Evaluation of Electricity Storage Technologies for Renewable Energy Production: A Proposed Model

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Abstract

Growing public awareness of CO_2 emission and depletion of fossil fuel has raised the level of our reliance on wind, sun and other sources of renewable energy. In order to utilize renewable sources of energy efficiently, share of intermittent electricity produced with renewable energy is increasingly important. This research aims to develop a technology evaluation model to analyze several promising electricity storage technologies.

Subject technologies including electrochemical supercapacitors, flow batteries, lithium-ion batteries, superconducting magnetic energy storage (SMES) and kinetic energy storage. In addition to these currently available technologies, some under developing ones are also incorporated in the model. Although energy density and power density are the most prominent criteria used to assess electricity storage technologies, other evaluation criteria such as deep-cycle life and/or charge-discharge cycles, operation costs, safety, and other technological characteristics are also the concerns.

A research methodology which combines Scenario Analysis, SA and Multi-criteria Evaluation Model, MCEM is developed. The proposed research process uses expert panel to identify decision criteria and decision elements in the MCEM by a group of experts who have profound technological knowledge and experiences in the technologies. Next, applying scenario analysis process, decision uncertainties are identified and scenarios are constructed. Under each given scenario, the expert panel utilizes judgment quantification method to rank the subject technologies in the MCEM. The research result should be able to facilitate decision makers in the industry of renewable energy to streamline investment in developing and/or adopting electricity storage technologies.

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- Introduction
- Literature Review
  - Electricity Storage Technologies
  - Technology Evaluation Methods
- Proposed Research Model
- Expected Results
- Discussion and Conclusion

Introduction

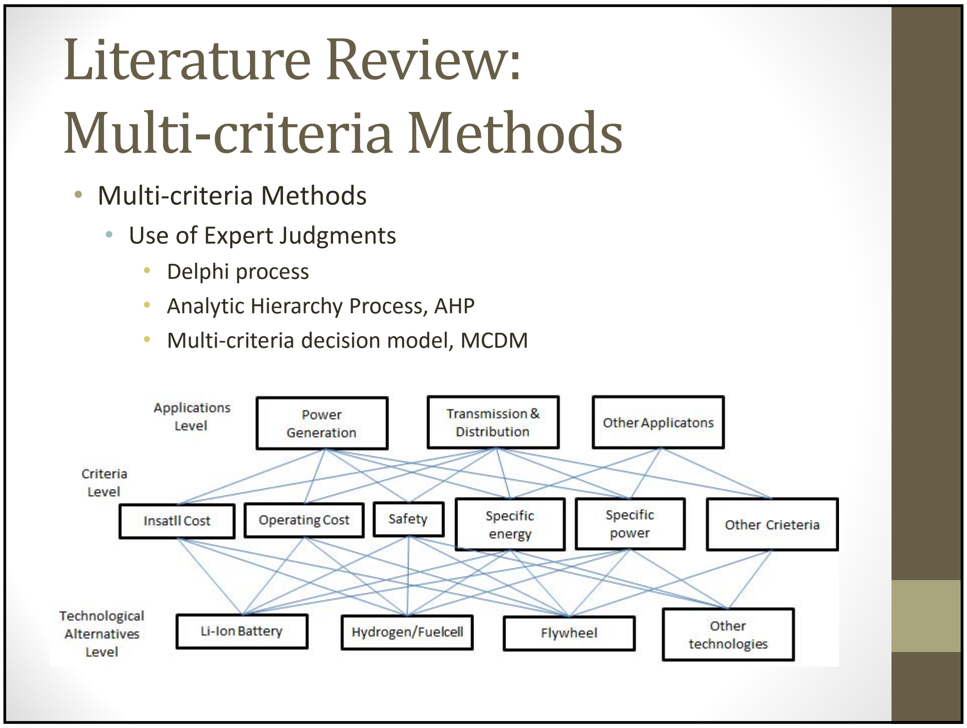
- The Needs
  - Environmental Awareness and Concerns
  - Continuous investment in renewable energy technologies (RETs) around the globe.
- The Barriers to Adopt RETs
  - Technology, cost, commercial viability, finance, environment impact and benefit, and socio-economic impact are the potential barriers.
- Electricity storage technologies (ESTs), as part of RETs, become critical facilitators to commercialization of RETs.
- ESTs not only accumulate intermittent electricity but have the capability to moderate between production and consumption of electricity produced by RETs. In sum, ESTs are essential complementary to RETs.

