




THE UNIVERSITY of ADELAIDE

MINE ELECTRIFICATION

Towards an electric and renewables mining future – University of Adelaide vision capabilities and research

The electrification of mining operations is rapidly emerging as a central issue for the resources sector and its efforts to improve reliability and health/safety, and to reduce cost.

The reliance on fossil fuel and gas generated electricity is a significant proportion of current mining operational costs and the prevalence of diesel fuel usage is a significant health and safety concern.

The use of electric vehicles and machinery combined with partial or stand-alone renewable energy powered microgrids provides a pathway to more efficient, sustainable and safer mining operations, both for underground mining and open-pit mining.

Electrification also presents an opportunity to integrate new and adaptive IoT technologies such as autonomous vehicles and machinery, communications networks and data analysis to make operations safer and more efficient. Digitalization and automation is the solution to reduce operational costs in areas related with concentration and transport.

The transition to an electric mining future is complex and will require substantial investment in infrastructure, technologies, and hardware as well as newly skilled workforce in Australia.

Realising this future will be benefited by the collaboration between the mine operators and their service industries, research organisations and regional, State and Federal governments.

This paper provides an overview of the status of mine electrification and highlights the research capabilities of the University of Adelaide mainly around the unique Flexible and Mobile Microgrid Test Platform that is adaptable to any remote locations and mining sites in Australia.

The primary aim is to help shape the resource industries transition to an electric and renewables mining future.

There is a synergy between the grid transformation in domestic/industrial power networks and mining power networks, which is likely to produce a greater combined effect specifically in Australia. The integration of distributed energy technologies, electric vehicles and energy management concepts for the off-grid or the fringe of grid networks are very similar to the networks servicing regional and remote mine sites.

Moreover, the microgrid concept has provided a pathway to achieve reliable electricity networks by quickly responding to the generation and demand imbalance and possibly by integrating localised charging points for electric vehicles (EVs) in the near future. The same concept has been imitated in various mining sites to transition towards more-electric and all-electric mining with an ideal target to utilise 100% renewable resources.

Technology readiness, successful demonstrations and industry acceptance are the primary reasons for such developments. Other factors are the cost of mining and safety. For example, ventilation, heating and refrigeration takes up a large portion of operating costs in underground mining, which is primarily caused by the operation of diesel vehicles in mines.

When battery EVs are utilised (which significantly reduce emissions and minimizes environmental impacts), significant energy saving is expected on ventilation and cooling systems. For instance, a study shows that an energy saving of 40% in ventilation and 30% in cooling can be achieved for a mine at Onaping Depth, Canada, due to transportation electrification.

Furthermore, unlike the electrical cable-tied systems (in the form of overhead or underground), battery-powered machinery also increases safety while reducing the risk of flashover and electrocution in harsh mining environment. Moreover, impact of diesel particulate matter (DPM) on human health will be completely eliminated by electric-powered machinery.

Opportunity for improvements to mining site electricity grids are envisaged by the emergence of new batteries, hydrogen/fuel cells, autonomous mining machinery, and the integration of Internet of Things (IoT), Internet of Everything (IoE) and data mining and analysis applied to the mining process. Enhanced productivity and greater efficiency and performance are by-products of these improvements.

Although the above improvements can easily be foreseen, there are numerous unique characteristics and challenges in mining applications that still need to be carefully considered.

For example, electric haul trucks are used in mining for ore transportation usually in difficult geological conditions with more stringent safety issues than conventional transportation.

The unique characteristics and challenges in mining can be listed as below.

- Continuously evolving mining sites, electric grid and production practices due to the changes in landscape as a result of ore production
- Additional safety requirements of employees and environmental impacts.
- Types of mining: surface or underground
- Small margins in low grade ore-bodies.
- Energy-intensive production.
- Reduced reliability of supply due to grid connection, and susceptibility of the distribution lines to environmental conditions.
- Large variability and unpredictability of electrical loads.
- Availability, accessibility and sustainability of energy resources (gas, petrol, renewables) in mining sites.
- Harshness of the environment and altering landscape.

In the light of the aforementioned characteristics, the major factors that drive and accelerate mining electrification can be classified and summarised as in Table 1.

As stated above 30-50% of the total mine's energy usage is related to diesel used by the major mining vehicles that have a number of undesirable characteristics. Note that internal combustion engine-based vehicles are about to disappear from the domestic market within the next few decades.

