RESOURCES, SYSTEMS AND TECHNOLOGIES

Chaired by Dr Bishal Bharadwaj

Curtin University

DAY THREE, 16 FEBRUARY

SESSION 1.1

THE LANTERN

ERICA
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COUNCIL FOR AUSTRALIA

An electro-geothermal battery for large-scale ultra-supercritical energy storage based on Aquifer Thermal Energy Storage (ATES)

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Pumped-storage hydroelectricity plants are the current largest technologies for energy storage of renewable GW-scale power systems. However, Aquifer Thermal Energy Storage ATES systems are limited to low- to intermediate-grade heat storage (<120°C) and capacities to match 5-30 MW power generation. We propose to leverage this proven concept to extend ATES to ultra-supercritical energy storage for large-scale power systems.

Our proposed electro-geothermal battery would store heat in the subsurface for supercritical CO_2 and H_2O cycles. This approach builds on the proven technology of storing gas in sedimentary formations for conventional energy storage. New ultra-supercritical H_2O and CO_2 generators operate at extreme temperatures (>600°C) with near-50% efficiency, promising to lower emissions of thermal power plants. However, these generators pose new challenges for energy storage, especially when coupled with renewable energy sources such as Concentrated Solar Power (CSP).

We present a pilot study on the use of ATES for thermal energy storage in the subsurface and suggest optimal designs for standalone CSP supercritical geothermal batteries and hybrid coupled geothermal-solar-thermal energy storage solutions.

Geothermal/Ground source heat pumps - tapping the potential reduction in peak demand, urban heat island effect and embodied carbon

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To date, there have been very few deployments of ground source heat pump or district energy schemes in Australia, despite their adoption in other countries with similar climates. One such deployment example is the ARENA Residential Heat Pump Study as part of the Fairwater Living Laboratory in western Sydney, which was a collaboration between Climate-KIC, Curtin University and UTS. This project demonstrated the impact on total and peak electricity consumption and costs, but were inconclusive in regards to the potential urban heat island reduction from GSHP. The GeoAir system deployed at Fairwater used R410A refrigerant (with a GWP of 2,088) and provided a saving of 21% in electricity use and 3 kW per household in peak electricity demand.

At the same time, anecdotal evidence is indicating that efforts to decarbonise heating, ventilation and air conditioning (HVAC) in buildings by replacing gas boilers with heat pumps is often hampered by a lack of plant room space, due to the relatively larger size of heat pumps relative to gas boilers. GSHP potentially provide an alternative solution to save plant room space within an individual building, and more so if the GSHP is incorporated into a district energy or heating/cooling (DHC) scheme, such as those used widely throughout Europe, UK, Japan and Korea.

However, significant research gaps still exist, particularly relating to understanding the spatial and temporal subsurface temperature variation, its impacts on shallow thermal energy accessibility with the ultimate goal of optimal design and deployment of GSHP systems with lower greenhouse gas intensities, and for non-residential applications. For example, the current tendency to assume consistent ground temperatures has led to sub-optimal system designs, which adversely affect cost estimates and thermal efficiencies. Emerging data has indicated an increase in subsurface temperatures due to underground developments and activities in cities, such as transport and utility infrastructure.

This research project will collect data from wireless sensors, such as basements, car parks, train stations, and tunnels, to assess the subsurface energy potential using large-scale integrated subsurface models, including soil and rock thermal characterisation. This will be converted into a geothermal potential map, similar to wind energy resource maps which were developed decades ago for the wind industry. These will highlight areas with the highest potential for subsurface energy resources and GSHP deployment and will be matched to data on energy consumption to create an enviro-economic benefits maps.

Given the current focus on embodied carbon, it is also possible to design GSHP with lower embodied carbon, by using water or carbon dioxide and using scheduling to optimise electricity consumption during the solar soak period, while reducing consumption during the peak period (summer afternoons/early evenings). Similarly, further detailed work is required to understand the potential contribution of GSHP to reducing the UHI effect, by removing heat from above ground and transferring it to subsurface reservoirs and this will be assessed as part of this research.

Broken Hill battery energy storage system: Supporting the reliable supply of electricity in the NEM

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Australia is one of the leading countries in the inverter-based resource (IBR) energy transition, and the National Electricity Market (NEM) is intended to securely operate with up to 75% of variable renewable generation by 2025. However, as the generation mix is shifting from synchronous generators to variable IBRs such as wind and solar PV, the dynamic behaviour of the NEM becomes more dependent on the fast response of power electronics and converter control dynamics. Interactions that emerge between converter controls and the grid as well as among converter controls are impacting the overall operation and stability of Australia's largest power system.