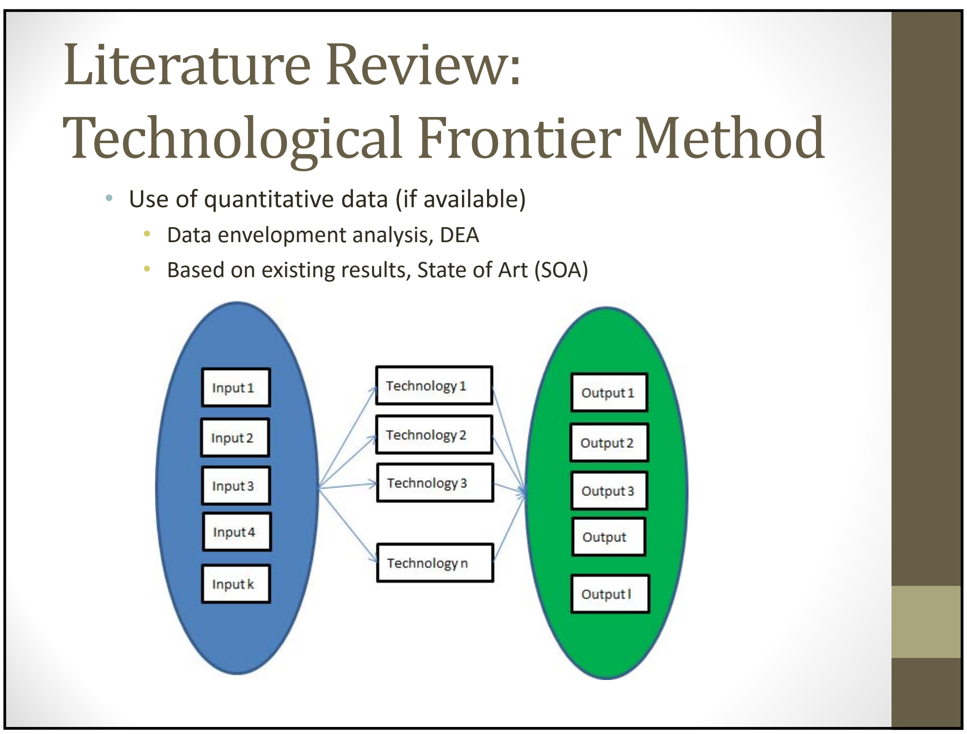
Literature Review: ESTs

- The Science of ESTs
- Chemical Energy Storage
  - Electrochemical Capacitors (Super Capacitors)
  - Solid-state Batteries : Li-ion and other leading solid-state batteries
  - Flow batteries: polysulphide bromide (PSB), vanadium redox (VRB) and zinc bromide (ZnBr).
  - Fuel cells: Hydrogen fuel cell, and others
- Mechanical Energy Storage
  - Pumped-storage hydroelectricity, Flywheel, Compressed-Air Energy Storage, Cryogenic energy storage

Literature Review: Techno-economic Methods

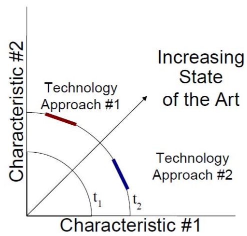
- Evaluation over techno-economic factors (e.g. Life cycle and lifetime, Autonomy, Feasibility and adaptation to the generating source, Self-discharge, Mass and volume densities of energy, Monitoring and control equipment, Design and operational constraints, Reliability, Safety and environmental impact, including recyclability, Technical maturity)and (economic efficiency factors: initial investment cost (including facility cost, accessories cost, installation cost and engineering cost), maintenance cost, operating cost.