To justify the uptake of EVs, a comparison of diesel and mining EVs is done in Table 2. Note that Epiroc offers "Batteries-as-a-Service" to speed customer acceptance of electrical replacements for all its diesel machines.

Also of note is that energy management is possible in EVs but not in diesel vehicles, and mining EVs can offer reliability, long life, precision and performance.

Compared to the EVs used in domestic applications, autonomy in mining EVs is much simpler, which can reduce the overall operation costs.

This can be achieved by the predictability of the path and the features of terrains in mining considering the capability of electric motors to respond to a given change in demand in one tenth of the time of diesel engines.

Mining Electric Vehicles

Although the history of cable-tied mining EVs goes 50 years back, the modern battery-operated mining machines are in development since 2015.

The major electrically/battery powered mining machines currently available in the market are summarised in Table 3.

In one of the landmark applications, Canadian Goldcorp mining company's fully electric underground mine (near Chapleau in Ontario) uses an all-electric mobile equipment fleet (ranging from battery-powered underground vehicles, drilling and blasting equipment, to electric bolters and personnel carriers) offering high efficiency and improve health, safety and performance.

FACTORS	KEY REMARKS
Greater energy consumption and high cost	• Ventilation energy is required for cooling or for removing hazardous gasses in underground mining, which can be as high as 70% of the total operation cost? • The deeper the mine, the higher the ventilation and cooling cost. • Although specific energy of batteries is much less than fuel (13 kWh/kg versus ~250 kWh/kg), electric trucks use 1/4 of energy per tonne hauled compared to diesel trucks. • Between 30-50% of a mine's total energy use is the diesel for haul trucks.
Poor reliability/power quality, and high mitigation cost	• If not off-grid, dependent on the reliability of the main grid. • Blackouts have a detrimental impact on mining process especially in smelters. • Mining company pays the cost of both the transmission lines, upgrades and responsible for grid improvement systems (such as SVCs and STATCOMs). • Due to starting and load characteristics of mining machinery, mining grid experiences frequent power quality problems. • Poor power quality also means higher health risk and poor reliability
Health and safety of sites and workers, and environmental issues	• Diesel engines produce significant emissions (DPM) and heat. • Combustion engines have a serious health issues in underground mining • Electric equipment/processes and vehicles offer cost savings in ventilation, fuel, consumables (such as respirators), regulation checks and maintenance.
High maintenance cost	• Internal combustion vehicles are complex and require high maintenance and highly skilled mechanics.
Changes of infrastructure and high cost	• Mine sites are usually remote with varying terrain, which changes with ore production. • Support system and energy supply should adapt to topographical changes of the mine site including electric substations, lines/cables, transformers, sockets, loads and rails, and supply links. • In addition to the high cost of the adaptive measures, further costs also exist. For example, trolley assist systems, requiring an overhead cable with the infrastructure cost per truck (which is about 75% of the total truck price).
Poor productivity	• Conventional mining machinery is not suitable for timely integration into the mining process, monitoring of EVs (such as for state of charge and range) can improve the productivity. • Difficulties and high cost of fuel transportation and storage in remote locations

Table 1. *The factors that drive mining electrification.*

DIESEL VEHICLES	ELECTRIC VEHICLES
Longer operating range High specific fuel energy, ~13kW/kg Lower capital cost (due to established mass production) Fast and easy refuelling	• Limited operating range • Requires different fuelling (charging) infrastructure • Low specific "fuel" energy battery (~250W/kg) or fuel cell (1kWh/kg)/hydrogen (33kWh/kg) • Currently slow re-charging • Limited battery life • Higher cost (but very likely to reduce by mass production and increased competition and new power electronics devices)
• Low engine efficiency (~35%) • Low overload capacity • High maintenance cost • Requires skilled mechanics for maintenance • Dependency to volatile diesel price • Transport and storage difficulties of fuel • Higher noise (~105 dB) and vibration for employees • Can cause fog formation • High heat generation • Difficult to build autonomous system • High component counts and low reliability • Difficult for data gathering and remote monitoring	High electric motor efficiency (>95%) High overload capacity Zero local emission (avoiding large and noisy ventilation system and resulting low ventilation, fuel, consumables, regulation checks and maintenance cost) Low heat generation Low kWh energy cost Low maintenance Lower noise (~85 dB) and vibration Ideal platform for autonomous systems (including re-charging) Modularised components and high reliability Easy to obtain monitoring data

