CAPITAL COSTS FOR TRANSMISSION AND SUBSTATIONS

Updated Recommendations for WECC Transmission Expansion Planning

B&V PROJECT NO. 181374

PREPARED FOR

WECC

Western Electricity Coordinating Council

Under Subcontract to Energy + Environmental Economics

FEBRUARY 2014

BLACK & VEATCH
Building a world of difference.

Principal Investigators:

Ryan Pletka, Project Manager

Jagmeet Khangura

Andy Rawlins

Elizabeth Waldren

Dan Wilson

Assumptions and Limitations Disclaimer

This report was prepared for the Western Electric Coordinating Council (WECC) by Black & Veatch Corporation (Black & Veatch) and is based on information not within the control of Black & Veatch. Black & Veatch has assumed that the information both verbal and written, provided by others is complete and correct; however, Black & Veatch does not guarantee the accuracy of the information, data, or opinions contained herein.

Any information shared with WECC prior to the release of the report is superseded by the Report.

Black & Veatch owes no duty of care to any third party and none is created by this report. Use of this report, or any information contained therein, by a third party shall be at the risk of such party and constitutes a waiver and release of Black & Veatch its directors, officers, partners, employees and agents by such third party from and against all claims and liability, including, but not limited to, claims for breach of contract, breach of warranty, strict liability, negligence, negligent misrepresentation, and/or otherwise, and liability for special, incidental, indirect, or consequential damages, in connection with such use.

Table of Contents

Assumptions and Limitations Disclaimer ii
1.0 Introduction and Summary 1-1
1.1 Recommendations 1-1
1.2 Peer Review Process 1-2
1.3 Variability of Costs 1-2
1.4 Report Organization 1-2
2.0 Transmission Capital Costs 2-1
2.1 Transmission Capital Cost Updates 2-1
2.1.1 Annual Inflation Multiplier 2-1
2.1.2 HVDC 600 kV Bi-Pole 2-2
2.2 New Transmission 2-2
2.2.1 Baseline Costs 2-3
2.2.2 Conductor Type 2-3
2.2.3 Transmission Structure Type 2-4
2.2.4 Length of Line 2-4
2.3 Re-conductoring 2-5
2.4 Terrain Multiplier 2-6
2.5 Right of Way Costs 2-6
2.5.1 Right of Way Widths 2-6
2.5.2 Right of Way Costs per Acre 2-7
2.6 Transmission Calculation Methodology 2-8
2.7 Transmission Loss Calculation Methodology 2-8
3.0 Substation Capital Costs 3-1
3.1 Substation Capital Cost Updates 3-1
3.1.1 Annual Inflation Multiplier 3-1
3.1.2 HVDC 600 kV Converter Station 3-1
3.2 New Substation Base Cost 3-2
3.3 Line and Transformer Positions 3-2
3.4 Transformers 3-3
3.5 Reactive Components 3-3
3.6 High Voltage Direct Current Converter Station 3-4
3.7 Substation Calculation Methodology 3-4
4.0 Summary of Capital Costs 4-1
4.1 Transmission Capital Costs 4-1
4.2 Substation Capital Costs 4-5
4.3 Allowance for Funds Used During Construction and Overhead Costs 4-8
4.4 Total Project Cost 4-8
5.0 Cost Calculator 5-1

5.1 Transmission Cost Calculator 5-1
5.2 Transmission Line Loss Calculator 5-2
5.3 Substation Cost Calculator 5-3
5.4 Cost Totals 5-4

LIST OF TABLES

Table 1-1 Multi-Year Comparison of Calculated Capital Costs per mile for a 230 kV Single Circuit Line 1-1
Table 1-2 600 kV HVDC Substation and Transmission Calculated Capital Costs 1-1
Table 2-1 Baseline Transmission Costs 2-3
Table 2-2 Conductor Cost Multipliers 2-4
Table 2-3 Transmission Structure Type Cost Multipliers 2-4
Table 2-4 Transmission Length Cost Multipliers 2-5
Table 2-5 Terrain Cost Multipliers 2-6
Table 2-6 Right of Way Widths by Voltage Class 2-7
Table 2-7 BLM Land Rental and Land Capital Costs by Zone 2-7
Table 2-8 Transmission Line Configuration Adopted from WREZ 2-8
Table 2-9 Transmission Line Conductor Size and Resistance 2-9
Table 2-10 Load Adjustment Factor at Sample Line Utilization Values 2-10
Table 3-1 New Substation Base Capital Costs 3-2
Table 3-2 Line/Transformer Position Cost and Multipliers 3-3
Table 3-3 Transformer Capital Costs 3-3
Table 3-4 Reactive Component Capital Costs 3-4
Table 3-5 HVDC Converter Station Costs 3-4
Table 4-1 2012 Transmission Capital Cost Summary 4-2
Table 4-2 2013 Transmission Capital Cost Summary 4-3
Table 4-3 2014 Transmission Capital Cost Summary 4-4
Table 4-4 2012 Substation Capital Cost Summary 4-5
Table 4-5 2013 Substation Capital Cost Summary 4-6
Table 4-6 2014 Substation Capital Cost Summary 4-7
Table 4-7 Black & Veatch Survey of AFUDC and Overhead Costs and Recommended Values 4-8

LIST OF FIGURES

Figure 5-1 Transmission Cost Calculator Sheet of Cost Calculator Workbook 5-1
Figure 5-2 Transmission Loss Calculator in Cost Calculator Workbook 5-3
Figure 5-3 Substation Cost Calculator Sheet of Cost Calculator Workbook 5-4
Figure 5-4 Cost Totals Sheet of Cost Calculator Workbook 5-5

1.0 Introduction and Summary

As part of the Western Electricity Coordinating Council (WECC) transmission planning process, Black & Veatch, under subcontract to Energy + Environmental Economics, was asked to provide updated assumptions for transmission and substation capital costs. The effort was completed under the auspices of a peer review workgroup composed of regional transmission experts to ensure that the resulting cost updates were appropriate for WECC's current and future requirements.

The scope of this report is to document the updates to the original Black & Veatch report *Recommendations for WECC Transmission and Expansion Planning* released in October 2012. The original report contains detailed information regarding methodology and assumptions that were used to develop the transmission and substation capital costs provided to WECC in 2012. Readers should review that report for a full description of the methodology and assumptions. This report revisits those baseline assumptions as an addendum to the original report and documents changes based on the current recommendations.

1.1 RECOMMENDATIONS

The following recommended updates were accepted by stakeholders during a meeting on February 12, 2014 for implementation in the WECC transmission planning process:

- Update transmission and substation capital costs using annual inflation multipliers.
- Add capital costs for a 600 kV HVDC (High Voltage Direct Current) transmission voltage class.
- Include a line loss calculator.

Under these recommendations, transmission and substation equipment costs were inflated at 1.5 percent from 2012 to 2013, and at 2.0 percent from 2013 to 2014. Table 1-1 is included below to demonstrate the cost impact of this escalation, comparing the baseline capital costs from an example project using 2012, 2013, and 2014 capital cost assumptions.

Table 1-1 Multi-Year Comparison of Calculated Capital Costs per mile for a 230 kV Single Circuit Line

2012	2013	2014
$927,000	$940,900	$959,700
Assumptions: Aluminum Conductor Steel Reinforced (ACSR), Tubular (230 kV)/ Lattice (345 kV – 600 kV), > 10 miles		

In addition, Black & Veatch developed capital cost estimates for the 600 kV HVDC voltage class. Table 1-2 reflects the 600 kV HVDC major capital cost additions.

