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Cost-Effective Load Shifting for Hybrid Power Systems Using Power Pinch Analysis

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Abstract

Load shifting from peak to off-peak hours changes the electricity load profile and allows users to control the peak electricity demand and optimise the electricity cost. Power Pinch Analysis (PoPA) has been used recently to guide load shifting aimed at reducing the electricity maximum demand. This work applies the PoPA to optimise the overall electricity cost for a hybrid power system by performing cost-effective load shifting that takes advantage of the peak and off-peak electricity tariff. Two new heuristics for load shifting are proposed in this work. The results show that the total outsourced electricity during the peak hours has been successfully distributed to the off-peak hours to minimise the electricity cost.

Power Pinch Analysis (PoPA); Hybrid Power Systems (HPS); load shifting; electricity

1. Introduction

Load shifting is defined as the process of reallocating the electricity demands from the peak periods when the electricity tariff is high, to off-peak periods when the electricity tariff is low [1]. Load shifting is a form of load management that has been widely applied in the industrial sectors. A number of simulation and stochastic optimisation studies have been conducted on load shifting in power systems considering the dynamic pricing of electricity. Demand Side Management (DSM) strategies for hybrid power systems (HPS) comprising of one or more renewable energy (RE) sources and storage has been designed by

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Iglesias et al. [1]. A novel control strategies based on load identification is included in the strategies development. The use, behaviour and running time of the loads were identified and configured. Lujano-Rojas et al. [2] determined the optimal relationship between hourly electricity prices and the use of different household appliances with an optimal load management strategy. The proposed model can efficiently reduce the electricity bill and allows the users to control their energy consumption.

The Pinch Analysis concept [3] for load shifting in HPS has been presented by Wan Alwi et al. [4]. The authors applied the Power Pinch Analysis (PoPA) for load shifting in HPS in order to reduce the system's storage capacity and the maximum demand. Ho et al. [5] extended the Electric System Cascade Analysis approach to manipulate the electricity supply and demand in order to reduce the capacity of storage and RE generators. Application of the insight-based PoPA approaches on load shifting that considers the peak and off-peak electricity pricing for a HPS however has not been presented. In this paper, PoPA is applied to provide insights to formulate a cost-effective load shifting strategy by manipulating the peak-off-peak loads in a HPS. The shifting strategies are developed based on two newly proposed heuristics. For each shifting strategy, the electricity cost and the total savings are calculated.

2. Methodology

The power allocation at each time interval can be determined using the graphical PoPA tool called the Outsourced and Storage Electricity Curves – OSEC [4]. The visualisation insights from the OSEC, i.e. the time intervals where outsourced electricity, storage and maximum demand occur provide a useful guideline for the load shifting procedure. Table 1 shows the limiting power sources and demands to demonstrate the application of the OSEC for load shifting in a HPS. The Illustrative Case Study is a small scale HPS with three REs, i.e. solar, wind and biomass as the power sources. The system consists of five appliances as the load demands. It is assumed that all the loads can be operated at any time throughout the day and can be shifted to any time interval. In real cases, the flexible and the non-flexible loads should be identified by the designers prior to the load shifting procedure.

Table 1. Limiting power sources and demands for Illustrative Case Study [4].

No.	Power Type	Description	Time, h		Power rating, kW
			From	To	
S1	Source	Solar	8	18	500
S2	Source	Wind	0	12	400
S3	Source	Biomass	12	24	600
D1	Demand	Appliance 1	6	12	300
D2	Demand	Appliance 2	8	18	350
D3	Demand	Appliance 3	8	12	500
D4	Demand	Appliance 4	0	12	350
D5	Demand	Appliance 5	12	24	500