Table 2. *Comparison of diesel versus mining EVs*

MACHINERY	SOME REMARKS AND COMPANIES INVOLVED
Electric rope shovels	• First cable-fed mining vehicle in USSR and France around 1975. • Used in surface mining and for loading in-pit crusher-conveyor systems and haul trucks • DC type available by Komatsu, Caterpillar and IZ-KARTEX, Liebherr, Hitachi
Electric Load-haul-dump (eLHD) trucks	• Commonly used underground vehicles. • Can offer high power density allowing better access. • By GE, Caterpillar (with fast on-board charging), Epiroc
Electric Haul Trucks	• Electric haul trucks are employed for ore transportation typically in difficult geological conditions, under stringent safety issues, and with large production requirements • Komatsu using battery and hydrogen fuel cell technology (similar to Electric Nikola Badger Pickup Truck) • Sandvik Artisan: 50 ton payload, 3x more power than a diesel. • The emerging market includes a number of companies: Caterpillar, Volvo Group, John Deere, CNH Industrial, Komatsu and Epiroc. • ABB and CAT: trolley based systems
Electric Drills	• An all-electric drill uses AC electric motor driving a hydraulic circuit which moves hydraulic percussive rotary hammers. • The drill can be transported from one location to another using an electric vehicle. • By Sandvik and IZ-KARTEX, Epiroc (Atlas Copco)
Electric Service Vehicles	• Utility EVs used at an underground gold mine by Bortana EV
Primary electric crashers	• By Volvo Construction Equipment in partnership with Skanska Sweden
Battery operated scoops electric Boomer and smaller truck models	• By Epiroc (Atlas Copco)
Electric locomotives	• Driver assist and unmanned types • Anglo American Platinum has launched a platinum-based fuel cell-powered mine locomotive
Battery-electric explosives charger	• By Normet
Rock bolting rig	• Electro-hydro
Battery-Powered LED Light Tower	• By Atlas Copco
Conveyors	• Multiple companies, distributed/central, induction motors

Table 3. *Electrically/battery powered mining machines and supporting devices*

Mining Microgrids

In general, microgrids can serve as autonomously working energy hubs to have access to different renewable energy sources and distribute it in the most efficient and cost effective manner (Fig.1). The mine site deployment of an electricity microgrid with distributed energy resources and integrated battery energy storage can:

- offer relatively continuous power;
- provide power at a higher levels of reliability,
- offer low variable cost and low maintenance cost;
- present higher capacity factor and hence reduces overall electricity cost;
- serve low power demands continuously and using sustainable renewable sources of power;
- reduce the system losses due to close proximity to the loads; and,
- has a positive impact on the power quality (specifically on voltage sag).

Mine electrification means increased flexibility and this calls for an integrated view of not only for system operation but also for coordination and optimisation.

Microgrid systems require unique electronic controllers. Some of the key players in microgrid controllers include Eaton, Schweitzer Engineering Laboratories, ABB, Honeywell, Power Analytics, Go Electric, S&C Electric, Siemens, Lockheed Martin, Homer Energy, GE Power, Emerson, Qinous, Advanced Microgrid Solutions, Princeton Power Systems and Emerson.

The number of microgrid controller developers available in the market is indicative of the acceptance and future of the microgrid technology.

Additional comments about the benefits of mining electrification with renewable sources in a microgrid structure can be also be made at this time.

- The common practice in underground mining is to ventilate the entire mine at all times. When the emission level is reduced by electrifying mining vehicles, ventilation on demand would be lower so that it can easily be accommodated using variable speed drives, which offers further energy savings.
- The cost of solar PV energy has been lower than diesel costs since around 2012 due to subsidies. However, “true grid parity” has also been reached (considering its intermittent nature and storage requirements) when we consider the absence of long transmission lines as well as the absence of power quality improvement devices at the point of common couplings.
- Low-cost renewable energy is likely to allow the integration of refining, processing and smelting industries, hence adding value and reducing shipping cost of raw ore material.
- Mine electrification is more than technology advancement. It has the potential to contribute to the sustainability of the microgrid industry and EVs in domestic applications as well as in remote towns. In addition, it can improve project economics and strengthen licencing to operate in Australia and overseas (specifically in island nations).
- Serious health risk from diesel fumes and particulates in underground mines as well as centralised air conditioning prompts fears on the employees’ health, possibly more in the light of future pandemics.

