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# Impacts of transmission tariff on price arbitrage operation of energy storage system in Alberta electricity market

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ABSTRACT

This paper investigates the application of existing tariff structures to understand how they impact the economic operation of energy storage system (ESS) for arbitrage. The scope of this research covers impacts on profitability, operating cost, energy-traded volume, and price volatility. Two facilities of different scales are considered: an ESS unit small enough to have no impact on price, and an ESS unit, large enough to have a quantifiable impact on pool price. The hourly impact of ESS operations on the pool price is estimated by modeling the price sensitivity quota curve from actual hourly market data.

## 1. Introduction

Increasing commercial interest in investment in energy storage systems (ESSs) has generated a need to investigate factors that can affect the profitability of arbitrage operation in relevant electricity markets. Common to all ESS facilities, operation and maintenance cost, capital cost, price variation, round-trip efficiency, energy capacity-to-power ratio and self-discharge loss (Bradbury et al., 2014) all impact operational profitability of ESS. The capital cost is rapidly changing and has been projected to decrease significantly by 2020 in a report by Viswanathan et al. (2013) from Pacific Northwest National Laboratory. Unique to each electricity market, the regulatory policy on storage operation also has significant impact. Several jurisdictions in North America are reviewing existing policies or formulating new policies to aid the integration of energy storage into the electricity market.

From a policy perspective, the past three years have been very interesting for energy storage. The U.S. Federal Energy Regulatory Commission (FERC) implemented a series of related orders (755, 784, and 792) applicable to the electric power markets of Pennsylvania, Jersey, Maryland (PJM), Midcontinent Independent System Operator (MISO), California Independent System Operator (CAISO), New York Independent System Operator (NYISO), and Independent System Operator for New England (ISO-NE). FERC order 755 ensures system operators develop pay for performance tariff for ancillary services (Masiello et al., 2014); order 784 requires system operator to consider speed and accuracy in formulating requirement for ancillary services, while order 792 places energy storage on same level with conventional generators by considering it as a power source (Kintner-Meyer, 2014). Kintner-Meyer (2014) exhaustively discusses the details of the implementation in each of those jurisdictions. Even though the Independent System Operator in Alberta; Alberta Electric System Operator (AESO) is still formulating suitable regulatory policy applicable to ESS, in general, the most important policy to energy storage proponents in Alberta at the time of writing is the transmission tariff policy. Transmission tariffs are important because merchant energy storage proponents are very interested in how tariffs will affect their operating profit. ESS are not currently allowed to participate in the ancillary service market, only synchronous facilities are allowed based on the current operating reserve technical requirements (Chen, 2013). The approval of the proposed Western Electricity Coordinating Council (WECC) Contingency Reserves Standard is expected to allow non-synchronous facilities to participate in the regulating and spinning reserve market in Alberta (AESO, 2015a), and this is expected to be a good source of revenue for ESS merchants.

The existing tariff structure in Alberta was not formulated with the consideration of bulk energy storage facilities. There have been back-and-forth arguments as to how best to classify ESS. Some are of the opinion that it should be treated as a transmission facility because its operation has the benefit of deferring new investment in transmission asset and that it does not generate energy on its own but merely withholds energy from the system to subsequently releases it back (Bubik, 2014). Klinkenborg (2014) is of the opinion that their operation is in no way different than that of conventional generators when discharging and another opinion is that they act as either load or generator (Cheng, 2014). The fact that their operational modes can be regarded as either load or generation has led to suggestions that the current tariff structure for demand and supply may be suitable. Several studies have been conducted to estimate the potential profitability of arbitrage

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**Notations**

*Index*

| | |
|---|---|
| k | step size for Bid blocks |
| s | step size for Offer blocks |
| t | time in hours |

*Parameters*

| | |
|---|---|
| $\lambda^{t,s}$ | Hourly price factoring impact offer block s |
| $\lambda^{t,k}$ | Hourly price factoring impact of bid block k |
| $\gamma_s$ | Storage efficiency |
| $\gamma_c$ | Conversion efficiency |
| $B_d^k$ | Bids in blocks of 10 MW |
| $L_f$ | Loss factor |
| $N_k$ | total number of Bid steps |
| $N_s$ | total number of Offer steps |
| $O_f^s$ | Offers in blocks of 10 MW |
| $TRD_c$ | Trading charge by the system operator |
| $VOM_c$ | Variable operation and maintenance cost |

*Variables*

| | |
|---|---|
| $B^{t,k}$ | Bid variables ranging from 0 to 9 MW |
| $D_{od}$ | Depth of discharge$O^{t,s}$ offer variables ranging from 0 to 9 MW |
| $P_{ch}^t$ | Power from the grid to charge the system |
| $P_{dch}^t$ | Power discharged to the grid |
| $S_0$ | Initial state of charge |
| $S^t$ | State of charge at any time t |
| $U^{t,k}$ | Binary variable indicating active bid block and charging status at any time t |
| $X^{t,s}$ | Binary variable indicating active offer block and discharging status at any time t |

operation in various electricity markets. The existing literature has covered deregulated electricity markets in Europe, North America, and elsewhere.

