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Electricity Load Reduction in Hybrid Power Systems Using Power Pinch Analysis

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Abstract

Energy savings in an electrical system can be achieved through the use of energy-efficient appliances to minimise electricity consumption. This work applies the Power Pinch Analysis (PoPA) to guide electricity load reduction at the demand side of a HPS. The reduction in electricity load as well as cost can be determined from the power rating and operating hours of appliances in a HPS. Four new heuristics for load reduction have been proposed in this work. The results show that systematic efficiency improvement of the appliances has successfully reduced the total electricity consumption and cost.

Keywords: Power Pinch Analysis (PoPA), load reduction, energy efficiency

1. Introduction

The rapid growth in electricity demand has encouraged widespread energy-saving efforts especially in the industrial, commercial and domestic sectors. Energy-saving measures in an electrical power system include the use of energy-efficient equipment and appliances, abiding by the energy-efficiency regulations and implementation of good housekeeping techniques. Opportunities to reduce electricity consumption can be specifically achieved through the improvement of lighting, electric motors and heating, ventilating and air conditioning (HVAC) systems. Popovic-Gerber et al. (2012) reported that lighting consumes over 20 % of all electricity generated in the U.S, while electric motors account about for 30–80 % of the total industrial energy use according to Hasanuzzaman et al. (2011). Improvement of energy efficiency in industrial systems through the use of energy-efficient technology has become an important demand side management strategy (Du Plessis et al., 2013). Some typical measures to enhance the industrial energy efficiency include replacing inefficient incandescent lights with the more efficient compact fluorescent lamps (e.g. change T8 to T5 or LED) and the use of the high efficiency motors or variable speed drives (VSD) as alternatives for the standard motors in motor driven systems (e.g. conveyors, fans, pumps and chillers). A total implementation of energy-efficient appliances in electrical systems is not always economically feasible due to the additional costs incurred. However, given the correct strategies and magnitude of reduction, this extra cost would be a worthwhile investment in exchange for the potential reduction in electricity bills over time, as a result of the use of the energy-efficient appliances.

Studies to investigate electricity savings potential by improving appliance efficiency in industrial systems have been conducted extensively. Electricity saving potentials in the German paper industry are scrutinised by Fleiter et al. (2012). Technology-specific information is integrated in a bottom-up model to identify the energy efficiency potentials and to evaluate their cost-effectiveness. Du Plessis et al. (2013) developed a novel real-time energy management system to improve the electricity and cost efficiency of cooling systems. In situ experiments on various cooling systems were carried out and 33.3 % electricity saving is realised. Bortoni et al. (2013) presented a model development for the energy consumption estimation as well as peak demand reduction. Motor efficiency curves, annual working hours and efficiency loading are taken into account in the model construction.

Pinch Analysis concept has been widely used for heat (Klemeš and Varbanov, 2013), mass and water minimisation (Klemeš, 2013). Its application has been recently extended to power systems – see e.g. Wan Alwi et al. (2012) and Mohammad Rozali et al. (2013). However, the use of Pinch Analysis to explore the electricity savings potential in power systems has not been reported. Power Pinch Analysis (PoPA) has been applied by Wan Alwi et al. (2013) to reduce the storage capacity and the maximum demand in a Hybrid Power System (HPS). The total electricity load reduction has been achieved by performing load shifting. Load reduction through energy efficiency improvement however is not considered. In this paper, PoPA is applied to provide insights on the electricity allocations in HPS to guide load reduction in the total end-use electricity consumption. The reduction in electricity load as well as cost can be determined from the power rating and operating hours of appliances in a HPS.

2. Methodology

The baseline (using the standard level of appliance energy efficiency) power allocation at each time interval is determined using the graphical PoPA tool called the Outsourced and Storage Electricity Curves – OSEC (Wan Alwi et al., 2013). Figure 1 shows the OSEC combination during start up and continuous 24 h operation for the Illustrative Case Study data as tabulated in Table 1.

Table 1. Limiting power sources and demands for Illustrative Case Study.

No.	Power Type	Description	Time, h		Power rating, kW
			From	To	
S1	Source	Solar	8	18	70
S2	Source	Wind	2	10	50
S3	Source	Biomass	0	24	80
D1	Demand	Fans	0	24	40
D2	Demand	Compressors	8	18	60
D3	Demand	Lighting	0	24	30
D4	Demand	Pumps	8	18	50
D5	Demand	Conveyors	8	20	50