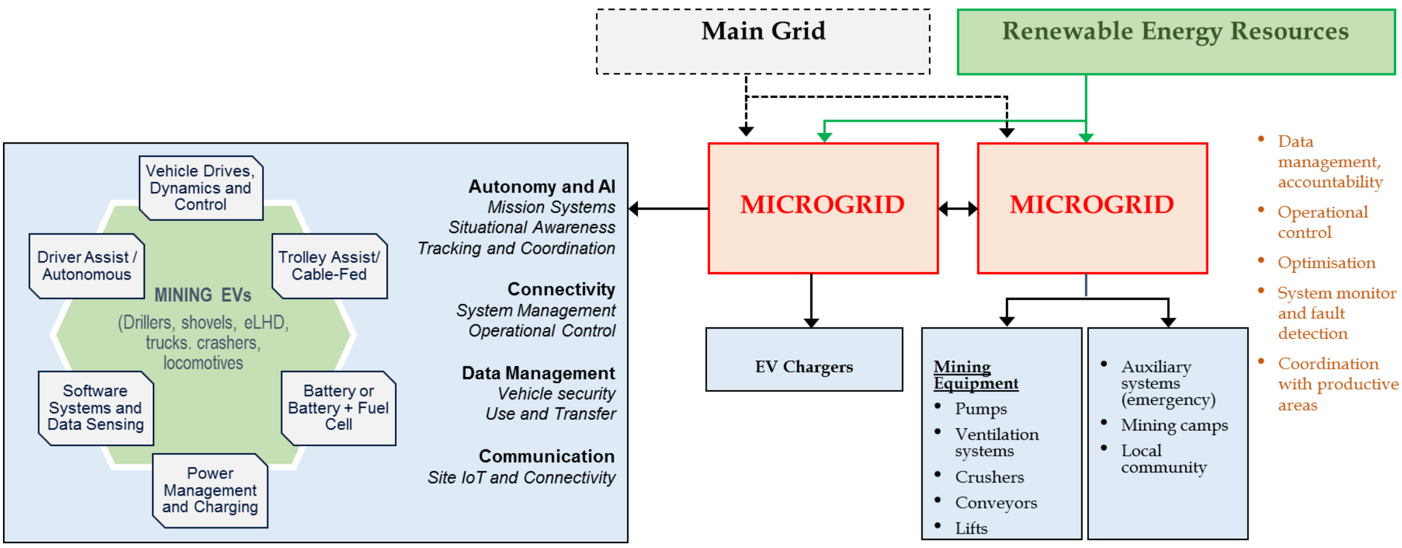

Figure 1. *The basic components of mine site electric vehicles and their relationship with the broader mining microgrid.*

Although not all big mining companies share an agreed vision on the future of all-electric mining, there is agreement on the reliability of the energy, energy cost and safer and healthier work environment.

From this, significant developments have already occurred around the world on mining EVs and mining microgrids. Some selected mining microgrid examples and management systems around the world are given below.

- BHP Escondida Copper Mine (currently on gas) microgrid project in Chile to use 100% renewable energy. Note that Escondida's power requirements have risen due to an investment in a seawater desalination plant, and declining mineral grades. Note also that the mine site has access to excellent solar radiation and high winds.
- EDL's Coober Pedy microgrid project (a mix of wind, solar, batteries, flywheels, diesel and resistors, since 2017) offering the average share of renewables of about 70 %.
- Agnew gold mine microgrid in Western Australia: a hybrid system involving wind, solar, battery, gas turbines and back-up diesel.
- Rio Tinto aimed to reduce the annual carbon footprint associated with Kennecott Utah copper mine by 65%, by purchasing renewable energy certificates and permanently shutting its coal power plant.
- 100% renewable energy in Chilean copper mining company Antofagasta by a mix of hydro, solar and wind.
- A solar power array with photovoltaic tracker (from Nomad solar PV tracker designed to be deployed in scalable 30kW segments) at Newmont's Akyem gold mine in Ghana.
- A solar-diesel hybrid microgrid for Zijin's Bisha copper and zinc mine in Eritrea.
- Hybrid solar-battery microgrid by Aggreko at Gold Fields' Granny Smith in WA.
- Pilbara iron ore mines with Alinta Energy built a solar power facility with battery storage connected to Alinta's Newman gas power station at Chichester, which includes the Christmas Creek and Cloudbreak mines. Aimed to provide 100% of Chichester's daytime stationary energy requirements and long-term cost reductions.
- Antofagasta's Centinela to achieve 100% renewable energy supply together with Engie Energía Chile, hence reducing power costs significantly in stages from 2020 onwards and cancelling power purchase agreements by 2027.
- Galaxy Resources' Mt. Cattlin lithium mine in WA currently uses renewable energy sources for up to 15% of its total power, using solar PV tracking panels and has a plan to entirely power from solar and wind power, in the next three years, developed by Swan Energy.
- ABB Developed mining digitalisation through automated scheduling software, and,

