University of South Australia

Maximising solar PV with phase change thermal energy storage

Project results and lessons learnt

Lead organisation:	University of South Australia
Project commencement date: 1 May 2016	**Completion date:** 7 May 2019
Date published:	13 February 2019
Contact name:	Frank Bruno
Title:	Prof
Email: frank.bruno@unisa.edu.au	**Phone:** 08 8302 3230
Website:	www.unisa.edu.au

Table of Contents

Executive Summary

Phase change materials (PCMs) are materials which store a large amount of energy for heating, cooling or refrigeration by melting/freezing at a specific temperature. PCM thermal energy storage together with a refrigeration system can be used like an electric battery storing renewable energy generated by solar PV. This project involved developing a suitable PCM thermal energy storage system which can be used for refrigeration applications such as cold storage facilities, wineries and dairies. To successfully operate with variable renewable energy sources and electricity pricing a robust optimal control strategy was developed. To maximise the commercial potential of this research, this technology was successfully demonstrated in a fridge/freezer application at The Bends Motorsports Park in South Australia.

Project Overview

Project summary

This project involved developing and successfully demonstrating a new low cost phase change material (PCM) thermal energy storage technology which used optimal control to integrate with solar PV, maximising the electricity cost savings to the end user. PCM thermal energy storage can effectively operate like an electric battery and be up to five times less capital cost. The storage system developed was tailored towards commercial refrigeration applications using natural refrigerants such as CO_2. The project was built on 20 years of research at the University of South Australia (UniSA) together with its industry partner, Glaciem Cooling Technologies.

Project scope

PCMs are materials which store a large amount of thermal energy per unit volume by melting and freezing, ice being the classical example. UniSA has developed and commercialised a PCM thermal storage technology for refrigeration applications compatible with ammonia systems. This PCM melts at -11˚C and was demonstrated at a South Australian potato farm cold storage facility in 2014. This technology was awarded the 2015 ANSTO Eureka Prize for Innovative Use of Technology. Ammonia refrigeration systems were anticipated to experience rapid growth with the carbon tax making traditional HFC refrigeration too expensive for the refrigeration sector. The PCM technology was primarily planned to be used for peak/off peak load shifting. With the removal of the carbon tax, ammonia refrigeration was no longer a technology of interest in the market, and the PCM developed froze at too low a temperature for conventional HFC systems. Furthermore, a shift towards demand tariffs and the uptake of solar PV reduced the attractiveness of PCM thermal storage operating in a classical load shifting role. This research project aimed to re-develop the PCM storage technology suitable for these new market conditions.

To overcome these circumstances the following research objectives were developed:

1. To develop a reliable PCM which freezes at -6 ˚C. This temperature is compatible with all refrigeration systems.
2. To enhance the heat transfer in the PCM storage system in order to reduce its cost.
3. To develop an optimal control algorithm capable of maximising energy cost savings in a variety of electricity cost regimes coupled with solar PV electricity.
4. To demonstrate this technology to support commercial interest from the industry.

Outcomes

The research achieved the objectives, successfully demonstrating a PCM thermal storage system operating together with solar PV in a refrigeration application to TRL 7. Specifically:

- A new PCM which freezes at -6 ˚C was developed and proved reliable. This PCM was tested in both in-house controlled conditions and in the field within a demonstration system.

- A low cost design of the PCM storage system with effective heat transfer was developed and demonstrated.
- An advanced control and forecasting algorithm (ACFA) was developed. This control algorithm determines the optimum charge and discharge profile of the PCM thermal storage system when operating with solar PV. ACFA was demonstrated to reliably reduce electricity costs when using actual forecasts of price and solar output.
- Two demonstration systems were built, an in-house system for controlled experiments (Fig. 1) and an in-field system at The Bends Motorsports Park (MSP) in South Australia (Fig. 2), used for a fridge/freezer application in a commercial kitchen.

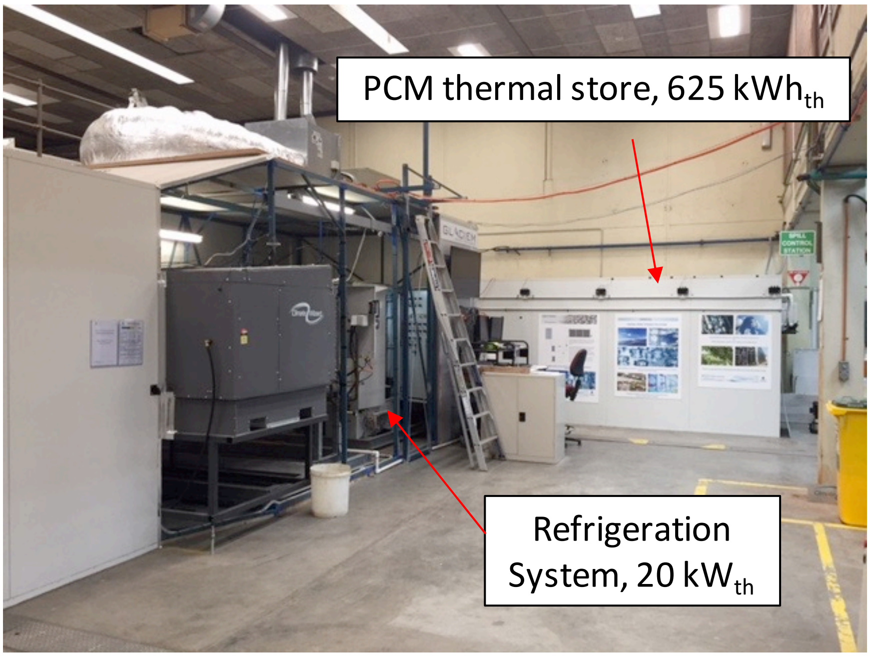

Fig. 1 In house demonstration system at UniSA for controlled experiments in the laboratory.

