Renewable and Sustainable Energy Reviews 66 (2016) 834–842

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Process Integration for Hybrid Power System supply planning and demand management – A review

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A R T I C L E I N F O

Article history:
Received 17 August 2015
Received in revised form
31 July 2016
Accepted 23 August 2016

Keywords:
Power Pinch Analysis (PoPA)
Hybrid Power Systems (HPS)
Renewable energy (RE)
Process Integration (PI)

A B S T R A C T

Modeling tools for the optimal Hybrid Power Systems (HPS) supply planning and demand management have been relatively established. However, complementary tools that can provide planners, decizion-makers, energy managers and electrical as well as power engineers with graphical and visualization insights that are vital for better conceptual understanding of the problems, particularly at the onset of hybrid power systems planning and design, have just been developed over the last five years. This paper reviews the six-year development of the insight-based graphical and algebraic Process Integration (PI) tools for the optimal HPS supply planning and demand management, i.e., from its inception in the year 2011, until 2016. Known as the Power Pinch Analysis (PoPA), the tool has been among the next-generation PI techniques for resource conservation following the developments of the heat, mass, water, gas, materials, property, solid and carbon emission pinch analysis techniques. This paper discusses the progress, challenges and contributions of PoPA in promoting Renewable Energy (RE) utilization in HPS. Case studies on implementation of PoPA for HPS planning and design presented in the paper show encouraging improvement on HPS profitability and reliability.

Contents

Abbreviations: AC, Alternating current; DC, Direct current; AEEND, Available excess electricity for next day; ESCA, Electric System Cascade Analysis; DCC, Demand composite curves; SCC, Source composite curves; GCC, Grand Composite Curves; HPS, Hybrid Power Systems; MOES, Minimum outsourced electricity supply; RE, Renewable energy; OSEC, Outsourced and Storage Electricity Curves; PI, Process Integration; PoPA, Power Pinch Analysis; PCC, Power Composite Curves; PCT, PoWer Cascade Table; SCT, Storage Cascade Table; SAHPPA, Stand-alone hybrid system power pinch analysis

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http://dx.doi.org/10.1016/j.rser.2016.08.045
1364-0321/

1. Introduction

The International Energy Agency has estimated a renewable power escalation of 40%, and expected the Renewable Energy (RE) to make up almost a quarter of global power mix [1]. The most impressive projected gain is fueled by three types of RE - namely wind, solar and biofuels with five times higher demand in 2040 as compared to 2010 [2].

An HPS combines the use of intermittent electrical energy from various RE sources including solar photovoltaic, wind, wave, biomass and geothermal with "purchased" or outsourced power that are either supplied from the grid or self-generated onsite using conventional fuel sources. The Hybrid Power System (HPS) is more suitable for industrial applications as compared to using individual RE that can either be too dependent on one RE source (e.g. in the case of biomass), or cater for small loads (i.e. in the case of solar).

This paper reviews the developments of the insight-based graphical and algebraic Process Integration (PI) tools for the optimal HPS supply planning and demand management. Pinch Analysis (PA) is one of the PI methods that rely on thermodynamics and physical insights in establishing the minimum targets and optimal design of resource conservation networks. Resource optimization problems have progressed along two popular routes namely the insight-based and the mathematical programming (MP) approaches. While the MP approach offers advantages in handling complex systems involving multiple resources, the formulation can be difficult to master. The MP typically provides designers with relatively less control over the solution space as well as little insights on the resource conservation network targets and design. On the other hand, the insight-based techniques such as the Problem Table, the Cascade Table and the Composite Curves are easier to master and apply. The insight-based PI techniques are therefore most vital as visualization tools for network targeting and design, thereby allowing industrialists as well as policy makers to have better understanding and control over the decizion making process. The PI is typically preferred when unit-wise and step by step build scale integration are required.