Table 1-2 600 kV HVDC Substation and Transmission Calculated Capital Costs

TRANSMISSION BASELINE COST/MILE	HVDC CONVERTER COST/UNIT
$1,613,200	$506,779,350

The body of this report documents the implementation of the changes identified above, while providing a more granular understanding of the impact on capital costs.

1.2 PEER REVIEW PROCESS

In 2012, WECC assembled a Peer Review Group to review and comment on the methodology and recommendations developed. The group provided valuable information about specific transmission line costs to assist in the validation of the methodology, and ensure the costs proposed were reasonable. The group provided valuable written input and discussion of assumptions during several conference calls between June and September of 2012.

In 2014, to ensure that the proposed costs and cost methodology updates were appropriate for the task, WECC reconvened a peer review group composed of regional transmission experts to review and provide recommendations on the costs and methodology. The WECC Technical Advisory Subcommittee (TAS) group met on December 15, 2013 to discuss initial recommendations regarding 2013 and 2014 annual inflation variables. Written input was accepted from the TAS in the weeks following the presentation.

During the open feedback period, Black & Veatch was asked to calculate 600 kV HVDC capital costs and to implement a line loss calculator tool. The resulting modifications were presented to the TAS group on January 15, 2014. Following the presentation, TAS was given another opportunity to provide written comment regarding the proposed updates. During this period, no further comments were received. The WECC Technical Advisory Subcommittee reconvened on February 12, 2014 and accepted the recommended updates to the transmission capital cost estimates.

1.3 VARIABILITY OF COSTS

The costs included in this report are believed to reasonably represent the cost to develop transmission and substation facilities in the WECC region. It is imperative to note, however, that transmission lines and substations are all unique, and the cost of a specific line or substation may be significantly different than the costs provided here due to a variety of factors. Most new transmission and substation facilities interconnect to the existing grid, and a "typical" transmission project will include some level of new equipment and some upgrades to existing equipment. Furthermore, transmission facilities are developed not only to transmit incremental power generation, but also to provide additional system reliability and serve load. It is often impossible to segregate "capacity costs" from the cost to provide reliability and serve load. The costs here should be used as a guide to develop approximate costs for new transmission, but should not be used to measure the cost or cost-effectiveness of any specific transmission facility.

1.4 REPORT ORGANIZATION

Following this Introduction, this report is organized into the following sections:

- **Section 2 Transmission Capital Costs –** This section covers the methodology used to implement the recommended transmission capital cost updates.
- **Section 3 Substation Capital Costs –** This section presents the methodology used to implement the recommended substation capital cost updates.
- **Section 4 Summary of Capital Costs** – This section provides the transmission and substation capital cost values for years 2012, 2013, and 2014.

- **Section 5 Cost Calculator** – This section discusses the cost calculator workbook and provides screenshots for each of the calculators.

2.0 Transmission Capital Costs

Previously, Black & Veatch developed a methodology and tool to calculate indicative capital costs for transmission infrastructure projects throughout the WECC region. This methodology begins with using the current cost of specified transmission equipment and the expected cost of land. The costs are then adjusted to identify the differential cost of developing on different land with different terrain factor adjustments. In 2012, Black & Veatch identified the following categories and sub-categories to consider from a capital cost perspective:

- Voltage Class
  - Alternating Current (AC) - 230 kV, 345 kV, and 500 kV (single and double circuit)
  - HVDC 500 kV Bi-Pole
- Line Characteristics
  - Conductor Type
  - Pole Structure
  - Length of line
- New Construction or Re-conductor
- Terrain Type
- Location

In 2014, Black & Veatch recommended adding the following cost categories and sub-categories:

- Annual Inflation Multiplier
  - Year 2013
  - Year 2014
- Voltage Class
  - HVDC 600 kV Bi-Pole

To implement these recommendations, Black & Veatch used existing transmission methodology and internal knowledge of transmission equipment component costs.

2.1 TRANSMISSION CAPITAL COST UPDATES

This section of the report describes the methodology used to develop the recommended transmission capital cost revisions. The following sections of the report will describe the implementation of these recommendations in the context of the original transmission capital cost methodology.

2.1.1 Annual Inflation Multiplier

The primary purpose for revisiting 2012 capital cost recommendations was to determine 2013 and 2014 inflation values to better estimate the capital cost of transmission projects constructed during these years. Inflation multipliers were developed based on the commodity prices of raw materials, engineering records of construction costs, and overall Consumer Price Index (CPI) data.

In 2013, copper and aluminum commodity prices were down about 10 percent from 2012 averages. Steel prices were estimated to have increased 1.6 percent by the Engineering News-Record (ENR) during this same time period.[1] Aluminum is a primary metal used in transmission line conductor and steel is the primary material found in transmission towers. Price variations in these commodities will impact the base equipment cost of a transmission line. Furthermore, ENR estimates general construction costs are up 2.7 percent in 2013 over 2012, and the Consumer Price Index (CPI) estimates a 1.7 percent increase in overall goods and service costs.[2] Combining these data points, an overall inflation multiplier of 1.5 percent was estimated for 2013 capital costs over 2012 costs.

The 2014 inflation predictions were based on the expected general inflation rate. This value is estimated to be 2 percent and is used as the estimation basis for the 2014 capital cost increase over 2013 costs.

The multipliers defined above were applied to all substation and transmission capital costs previously reported in 2012 dollars.

2.1.2 HVDC 600 kV Bi-Pole

During the process of updating capital costs, a recommendation was made by a member of the TAS group to include an additional voltage class for 600 kV HVDC bi-pole transmission. The 2012 report included only 500 kV HVDC. This request was made because 600 kV HVDC has lower line losses than 500 kV HVDC at a relatively small increase in capital cost. Based on a preliminary comparison to 500 kV AC and 500 kV HVDC, it appears that 600 kV HVDC may be the lowest life-cycle cost in certain applications. This report has been updated to include this voltage class.

The transmission line capital cost for the 600 kV HVDC voltage class was estimated based on the 500 kV HVDC capital costs. Line capacity was defined to be 3000 MW (matching the capacity of the 500 kV HVDC bi-pole class) based on typical system planning practice. The resulting baseline capital costs for 600 kV HVDC were estimated to increase 5 percent over the 500 kV HVDC capital costs, due primarily to increases in transmission structure and insulation size.

The next sections of this report will describe the application of the 2013 and 2014 inflation multipliers and inclusion of the 600 kV HVDC voltage class in the context of the transmission capital costs methodology developed during 2012.

2.2 NEW TRANSMISSION

There are many factors that contribute to the total transmission line cost. To develop representative costs, Black & Veatch identified physical considerations. Three key factors were determined to be the most important cost considerations:

- Conductor type
- Structure type
- Length of line

This section presents base cost assumptions and the impacts of each factor on the cost.

[1] http://enr.construction.com/economics/
[2] http://www.bls.gov/news.release/cpi.nr0.htm

2.2.1 Baseline Costs

In the 2012 report, Black & Veatch started from the transmission capital costs developed in the Western Renewable Energy Zones (WREZ) project for the U.S. Department of Energy and the Western Governors' Association. The initial costs per mile for transmission from the WREZ model were escalated from the original 2008 values to 2012.