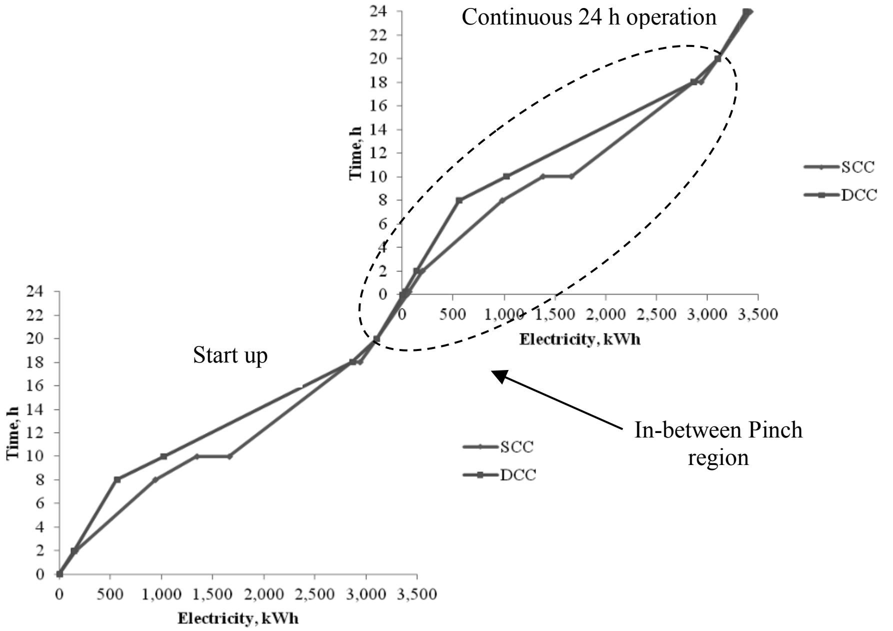

Figure 1. OSEC for start up and continuous 24 h operation

The OSEC is constructed by allocating the Source Composite Curve (SCC) directly to the Demand Composite Curve (DCC) within each time interval (Wan Alwi et al., 2013). Prior to the load reduction, the total electricity consumption is 3,380 kWh with minimum outsourced electricity supply (MOES) requirement of 360 kWh during continuous 24 h operation. In order to determine the load and magnitude of reduction, the outsourced electricity allocations are identified. The OSEC plot shows that 280 kWh of outsourced electricity is required between time intervals 10 and 18 h. Between time intervals 18 and 20 h, 80 kWh is needed, which represents the maximum demand of 40 kW for the system. Electricity is stored during the rest of other time intervals, with the maximum storage capacity occurs between time intervals 2 and 8 h (420 kWh).

As mentioned earlier, load reduction via appliance efficiency improvement involve a trade-off between the appliance cost and electricity bill. While the reduction of load consumption can lead to electricity bill payment reduction, it may also increase the storage size, and thereby increase the cost of storage system. Besides, reduction limit should also be specified in order to avoid electricity excess, where the available excess electricity for the next day (AEEND) is higher than the MOES. Bearing in mind these factors, four heuristics are proposed to guide the load reduction;

i. Reduction of load demand operating when the MOES and maximum demand occurs to reduce the total outsourced electricity requirement.
ii. Reduction of load demand operating within the in-between Pinch region to avoid storage capacity increment.
iii. Reduction of load demand operating across the Pinch location is not favoured to avoid storage capacity increment.
iv. Reduction magnitude should not exceed the amount of MOES to avoid electricity excess.

Referring to the OSEC plot, it is found that all demands operated within the MOES occurrence i.e. 10 to 20 h (Heuristic 1). Based on Heuristic 3, consumption of D1 and D3 are not feasible to be reduced because they operate across the pinch location at *t*=20 h. Following the second heuristic, the loads that are left for the load reduction procedure are D2 (compressors), D4 (Pumps) and D5 (conveyors). These loads are driven by electric motors. Therefore, VSD installation is considered as an alternative to improve the efficiency, and consequently to reduce the electricity consumption. Based on Heuristic 4, the magnitude of reduction is determined. As can be seen, the total MOES for a 24 h operation is 360 kWh (280 + 80 = 360 kWh). The limit of the reduction is therefore set to 360 kWh. A constant 0.25 speed reduction ratio, S_R is considered in the load reduction for all the three demands.

2.1 Reduction of D2 consumption

The 60 kW compressors operate between time intervals 8 and 18 h, with total daily consumption of 600 kWh. After the installation of VSD with S_R of 0.25, the new rated power of the compressors is calculated using Eq.(1) (Abdelaziz et al., 2011) to give 34 kW. This alternative comply with Heuristic 4 because the magnitude of reduction is 260 kWh ((60 kW – 34 kW) × 10h).

$$EC_{VSD} = EC_i \times (1 - S_R)^2 \tag{1}$$

Where the EC_{VSD} is the electricity consumption after VSD installation, EC_i is the baseline electricity consumption, S_R is the speed reduction ratio.

The effect of this load reduction is visualised using OSEC and is illustrated in Figure 2. It can be observed that the MOES requirement has been reduced to 120 kWh, which gives a reduction of 67%. The maximum demand however are not affected (40 kW).

2.2 Reduction of D4 consumption

To reduce the electricity consumption of the 50 kW pumps, VSD with S_R of 0.25 is installed. Using Eq.(1), the new rated power of the pumps after the energy efficiency improvement is calculated as 28 kW. It indicates a total reduction magnitude of 220 kWh. Figure 3 presents the effect of D4 reduction. 61 % of total MOES reduction (from 360 kWh to 140 kWh) has been successfully achieved by this option, but the maximum demand remains at 40 kW.

