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Study of the Effects of Seasonal Climate Variations on Hybrid Power Systems Using Power Pinch Analysis

Nor Erniza Mohammad Rozali*, Muhammad Syu`aib Mohamed Yahaya

Department of Chemical Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

Abstract

The role of renewable energy (RE) resources as clean alternatives to fossil fuel in power generation has been increasing. Widespread deployment of RE sources in Hybrid Power Systems (HPS) however can be a challenging task due to the stochastic nature of RE. Solar and wind are intermittent with weather variations, and the end use demands are also climate dependant. In this paper, Power Pinch Analysis (PoPA) method is applied to assess the different RE generation and load profiles from two seasonal climates namely winter and summer. The minimum electricity targets established from PoPA allows the designer to visualise the feasible limits for the sizing of HPS. Results show that HPS operation during winter demands a substantial amount of outsourced electricity, while summer operation requires higher investment on the PV generator and storage.

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Keywords: Power Pinch Analysis (PoPA); hybrid power systems; renewable energy; seasonal variations

1. Introduction

Sustainable development has been the key factor that enhanced the role of renewable energy (RE) resources in power network. RE technologies can be an effective measure to mitigate environmental emissions due to the burning of fossil fuels in conventional power generation. Widespread deployment of RE sources in Hybrid Power Systems (HPS) however can be a challenging task due to the stochastic nature of RE. Renewable solar and wind resources for example are intermittent with daily and seasonal variations. In addition, the end use demands are also climate dependant. These uncertainties can lead to a mismatch between different RE production and the time distribution of load demands. Incorporation of the variability associated with both power source and demand is therefore vital in HPS design, as it affects the performance and reliability of the overall system.

A number of studies on the design of renewable energy system considering the climate variations have been conducted. Abedi et al. [1] scrutinized the uncertainties associated with RE sources in HPS using Weibull and Beta probability distribution function. The authors developed monthly power management strategy (PMS) adapting the various climatic changes during a year. Based on the PMS parameters, optimal system that meet the operational constraints were obtained. Three typical wind speed diurnal profiles

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* Corresponding author. Tel.: +605-368 7582; fax: +605-365 6176.
E-mail address: erniza.rozali@petronas.com.my

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namely fairly flat, weakly fluctuating and strongly fluctuating were considered by Carapellucci and Giordano [2] in the design and sizing of wind power plants in Italian locations. Results show that the diurnal variation of wind speed highly influences the off-grid wind system, especially the capacity of storage. The grid-connected wind plants on the other hand demonstrate that the diurnal change effects are more pronounced on the amount of self-consume electricity, purchased electricity amount and the net present value. The economic and technical feasibility of hybrid PV-diesel system for the different climatic zones in Tamil Nadu has been the focus of Kumar and Manoharan [3]'s study. The optimum climatic zone for the installation was established using HOMER software based on the net present cost, renewable fraction, carbon emission and annual diesel consumption. Gan et al. [4] examined the effects of peaks and troughs of wind speed and solar irradiation profile over a year period in sizing hybrid wind-PV-diesel systems for the daily and long term operation. The components of the hybrid system as well as its life-cycle cost was mathematically modelled to determine the optimum hybrid configuration.

The development of the insight-based Power Pinch Analysis (PoPA) for HPS design and optimisation has covered a wide range of applications, including power and storage allocations with energy losses considerations [5], HPS sizing [6], storage optimisation [7] and load shifting [8]. However, the effects of seasonal climate variations on the performance of HPS has yet to be explored using PoPA. Previous PoPA methods were developed by assuming that the same power source and demand profiles can be applied throughout the year. This might not be the actual case as both RE generation and power consumption may vary drastically due to the changing of seasons, especially during winter and summer. In this paper, both the RE generation and load profiles for different seasonal climates are analysed. PoPA is applied to establish the minimum electricity targets for each season, before the best generation and load profiles are selected for the in-depth analysis at the design and sizing stage.

2. Methodology

The effects of seasonal climate variations on HPS performance is mainly due to the difference in the renewable electricity generation as well as the end use demands data. Therefore, different seasonal climates were selected for the analysis. Winter and summer were considered because both have the most extreme climate switches among the four seasons.