Most recently, Black & Veatch escalated 2012 baseline costs to develop 2014 values based on the inflation multipliers described in Section 2.1.1. Baseline costs were also developed for the new 600 kV HVDC voltage class using the 5 percent adder described in Section 2.1.2. These updates have been included in Table 2-1.

Table 2-1 Baseline Transmission Costs

LINE DESCRIPTION	NEW LINE COST 2014 ($/MILE)
230 kV Single Circuit	$959,700
230 kV Double Circuit	$1,536,400
345 kV Single Circuit	$1,343,800
345 kV Double Circuit	$2,150,300
500 kV Single Circuit	$1,919,450
500 kV Double Circuit	$3,071,750
500 kV HVDC Bi-pole	$1,536,400
600 kV HVDC Bi-pole	$1,613,200
Assumptions: Aluminum Conductor Steel Reinforced (ACSR), Tubular (230 kV)/ Lattice (345 kV – 600 kV), > 10 miles	

2.2.2 Conductor Type

Black & Veatch previously identified three common conductor types that could be used in new transmission lines: ACSR, Aluminum Conductor Steel Supported (ACSS), and High Tensile Low Sag (HTLS). Cost multipliers were developed for each of these conductor types, which could be multiplied against the base transmission cost for each voltage level.

Table 2-2 below shows the conductor cost multipliers for all voltage classes. An additional column had to be added to incorporate a 600 kV HVDC bi-pole transmission alternative that was not included in 2012. To populate this column, it was assumed that the conductor cost multipliers would remain constant for the 600 kV HVDC Bi-pole voltage class. This is consistent with the assumed multipliers for all other voltage classes.

Table 2-2 Conductor Cost Multipliers

CONDUCTOR	230 KV SINGLE	230 KV DOUBLE	345 KV SINGLE	345 KV DOUBLE	500 KV SINGLE	500 KV DOUBLE	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
ACSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ACSS	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
HTLS	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60

2.2.3 Transmission Structure Type

In 2012, Black & Veatch quantified the capital cost multipliers associated with each type of transmission support structure. Structure types included lattice towers and tubular steel.

Table 2-3 below shows the transmission structure type cost multipliers for all voltage classes. An additional voltage class was added for the 600 kV HVDC bi-pole alternative based on the 500 kV HVDC bi-pole multiplier. The 500 kV HVDC bi-pole multiplier was originally developed based on the relative costs of lattice structures and tubular steel at very high voltage.

Table 2-3 Transmission Structure Type Cost Multipliers

STRUCTURE	230 KV SINGLE	230 KV DOUBLE	345 KV SINGLE	345 KV DOUBLE	500 KV SINGLE	500 KV DOUBLE	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
Lattice	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00
Tubular Steel	1.00	1.00	1.30	1.30	1.50	1.50	1.50	1.50

2.2.4 Length of Line

In general, the longer the transmission line, the less it costs per mile. This is because fixed construction, engineering, and equipment costs are recovered in a smaller overall project cost for short transmission lines. In 2012, Black & Veatch developed transmission length cost multipliers to account for this variable.

Table 2-4 below shows the transmission length cost multipliers for all voltage classes. An additional voltage class was added for the 600 kV HVDC bi-pole transmission alternative. To populate this column, it was assumed that transmission line length cost multipliers remain constant at all voltage levels.

Table 2-4 Transmission Length Cost Multipliers

LENGTH	230 KV SINGLE	230 KV DOUBLE	345 KV SINGLE	345 KV DOUBLE	500 KV SINGLE	500 KV DOUBLE	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
> 10 miles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3-10 miles	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
< 3 miles	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50

2.3 RE-CONDUCTORING

Previously, Black & Veatch determined that in areas where there are existing transmission lines, it may be necessary or more cost-effective to re-conductor an existing transmission line rather than to build a new line. Re-conductoring can be defined many different ways, but for simplicity re-conductoring in this effort is defined as replacing an existing conductor to increase ampacity. This assumes that the new conductor would be of similar size and weight; hence no upgrading of poles or insulators is required.

To quantify the capital costs associated with re-conductoring a transmission line, Black & Veatch made the following list of assumptions which have been revised to include the 600 kV HVDC Bi-Pole conductors:

- 230 kV Transmission Conductors
  - 2 conductors per phase
  - Conductor assumed to be 35 percent of total capital cost
- 345 kV Transmission Conductors
  - 3 conductors per phase
  - Conductor assumed to be 45 percent of total capital cost
- 500 kV Transmission Conductors
  - 4 conductors per phase
  - Conductor assumed to be 55 percent of total capital cost
- 500 kV Bi-Pole Transmission Conductors
  - 3 conductors per pole
  - Conductor assumed to be 55 percent of total capital cost
- 600 kV Bi-Pole Transmission Conductors
  - 3 conductors per pole
  - Conductor assumed to be 55 percent of total capital cost

The 600 kV bi-pole transmission re-conductor assumptions were the same as the 500 kV bi-pole transmission class. Both voltage classes utilize three circuit bi-pole configurations and conductor cost is assumed to remain a constant percentage of the baseline capital cost of the project.

2.4 TERRAIN MULTIPLIER

In 2012, Black & Veatch identified nine different terrain types and then developed cost multipliers to compensate for the difficulty of construction in each terrain type. The lowest cost of development was identified as scrub or flat terrain, and the most difficult and expensive type of terrain is forested areas. Table 2-5 identifies the different types of terrain assessed.

No modifications were recommended to these terrain cost multipliers.

Table 2-5 Terrain Cost Multipliers

TERRAIN	PG&E[3]	SCE[4]	SDG&E[5]	WREZ	WECC
Desert	1.00	1.10	1.00	-	**1.05**
Scrub / Flat	1.00	1.00	1.00	1.00	**1.00**
Farmland	1.00	1.00	1.00	1.10	**1.00**
Forested	1.50	3.00	-	1.30	**2.25**
Rolling Hill (2-8% slope)	1.30	1.50	-	-	**1.40**
Mountain (>8% slope)	1.50	2.00	1.30	-	**1.75**
Wetland	-	-	1.20	1.20	**1.20**
Suburban	1.20	1.33	1.20	-	**1.27**
Urban	1.50	1.67	-	1.15	**1.59**

2.5 RIGHT OF WAY COSTS

Previously, Black & Veatch developed estimates for both right of way widths and right of way costs per acre which can be applied across the WECC region.

2.5.1 Right of Way Widths

To obtain the original right of way widths, Black & Veatch drew from a large set of data sources which focused on utilities and projects in the WECC region. Table 2-6 below shows the right of way widths specified for each voltage class in each data source. This was based on adopting the most common value from the various data sources for each voltage class, and also ensuring a logical progression so that widths increased at successively higher voltages and double circuit line widths were greater than those for single circuits.

The same methodology was used when adding the 600 kV HVDC bi-pole voltage class. The 600 kV HVDC right of way was assumed to increase over the 500 kV HVDC at the same rate as the increase demonstrated between a 345 kV single circuit and a 500 kV single circuit.

