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INNOSTORAGE – USE OF INNOVATIVE THERMAL ENERGY STORAGE FOR MARKED ENERGY SAVINGS AND SIGNIFICANT LOWERING CO_2 EMISSIONS

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D7.2 - Report on Staff Exchanges

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1 Objectives

The objectives of the project are:

- Firstly, energy simulation of an industrial consumer should be carried out with just a conventional energy system connected to the electricity grid, then a black box cold TES (ice or PCM) with variable storage capacities could be considered to identify an optimal operation which can achieve maximum economic return.
- Secondly, the addition of an off-grid solar PV with and without storage should be analysed.
- Thirdly, optimization-based simulation will be carried out to find out the optimum hourly charging/discharging rates of the heat taking into account solar PV and TES storage with different capacities contracted powers during different tariff periods, and to find the optimum economic benefits with regard to the climate zone.
- Scientific results of the research will be published in accredited journals of energy and building science and national/international conferences.

2 Introduction

About 40% of total energy-related CO_2 emissions come from the industrial sector. Peak electricity demand is a global policy concern which causes transmission constraints and congestion, and increases the cost of electricity for all end-users. Further on, a huge investment is needed to upgrade electricity distribution and transmission infrastructure, and build generation plants to provide power during peak demand periods. Moreover, service suppliers charge a higher price for peak-time services than for off-peak services in order to compensate for the costly electricity generation at peak hours. On the grounds, cutting off some of this peak demand would benefit the whole energy system since, on one hand, it would eliminate the need to install expensive extra generation capacity for peak hours and on the other hand, industrial consumers can eliminate surplus charges due to exceeding power demands in their electricity bill. Applying energy management systems allow companies to manage and control their energy use, enabling them to lower energy costs, and enhance productivity and competitiveness. Demand side management (DSM) using thermal energy storage (TES) and off-grid solar photovoltaic technologies could enhance the performance of energy systems and reduce on-peak demand for industries. Energy storage technologies can have a valuable role to play in any energy system, including those with high and low proportions of renewable generation (e.g. solar PV) with variable nature due to weather conditions. A considerable amount of literature has been published on DSM and load shifting using TES, however, further research and advancement are required for electric load management to address the potential energy savings and peak load shaving regarding the new time-of-use tariff structure and elevated electricity prices, high surplus demand charges, and variable solar PV share and its uncertainties in the energy system. Very few publications can be found regarding the impact of TES to increase the energy savings when it is coupled with solar PV technology. The scope of the present research is to determine the optimal economic design of applying solar PV together with cold TES (ice or PCM) considering appropriate time-of-use tariff structures, principally peak electrical demand.

3 Description of work

The main objective of the present research is to reduce the compressor electric energy use of an industrial consumer using TES with a determined capacity and off-grid solar PV at different capacities. Particular interests are to reduce the peak cooling load from the grid at shoulder demand and peak demand periods, and eventually savings the final electricity bill.

For a given hour based on the cooling load, and a given power level from the compressor, charging or discharging can occur constrained by the cooling load. Optimisation is necessary to identify the most optimal hourly grid power input profile over the period which will minimise total energy costs. Therefore the objective is to have the minimum energy costs for a given TES and solar PV system.

Fundamentally, charging should be allowed only when there is export and when grid electricity is cheap. Outside of these times discharging can be allowed. Additionally, for both charging and discharging the power input is limited by the requirement to meet load. Therefore if the load is e.g. 200 kW_{th} then charging can only occur above this amount, as well as below the maximum charging level e.g. from 200 to 350 kW_{th}. So, the compressor power can be varied between these two limits. For discharging if the load is 200 kW, then the compressor power can be varied to either meet the 200 kW or 100kW since the max TES discharge rate is 100 kW. Therefore, for each hour by specifying the charging or discharging mode it is possible to define the range of compressor power levels. If we limit the number of choices to four different capacities of 200 kW, 275 kW, 312.5 kW, and 350 kW in the case of charging, then for each hour we only have four choices of power level. Then we have four capacity options at each hour.