Fig. 2 The 20 kW refrigeration plant and PCM tank at The Bends Motorsports Park.

Transferability

Overall the technology is directly transferrable to all energy storage systems used in the distributed electricity system. This includes conventional thermal storage technology such as chilled and hot water storage for building air conditioning and hot water heating, high temperature thermal storage and battery technology.

An analysis has shown that payback periods of the PCM storage technology with ACFA range from 4-8 years covering applications including wineries, cold storage, dairies, dairy processing plants and commercial HVAC.

The technology can be used to support generation and network based demand management. The ACFA technology can be expanded to include demand management and operate as a whole of site energy management control strategy to minimise electricity costs.

The approach used in knowledge sharing was to have a twin focus on disseminating information to both potential end users and industry stakeholders as well as academic networks.

The research contributed to and also took benefit from other research projects carried out at the University of South Australia all in the field of energy storage, funded by the Australian Solar Thermal Research Institute, CRC for Low Carbon Living and a South Australian Government International Research Grant.

Publications

Below is a list of journal publications produced from the research conducted:

1. Mohammad Saffaria, Alvaro de Graciab, Cèsar Fernándeza, Martin Belusko, Dieter Boer, Luisa F. Cabeza 2018, Optimized demand side management (DSM) of peak electricity demand by coupling low temperature thermal energy storage (TES) and solar PV, Applied Energy, 211, 604-616.
2. Gasia J. Tay N.H.S., Belusko M., Cabaza L., Bruno F. (2017) Experimental investigation of the effect of dynamic melting in a cylindrical shell-and-tube heat exchanger using water as PCM, Applied Energy, 185, 136.
3. Joaquim Romaní, Martin Belusko, Alemu Alemu, Luisa F. Cabeza, Alvaro de Gracia, Frank Bruno, 2018, Optimization of deterministic controls for a cooling radiant wall coupled to a PV array, Applied Energy, 229, 1103-1110.
4. Rhys Jacob, Martin Belusko, Ming Liu, Wasim Saman, Frank Bruno, 2019, Using renewables coupled with thermal energy storage to reduce natural gas consumption in higher temperature commercial/industrial applications, Renewable Energy, 131, 1035-1046.
5. N.H.S. Tay, M. Liu, M. Belusko, F. Bruno, Review on transportable phase change material in thermal energy storage systems, Renewable and Sustainable Energy Reviews, 75, 264-277.

Intellectual Property: Patents / Licences

The PCM technology and ACFA developed in this project has been licensed to Glaciem Cooling Technologies Pty. Ltd.

Awards

National awards received from the technology developed in this project is as follows:

- Winner of the Applied Innovation Award for the 2017 Carbon Neutral Adelaide Awards.
- Winner of the 2018 AIRAH Excellence in Refrigeration Award, which recognises recently completed refrigeration projects including systems, upgrades and retrofits. This award was for the MSP demonstration system.

Conclusion and next steps

The technology has a promising commercial pathway with a number of potential installations being considered. If commercial uptake can be achieved, the technology can be deployed to operate with up to 23% of the annual electrical energy used in the NEM, offering significant demand management opportunities and expanding solar PV installations with end users. Internationally, there is a pathway to deploy/license this technology in China, the Middle East and India once local deployment has proved successful. Both China and India provide regulatory incentives for thermal storage. Furthermore with the global phase out of HFC refrigerants, these markets require new energy efficient refrigeration solutions which thermal energy storage is able to deliver with natural refrigerants. Future research pathways have been identified which can improve the techno-economic performance of the technology for all these markets.

Lessons Learnt

Lessons Learnt Report: Importance of multiple demonstrations

Project Name: *Maximising solar PV with phase change thermal energy storage*

Knowledge Category:	Technical
Knowledge Type:	Community Engagement
Technology Type:	Storage
State/Territory:	SA

Key learning

To validate research for various audiences, multiple demonstrations are needed. Specifically, technical audiences require controlled laboratory experiments, while commercial audiences require in the field demonstrations.

Implications for future projects

This project resulted in two demonstration systems, future projects will aim to have multiple demonstrations.

Knowledge gap

n/a

Background

Objectives or project requirements

A single demonstration system was originally planned both for testing and as an example for potential end users. It was clear from feedback that end users are only convinced of the viability of research in a demonstration that matches their specific requirements.

Process undertaken

An opportunity arose to conduct a second demonstration system with additional funding from industry and UniSA.

Lessons Learnt Report: Practicality of optimal control

Project Name: *Maximising solar PV with phase change thermal energy storage*

Knowledge Category:	Technical
Knowledge Type:	Inputs
Technology Type:	Storage
State/Territory:	SA

Key learning

It was critical to develop an optimum control strategy which could be practically implemented.

Implications for future projects

In developing/improving control strategies, design and evaluation of the practical implementation will be conducted.

Knowledge gap

n/a

Background

Objectives or project requirements

The optimal control strategy was to be evaluated through simulation. This was successfully achieved. However, the complexity of the control strategy and its uniqueness relative to the conventional control options applied to the thermal storage system could not be ignored.

Process undertaken

The output of the control strategy is to provide modes of operation. The nature of these modes and how the thermal storage system would respond was iteratively reviewed until a satisfactory mode definition was established. The optimal control operates on forecasts, and therefore relevant forecast internet feeds were added through software and the control strategy applied. The reliability and speed were tested and the compatibility to controlling thermal storage systems evaluated. Furthermore, the impact of the accuracy of these forecasts was tested on a case study.