The OSEC is constructed by allocating the Source Composite Curve (SCC) directly to the Demand Composite Curve (DCC) within each time interval [4]. Fig 1(a) shows the OSEC during start up for the Illustrative Case Study data. The required outsourced electricity (deficits) and the power storage (surpluses) allocation at each time interval is observed. The period (peak or off peak hours) of when the storage or outsourced electricity occurs is identified in order to plan an effective shifting strategy. The time intervals between 8 and 22 h are defined by Tenaga Nasional Berhad [6] as the peak hours.
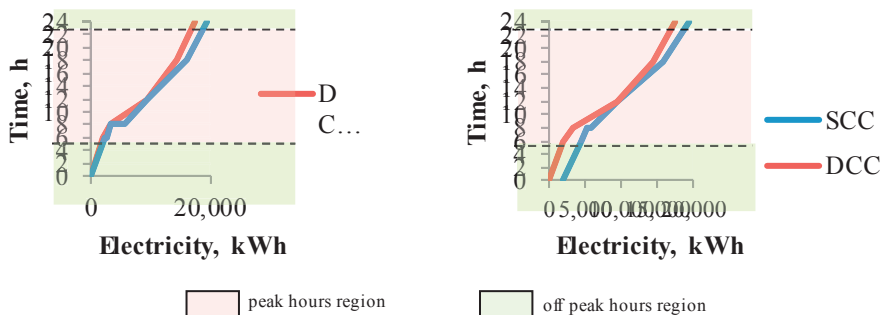
Fig. 1. OSEC Illustrative Case Study 1 (a) start up; (b) continuous 24 h operation

The OSEC plot for start-up shows that there are two instances where the outsourced electricity is needed. 200 kWh of outsourced electricity is required between time intervals 6 and 8 h (off-peak period). Between time intervals 8 and 12 h (peak period) 2,400 kWh is needed The maximum storage capacity of 2,100 kWh occurs between time intervals 18 and 24 h, and 1,500 kWh of electricity is also stored during peak hours (between 12 and 18 h). Allocations for continuous 24 h operation (Figure 1(b)) show that the maximum storage of 2,400 kWh occurs during the off-peak periods (between 0 and 6 h). The highest outsourced electricity is required between time intervals 8 and 12 h - during the peak periods.

With the reduction in the total electricity cost as the main objective, two heuristics are proposed to guide the load shifting as follows;

Heuristic 1: The amount of outsourced electricity requirement during peak hours can be reduced by reallocating it to the time intervals with electricity surpluses occurring during off-peak hours

The load that consumes electricity between this time intervals i.e. D3 is shifted to time '0 to 4 h', which has electricity surpluses and occurs during off peak hours. Fig 2(a) shows the effect of shifting the D3 (strategy 1). As can be seen, the deficits between time intervals 8 and 12 h have been distributed to other time intervals during off peak hours. This reduced the total outsourced electricity during peak hours.
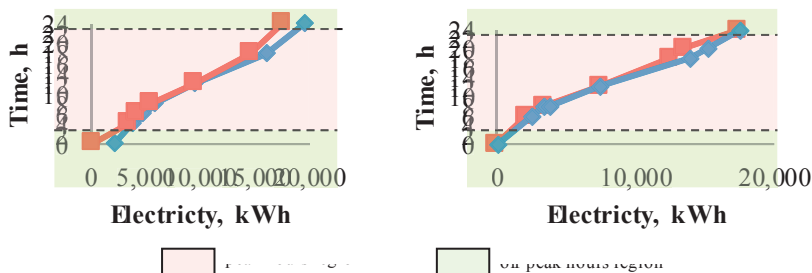

Fig. 2. OSEC during 24 h operation after (a) shifting strategy 1; (b) shifting strategy 2

Heuristic 2: Electricity demand during peak hours can be shifted to the time intervals straddling the peak and off-peak hours, provided that the time interval where the demand is shifted to is preceded by the time interval with a large electricity storage [4].