The study by Walawalkar et al. (2007) investigated the economics of energy storage operation in the electricity market of New York by using market data from 2001 to 2005. The study shows that operation of Sodium Sulphur battery and flywheel for arbitrage and regulation operation in the New York City region has high probability of positive net present value. In the Electricity Reliability Council of Texas (ERCOT) market, the maximum potential revenue obtainable from operating a hypothetical 8 MW, 32 MWh battery connected to HB_Houston node is estimated by Byrne and Silva-Monroy (2015), for both energy arbitrage and regulation. This study emphasized how largely dependent potential revenue is on market price fluctuation. The study by Fertig and Apt (2011) investigated the economics of pairing Compressed Air Energy Storage (CAES) with wind farm in Houston using 2008 hourly ERCOT electricity market price. Results showed that pairing CAES with a wind farm to smooth dispatchable power from the farm or storing energy from the wind farm for arbitrage opportunity is not economically viable. Considering performance-based regulation and battery life cycle, He et al. (2015) proposed an optimal bidding strategy for a battery energy storage system to maximize profit in markets that have implemented performance-based regulation (PBR) such as PJM. The study shows that incorporating PBR and battery life cycle modeling could significantly improve overall economics of Battery Energy Storage System (BESS).

Using five-year historical data, Adebayo et al. (2016) examined the economic viability of arbitrage operation of battery in Alberta electricity market with a case study of 30 MW, 120 MWh Vanadium Redox Battery (VRB) considered large enough to have impact on the pool price of electricity. Taking both impact of the battery operation on price and 2020 projected capital cost estimate into consideration, the study showed that with a 34% reduction of capital cost, the case study considered could become economically viable. Another study of Canada's second electricity market by Khani and Dadash Zadeh (2015) assessed the economic viability of arbitrage operation of cryogenic energy storage with 60% round-trip efficiency in Ontario electricity market, showing that the system cannot return expected revenue and proposes a price modulation algorithm to competitively offer subsidy to the merchant.

In Europe, two different studies by Kazempour et al. (2009) and Moghaddam and Saeidian explore the profitability of arbitrage operation of two different battery technologies; Sodium Sulphur (NaS) and Vanadium Redox Battery (VRB) in the electricity market of Mainland Spain and reached a similar conclusion. Findings by Kazempour et al. (2009) show that the 10 MW, 70 MWh NaS operating in energy, regulating, and spinning reserve market cannot generate a return up to the minimum acceptable return and thus proposed support mechanisms in form of tax benefits and gratuitous loan to potential merchant. Similarly, Moghaddam and Saeidian (2010) concluded that a VRB of equivalent power rating and storage capacity is also not economically viable.

Optimal operational strategy for an energy storage system to maximize arbitrage profit in the real-time electricity market of Denmark is investigated in the study by Hu et al. (2010), with a comparison of two battery technologies; VRB and Polysulfide-bromine (PSB). Numerical results from this study show that PSB is a better investment choice as it has shorter payback time than VRB. With a special focus on Finland in the Nordic electricity market, Zakeri and Syri (2014) examined the economics of various energy storage technologies, noting that the ESS considered will require additional benefit to become economically attractive. Ippolito et al. (2015) analyzed the economic viability of operating customer-side NaS battery in the Italian electricity market and concluded that at the current hourly price, it is currently not economically viable due to high initial investment cost. The economics of operating compressed air energy storage in Turkish power market using probabilistic price estimation to obtain annual profit from 2011 to 2041 is examined in a study by Yucekaya (2013). Based on net present value and payback period estimates, this study shows that investment in such a project can be economically viable. Steffen (2012) investigated the economic prospect of operating Pumped hydro storage system in Germany using estimates of arbitrage profit from year 2002–2010. Internal rate-of-return (IRR) estimates from this study are noted to be below average industry requirement but increase in renewable energy penetration could expand opportunity.

Policies in different jurisdictions may affect the economics and general operation of EES. In this paper, we investigate the impact of transmission tariff policy on the economics of arbitrage operation of ESS in the Alberta electricity market. Using the AESO's tariff policy documents accessible on the AESO website, we incorporate all the potential tariff structures applicable to the ESS operation into a Mixed Integer Linear Programming (MILP) self-scheduling optimization model to obtain operating profit for ESS large enough to impact the pool price and another one considered to be small scale with negligible impact on price. The contributions of this paper are to:

- Formulate a price-maker model using actual historical data from hourly supply curve in Alberta electricity market;
- Incorporate Alberta's transmission tariff into an economic dispatch model for both price taker and price maker ESSs; and