[3] **2012 PG&E Per Unit Cost Guide - http://www.caiso.com/Documents/PGE_2012FinalPerUnitCostGuide.xls**
[4] **2012 SCE Per Unit Cost Guide - http://www.caiso.com/Documents/SCE_2012FinalPerUnitCostGuide.xls**
[5] **2012 SDG&E Per Unit Cost Guide - http://www.caiso.com/Documents/SDGE_2012FinalPerUnitCostGuide.xls**

Table 2-6 Right of Way Widths by Voltage Class

	230-KV SINGLE CIRCUIT	230-KV DOUBLE CIRCUIT	345-KV SINGLE CIRCUIT	345-KV DOUBLE CIRCUIT	500-KV SINGLE CIRCUIT	500-KV DOUBLE CIRCUIT	500-KV DC BI-POLE	600-KV DC BI-POLE
ROW (ft)	125	150	175	200	200	250	200	225
Acres/mile*	15.14	18.17	21.20	24.23	24.23	30.29	24.23	27.27

*Acres/mile values were calculated by multiplying the right of way width by 5,280 feet per mile and dividing by 43,560 sq. ft. per acre.

2.5.2 Right of Way Costs per Acre

To develop estimates of right of way costs, the Peer Review Group adopted a methodology based on the Bureau of Land Management's (BLM) Linear Right of Way Schedule for Year 2015 (taken from 43 CFR Parts 2800, 2880, 2920).[6] Table 2-7 lists the BLM land rental costs by zone and the equivalent capital cost by zone.

No modifications were recommended to the BLM land rental costs by zone. The costs were already estimated for 2015 based on the BLM Linear Right of Way Schedule.

Table 2-7 BLM Land Rental and Land Capital Costs by Zone

BLM ZONE NUMBER	LAND RENTAL COST ($/ACRE-YEAR)	LAND CAPITAL COST ($/ACRE)
1	$ 9	$ 85
2	$ 17	$ 171
3	$ 34	$ 341
4	$ 52	$ 512
5	$ 69	$ 683
6	$ 103	$ 1,024
7	$ 172	$ 1,707
8	$ 345	$ 3,414
9	$ 690	$ 6,828
10	$ 1,035	$ 10,242
11	$ 1,724	$ 17,071
12	$ 3,449	$ 34,141

[6] http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/cost_recovery.Par.47392.File.dat/RentLinearRentSchedule2009-2015-NoHighlight.pdf

2.6 TRANSMISSION CALCULATION METHODOLOGY

Multiplying the right of way acres per mile by the land cost per acre yields the total right of way cost per mile of transmission line. This value was added to the base transmission costs discussed in Sections 2.2, 2.3, and 2.4 to develop the total transmission line capital cost.

Total Transmission Line Cost = [(2014 Base Transmission Cost) x (Conductor Multiplier) x (Structure Multiplier) x (Re-conductor Multiplier) x (Terrain Multiplier) + (ROW Acres/Mile) x (Land Cost/Acre)] x (# of Miles)

2.7 TRANSMISSION LOSS CALCULATION METHODOLOGY

During the 2014 update, Black & Veatch added a line loss calculator to the Transmission Cost Calculator to enable the comparison of power loss between transmission alternatives. This tool provides high level, "back of the envelope" estimates of transmission power losses that can be used for additional consideration when comparing the capital costs of various transmission alternatives. This tool is conceptual and is not meant to replace more sophisticated approaches used in load flow or production cost models.

Previously, Black & Veatch created a line loss calculator for the WREZ project, and this same methodology was adopted for the line loss calculator included in the WECC Transmission Cost Calculator. The WREZ transmission loss calculator included line capacity and configuration assumptions for each voltage class as shown below in Table 2-8. The 600 kV HVDC bi-pole values were added for 2014 and were based on the existing WREZ 500 kV HVDC bi-pole values.

Table 2-8 Transmission Line Configuration Adopted from WREZ

	230 KV SINGLE CIRCUIT	230 KV DOUBLE CIRCUIT	345 KV SINGLE CIRCUIT	345 KV DOUBLE CIRCUIT	500 KV SINGLE CIRCUIT	500 KV DOUBLE CIRCUIT	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
Capacity (MW)	400	800	750	1500	1500	3000	3000	3000
No. of Conductors Per Phase	1	1	2	2	3	3	3	3
No. of Circuits Per Line	1	2	1	2	1	2	2	2

Conductor selection for each configuration was based on the calculated line ampacity for each line. The following assumptions were made regarding the selected conductor resistance:

- Conductor options matched WECC conductor types (ACSR, ACSS and HTLS)
- Assumed an operation temperature 50°C for ACSR conductor.
- Assumed an operation temperature of 75°C for ACSS and HTLS conductors.

- Used manufacturer data sheets and thermal rating program to develop final resistance values.[7]

Table 2-9 below includes conductor sizes and resistance values used for each voltage class.

Table 2-9 Transmission Line Conductor Size and Resistance

	230 KV SINGLE CIRCUIT	230 KV DOUBLE CIRCUIT	345 KV SINGLE CIRCUIT	345 KV DOUBLE CIRCUIT	500 KV SINGLE CIRCUIT	500 KV DOUBLE CIRCUIT	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
ACSR								
Size (kcmil)	1272	1272	795	795	1590	1590	1780	1780
Resistance (Ohm/Mile)	0.083	0.083	0.128	0.128	0.068	0.068	0.057	0.057
ACSS								
Size (kcmil)	477	477	336.4	336.4	605	605	636	636
Resistance (Ohm/Mile)	0.225	0.225	0.319	0.319	0.178	0.178	0.154	0.154
HTLS								
Size (kcmil)	477	477	336	336	557	557	636	636
Resistance (Ohm/Mile)	0.228	0.228	0.315	0.315	0.186	0.186	0.164	0.149

Transmission losses increase with line load (current). Since lines rarely operate at full load, it is necessary to adjust the loss calculation to account for lower loads. Full load adjustment factors were developed in the WREZ project to account for the expected line utilization values. The method for calculating the full load adjustment factor from the capacity factor is to average the maximum possible load and minimum possible load at a given capacity factor.

For example, a 60 percent capacity factor, or line utilization, would correspond to a maximum utilization of 60 percent of hours at full load and a minimum utilization of all hours at 60 percent of full load. The average of these values would be equivalent to ((0.6 * Full Load) + (0.6^2 * Full Load))/2 = 0.48 * Full Load. This is called a 48 percent Load Adjustment Factor.

[7] ACSR
http://www.southwire.com/ProductCatalog/XTEInterfaceServlet?contentKey=prodcatsheet16,
ACSS
http://www.southwire.com/ProductCatalog/XTEInterfaceServlet?contentKey=prodcatsheet28
HTLS
http://multimedia.3m.com/mws/mediawebserver?mwsId=66666UF6EVsSyXTtmxME4xM6EVtQEVs6EVs6EVs6E666666--&fn=ACCRSpecSheet_9802792.pdf

Table 2-10 reflects example Load Adjustment Factors for various line utilization values.

Table 2-10 Load Adjustment Factor at Sample Line Utilization Values

	30 PERCENT UTILIZATION	50 PERCENT UTILIZATION	70 PERCENT UTILIZATION	90 PERCENT UTILIZATION
Load Adjustment Factor	0.195	0.375	0.595	0.855

Using the transmission configuration, conductor and full load adjustment assumptions detailed above, transmission line losses are calculated according to the following equation:

Total Transmission Loss (Per Mile) = {[(Phase Current)/ (No. Conductors per Phase)]^2 **x** (Resistance per mile) **x** (No. Conductor per Phase) **x** (No. Circuits per Line) **x** (No. Phases)} **x** (Full Load Adjustment)

3.0 Substation Capital Costs

This section quantifies the substation costs associated with transmission infrastructure development.