  Ability Operations Management System, to enable miners to get greater visibility and control of their mining operations delivering automation, electrification and instrumentation solutions for the Hydrogen Energy Supply Chain pilot project at Port of Hastings, Victoria.
- GE Mining, a division of GE Transportation, offers a broad range of mining equipment, propulsion systems and services as well as innovative solutions in mine electrification. GE's Advanced Energy Management Systems (AEMS) provides real-time data monitoring to better understand current and future energy usage and enable informed, proactive decisions about transmission of renewable energy. GE Mining also showcased its digital industrial solutions for the mining industry and introduced the Predix™-powered monitoring analysis and event management including collision detection.
- ComAp introduced Cloud Forecasting System for PV-Diesel hybrid microgrid applications.

Contact

Associate Professor Nesimi Ertugrul
School of Electric and Electronic Engineering
Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide
SA 5005
Australia

Telephone	+61 (0)8 8313 5465
Email	Nesimi.Ertugrul@adelaide.edu.au
Website	ecms.adelaide.edu.au/electrical-electronic-engineering/

POTENTIAL ISSUES IN MINE ELECTRIFICATIONS

The current mining EVs, listed in Table 3, can be considered as the pioneer of the future autonomous mining systems. They are likely to provide significant reference data from harsh mining environments to help the development of the future high-performance and networked vehicles with modularized spare units (for minimum maintenance, rugged, low-cost, high power density).

Understanding electricity generated from braking when the mining vehicle is going along, swinging, rotating and dropping; developing compact motors and other actuators to offer more responsive and manoeuvrable vehicles; adaptation to the varying conditions.

Some critical mining EV technologies may include task specific electric motors, traction/auxiliary battery systems and battery charging and/or swapping/replacement technologies, energy recovery and storage systems (such as super/ultracapacitors), and Power Electronics with more features (such as on-board fast charging using wide band gap devices, vehicle to microgrid and even vehicle to vehicle power transfer).

There is a number of mining vehicles among the most power-hungry systems. Their fast charging requires unique approach to consider battery type, high power charging resource development and on-board fast charging under harsh environments.

Although logistical downtime can be very high in LHD vehicles (>35% in eLHD) which directly impacts mine efficiency, it can be avoided if the mining process is streamlined by communications, autonomy and control, which relies on fully electrified mines.

Open pit distribution systems are complex systems having time varying topologies and highly dynamic load changes. Voltage regulation and power quality issues are recurrent in these types of power distribution systems. These problems have a high impact in the efficiency and reliability of the distribution system. We can study battery storage systems to offer solutions to these problems to develop a reliable and quality energy supply for modern open pit mines.

Moreover, one of the main characteristics of mine´s electrical power distribution systems is the use of large power loads (high power motors in MW range) and static power converters. The operation of such loads also generates power quality problems which require investigating reactive power compensator solutions. Furthermore, power demand control in mine´s power distribution systems can avoid power quality problems, specifically associated with operations of shovels and drillers.

AESKB system can be utilised to investigate how to develop a multi-mode and transportable "mobile substation" for powering the components of mining microgrid as illustrated in Fig.1.

Artificial intelligence (AI) can be used to improve operational efficiency, mine safety, and production workflow, which will involve coordinated mining-EVs with standardised communications. Note that electrified mining will become a highly controlled and data-rich environment, including the state of the energy utilisation, ventilation and pump data.