2.1 Data extraction

The Illustrative Case Study involves HPS with wind and solar as the power producer. Fig. 1 shows the power generation profiles from wind and solar, respectively for both winter and summer. The load profile for the system during the two climates are presented in Fig. 2.

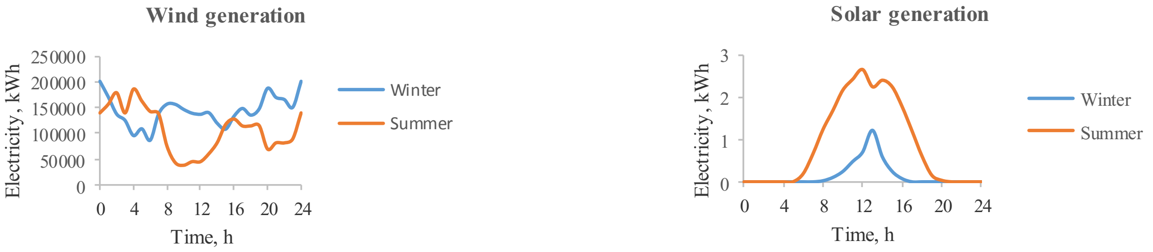

Fig. 1. (a) Wind generation profile; (b) Solar generation profile.

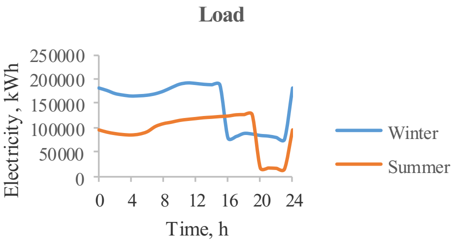

Fig. 2. Load profile

The profiles for RE generation and load demand for the two seasons show significant differences. It can be observed that the wind and solar generations are complementary. While wind generation is low during summer, the insolation of sun is high, thus producing more solar electricity. In winter, the wind electricity is high due to the high wind velocity, whereas the solar generation is very minimal throughout this season. Load profile overview show that the total consumption in winter is higher than during summer. This may be due to higher energy requirement to run heaters for heating purpose.

2.2. Determine the minimum electricity targets for each climate

The effects of the two studied seasonal climates were visualized using the PoPA tools known as the Power Composite Curves (PCC) and the Continuous PCC (CPCC). The step-wise construction is as described in Wan Alwi et al. [9];

1) Y-axis represents the time scale, while X-axis is the electricity generation or consumption in kWh.
2) Based on the generation profile data (see Fig. 1), individual source lines ware plotted corresponding to the time when the source are available. Similarly, individual demand lines were plotted according to their time of availability based on Fig. 2.
3) The sum of electricity sources (or electricity demands) within a time interval gives the source (or demand) composite line. The procedure was repeated for the rest of the system time intervals. After that, all the composite lines for each time interval were cumulatively added from time 0 h to 24 h, to generate the source (or demand) composite curve for the system.
4) The source and demand composite curves were combined in the same graph, with the source composite curve (SCC) placed on the right hand side of the demand composite curve (DCC). The SCC was shifted to the left hand side until it touches the DCC in order to determine the pinch point. The final plot after the shifting gives the complete PCC for the system.
5) The excess demand line below the pinch represents the minimum outsourced electricity supply (MOES) target for the first day operation. This is the amount of electricity that need to be purchased from external power supply.
6) The excess electricity source line above the pinch gives the target for the available excess electricity (AEE), which can be brought and used for the following days.
7) The amount of MOES and AEE for the normal 24-h operation (from the second day onwards) were obtained by merging the PCC for Day 1 with the next day's PCC. The SCC end for Day 1 was linked to the beginning of the SCC for Day 2, and give the continuous PCC or also known as the CPCC.

Fig. 3 shows the CPCC plots for both studied seasonal climates.