In 2012, WECC approved a methodology for estimating substation capital costs for various sized substations with different line and transformer positions, additional reactive equipment, or new transformers. The following cost components were identified to calculate the substation cost:

- Base Substation Cost
- Line/Transformer Positions
- Transformers
- HVDC Converter Station
- Static VAR Compensators, Shunt Reactors and Series Capacitors

In 2014, Black & Veatch has recommended the addition of the following cost components to calculate the substation cost:

- Annual Inflation Multiplier
  - Year 2013
  - Year 2014
- Year 2014 HVDC Converter Station
  - HVDC 600 kV Bi-Pole Converter Station

3.1 SUBSTATION CAPITAL COST UPDATES

This section 3.1 of the report describes the methodology used to develop recommended substation capital cost components. Sections 3.1-3.7 of the report will describe the implementation of these recommendations in the context of the original substation capital cost methodology.

3.1.1 Annual Inflation Multiplier

The inflation multipliers used to calculate substation capital costs for years 2013 and 2014 are consistent with the inflation multipliers used to calculate transmission capital costs over the same period. Inflation for 2014 capital costs are predicted to be roughly 2 percent over 2013 costs, which were estimated to be roughly 1.5 percent over 2012 costs. Section 2.1.1 contains detailed information regarding the development of these multipliers.

Inflation multipliers were applied to all substation capital costs previously reported in 2012 dollars.

3.1.2 HVDC 600 kV Converter Station

A 600 kV HVDC converter station was added to the set of substation capital cost components based on the addition of a 600 kV HVDC transmission alternative. Consistent with previous methodology, a 600 kV HVDC transmission alternative would require new converter facilities to convert HVDC power and to connect to the existing grid.

Black & Veatch estimated that 600 kV HVDC converter station costs would increase roughly 10 percent over the capital cost of a 500 kV HVDC converter station. Primary drivers for this increase include upgrades to power electronics voltage ratings, greater equipment insulation size, and larger space requirements to meet increased electrical clearances.

It is assumed that the DC/AC conversion stations will convert the 600 kV HVDC power to AC power at typical transmission voltages. Since typical AC voltages in WECC are limited to levels of 500 kV AC and below, 600 kV AC equipment costs were not considered, and only the HVDC converter equipment costs were revised to include a 600 kV component.

Detailed information regarding the recommendation of a 600 kV HVDC transmission alternative can be found in Section 2.1.2.

The remainder of Section 3.0 will describe the implementation of these recommendations within the framework of assumptions and methodologies previously adopted by WECC.

3.2 NEW SUBSTATION BASE COST

The first component of the substation cost is the base cost for a substation without any equipment. New substation base costs in this methodology assumed flat, barren land with relatively easy site access and included land costs, substation fencing, and the control building.

Black & Veatch has recommended updated new substation base costs for 2014 as shown in Table 3-1. These values were developed using the 2013 and 2014 inflation multipliers as previously described in Section 3.1.1.

Table 3-1 New Substation Base Capital Costs

EQUIPMENT	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Base Cost	$1,706,250	$2,132,700	$2,559,250

3.3 LINE AND TRANSFORMER POSITIONS

In addition to the new substation base cost, Black & Veatch previously considered the cost of breaker positions necessary to interconnect lines and transformers for new and existing substations. These considerations were used to develop line/transformer position costs and multipliers.

Table 3-2 provides line/transformer position costs that have been updated for 2014. Costs have been developed by applying 2013 and 2014 inflation values. Line/transformer position multipliers were assumed to remain constant from 2012 to 2014 as the physical configuration of these layouts has not changed.

Table 3-2 Line/Transformer Position Cost and Multipliers

COST / MULTIPLIER	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Ring Bus Multiplier	1	1	1
Breaker and a Half Multiplier	1.5	1.5	1.5

3.4 TRANSFORMERS

Black & Veatch identified the capital costs associated with each voltage class of transformer in a cost per mega-volt ampere (MVA) unit. Table 3-3 below reflects transformer capital costs that have been updated with 2014 values.

Table 3-3 Transformer Capital Costs

TRANSFORMER COST ($/MVA)	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
115/230 kV XFMR	$7,250	-	-
115/345 kV XFMR	-	$10,350	-
115/500 kV XFMR	-	-	$10,350
138/230 kV XFMR	$7,250	-	-
138/345 kV XFMR	-	$10,350	-
138/500 kV XFMR	-	-	$10,350
230/345 kV XFMR		$10,350	-
230/500 kV XFMR	$11,400	-	$11,400
345/500 kV XFMR	-	$13,450	$13,450

3.5 REACTIVE COMPONENTS

In 2012, Black & Veatch identified three key reactive components commonly used for transmission level grid support. Each piece of equipment has its own level of complexity, size, and cost.

- Shunt Reactor
- Series Capacitor
- Static VAR Compensator (SVC)

Reactive component costs are considered to be "turnkey" installations including engineering, design, and construction support. 2014 updates for reactive component costs are shown in Table 3-4 and include shunt reactors, series capacitors and SVCs.

Table 3-4 Reactive Component Capital Costs

EQUIPMENT	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Shunt Reactor ($/MVAR)	$20,700	$20,700	$20,700
Series Capacitor ($/MVAR)	$31,000	$10,350	$10,350
SVC ($/MVAR)	$88,000	$88,000	$88,000

3.6 HIGH VOLTAGE DIRECT CURRENT CONVERTER STATION

Previously, Black & Veatch determined the various costs associated with a 500 kV HVDC converter station. To calculate the cost of a 600 kV HVDC station, the total 500 kV HVDC converter station cost was escalated 10 percent as described in Section 3.1.2. The capital costs in Table 3-5 are for the HVDC converter station in 2014 dollars.

Table 3-5 HVDC Converter Station Costs

HVDC CONVERTER STATIONS	
MW Rating	3000 MW
500 kV HVDC Converter Station	$460,708,500
600 kV HVDC Converter Station	$506,779,350

3.7 SUBSTATION CALCULATION METHODOLOGY

Using the substation components detailed above, the total substation cost is calculated using the following equation, including cost for the HVDC converter station if applicable:

Total Individual Substation Cost = [(Substation Base Cost) + (Line/XFMR Position Base Cost) x (# of Line/XFMR Positions) x (RB or BAAH Multiplier) + (XFMR Cost/MVA) x (XFMR MVA Rating) x (# of XFMRs) + (SVC Cost/MVAR) (# MVARs) + (Series Cap. Cost/MVAR) x (# MVARs) + (Shunt Reactor Cost/MVAR) x (# MVARs) + (HVDC Converter Station Cost)]

If the substation has a high side and a low side voltage, both Line/XFMR Position costs have to be calculated; however, the Substation Base Cost does not have to be added again. The highest voltage of the substation will be the basis for the Substation Base Cost.

4.0 Summary of Capital Costs

The methodology in Sections 2.0 and 3.0 above considers multiple components to compute a complete capital cost for a transmission infrastructure project. The capital costs above are summarized in the sections below.

4.1 TRANSMISSION CAPITAL COSTS

Using the methodology discussed in Section 2.0, Black & Veatch surveyed various transmission costs as well as used internal industry knowledge to determine typical values for transmission costs. While industry costs can vary substantially, the Peer Review Group determined that these values are reasonable for projects installed in the WECC region, except potentially for those in California.[8]

Using the numbers from tables below and the equation below, the total capital cost for a transmission line can be calculated.