Electric rope shovel is a major piece of equipment in coal mines consuming significant power. Hence, commissioning a new shovel in an existing power network requires a careful analysis of its impact on the network (including load flow, fault analysis, protection coordination, harmonic analysis and arc flash studies. A mobile microgrid (as in AESKB Microgrid) can eliminate the above concerns and require a local study in the light of a subject mine site.

The trend in mining electrification is to go off-grid since many mining sites are remote and national power networks are vulnerable to weather conditions and cybersecurity attacks. However, these issues can be studied for a specific mine to improve reliability, control, monitoring and cyber security.

Energy consumption modelling, operational and infrastructure adaptations and change in management structure can be studied. Proactive consumption methods can be explored and tools can be developed that the industry can use to manage energy consumption. Furthermore, data analytics tools can be developed to analyse electrical systems and make them work better.

Investigation of other methods to accelerate the advancement and adoption of mining electrification technologies, including direct current (DC) microgrid solution for mines to improve reliability and efficiency

Mining microgrids' investigation can include:

- exploring intelligent/autonomous controls to address system issues and faults, including automatic fault location, isolation and restoration (FLIRS) systems
- charging mining EVs and their utilisation as backup power
- mining town integration

Table 4. *An introduction to some potential issues that face the electrification of mining operations.*

Additional Material

Capabilities/Research

The University of Adelaide has a number of activities and initiatives directly related to mining electrifications which are listed below with brief explanations.

Australian Energy Storage Knowledge Bank Project

- The details of this project can be found at www.aeskb.com.au
- Mobile and highly flexible microgrid system (270 kW/270 kWh) is available for deployment in any remote locations in Australia including mining sites.
- Our aim is to cover three main streams of works under the web page given above Web page for knowledge sharing: Electric Vehicles, Mining Electrifications and Microgrids.

2nd Grid Transformation Technical Development Seminar on Mining Electrifications

- This is a continuation of the "1st Grid Transformation Technical Development Seminar on Microgrids", delivered in 2019.
- However, its delivery time has been postponed due to the current restrictions, and we are considering delivering it on-line.

Control of Multiple-Microgrids for Off-Grid and Grid-Connected Networks

- Continuing PhD Project.
- Potential ARC Linkage project on "Development of a flexible microgrid controller to reduce deployment time and cost".

Electric Vehicles for Australia

- To provide a training hub towards more sustainable and cleaner transportation and a training hub for the future workforce.
- Transfer knowledge from domestic applications to fleet and industrial vehicles (such as in mining and farming).
- With an ultimate aim to achieve fully autonomous vehicles.

Enhancing Photovoltaic Converter Performance by using Wide Bandgap Devices and System Integration

- Currently developing an ARC Linkage application.

Active partner in developing Heavy Industry Low-carbon Transition CRC

- To develop digital twins for Iron/Steel/Zinc/Lead/Alumina mines by adopting system of systems approach for hybrid energy system.
- To create algorithms for technical and financial feasibility study of multi-energy systems and deigning the future low-carbon mining industry.

Investigation and Analysis of Remote Towns in South Australia for Microgrids with DERs

- Grant application with Cowell Electric and S&C Electric.

Other Research Projects

- Steering by Braking to Obtain Safe-State in Autonomous Vehicles Under Fault.
- Battery charging systems for Photo Voltaic systems using wide band gap devices for high power density (in high temperature environment and high efficiency).
- Light Hybrid Electric Vehicles for Defence Industry.
- A mobile and flexible microgrid test system for community level and remote areas.
- Electric motor designs (such as drivetrain and cooling motors) with varying in cost and performance and with emerging magnetic materials; using efficiency-mapping techniques to improve EV system efficiency.
- Reduction and elimination of sensors/feedback devices in the motor-control to improve performance hence reducing system cost and increasing reliability.
- Coordinated charging and discharging of domestic EVs considering the physical constraints of the grid at low-voltage level.
- EVs' vehicle-to-grid operation optimisation and aggregation to provide services in the wholesale electricity market for additional revenues.
- Li-Ion battery degradation modelling that can be used for optimal operation of stationary batteries as well as optimal charging of EVs.
- Optimal microgrid design through technology selection and sizing of generation and storage considering uncertainties in intermittent renewable generation and load demand.
- Optimal energy management systems of microgrid with multiple energy sources and storage under uncertain conditions.

