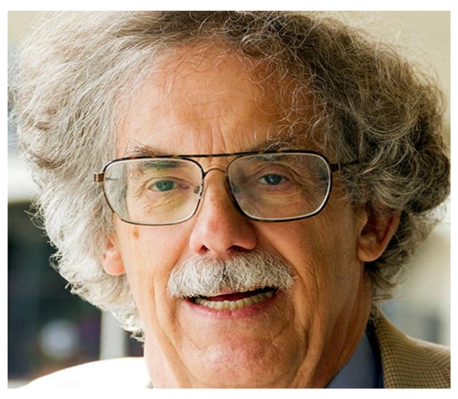
A Financial Algorithm for Computing the Levelized Cost (US$/MWh;€/MWh) of Storing Wind Power (LCOS)

PO. 208



Michael STAVY[1]

The Renewable Energy Finance and Technology Consultancy© michael@michaelstavy.com

ENERGY STORAGE FACTS

Wind electricity is energy and is measured in MWh

WindPower is measured in MW

Energy storage capacity is measured in MWh

Energy storage power output is measured in MW

Energy storage capacity can also be measured by time duration (i.e. hours at full power).

THE LEVELIZED COST (LC) ALGORITHM IS

1. a simple "back of the envelope" method
2. an accurate, first approximation of the cost (US$/MWh; €/MWh) of storing bulk wind energy

THE PAPER

discusses the energy storage (ES) cycle (charge, storage, discharge). The LC algorithm is technology neutral. The paper presents the algorithm, the algorithm equations and the nine ESS specifications (specs). The algorithm is also presented as an Excel worksheet for quick computation. The ESS specs are defined and two major case studies are used to demonstrate the LC algorithm and the acquisition of the nine ESS spec values.

THE ABSTRACT

This paper discusses the financial and technical principles underlying the levelized cost (LC) method of computing the cost (US$/MWh; €/MWh) of the bulk (utility-scale) storage of wind electricity (LCOS). The paper presents a LC algorithm. The algorithm equations are presented. The algorithm uses nine recognized energy storage system (ESS) specifications (specs) to compute the levelized cost of bulk stored wind electricity. Published and developed spec values for the Eos Aurora® ESS (a utility-scale [1 MW | 4 MWh] DC battery manufactured by Eos Energy Storage) and for the Cabin Creek ESS (a utility-scale [300 MW | 1,450 MWh] Pumped Storage Plant in Clear Creek County, Colorado owned by Xcel Energy) are used as case studies to demonstrate the algorithm. Other examples are provided. An addendum case study of the San Vicente (a proposed utility-scale [500 MW I 4,000 MWh] Pumped Storage Plant in San Diego County, California to be developed and owned by the San Diego County Water Authority and the City of San Diego) is also presented. For rapid computation, an Excel worksheet of the LC algorithm is presented. The goal of this paper is to present a standard computational algorithm for financial analysts to use. A financial analyst can do a LC computation based on the paper's LCOS algorithm and on the algorithm's nine ESS specs. The paper's LCOS algorithm gives the analyst who has the nine ESS spec values, a quick "back of the envelope" verification of a developer's value for the levelized cost of bulk stored wind electricity. The algorithm is not designed to compute the cost of providing ancillary services to the grid. A different algorithm is required and is presently under development. A complication arises for the public financial analyst when using this paper's LC algorithm. The complication is that "published bulk ESS spec values" are limited. On the other hand, a financial analyst who works for an ESS developer would be able to get the nine spec values from the developer's internal documents for use in computing the LCOS for the first round internal analysis of a proposed ESS.

THE TABLE I LC WORKSHEET

with the paper's two major case studies (Aurora®; Cabin Creek) is presented below. The algorithm uses a financial annuity to compute the LC of the stored energy **(LCOS)**. For the Aurora® Column, the Annual Capital Amortization-ACA-US$/yr (Line H) is one constant end of year financial annuity payment of US$65,185 for an annuity having a principal amount borrowed of US$640,000, ESS Plant CapEx-US$/ESS Plant (Line B), a loan period of 20 years (Line 8) and an interest rate of 8% (Line 9). The 0.1019 Capital Amortization Factor-CAF (Line G) is the annual end of year payment for a financial annuity having US$1.00 as the principal amount borrowed, a loan period of 20 years and an interest rate of 8%. This yearly level capital amortization payment gives the levelized cost method its name. The first year's payment is almost all interest, while the last year's payment is almost all principal (i.e. amortization [depreciation]). The other Aurora® specs are 1 MW of power output (Line 1), 4 MWh of energy storage capacity (Line 2), a plant CapEx of US$160,000/MWh (Line 3), a round trip efficiency of 75% (Line 4), a Fixed O&M (Line 6) that is 0.5% of Line B, a Variable O&M of US$1.00/MWh (Line 7) and a US$50.16/MWh cost of the wind electricity to be stored (Line 5). On your own, you can now study the nine spec values in the Cabin Creek Column. With the nine spec values entered, the difference between the Aurora® and the Cabin Creek ESS LCOS is only US$0.48/MWh. This is a coincidence! Other differences are discussed in the Results Box and in the paper. The paper's narrative discusses where the published spec values are from and when and why they are sufficient. The narrative also discusses the development of each of the ESS spec values when the published (or internal) spec values are limited or not sufficient.

[1]The author's family name, STAVY, is in CAPS because French was the host language for the 2015 Paris Climate Agreement. In French, the family name is in CAPS!