4 Methodology

4.1. South Australia Power Networks (SAPN) business actual demand tariff

SA Power Networks manages the electricity distribution network of South Australia. What customers pay for network charges is determined by a number of factors, including their electricity use, connection voltage, load profile, and the structure of their electricity tariff. Customers on actual demand tariff are charged in a way that reflects their individual maximum energy demand on the distribution network, particularly during peak usage times (see Figure 1).

A customer's peak demand during these times largely drives the network investment required to supply their electricity. By charging customers in this way, it can be ensured that customers pay a fairer share based on how they use the network. Such tariffs also encourage customers to use the network as efficiently as possible.

The tariff provides for three demand periods:

1. Summer Peak Demand Period; this is any half hour period between 4pm and 9pm (local time) on work days, between November and the end of March.
2. Shoulder Demand Period; this is any half hour period between 12noon and 4pm (local time) on work days, all year round.
3. Off-peak Demand Period; this is any half hour period outside of the Peak and Shoulder Demand periods. It should be noted that: Weekends and Public holidays are not considered work days and therefore are exempted from shoulder and peak periods.

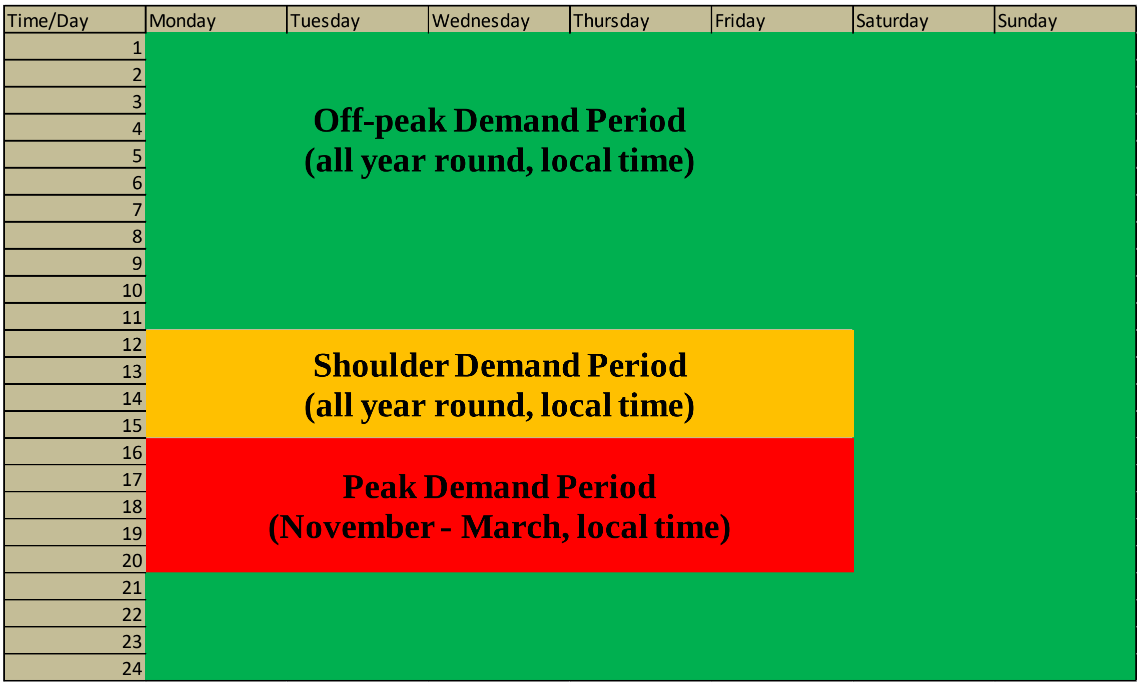

Figure 1. South Australia actual demand tariff structure.

4.2. Thermal energy storage model

A low temperature TES was integrated into the system for peak load reduction. The PCM thermal storage system is rated at 100 kW_{th} maximum cooling capacity storing 1200 kWh_{th}. The storage model and corresponding charging and discharging modes are similar to the method presented by Ihm et al. [1]. The capacity of storage model can be characterized by a charge and discharge rate as shown in Eq. (1):

$$\dot{Q}_{str} = x \frac{SL}{\Delta t} \quad (1)$$

$$f(x) = \begin{cases} inactive\ mode, & x = 0 \\ charging\ mode, & x = 1 \\ discharging\ mode, & x = -1 \end{cases}$$

where $\dot{Q}_{str}$ is the TES charge (+)/discharge (−) rate (kW), SL is the low temperature TES capacity (kWh), x the charge/discharge rate (fraction), and Δt the simulation time step.