Member of Cooperative Research Centre; Future Battery Industries (FBI CRC)

- Partner in the "Key Techno-Economic Solutions to Drive Mass-Uptake of Australian-Manufactured Battery Systems", led by the University of Western Australia.
- Potential partner in the Battery testing centre project, led by Queensland University of Technology.
- Potential partner in the "Whole of Systems approach for assessment of battery investment options".

Major Hardware Available

In addition to the Australian Energy Storage Knowledge Bank flexible microgrid test system,

- Three-phase high band width power analysers (4).
- Three-phase, programmable power supply (DC-AC 5kHz, programmed shape).
- 3 Programmable electronic loads (DC, inductive/capacitive).
- OPAL-RT Real-Time simulator.
- High bandwidth data logging systems with LabView.
- 4-Quadrant computer controlled electrical machines test setup.
- Computer aided Electrical Machines Laboratory.

Interests/Visions

The analysis of a survey of miners and mining original equipment manufacturers commissioned by EY reveals that obtaining the full benefits of electrified mining require further skills and competencies for smart mining, involving numerous sectors and rethinking the fundamentals of mine design. ["Electrification in mining survey" at www.ey.com/en_gl/mining-metals/].

This document can be considered as a discussion paper to identify and define the key challenges as well as help articulate possible approaches towards acceptable solutions.

The following table (Table 4) has been prepared to initiate these discussions on "potential issues mining electrifications".

Below. The Australian Energy Storage Knowledge Bank flexible microgrid system, Thebarton Campus, University of Adelaide. The building behind is the University's wind tunnel facilities with large motor loads. The diesel generator's fuel tank and switchboard/cable trays are on the right-hand side.

Recent Publications

N. Ertugrul and D. Abbot, "DC Is the Future", *Proceedings of IEEE*., Vol. 108, No. 5, May 2020.

L. Morán, D. Sbarbaro, N. Ertugrul, J. Espinoza1 and R. Peña, Micro Grids and Operational Excellence in Open-Pit Mine Power Distribution Systems, *5th International Conference on Operational Excellence in Mining*, 9-10 December 2020, Santiago, Chile.

N. Ertugrul, "Small-Scale PV Systems Used in Domestic Applications", Chapter 19, pp. 333-350, 18 pages, A Comprehensive Guide to Solar Energy Systems: with special focus on photovoltaic systems, Edited by T. M. Letcher and V.M. Fthenakis, *Elsevier Academic Press*, 19th May 2018.

S Tarca, M Roughan, N Ertugrul and N Bean, Dispatchability of Wind Power with Battery Energy Storage in South Australia, *Elsevier Energy Procedia*, Volume 110, March 2017, Pages 223–228.

N. Ertugrul and G. Haines, Impacts of Thermal Issues/Weather Conditions on the Operation of Grid Scale Battery Storage Systems, *13th IEEE International Conference on Power Electronics and Drive Systems (IEEE PEDS 2019),* Toulouse, France, 9– 12 July 2019.

G, Haines, N. Ertugrul, G. Bell and M. Jansen, Microgrid System and Component Evaluation: Mobile Test Platform with Battery Storage, *IEEE Innovative Smart Grid Technologies - Asia (ISGT-Asia) Conference*, Auckland, New Zealand, Dec 4 –7, 2017, pp.1-5.

N. Ertugrul, C. McDonald and J. Makestas, Home Energy Management System for Demand-Based Tariff Towards Smart Appliances in Smart Grids", *12th IEEE International Conference on Power Electronics and Drive Systems (IEEE PEDS 2017)*, Hawaii, USA, 12 -15 December 2017, pp.1-8.

N Ertugrul, G Bell, GG Haines and Q. Fang, Opportunities for battery storage and Australian energy storage knowledge bank test system for Microgrid Applications, *26th Australasian Universities Power Engineering Conference (AUPEC),* Brisbane, Australia, 25-28 Sept. 2016, pp.1-6.

B Young, N Ertugrul and H.G. Chew, Overview of optimal energy management for nanogrids (end-users with renewables and storage), *26th Australasian Universities Power Engineering Conference (AUPEC),* Brisbane, Australia, 25-28 Sept. 2016., pp.1-6.

N. Ertugrul, Battery storage technologies, applications and trend in renewable energy, (ICSET), *2016 IEEE International Conference on Sustainable Energy Technologies*, Hanoi, Vietnam, 14-16 Nov. 2016 (invited paper), pp. 420-425.