COLOR CODING	
Spec Value	Checked Value
Computed Value	Transferred Value

	Table I	EOS	Cabin
	EES Plant CapEx	Aurora®	Creek
1	ESS Plant-Power Output-MW	1	300
2	ESS Daily Energy Storage Capacity-MWh/day	4	1,450
A	ESS Yearly Energy Storage Capacity-MWh/yr	1,460	529,250
3	ESS Plant CapEx-US$$_{17}$/MWh	$160,000	$283,000
√	ESS Plant CapEx-US$$_{17}$/kWh	$160	$283
B	Total EES Plant CapEx-US$$_{17}$/ESS Plant	$640,000	$410,350,000
	Cost of the Stored Wind Electricity		
4	ESS Plant Round Trip Efficiency-η-%	75%	80%
5	Cost of the Wind Electricity to be Stored-COE-US$/MWh	$50.16	$50.16
C	Cost of the Stored Wind Electricity-COSE-US$/MWh	$66.88	$62.70
D	Extra Cost (COSE-COE) of the Stored Wind Electricity-US$/MWh	$16.72	$12.54
	Energy Storage Costs		
6	Annual Fixed O&M Cost-% Total ESS CapEx-Line B	0.50%	0.50%
F	Annual Fixed O&M Cost-US$/yr	$3,200	$2,051,750
7	Variable O&M Cost-US$/MWh	$1.00	$1.00
8	Physical Life of the ESS Plant-Years	20	100
9	Interest/ROE Rate-%	8%	6%
G	Capital Amortization Factor-CAF	0.1019	0.0602
H	Annual Capital Amortization-ACA-US$/yr	$65,185	$24,693,778
	Computation of the Levelized Cost of the Stored Wind Electricity-US$/MWh		
I	Annual Capital Amortization-ACA-US$/MWh	$44.65	$46.66
J	Fixed O&M Cost-US$/MWh	$2.19	$3.88
K	Variable O&M Cost-from Line 7 above-US$/MWh	$1.00	$1.00
L	Cost of the Stored Wind Electricity-COSE- Line C above-US$/MWh	$66.88	$62.70
M	Levelized Cost of the Stored Wind Electricity-LCOS-US$/MWh	$114.72	$114.23
N	Levelized Extra Cost of the Stored Wind Electricity-LECOS-US$/MWh	$64.56	$64.07

RESULTS AND A COMPLICATION

This paper presents an accurate "back of the envelope" financial algorithm that computes the LC of storing wind electricity in an ESS. The paper converts certain US$ values into €. The LC algorithm requires nine ESS specs. While going over the Table I Worksheet, the paper narrative discusses the technical, mathematical and economic basis for the financial algorithm. The paper then uses case studies of published ESS specs to demonstrate how to develop reasonable values for the nine ESS specs that are entered on Table I. Two major case studies (Aurora®; Cabin Creek) are presented in Table I. For both of these ESS cases, the computed LCOS is double the cost of the wind electricity being stored. Market conditions determine whether the Table I computed LCOS are competitive. How the effect of a change (Δ) in the any of nine spec values causes a change in the computed LCOS (LCOS Δ) is discussed in the paper. The Aurora® US$160/kWh CapEx is *à la carte*. When a more all-inclusive US$400/kWh CapEx (a US$240 Δ or a 150% increase) is used, the LCOS goes from US$114.72 to US$184.98 (a US$70.26 Δ or a 61.2% increase). If Cabin Creek's round trip efficiency is increased from 80% to 95% (a 15% Δ or a 18.8% increase), the LCOS goes from $114.23 to US$104.33 (a US$9.90 Δ or a 8.7% decrease). The complication in using this paper's financial algorithm is that published (or internal) ESS spec values maybe limited or insufficient. The case studies are presented to help the reader learn how to overcome this complication.

For FREE (Unentgeltlich) at my website (↓ my website address is below ↓), you can download the complete paper, the paper's Excel worksheets and the current version of this poster.

SELECT REFERENCES

1. Electric Power Research Institute, Inc. (EPRI), *Energy Storage Technology and Application Cost and Performance Data Base-2010*, Palo Alto, CA Dated: 15 December 2010; Downloaded: 6 July 2018 https://tinyurl.com/ya6dswl5

2. Eos Energy Storage Corporation, *Technology and Products; EOS Aurora, Grid-Scale Energy Storage*, https://tinyurl.com/ycvvugsv Downloaded: 6 July 2018

3. Xcel Energy, *Cabin Creek Generating Station*, https://goo.gl/hgGiLq Downloaded: 6 July 2018

8. M Stavy (2002-2), *A Financial Worksheet for Computing the Cost (¢/kWh) of Solar Electricity Generated at a Grid Connected Photovoltaic (PV) Generating Plant*, ASME J. of Sol. Energy Eng., **Vol 124**, pp. 319-321

13. *Compendium of Pumped Storage Plants in the United States,* Ralph R Roza JR, Committee Chairman, Task Committee on Pumped Storage of the Hydropower Committee of the Energy Division of the ASCE, New York, NY American Society of Civil Engineers 1993 750 pp. Cabin Creek Pumped Storage Plant, page 199.

18. Federal Energy Regulatory Commission (FREC), *Pumped Storage Projects Website*, Dated: 23 January 2017 https://ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp Downloaded: 10 April 2018

Download the paper at www.michaelstavy.com