The design is based on three operation schedules over the continuity of charge/discharge rates:

- Inactive mode: when the TES system is not working, for instance at the weekends, the charge/discharge rate is set to zero in a sub-hourly schedule defined specifically for the TES operation.
- Charging mode: the dedicated TES chiller integrated in the TES module produces cold at the charging rate, x, during off-peak hours (the cheapest period) with the maximum charging rate of 350 kW_{th}.
- Discharging mode: in this stage the TES system supplies cooling with a maximum capacity of 100 kW to meet the cooling demand during on-peak hours (avoiding or reducing compressor operation).

Further on, the following conditions were applied to the TES model:

- At hour 1 the storage is fully charged at 1200 kWh capacity.
- Charging is only allowed at off-peak hours (1:00-7:00) and (21:00 to 24:00) all weekdays.
- Charging is allowed while the storage level is less than 1000 kWh.
- Discharging is allowed only at on-peak hours (also it could be optimized based on solar availability).
- Discharging is allowed if the storage level is greater or equal to 100 kWh.

4.3. Solar PV model

The PV model describes the simplest model for predicting photovoltaic energy production. In this model the user specifies the efficiency with which surfaces convert incident solar radiation to electricity. The model accepts arbitrary conversion efficiencies and does not require actual production units be tested to obtain empirical performance coefficients. Eq. (2) shows the usable electrical power produced by a PV surface [2]:

$$P = A_{surf} \times f_{activ} \times G_T \times \eta_{cell} \times \eta_{invert} \quad (2)$$

where P is electrical power produced by photovoltaics [W]; A_{surf}, net area of surface (m^2); f_{activ}, fraction of surface area with active solar cells (); G_T = Total solar radiation incident on PV array (W/m^2); η_{cell} is module conversion efficiency (); and η_{invert} DC to AC conversion efficiency ().

It should be added that, for solar PV generation the hourly global horizontal radiation of Adelaide, Australia was used.

4.4. Heat pump model

In the present study only the electrical load from the refrigeration system was considered. Figure 2 illustrates the load profile of the industrial consumer. Additionally, coefficients of performance (COP) correlations were developed from Bitzer data for semi-hermetic screw compressors with R404A [3]. The sizing chosen are scalable and so the analysis is applicable to much larger systems.

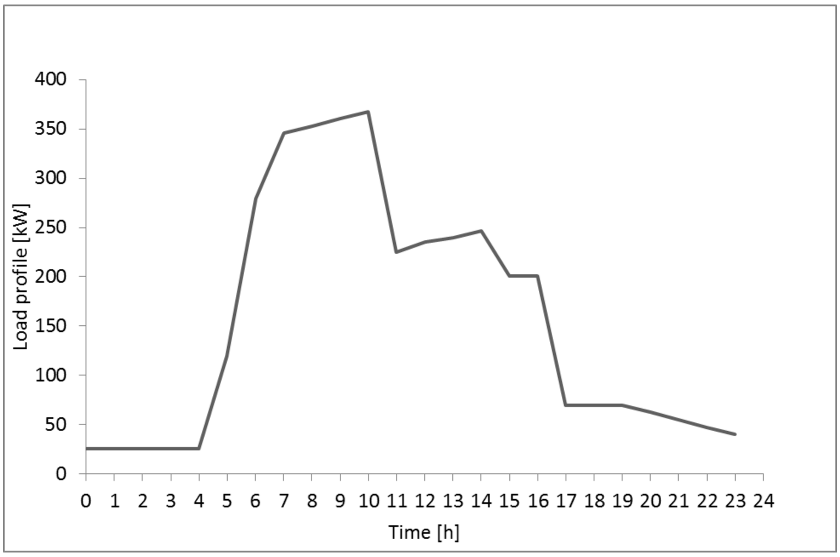

Figure 2. Load profile of the factory (thermal load).