Total Transmission Line Cost = [(Base Transmission Cost) x (Conductor Multiplier) x (Structure Multiplier) x (Re-conductor Multiplier) x (Terrain Multiplier) + (ROW Acres/Mile) x (Land Cost/Acre)] x (# of Miles)

For reference, tables have been included for 2012, 2013 and 2014 transmission capital costs.

[8] In the 2012 report, the methodology was benchmarked against actual project costs and found to provide reasonable planning-level estimates for total costs. However, applying the methodology to California projects (e.g., Tehachapi and Sunrise) was difficult due to the unique nature of those projects. For this reason, further review of California-specific factors is recommended before this methodology is broadly applied there.

Table 4-1 2012 Transmission Capital Cost Summary

	230 KV SINGLE CIRCUIT	230 KV DOUBLE CIRCUIT	345 KV SINGLE CIRCUIT	345 KV DOUBLE CIRCUIT	500 KV SINGLE CIRCUIT	500 KV DOUBLE CIRCUIT	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
Base Cost ($/mi)	$927,000	$1,484,000	$1,298,000	$2,077,000	$1,854,000	$2,967,000	$1,484,000	1,558,200
Multipliers								
Conductor								
ACSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ACSS	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
HTLS	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Structure								
Lattice	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00
Tubular Steel		1.00	1.30	1.30	1.50	1.50	1.50	1.50
Length								
> 10 miles	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3-10 miles	1.50	1.20	1.20	1.20	1.20	1.20	1.20	1.20
< 3 miles		1.50	1.50	1.50	1.50	1.50	1.50	1.50
Age								
New	0.35	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Re-conductor		0.45	0.45	0.55	0.55	0.65	0.55	0.55
Terrain								
Desert	1.00	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Scrub / Flat	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Farmland	2.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Forested	1.40	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Rolling Hill (2-8% slope)	1.75	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Mountain (>8% slope)	1.20	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Wetland	1.27	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Suburban	1.59	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Urban	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59

Table 4-2 2013 Transmission Capital Cost Summary

	230 KV SINGLE CIRCUIT	230 KV DOUBLE CIRCUIT	345 KV SINGLE CIRCUIT	345 KV DOUBLE CIRCUIT	500 KV SINGLE CIRCUIT	500 KV DOUBLE CIRCUIT	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
Base Cost ($/mi)	$940,905	$1,506,260	$1,317,470	$2,108,155	$1,881,810	$3,011,505	$1,506,260	$1,581,573
Multipliers								
Conductor								
ACSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ACSS	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
HTLS	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Structure								
Lattice	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00
Tubular Steel	1.00	1.00	1.30	1.30	1.50	1.50	1.50	1.50
Length								
> 10 miles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3-10 miles	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
< 3 miles	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Age								
New	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Re-conductor	0.35	0.45	0.45	0.55	0.55	0.65	0.55	0.55
Terrain								
Desert	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Scrub / Flat	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Farmland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Forested	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Rolling Hill (2-8% slope)	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Mountain (>8% slope)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Wetland	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Suburban	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Urban	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59

Table 4-3 2014 Transmission Capital Cost Summary

	230 KV SINGLE CIRCUIT	230 KV DOUBLE CIRCUIT	345 KV SINGLE CIRCUIT	345 KV DOUBLE CIRCUIT	500 KV SINGLE CIRCUIT	500 KV DOUBLE CIRCUIT	500 KV HVDC BI-POLE	600 KV HVDC BI-POLE
Base Cost ($/mi)	$959,723	$1,536,385	$1,343,819	$2,150,318	$1,919,446	$3,071,735	$1,536,385	$1,613,204
Multipliers								
Conductor								
ACSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ACSS	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
HTLS	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Structure								
Lattice	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00
Tubular Steel	1.00	1.00	1.30	1.30	1.50	1.50	1.50	1.50
Length								
> 10 miles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3-10 miles	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
< 3 miles	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Age								
New	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Re-conductor	0.35	0.45	0.45	0.55	0.55	0.65	0.55	0.55
Terrain								
Desert	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Scrub / Flat	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Farmland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Forested	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Rolling Hill (2-8% slope)	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Mountain (>8% slope)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Wetland	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Suburban	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Urban	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59

In addition to the capital cost of equipment for transmission lines, the acquisition of land for ROW was determined based on BLM land values. The land costs are detailed on Table 2-7.

4.2 SUBSTATION CAPITAL COSTS

As with transmission costs, the Peer Review Group determined that substation values are reasonable for projects installed in the WECC region, with the key assumption that the substation would be constructed on flat, barren land with relatively easy site access. For reference, tables have been included for 2012, 2013 and 2014 substation capital costs.

Table 4-4 2012 Substation Capital Cost Summary

EQUIPMENT	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Base Cost (New Substation)	$1,648,000	$2,060,000	$2,472,000
Cost Per Line/XFMR Position	$1,442,000	$2,163,000	$2,884,000
Ring Bus Multiplier	1	1	1
Breaker and a Half Multiplier	1.5	1.5	1.5
500 kV HVDC Converter Station	-	-	$445,000,000
600 kV HVDC Converter Station	-	-	$489,500,000
Shunt Reactor ($/MVAR)	$20,000	$20,000	$20,000
Series Capacitor ($/MVAR)	$30,000	$10,000	$10,000
SVC Cost ($/MVAR)	$85,000	$85,000	$85,000
Transformer Cost ($/MVA)			
115/230 kV XFMR	$7,000	-	-
115/345 kV XFMR	-	$10,000	-
115/500 kV XFMR	-	-	$10,000
138/230 kV XFMR	$7,000	-	-
138/345 kV XFMR	-	$10,000	-
138/500 kV XFMR	-	-	$10,000
230/345 kV XFMR		$10,000	-
230/500 kV XFMR	$11,000	-	$11,000
345/500 kV XFMR	-	$13,000	$13,000

Table 4-5 2013 Substation Capital Cost Summary

EQUIPMENT	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Base Cost (New Substation)	$1,672,720	$2,090,900	$2,509,080
Cost Per Line/XFMR Position	$1,463,630	$2,195,445	$2,927,260
Ring Bus Multiplier	1	1	1
Breaker and a Half Multiplier	1.5	1.5	1.5
500 kV HVDC Converter Station			$451,675,000
600 kV HVDC Converter Station			$496,842,500
Shunt Reactor ($/MVAR)	$20,300	$20,300	$20,300
Series Capacitor ($/MVAR)	$30,450	$10,150	$10,150
SVC Cost ($/MVAR)	$86,275	$86,275	$86,275
Transformer Cost ($/MVA)			
115/230 kV XFMR	$7,105		
115/345 kV XFMR		$10,150	
115/500 kV XFMR			$10,150
138/230 kV XFMR	$7,105		
138/345 kV XFMR		$10,150	
138/500 kV XFMR			$10,150
230/345 kV XFMR		$10,150	
230/500 kV XFMR	$11,165		$11,165
345/500 kV XFMR		$13,195	$13,195

Table 4-6 2014 Substation Capital Cost Summary

EQUIPMENT	230 KV SUBSTATION	345 KV SUBSTATION	500 KV SUBSTATION
Base Cost (New Substation)	$1,706,174	$2,132,718	$2,559,262
Cost Per Line/XFMR Position	$1,492,903	$2,239,354	$2,985,805
Ring Bus Multiplier	1	1	1
Breaker and a Half Multiplier	1.5	1.5	1.5
500 kV HVDC Converter Station			$460,708,500
600 kV HVDC Converter Station			$506,779,350
Shunt Reactor ($/MVAR)	$20,706	$20,706	$20,706
Series Capacitor ($/MVAR)	$31,059	$10,353	$10,353
SVC Cost ($/MVAR)	$88,001	$88,001	$88,001
Transformer Cost ($/MVA)			
115/230 kV XFMR	$7,247		
115/345 kV XFMR		$10,353	
115/500 kV XFMR			$10,353
138/230 kV XFMR	$7,247		
138/345 kV XFMR		$10,353	
138/500 kV XFMR			$10,353
230/345 kV XFMR		$10,353	
230/500 kV XFMR	$11,388		$11,388
345/500 kV XFMR		$13,459	$13,459

Using the above tables and the equation below, the capital cost for the substation can be calculated.

