Contract No. R-008-016

"Bulk Energy Storage for North Dakota Wind Energy Integration"

Submitted by Dakota Salts, LLC

Working with Dakota Salts will be Electric Power and Research Institute, Schlumberger and Tetra Tech

Principal Investigator(s): Don Dickie; J.T. Starzecki

PARTICIPANTS

Sponsor	Cost Share
Dakota Salts, LLC	$395,800
Dakota Salts, LLC	$149,000 (in-kind)
North Dakota Industrial Commission	$225,000
Total Project Cost	$769,800

Project Schedule – 8 months
Contract Date – August 12, 2010
Start Date – September 1, 2010
Completion Date – May 1, 2011

Project Deliverables:
Status Report on Geo-Mechanical Study: January 1, 2011
Status Report on Cost-Benefit Analysis and Impact on Wind Integration: January 1, 2011
Final Report on Geo-Mechanical Study: May 1, 2011
Final Report on Cost-Benefit Analysis and Impact on Wind Integration: May 1, 2011

OBJECTIVE/STATEMENT OF WORK:

The goal of this project is to utilize compressed air energy storage (CAES) to store wind energy in North Dakota. Tasks to accomplish this will include performing an advanced subsurface geo-mechanical feasibility study to characterize North Dakota's salt formations for their utilization for Bulk Energy Storage (BES) and performing a cost-to-benefit analysis for installation of a CAES power plant for wind integration service in North Dakota.

These two tasks are necessary first steps toward utilizing CAES in North Dakota. If successful, CAES will provide a way to harness and utilize wind energy in a more consistent manner thereby reducing transmission requirements.

STATUS

Contract has been executed.

The Contractor provided an Interim Report dated July 18, 2011 which is linked to this website. The Interim Report states that the work done by Schlumberger Water Services is nearly complete -- Storage Target Location Assessment, the Geological Parameter Estimation, the Geomechanical Parameter Estimation and the Initial Cavern Geometry Selection phases of the project are complete with the Numerical Simulations 90% complete. The Electrical Power Research Institute was engaged to evaluate the economics of bulk energy storage. The interim report states that the detailed report is currently in draft form awaiting group evaluation of the findings and recommendations. The preliminary results of the study conclude:

- Optimal dispatch for the CAES plant is based on historical 2006-2008 real-time MISO data. Additional revenues from spinning reserve, frequency regulation and blackstart services are also included. These ancillary and capacity benefits will be critical components of the benefit mix.

- Benefit/cost ratios range from 4.07 to 7.26. This value of CAES in MISO is largely due to a latent economic value of bulk storage in MISO and not a result of wind penetration levels (which are around 4%). Higher wind penetration levels will tend to further improve the cost effectiveness of CAES systems.
- Average capacity factors are 30% to 50%, so that CAES runs like an intermediate-duty plant. A capacity of 30-50 hours appears suitable for this application in MISO.
- The annual average CAES CO_2 savings are estimated at 256,000 short tons of CO_2 per year, compared to a high performance combustion turbine.
- Bulk energy storage provides grid damping, enhances grid reliability and avoids higher operation costs. CAES systems are the most economical solution for bulk storage.

Recommendations to proceed include site selection, development of preferred design of an advanced CAES plant, refined cost estimates for this system, and comparison of CAES plant performance to a combustion turbine based plant providing similar generation services.

The Final Report dated September 1, 2011 has been received. The full report is linked to this website (see Final Report). The Executive Summary states in part:

"Schlumberger Water Services (SWS) has performed a regional scoping study; an analysis of newly acquired geophysical and geological data; an analysis of newly acquired drill cores from the Prairie Evaporite Formation within North Dakota; extensive data and literature research and review; and geomechanical analysis of various plausible solution mined operational scenarios through numerical modeling. The study has confirmed that a salt section of sufficient thickness and at workable depth is present near the eastern limit of the Prairie Evaporite Formation within the state. FLAC-3D numerical geomechanical simulations illustrate that caverns at the depths required in North Dakota and with height:width ratios relative to the available geology should remain stable over time. Numerical modeling which simulated the effect of cycling from compressed air injection and withdrawal combined with variations of system operational pressures indicated salt cavern stability is expected under the modeled conditions.

"Electrical Power and Research Institute (EPRI) has developed a North Dakota specific, economic dispatch model. Nominal generation power capacity (discharge) for this study is 390 MW. Cost:benefit ratios range from 4.07 to 7.26 with average capacity factors at 30% to 50% so that CAES runs like an intermediate-duty plant. A capacity of 30 to 50 hours appears suitable for this application in MISO. The average annual CAES CO_2 savings are estimated as 256,000 short tons, compared to a high performance combustion turbine.

"Recommendations and forward strategy are based on moving the study beyond concept stage. Dakota Salts has concluded that the primary risk to the project viability and economics lie within the ability to confirm that the required array of salt caverns can be sited, mined and operated in a cost effective manner. It has been further concluded that an expanded geomechanical investigation is required to further confirm the specific CAES subsurface design and the required geomechcnical integrity over time. Following successful confirmation of the above, more detailed surface considerations including plant design, construction and installation cost components would follow."

The Summary and Conclusions in the Final Report state in part:

“The SWS component evaluated the potential feasibility of a hypothetical CAES system in the Prairie Evaporite from a geological and geomechanical perspective. A regional scoping study was performed which involved integration of geophysical logging and associated petrophysical analysis along with data from mechanical testing of newly acquired whole core. This integration effort resulted in a representative “type” geologic and mechanical target formation model suitable for use as the basis for transient numerical modeling of CAES operational scenarios.