4.5. Brute Force optimization

The most straightforward, and computationally expensive, approach to solving discrete problems is to perform an exhaustive search – where all the possible options are enumerated and evaluated. The optimal solution can then be readily selected from the enumerated solutions as shown in Eq. (3):

$$\min_{x_i}(w_i) \qquad (3)$$

where

$x_i \in \{x_1, x_2, \dots, x_i\}$

$\{w_1, w_2, \dots, w_i\} \in R$

Where *i* is element number; w_i weight of i^{th} element; and R real number.

5 Results

Figure 3 shows the initial energy saving results by coupling TES and PV technologies to reduce energy and demand costs due to industrial cooling processes. It was achieved that using only 50 kW of PV system can lead to about 25% of annual energy savings. However, coupling TES at 1200 capacity can increase these savings to about 32%.

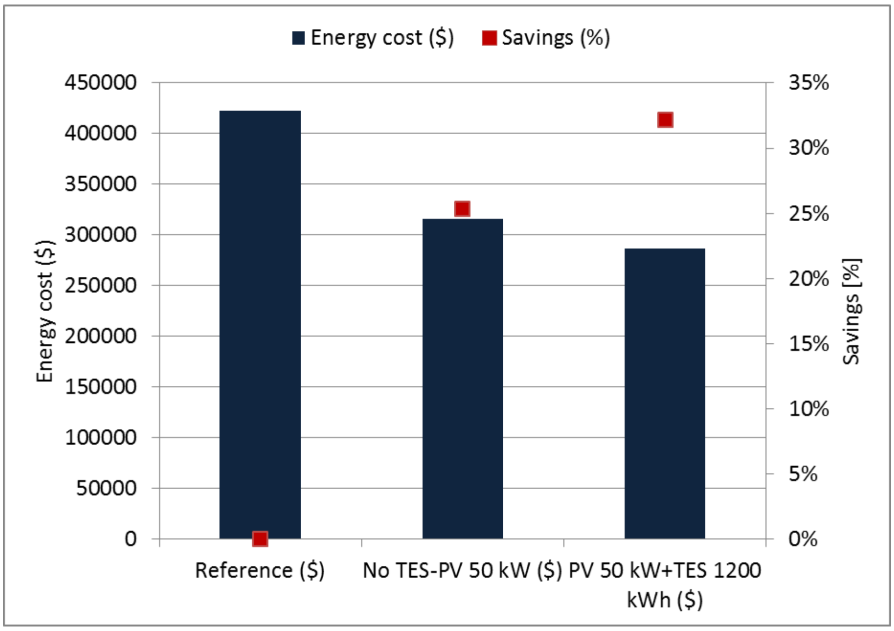

Figure 3. Annual energy savings using PV and TES technologies.

6 Outcomes or future work

Further work is necessary to apply optimization-based control for charging and discharging of TES which can lead to further reduction of peak demand and energy cost. Further on, a control strategy will be applied to heat pump to set an optimal capacity at each hour.

7 References

[1] P. Ihm, M. Krarti, G.P. Henze, Development of a thermal energy storage model for EnergyPlus, Energy and Buildings. 36 (2004) 807–814. doi:10.1016/j.enbuild.2004.01.021.

[2] Photovoltaic Arrays: Engineering Reference — EnergyPlus 8.7, (n.d.). https://bigladdersoftware.com/epx/docs/8-7/engineering-reference/photovoltaic-arrays.html#photovoltaic-arrays (accessed November 29, 2017).

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8 Assessment

My research stay at the University of South Australia (UniSA) was a great opportunity for me to grow my personal and professional experience. My experience at UniSA went beyond a regular PhD student research fellow. I had the opportunity to know other researchers and their area of research.

Further on, living in South Australia and carrying out research under the supervision of Dr. Martin Belusko gave me a wider horizon towards knowing the energy policies in South Australia and the current trends and advancement in the area of thermal energy storage and solar energy. Besides, I could participate in some cultural events to go further into the Australian culture.