A.M. J. Pemberton, T. D. Daly, N. Ertugrul, On-Shore Wind Farm Cable Network Optimisation Utilising a Multiobjective Genetic Algorithm, Wind Energy Journal, Volume: 37 issue, December 1, 201, pp 659-673.

N. Ertugrul and W-K Wong, "Power System Inertia in High-Renewable Penetration Power Systems and the Emerging Role of Battery Energy Storage", to be submitted to *10th IEEE PES International Innovative Smart Grid Technologies Conference*, 23-27 November 2020, Perth, Australia.

Q. Gao and N.Ertugrul, "Hybrid Off-Shore Wind and Wave Energy Conversion Systems", to be submitted to *10th IEEE PES International Innovative Smart Grid Technologies Conference,* 23-27 November 2020, Perth, Australia.

Kani, S. Ali Pourmousavi, Phil Wild, and Tapan Kumar Saha. "Improving predictability of renewable generation through optimal battery sizing." IEEE Transactions on Sustainable Energy 11.1 (2018): 37-47.

Hasan, Md Mehedi, and S. Ali Pourmousavi. "Battery Cell Temperature Estimation Model and Cost Analysis of a Grid-Connected PV-BESS Plant." 2019 IEEE Innovative Smart Grid Technologies-Asia (ISGT Asia). IEEE, 2019.

Kani, Seyyed Ali Pourmousavi, Ratnesh Sharma, and Babak Asghari. "Innovative framework combining cycling and calendar aging models." U.S. Patent No. 10,422,835. 24 Sep. 2019.

Kani, S. Ali; Shahnia, Farhad; Azim, M. Imran; Shoeb, Md Asaduzzaman; Shafiullah, G. M.: 'Microgrid control overview' (Energy Engineering, 2019), 'Variability, Scalability and Stability of Microgrids', Chap. 2, pp. 15-71, DOI: 10.1049/PBPO139E_ch2

Pourmousavi, Seyyed Ali, et al. "Learning from a 3.275 MW utility-scale PV plant project: Update and new remarks." (2018).

Vardanyan, Yelena, et al. "Optimal coordinated bidding of a profit-maximizing EV aggregator under uncertainty." *2018 IEEE International Energy Conference (ENERGYCON)*. IEEE, 2018.

Pourmousavi, S. A., and Tapan Kumar Saha. "Evaluation of the battery operation in ramp-rate control mode within a PV plant: A case study." Solar Energy 166 (2018): 242-254.

Hasan, Md Mehedi, et al. "The impact of temperature on battery degradation for large-scale BESS in PV plant." *2017 Australasian Universities Power Engineering Conference (AUPEC)*. IEEE, 2017.

Hooshmand, Ali, et al. "Optimal battery sizing for behind-the-meter applications considering participation in demand response programs and demand charge reduction." U.S. Patent No. 10,497,072. 3 Dec. 2019.

Kani, Seyyed Ali Pourmousavi, Babak Asghari, and Ratnesh Sharma. "Resilient battery charging strategies to reduce battery degradation and self-discharging." U.S. Patent No. 10,298,042. 21 May 2019.

Parandehgheibi, Marzieh, et al. "A two-layer incentive-based controller for aggregating btm storage devices based on transactive energy framework." *2017 IEEE Power & Energy Society General Meeting*. IEEE, 2017.

Kani, Seyyed Ali Pourmousavi. "Data-driven battery aging model using statistical analysis and artificial intelligence." U.S. Patent Application No. 15/015,377.

Mohan, Shankar, et al. "BSS sizing and economic benefit analysis in grid-scale application." *2016 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. IEEE, 2016.

Pourmousavi, S. Ali, Babak Asghari, and Ratnesh K. Sharma. "A novel algorithm to integrate battery cyclic and calendar agings within a single framework." *2016 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. IEEE, 2016.

Sharma, Ratnesh, Babak Asghari, and Syyed Ali Pourmousavi Kani. "Method for real-time power management of a grid-tied microgrid to extend storage lifetime and reduce cost of energy." U.S. Patent No. 9,020,649. 28 Apr. 2015.

Pourmousavi, S. Ali, M. Hashem Nehrir, and Ratnesh K. Sharma. "Multi-timescale power management for islanded microgrids including storage and demand response." *IEEE Transactions on Smart Grid* 6.3 (2015): 1185-1195.