2 mi South of downtown Minneapolis)
Crosstown 115 kV Substation (by 35 W and Hwy 62 interchange)

Substations--modified

Eden Prairie	add 345 kV ring bus
Aldrich	add 345 kV bus, open 115 kV tie breaker, 115 kV breaker addition

Alternative 3 is the "Quad Plan" configuration.

Lines--new	miles	conductor kcm
Cleveland-Hiawatha 345 kV	7	2 x 795 ACSR
Red Rock-Rodgers Lake 345 kV	6	2 x 795 ACSR
Aldrich-Parkers Lake 345 kV	7	2 x 795 ACSR
Cleveland-Lexington 115 kV	4	1 x 795 ACSS
Hiawatha-Midtown 115 kV dbl ckt	2 x 1.5	1 x 795 ACSS
Wilson-Crosstown 115 kV dbl ckt	2 x 3	1 x 795 ACSS
Total	33	

Lines--reconductor or rebuild		
none	reconductor	0
	Total	0

Transformers	MVA
Cleveland 345/115 kV	1 x 672
Hiawatha 345/115 kV	1 x 448
Black Dog 345/115 kV	1 x 672
Rodgers Lake 345 /115 kV	1 x 448
Total Increase	2240

Reactive (voltage control) facilities

Shunt Capacitors	MVAR
None identified	
Total Increase	0

Shunt Reactors	MVAR
None identified	
Total Increase	0

Substations--new

Cleveland 345/115 kV Substation (by Cleveland Ave and Hwy 280)
Hiawatha 115 kV Substation (~1 mi North of Southtown substation)
Midtown 115 kV Substation (~2 mi South of downtown Minneapolis)
Crosstown 115 kV Substation (by 35 W and Hwy 62 interchange)

Substations--modified

Eden Prairie	add 345 kV ring bus
Red Rock	add 345 kV breaker
Rodgers Lake	add 345 kV bus section and associated breakers
Aldrich	add 345 kV bus, open 115 kV tie breaker, 115 kV breaker addition
Black Dog	add 345 kV bus, 115 kV breaker additions.

Appendix A: Maps and Drawings (Base Plan & System Alternatives)

"115 kV Hiawatha Plan"