Total Individual Substation Cost = [(Substation Base Cost) + (Line/XFMR Position Base Cost) x (# of Line/XFMR Positions) x (RB or BAAH Multiplier) + (XFMR Cost/MVA) x (XFMR MVA Rating) x (# of XFMRs) + (SVC Cost/MVAR) (# MVARs) + (Series Cap. Cost/MVAR) x (# MVARs) + (Shunt Reactor Cost/MVAR) x (# MVARs) + (HVDC Converter Station Cost)]

4.3 ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION AND OVERHEAD COSTS

The transmission and substation costs described in Sections 2.0 and 3.0 above are given as "overnight" costs, i.e. the cost if the project could be engineered, procured and constructed overnight without financing or overhead costs. To address this, Black & Veatch previously developed estimates of Allowance for Funds Used During Construction (AFUDC) and overhead, which could be added to the transmission and substation costs to produce realistic total project cost estimates.

Black & Veatch surveyed a number of sources to understand the range of these estimates and to develop a recommended value which could be used by WECC to reasonably represent all types of project ownership structures. These estimates have not been revised, and the original sampling of AFUDC and overhead costs from 2012 are shown in Table 4-7 below.

Table 4-7 Black & Veatch Survey of AFUDC and Overhead Costs and Recommended Values

	INDEPENDENT DEVELOPER	INVESTOR-OWNED UTILITY	PUBLIC UTILITY
Source	B&V Estimate	NV Energy/PacifiCorp	BPA
AFUDC Cost	10.0%	8.6%	4.1%
Overhead Cost	10.0%	6.2%	23.0%
Recommended Values	7.5% (AFUDC) + 10.0% (Overhead) = 17.5%		

Based on the collected data, Black & Veatch recommended and the Peer Review Group adopted a value of 7.5 percent for AFUDC costs and 10.0 percent for overhead costs, for a total of 17.5 percent.

4.4 TOTAL PROJECT COST

Adding the cost of the transmission calculated in Section 2.0 and the substation costs calculated in Section 3.0 together will result in the total project capital costs prior to AFUDC and overhead. Using the above information on AFUDC and overhead cost assumptions, the entire cost of a project can be calculated.

Total Project Cost = [(Total Transmission Capital Cost) + (Total Substation Capital Cost)] x (1+AFUDC + Overhead)

5.0 Cost Calculator

After developing the capital cost estimates for transmission and substations described in Section 2.0 and Section 3.0, Black & Veatch created a cost calculator which incorporated all of the cost estimates for transmission and substations cost components into a single, user-friendly Excel-based tool. The cost calculator is simple but flexible, and can be used to estimate the costs of hypothetical transmission projects and associated substations within the WECC region. The calculator employs the cost formulas for transmission and substations to calculate total project costs (for the entire line length and on a per-mile basis), and is automated to the extent possible to allow for quick estimates. The cost calculator workbook is split into three different sheets, each of which is described below:

- Transmission Cost Calculator (including the Transmission Line Loss Calculator)
- Substation Cost Calculator
- Cost Totals

5.1 TRANSMISSION COST CALCULATOR

A screenshot of the Transmission Cost Calculator sheet workbook is shown in Figure 5-1 below.

Black & Veatch Transmission Line Capital Cost Calculator

Legend
User Selection
Auto-calculated
Adjustable Parameter

	Selection	Multiplier	Cumulative Cost/Mile
Voltage Class	345 kV Double Circuit	1	$ 2,150,318.10
Conductor Type		1	$ 2,150,318.10
Structure		1	$ 2,150,318.10
Length Category		1	$ 2,150,318.10
New or Re-conductor?		1	$ 2,150,318.10
Average Terrain Multiplier		1.00	$ 2,150,318.10

Voltage Class drop-down list: 230 kV Single Circuit; 230 kV Double Circuit; 345 kV Single Circuit; 345 kV Double Circuit; 500 kV Single Circuit; 500 kV Double Circuit; 500 kV HVDC Circuit; 600 kV HVDC Circuit

Terrain Type	Miles of Terrain Type	Multiplier	Weighted Miles
Forested	0.0	2.25	0.0
Scrubbed/Flat	100.0	1	100.0
Wetland	0.0	1.2	0.0
Farmland	0.0	1	0.0
Desert/Barren Land	0.0	1.05	0.0
Urban	0.0	1.59	0.0
Rolling Hills (2-8% Slope)	0.0	1.4	0.0
Mountain (>8% Slope)	0.0	1.75	0.0
Total Miles	100.0		

BLM Cost Zone Number	ROW Miles in BLM Zone	$/Acre	$/Mile of ROW	Zone ROW Costs
1	0.0	$ 85.34	$ 2,068.80	$ -
2	0.0	$ 170.68	$ 4,137.60	$ -
3	100.0	$ 341.45	$ 8,277.60	$ 827,760.00
4	0.0	$ 512.13	$ 12,415.20	$ -
5	0.0	$ 682.80	$ 16,552.80	$ -
6	0.0	$ 1,024.25	$ 24,830.40	$ -
7	0.0	$ 1,707.06	$ 41,383.20	$ -
8	0.0	$ 3,414.11	$ 82,766.40	$ -
9	0.0	$ 6,828.23	$ 165,532.80	$ -
10	0.0	$ 10,242.34	$ 248,299.20	$ -
11	0.0	$ 17,070.57	$ 413,832.00	$ -
12	0.0	$ 34,141.14	$ 827,664.00	$ -

AFUDC/Overhead Cost	17.5%

Project Cost Results	Per Mile	Total
Line Cost	$ 2,150,318.10	$ 215,031,810.00
ROW Cost	$ 8,277.60	$ 827,760.00
AFUDC/Overhead Cost	$ 377,754.25	$ 37,775,424.75
All Costs	$ 2,536,349.95	$ 253,634,994.75

	Per Mile (MW/Mile)	Total (MW)
Project Line Losses	0.3212	32.12

Figure 5-1 Transmission Cost Calculator Sheet of Cost Calculator Workbook

On this sheet, the user first selects the basic transmission line characteristics from a series of drop-down menus. The options for each follow the different equipment types and specifications described in Section 2.2. After that, the user must enter information about the line routing. This information consists of the number of miles of line which pass through each terrain type described in Section 2.4, and the number of miles of line which pass through each BLM cost zone described in Section 2.5. These line routing values are not calculated within this sheet—rather, the user must obtain these values by performing a separate Geographic Information System (GIS) analysis.