The earliest PA technique was pioneered by Linnhoff and Flower [3] for the design of optimal heat exchanger networks. The Power Pinch Analysis (PoPA) tool has been among the next-generation PI techniques for resource conservation following the developments of the heat [3], mass [4], water [5], mass and energy [6], gas [7], materials and property [8], solid [9] and carbon emission pinch analysis techniques [10]. PoPA development could complement the various existing MP approaches in the design and optimization of power systems. To date, research on PoPA has shown promising results in generating optimal design of HPS, proving that there are ample opportunities for PoPA development along the same line of its PA predecessors. This paper discusses the progress, challenges and contributions of PoPA techniques to promote RE utilization in HPS. The overview provided by this paper can inform researchers of the state-of-the-art of PoPA development and help them explore other potential avenues for further developments in this field. The review covers the six-year

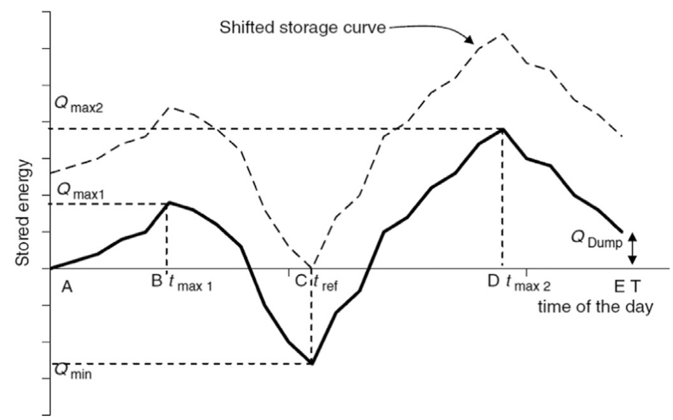

Fig. 1. Grand Composite Curve of stored energy vs time [11].

Table 1
Publications on PoPA key developments.

Key developments	References	Description	Number
HPS targeting using graphical approach	Bandyopadhyay [11]	Grand Composite Curves (GCC) as storage requirement representation in isolated RE systems.	3
	Wan Alwi et al. [13]	Power Composite Curves (PCC) and Continuous PCC (CPCC) for electricity targeting.	
	Wan Alwi et al. [14]	Allocations of storage and outsourced electricity using Outsourced and Storage Electricity Curves (OSEC).	
HPS targeting using algebraic approach	Mohammad Rozali et al. [16]	Power Cascade Table (PCT) and Storage Cascade Table (SCT) for electricity targeting and allocations.	1
HPS design with energy losses considerations	Ho et al. [17]	Electric System Cascade Analysis (ESCA) considering inverter and battery charging/discharging efficiencies.	3
	Ho et al. [18]	Incorporate energy losses as correction factors in Stand-Alone Hybrid System Power Pinch Analysis (SAHPPA) curves.	
	Mohammad Rozali et al. [19]	Modification of SCT to include energy losses and to consider AC-DC topology	
Sizing methods for optimal HPS	Ho et al. [17]	Apply ESCA to optimally design HPS with non-intermittent power generator.	4
	Ho et al. [20]	Apply ESCA to optimally design HPS with intermittent power generator.	
	Mohammad Rozali et al. [21]	Apply modified SCT to optimally design HPS with multiple generators (intermittent and non-intermittent)	
	Ho et al. [18]	Execute separate SAHPPA plots to size each intermittent and non-intermittent generator.	
Load shifting	Wan Alwi et al. [14]	Apply OSEC to reduce maximum storage capacity and maximum power demand via load shifting.	3
	Ho et al. [22]	Apply ESCA to optimize load profiles, storage capacities and charging/discharging schedule via load shifting.	
	Mohammad Rozali et al. [23]	Apply OSEC to reduce electricity cost via peak-off-peak load shifting.	
Cost-effective storage system for HPS	Mohammad Rozali [24]	A framework that applies PoPA to screen various energy storages in HPS considering the efficiencies, power trends and economics.	3
	Esfahani et al. [25]	Extended-Power Pinch Analysis (EPoPA) to design HPS with battery and hydrogen storages.	
	Esfahani and Yoo [26]	Considered water tank as storage in the system.	