The West Murray Zone (WMZ), among many others in the NEM, is an electrically remote area characterised by its very low short-circuit level and system strength capacity. Furthermore, the WMZ has attracted a significant number of renewable projects (≈4,000 MW) due to high wind speed and high solar irradiation resources. The increasing number of variable renewable plants together with low transmission investment infrastructure have caused the area to face stability problems in the form of voltage oscillations in a wide range of frequencies (7-10 Hz and 16-19 Hz).

Battery energy storage systems (BESSs) are among the prominent solutions as they can provide ancillary and essential grid services (e.g., frequency and voltage management and system restoration) while also coping with the inherent variability of renewable energy systems, contributing to energy balancing.

The Broken Hill Battery Energy Storage System (BH BESS) is a project that will provide storage and firming capacity to the NEM and the WMZ, while mitigating and eliminating voltage oscillations. This presentation will cover:

- The main technical challenges faced in Broken Hill, a weak and remote area of the NEM, due to the high penetration of variable renewable energy resources and the lack of system strength support.
- The proposed project of the grid-forming Broken Hill Battery Energy Storage System.
- Preliminary analysis and findings of the proposed solution demonstrating the potential impact of grid-forming battery energy storage systems (BESSs) when utilising novel methods and techniques. These include the mitigation of oscillations, provision of system strength, and increment of the hosting capacity of renewables in weak grids such as the Australian West Murray Zone.

Electrification of Mining Mobile Fleets and Machinery: The Role of Optimal Systematic Design

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The mining industry accounts for 4-7% of global GHG emissions and ranks as Australia's second-largest carbon emitter (about 100 Mt CO2-e pa), with the most substantial growth over three decades. Additionally, as electric vehicles and renewable energy technologies rise in demand, the need for critical minerals such as Lithium, Nickel, and Copper surges, potentially escalating the industry's carbon footprint if mining practices remain unsustainable. Particularly in underground mines where diesel trucks consume million litres of diesel per year emitting thousand tonnes of emission. Moreover, the diesel particulate matter in these confined spaces poses severe health risks to the workforce, necessitating energy-intensive ventilation systems that further increase the sector’s carbon footprint through fossil fuel consumption. Therefore, decarbonisation and electrification of mining mobile fleet and machinery present a dual advantage: it reduces carbon emissions and improves air quality in underground mines as well as enhances life quality in remote areas vulnerable to environmental degradation. Furthermore, the financial rationale for decarbonisation is compelling in a volatile economic landscape with fluctuating diesel prices. Given this scenario, decarbonisation within the mining industry is not just beneficial but an urgent matter.

Leading the Mine Operational Vehicle Electrification (MOVE) project at the University of Adelaide, we are at the forefront of mining vehicle electrification in Australia and one of the few initiatives worldwide. This project is a collaborative effort with BHP, IGO, MRIWA, and several other governmental entities, companies, and OEMs under the Future Battery Industries CRC. MOVE project mainly focuses on two interconnected work packages: electrified fleet management and electrified mine microgrid design. The first package involves simulation and optimisation studies to determine optimal fleet sizing, onboard battery capacity, and charging infrastructure design. We aim to find the most cost-effective, yet practical solution for a given mine site among various technologies, including fast charging, battery swapping, and trolley assist. A thorough net present cost-benefit analysis is conducted to find the trade-off between total cost while maintaining or exceeding mine productivity compared to the status quo. The second work package focuses on designing an optimised backbone energy infrastructure to meet the mining industry's electricity demand through green electrification. This involves the integration of a substantial proportion of renewable energy sources, battery energy storage systems, and backup generators.

In this presentation, we will showcase our latest prototype software for designing charging infrastructure in mines, demonstrating how varying parameters can significantly impact the optimal solutions. We will also explore the role of renewables in meeting the electricity demands of these vehicles and other mining operations. Crucially, our analysis will reveal the trade-offs between cost, productivity and emissions, providing a comprehensive sensitivity analysis to underscore the critical parameters that drive mine electrification. Offering practical solutions, attendees will gain insights that can be applied to the electrification of heavy-duty vehicles across various industries. By leveraging these findings, we can collectively accelerate progress towards industrial sustainability, with our research serving as a milestone on the path to a greener and more sustainable future.