“Numerical model tests were designed to simulate the performance of a CAES operation over a 30-year period and with various cavern designs and system operational parameters. Three cavern height/diameter designs were tested (0.33, 0.7, and 1), three different minimum-maximum operating ranges (50-90, 50-70, and 50-80 percent of overburden stress), and two different system rest models (rest at low pressure, rest at high pressure) were evaluated. Operational feasibility was assessed through model outputs of damage criteria, deformational stress ratio, and total cavity volume reducing creep displacement. An additional set of short term models were designed to determine the stability of the cavern with an initial cavern pressure drawdown from 90% of overburden to 10% of overburden stress.

“The fundamental conclusions presented are as follows:

- The regional scoping study identified the existence of evaporate thickness adequate for CAES feasibility in the West-Southwest part of the Prairie Evaporite in North Dakota.
- In this region the target formation lies at depths of greater than 6000’ below ground service, significantly deeper than existing CAES systems.
- The low creep stress exponent determined from laboratory tests resulted in very low values of long term creep in the numerical models.
- In the expected operating ranges tested for the cavern, the geomechanical analysis indicates the cavern is quite stable.
- The high levels of stability and low creep observed in this study suggest that the cavern operating pressures can be lowered without geomechanical instability or untimely cavern closure.
- Expanding the cavern roof to make a larger cavern with a lower height to diameter ratio resulted in slightly more creep, but in these models did not produce unstable conditions.
- The experiments performed tested creep over 30 years for operating pressures as low as 57% of overburden pressure without producing instabilities, and without significantly large amounts of creep.
- The initial drawdown test results indicated that the cavern would remain stable at very low pressures, and would only approach stresses likely to damage the cavern when the cavern pressure drops below 10% of the overburden stress.
- The above mentioned core analyses and numerical modeling results suggest that the potential operational challenges presented by greater operating depths might be offset by increased cavern stability.

“The EPRI component based the optimal dispatch for the CAES plant in this report on historical 2006-2008 real-time MISO data at the Minnesota load-weighted Hub. Additional revenue sources are also identified and considered critical components of the benefit mix.

“Economics in part compare two cases and present a cost/benefit analysis while market factors affecting CAES investments are identified. The fundamental conclusions presented are as follows:

- Annual average arbitrage benefit $24 million, frequency regulation value $16 million, spinning reserve value $3 million, potential capacity credits $3.1 million while black start service is application specific. Capex $312 million for a 390 MW plant.
- For cost/benefit analysis the present value of yearly revenue is uniform and an investment capital approach is used rather than a fixed charge rate approach.
- In Case A, the net value is $93 kw, the B/C ratio is 4.07, the MCR $312 million and the NPV $957 million; while case B is $187/kw, B/C ratio 8.18, MCR $312 million and NPV $2,241 million.
- The value of CAES in MISO is largely due to a latent economic value of bulk storage in MISO, and not a result of wind penetration values. Higher wind penetration levels will tend to decrease off-peak electricity prices and further improve the cost effectiveness of CAES systems.
- Other market changes affecting CAES investments include potential development of capacity credits in MISO, fuel costs, CO_2 emission costs and market facilitation of specific energy storage services.
- The unit appears well suited to supplying capacity and should be credited with spinning reserve and regulation service as applicable.
- Average capacity factors are 30%- 50%, so that CAES runs like an intermediate service plant. A capacity of 30-50 hours appears suitable.
- Actual plant operations and net value are sensitive to prices in the market; however, the fundamental conclusions appear unaltered when sensitivity analysis is applied to key variables considered.
- The annual average CAES CO_2 savings are 256,000 short tons compared to a high performance combustion turbine (CT).
- CAES systems provide such indirect benefits as reduction TG ramping and low load operation and minimizing renewable spillage off-peak by operating as a load (unlike CT’s).

The Recommendations stated in the Final Report are:

Based on the work performed in this study SWS makes the following recommendations:

1. **Based on results from core testing and simulation results, additional testing core should be conducted which includes increasing stress-step creep tests, cyclical variation of confining pressure, variable temperature, and long term (several days to a week) creep testing on full core diameter samples.**
2. **Future studies should include numerical models which are calibrated with the recommended long term cyclic pressure creep tests, as accounting for these effects will influence (increase) the creep results.**
3. **The presence of potash and gypsum layers in the salt may influence the overall creep response. These potash and gypsum layers should also be tested so that their creep properties can be accounted for in the models.**
4. **The operational parameters in future numerical studies should be constrained by realistic surface facility engineering and capacity demand considerations.**
5. **Due to the depths of operation for CAES in this region, future economic and engineering studies should include all subsurface system components from cavern to surface plant which may have significant impact on the cost and energy efficiency of the system.**

The following recommendations are based on the work performed by EPRI in this study:

- **Determine site selection for CAES plant following evaluation of selection criteria consideration and requirements.**
- **Determine the preferred plant configuration.**
- **Determine preferred CAES plant design following evaluation of design-based elements.**
- **Develop updated cost estimates following completion of site and design components as above.**
- **Perform an expanded sensitivity study on the economic potential of the preferred CAES plant.**
- **Perform a comparison of CAES plant performance to a CT providing similar generation services.**

This contract is now completed.

4/5/12