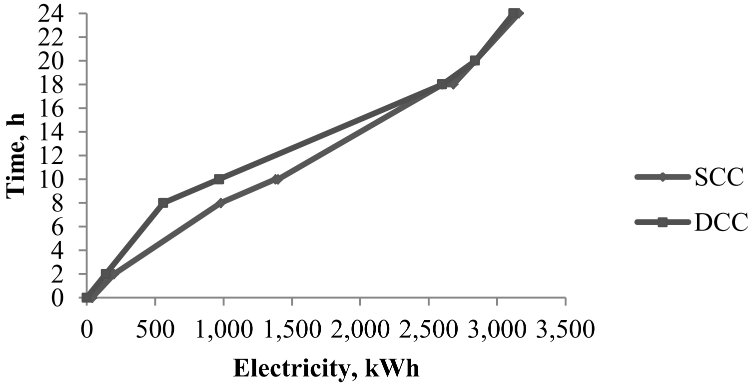

Figure 2. OSEC for continuous 24 h operation after the reduction of D2 consumption

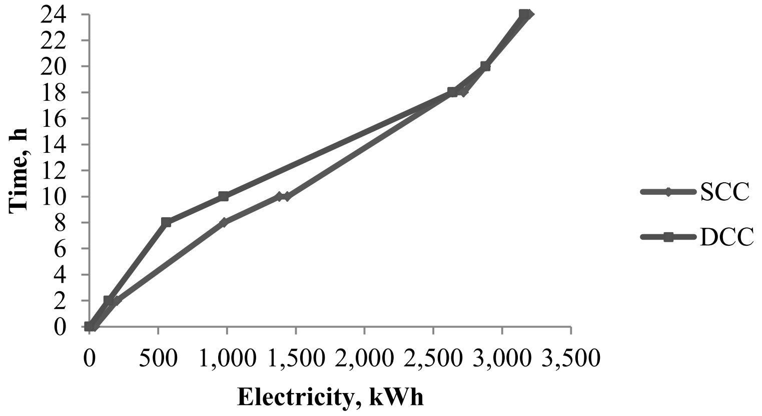

Figure 3. OSEC for continuous 24 h operation after the reduction of D4 consumption

2.3 Reduction of D5 consumption

The efficiency of the conveyors is also improved by installing the VSD with 0.25 S_R. The magnitude of the reduction is 264 kWh, because the rated power of the conveyors after the efficiency improvement is 28 kW. The OSEC visualising the effect of this load reduction is shown in Figure 4. Reduction of D5 consumption has reduced the MOES to 96 kWh (73% reduction). Besides, this alternative also contributes to a total 55% reduction in the maximum demand.

The results from the consumption reduction of the three demands show that the maximum capacity of the storage is successfully maintained at its initial size (420 kWh). The reduction of the maximum demand cannot be achieved after the D2 and D4 reduction because these demands operate between time intervals 8 and 18 h. The maximum demand on the other hand occurs between time intervals 18 and 20 h, and can only be reduced after the D5 (operating between 8 and 20 h) consumption is reduced.

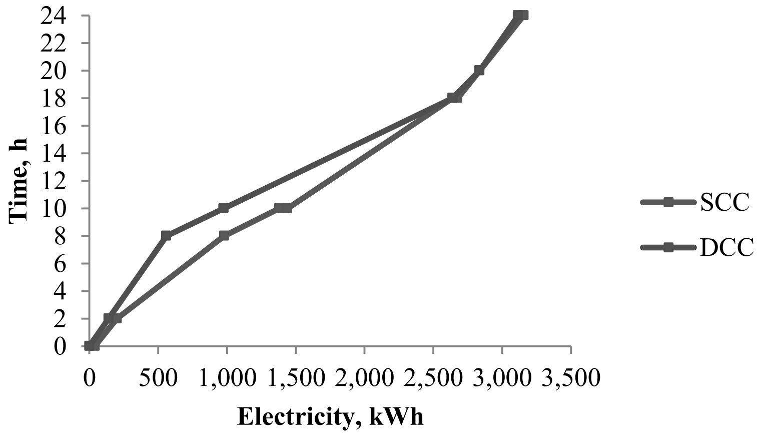

Figure 4. OSEC for continuous 24 h operation after the reduction of D5 consumption

3. Conclusions

PoPA has been successfully applied to guide load reduction via appliance efficiency improvement in a HPS. Considering various factors including the amount of MOES, storage size and amount of electricity excess, four heuristics have been developed to ensure the appropriate and feasible load reduction strategies. Results show that load reduction using PoPA has successfully reduced the total consumption and the MOES requirement of the system. Further studies are required to include the economic assessment to evaluate the economic feasibility. Besides, effects of the implementation of other alternatives such as the energy-efficient motors could also contribute to energy efficiency improvement in the system.

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