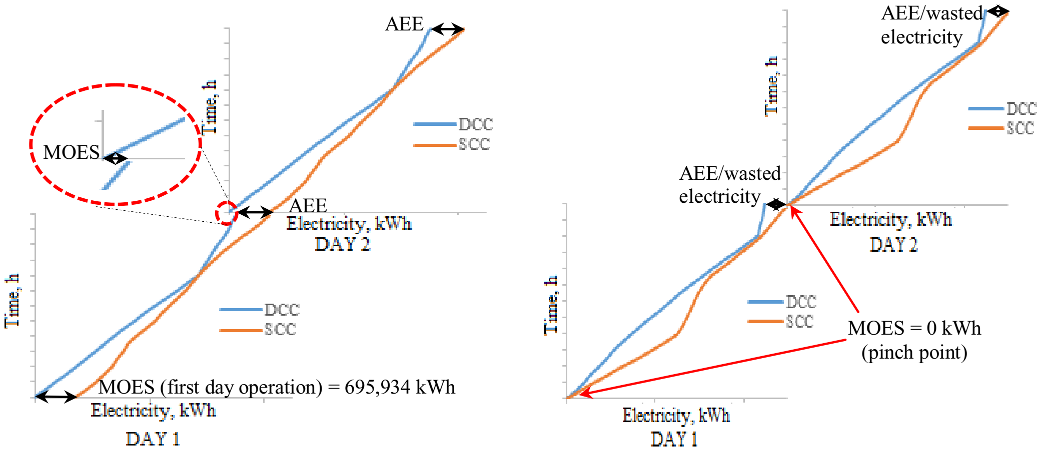

Fig. 3. CPCC for two subsequent days (a) Winter; (b) Summer.

The targets for MOES and AEE for the normal 24-h operation during winter and summer were extracted from the CPCC and are given in Table 1.

Table 1. Electricity targets for winter and summer climates

Targets	Winter	Summer
MOES (kWh)	121,024	0
AEE (kWh)	574,910	299,242

As observed, the electricity targets for the same site varies during the different climates. In winter, the system requires a high amount of MOES, while no power outsourcing was required during summer operation (MOES = 0 kWh). This may be explained by the load profile variations. Referring to Fig. 2, the profile for winter indicates higher power consumption, especially between time intervals 10 h and 15 h. It dropped and becomes lower than the summer load between 16 and 20 h, but nonetheless the consumption remains higher than the summer demand throughout the other time intervals. In addition, solar generation during winter is far lower than during summer. Even the ample wind generation in winter cannot compensate the shortage of the supply to the load. On the other hand, the total solar and wind generation during summer can sufficiently satisfy the lower load demand during summer and thus, no external electricity were required.

Based on Table 1, it can also be seen that both operations have excess of electricity at t = 24 h, or the AEE. Even though the AEE in winter is higher, it does not have any electricity surplus that is wasted (see Fig. 3). The surplus was stored for the next day's use. According to Wan Alwi et al. [9], CPCC plot for winter is categorized as Scenario 1, where the system has a reduced MOES amount (83% reduction, from 695,934 to 121,024 kWh) for the following days due to the AEE from the first day operation. On the other hand, summer operation demonstrates Scenario 2, as its AEE amount for both first day and normal 24-h operations is larger than the MOES amount. This excess cannot be brought to the subsequent days because it will accumulate and increase the capacity of storage.

The established targets can be used as a guideline for the sizing of generators and storage system. From the above analysis, it can be concluded that the operation in winter requires greater amount of outsourced electricity, thus higher electricity cost. During summer, no spending in electricity cost is needed but investment on the PV system and the storage will be higher compared to during winter. The decision is therefore up to the designers. The targets for both studied climates can be set as the feasible limits to decide on the size of the generators and storage, as well as to estimate the expenditure for the electricity cost.

3. Conclusion

A comparative study for hybrid power system's performance during different seasonal climates has been presented. The generation from RE as well as the load profiles for two climates namely winter and summer have been analysed. Minimum electricity targets for each data set have been established using PoPA method. Results from PoPA offers an overview of the feasible limits applicable for the sizing of generators and storage system. The demonstrated Illustrative Case Study shows that the electricity targets for winter and summer were significantly difference, which may influence the total investment on the HPS components, as well as the cost spent on outsourced electricity. Apart from the analysis using the same data set, i.e. construct PCC and CPCC using generation and load profiles from the same climate, the combination of generation profile from one climate with the load profile from another can be investigated.

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