Literature Review:
Multi-criteria Methods
Multi-criteria Methods
Use of Expert Judgments
Delphi process
Analytic Hierarchy Process, AHP
Multi-criteria decision model, MCDM
Applications Level
Power Generation
Transmission & Distribution
Other Applicatons
Criteria Level
Insatll Cost
Operating Cost
Safety
Specific energy
Specific power
Other Crieteria
Technological Alternatives Level
Li-Ion Battery
Hydrogen/Fuelcell
Flywheel
Other technologies


Literature Review:
Technological Frontier Method
Use of quantitative data (if available)
Data envelopment analysis, DEA
Based on existing results, State of Art (SOA)
Input 1
Input 2
Input 3
Input 4
Input k
Technology 1
Technology 2
Technology 3
Technology n
Output 1
Output 2
Output 3
Output
Output l

Literature Review: Technological Frontier Method

- Technological Forecasting DEA, TFDEA
  - Forecasting the development of SOA
  - Compare current SOA with those of previous years
  - Determine the rate of technological improvement, RTI in various OUTPUTs
  - Use the RTI to forecast future SOA (Technological Frontier)



Source: Inman, L. and Anderson, T., TFDEA: A New Approach for Technology Forecasting of New Product Development Targets. Portland International Conference on Management of Engineering and Technology (PICMET 04)

Literature Review: Scenario Analysis

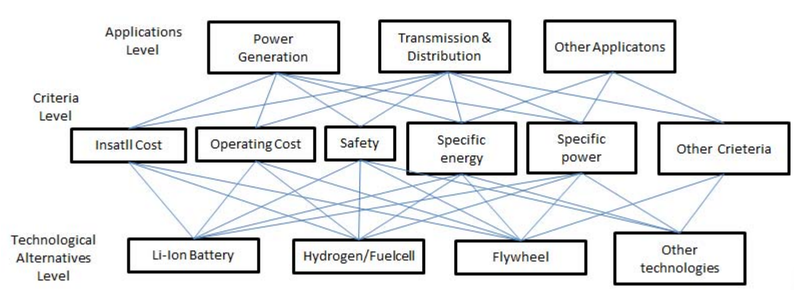
- Scenario Analysis
  - Involve uncertainties
    - Market, Policy, Technical, Social….etc.
  - Identify possible scenarios
  - Performance of technologies vary under different scenarios

Proposed Research Model

- Factors taken into consideration
  - Technological performance in various dimensions
    - Specific energy, specific power, cost of ownership, capacity, …etc.
  - Applications
    - Technical characteristics
  - Policies
    - Subsidies
    - Infrastructures
  - Environmental Context
    - Economical
    - Social

Research Approach- Step 1

- Construct a Multi-criteria Evaluation Model
  - Use expert panel to rank the decision elements



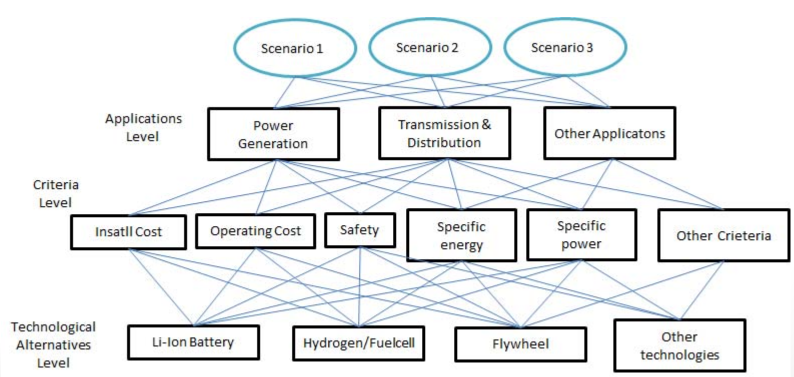
Research Approach- Step 2

- Construct Scenarios
  - Uncertain conditions imply various scenarios
  - Scenarios can be combined
  - Each scenario may have different effect on EST applications

EST Apps. / **Conditions**	Power Generation	Transmission & Distribution	Industrial Usage	Consumer Usage
Price Subsidy	S_{11}	S_{12}	S_{13}	S_{14}
Cost Subsidy	S_{21}	S_{22}	S_{23}	S_{24}
Power grid Coverage	S_{31}	S_{32}	S_{33}	S_{34}
Power Demand	S_{41}	S_{42}	S_{43}	S_{44}

Research Approach- Step 3

- Combining Scenarios and MCEM
  - Values of ESTs change with scenarios



Expected Results

- Priories of each EST for all possible applications
- Values of each EST under various scenarios
- Understanding the values of each EST and the differences under various scenarios.

Discussion and Conclusion

- Generate strategic implications for ESTs investment and development
- Improvement in multi-criteria evaluation model.
- Involve policy uncertainty in the evaluation process
- Provide flexibility for further applications

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