Once all selections are made and all values are entered, the transmission line, right of way, and AFUDC/overhead costs for the project are automatically calculated at the bottom of the sheet in the "Project Cost Results" section, for the entire line length and on a per-mile basis.

The calculator is also flexible. In addition to the cells highlighted in yellow, which indicate places where the user must select from a drop-down menu or enter a value, a number of cells are highlighted green, to indicate that the values in those cells are parameters that can be adjusted by the user. Adjusting these values allows the user to test the sensitivity of the project cost results to certain parameters. The following are parameters which can be adjusted on this sheet:

- Terrain type multipliers
- AFUDC/overhead cost adder
- Transmission base costs
- Conductor type multipliers
- Structure type multipliers
- Length category multipliers
- New vs. re-conductor multipliers
- Right of way width assumptions
- BLM zone land rental costs
- Land tax rate
- Capitalization rate
- Inflation variables

5.2 TRANSMISSION LINE LOSS CALCULATOR

A screenshot of the Transmission Line Loss Calculator located in the Transmission Cost Calculator sheet of the cost calculator workbook is shown in Figure 5-2 below.

Black & Veatch Transmission Line Loss Calculator

Assumed Line Utilization	60%
Full Load Adjustment	0.48

	230 kV Single Circuit	230 kV Double Circuit	345 kV Single Circuit	345 kV Double Circuit	500 kV Single Circuit	500 kV Double Circuit	500 kV HVDC Circuit	600 kV HVDC Circuit
Capacity	400	800	750	1500	1500	3000	3000	3000
Phase Current (amps)	1057	1057	1321	1321	1823	1823	3000	2500
No. Conductors Per Phase	1	1	2	2	3	3	3	3
No. Circuits Per Line	1	2	1	2	1	2	2	2
No. Phases	3	3	3	3	3	3	1	1
ACSR Size	1272	1272	795	795	1590	1590	1780	1780
Resistance	0.08305	0.08305	0.1278	0.1278	0.06765	0.06765	0.057344	0.057344
ACSS Size	477	477	336.4	336.4	605	605	636	636
Resistance	0.2253	0.2253	0.319	0.319	0.178	0.178	0.153776	0.153776
HTLS	477	477	336	336	557	557	636	636
Resistance	0.2275	0.2275	0.315	0.315	0.1860	0.1860	0.1635	0.1493

Line Loss MW / Mile	230 kV Single Circuit	230 kV Double Circuit	345 kV Single Circuit	345 kV Double Circuit	500 kV Single Circuit	500 kV Double Circuit	500 kV HVDC Circuit	600 kV HVDC Circuit
ACSR	0.1336	0.2672	0.1606	0.3212	0.1079	0.2159	0.1652	0.1147
ACSS	0.3624	0.7249	0.4009	0.8018	0.2840	0.5680	0.4429	0.3076
HTLS	0.3660	0.7319	0.3959	0.7918	0.2968	0.5936	0.4709	0.2986

Figure 5-2 Transmission Loss Calculator in Cost Calculator Workbook

The transmission line losses will be automatically calculated based on the line parameters entered in the Transmission Cost Calculator, as described in Section 2.7. The per mile and total losses will be recorded in MW in the Project Line Loss row located next to the Project Cost Results. The adjustable parameters in this section of the sheet are:

- Line utilization factor
- Line capacity in MW
- Number of conductors per phase
- Number of circuits per line
- Number of phases
- ACSR conductor size
- ACSR line resistance
- ACSS conductor size
- ACSS line resistance
- HTLS conductor size
- HTLS line resistance

5.3 SUBSTATION COST CALCULATOR

A screenshot of the Substation Cost Calculator sheet of the cost calculator workbook is shown in Figure 5-3 below.

Black & Veatch Substation Capital Cost Calculator				
				User Selection
				Auto-calculated
	Selection	Cost Component	Cost	Adjustable Parameter
Voltage	500 kV Substation	Base Cost	$ 2,472,000	
New or Existing Site?	New	Circuit Breakers	$ 17,304,000	
Circuit Breaker Type	Breaker and a Half	500 kV HVDC Converter	N/A	
# of Line/XFMR Positions	4	Transformer(s)	$ 11,000,000	
500-kV HVDC Converter?	No	SVC(s)	$ 10,000,000	
Transformer Type	230/500 kV XFMR	Shunt Reactor(s)	$ 10,000,000	
MVA Rating Per Transformer	115/345 kV XFMR	Series Capacitor(s)	$ 20,000,000	
# of Transformers	115/500 kV XFMR 138/230 kV XFMR	AFUDC/Overhead Cost	$ 12,385,800.000	
SVC MVAR Rating	138/345 kV XFMR 138/500 kV XFMR			
Shunt Reactor MVAR Rating	230/345 kV XFMR	Total Substation Cost	$ 83,161,800	
Series Capacitor MVAR Rating	230/500 kV XFMR			
AFUDC/Overhead Cost	345/500 kV XFMR 17.5%			

Figure 5-3 Substation Cost Calculator Sheet of Cost Calculator Workbook

On this sheet, the user selects the basic substation characteristics from a series of drop-down menus, and also enters appropriate values for certain characteristics (e.g., "# of Transformers"), according to the options described in Section 3.0. The cost for each substation component is shown on the right side, the AFUDC/overhead cost is automatically calculated, and the total substation cost is automatically summed at the bottom.

It is important to note that this sheet can be used to calculate costs for only one individual substation at a time. If a particular transmission project involves more than one substation, then information about each substation will need to be entered separately, and the total cost of each individual substation will need to be entered in the empty cells in the Cost Totals sheet of the workbook.

There are also a number of adjustable parameters in this sheet, which are:

- AFUDC/overhead cost adder
- Base substation costs
- Cost per line position
- Line position type multipliers
- HVDC converter station cost
- Shunt reactor cost
- Series capacitor cost
- SVC cost
- Transformer costs
- Inflation variables

5.4 COST TOTALS

A screenshot of the Cost Totals sheet of the cost calculator workbook is shown in Figure 5-4 below.

Black & Veatch Transmission and Substation Cost Totals

Project Cost Results	Per Mile	Total
Line Cost	$ 1,998,533.77	$ 463,873,675.03
ROW Cost	$ 41,649.31	$ 9,667,096.80
Substation #1	N/A	$ 83,161,800.00
Substation #2	N/A	$ 50,000,000.00
Substation #3	N/A	
Substation #4	N/A	
Substation #5	N/A	
AFUDC Cost	$ 357,032.04	$ 106,172,950.07
All Costs	**$ 2,397,215.12**	**$ 712,875,521.90**

User Selection
Auto-calculated

Figure 5-4 Cost Totals Sheet of Cost Calculator Workbook

On this sheet, the transmission and substation costs calculated on the other two sheets are summed to find the total project cost, for the entire line length and on a per-mile basis. The transmission line and right of way cost data are automatically transferred from the Transmission Cost Calculator sheet. Since it is anticipated that most projects will have multiple associated substations and each individual substation cost must be calculated separately, there are five empty cells in which the user can enter the cost of individual substations from the Substation Cost Calculator sheet. Once the substation costs are entered, the AFUDC and overhead cost is automatically calculated and the total project cost is automatically summed at the bottom.