The D3 is shifted from '8 to 12 h' to '20 to 24 h' (strategy 2). The '20 to 24 h' time intervals are located during both the peak (20 to 22 h) and off peak (22 to 24 h) periods, but preceded with storage capacity of 1,500 kWh. The effect of this shifting is presented in Figure 2(b). The total outsourced electricity imported during peak hours has been successfully reduced by this shifting strategy. Equation 1 gives the total savings as the difference between the electricity cost before and after load shifting.

$$CE_S = \sum_{\text{before}} (E_{on} \times T_{E,on}) + (E_{off} \times T_{E,off}) + (MD_{on} \times T_{MD}) - \sum_{\text{after}} (E_{on} \times T_{E,on}) + (E_{off} \times T_{E,off}) + (MD_{on} \times T_{MD}) \quad (1)$$

Where CE_s is the savings in electricity cost [RM]; E_{on} and E_{off} are the annual outsourced electricity required during peak and off peak hours [kWh]; $T_{E,on}$ and $T_{E,off}$ are the electricity tariff charged during peak and off peak hours [RM/kWh]; MD_{on} is the annual maximum demand per month during peak hours [kW]; T_{MD} is the maximum demand charged per month during peak hours = 37.00 RM/kW [6]. The industrial pricing and tariff currently implemented in Malaysia is used in the calculations. The cost of the grid electricity during the peak period is 0.355 RM/kWh , while the off peak usage tariff rate is 0.219 RM/kWh [6]. The total savings for the shifting strategies are in Table 2. It can be observed that the implementation of shifting strategy 1 yields higher savings in the electricity cost - RM 37,597. This is because, besides reallocating the load from peak to off peak hours, this strategy also shifts the maximum demand for start up to off peak hours. This reduces the cost of maximum demand.

Table 2. Total annual savings in the cost of electricity.

	Outsourced electricity, kWh		Maximum demand, kW	Electricity cost, RM/y		Maximum demand cost, RM/y	Cost savings, RM/y
	Peak	Off peak		Peak	Off peak		
Before shifting	184,400	200	1,975	65,462	44	73,075	-
Shifting strategy 1	146,000	38,600	1,100	51,830	8,453	40,700	37,597
Shifting strategy 2	146,000	36,600	1,200	51,830	8,015	44,400	34,335

3. Conclusion

The correct load shifting strategies from peak to off-peak periods have been proposed in order to achieve the maximum savings. Two new heuristics have been developed to ensure a cost-effective load shifting. PoPA tool called the OSEC was applied to identify the allocations of storage and outsourced electricity. The application of OSEC with the proposed heuristics for load shifting procedure has successfully led to savings in the total electricity cost. Further studies to include the effect of load shifting on storage capacity is required because the OSEC results show that, apart from reduction in the maximum demand, the storage capacity has also been reduced, thereby minimising the total investment of the system.

Acknowledgement

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Biography

Professor Jiří Jaromír Klemeš had been one of the key personalities of the world-leading Centre of Excellence in Process Integration at the University of Manchester Institute of Science and Technology and after the merge at The University of Manchester in the United Kingdom. He is currently the Head of Centre for Process Integration and Intensification (CPI^2) at the University of Pannonia in Hungary <www.cpi.uni-pannon.hu>. He has been a Distinguished Visiting Professor at a number of universities in Europe and Asia as at University of Maribor, Slovenia, Brno University of Technology, Czech Republic, Universiti Technologi Malaysia, South China University of Technology, Guangzhou and Xi'an Jiaotong University, Xi'an, Shaanxi, China. He is the Editor-in-Chief of Chemical Engineering Transactions, Subject Editor of ENERGY and the Journal of Cleaner Production, Regional Editor for Europe for Applied Thermal Engineering and Cleaner Technologies and Environmental Policy. He has been several times a Guest Editor for Applied Energy Journal. He is the founder and thePpresident of PRES (Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction) Conference. He is the chair of CAPE WP (Computer Aided Process Engineering) of European Federation of Chemical Engineering and has authored more than 200 archive papers.