Optimal Design and Sizing of Integrated Centralized and Decentralized Energy Systems

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Abstract

Concerns over sustainability of fossil fuels, and increasing awareness for the environment have encouraged countries all over the world to shift from the heavy reliance on fossil fuel to renewable energy (RE) resources for electricity generation. Although implementation of RE has been on the rise, large-scale deployment of RE still remains a challenge, especially in terms of economic and technicality. This paper proposes the integration of the current energy system (centralised energy system, CEG running on mainly fossil fuels) with the new energy system (decentralised energy system, DEG). Numerical analysis is developed to solve and target the proposed multiple DEGs and CEG integrated system at its optimum design and sizing. Two existing numerical approaches in Power Pinch Analysis are applied, i.e. Power Pinch Analysis (PoPA) for a smaller scale decentralised energy systems while the net energy deficit will be satisfied in a centralised energy system via Electric System Cascade Analysis (ESCA). The designated combination of Power Pinch methodology in this study is based on an hourly scale operation of both systems. With case study of five (5) DEG(s), the analysis indicates that DEG 1 has 540 MWh for energy-related capacity and 70 MW for power-related capacity. DEG 2, 480 MWh and 70 MW, DEG 3, 480 MWh and 120 MW, DEG 4, 1,000 MWh and 150 MW, and DEG 5, 100 MWh and 90 MW. The CEG power plants should have a total capacity of 48.3 MW with energy storage of 270.6 MWh and 45.1 MW.

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1. Introduction

Electrical energy produced at power stations is transmitted to sub-stations where it is distributed to the consumers through the use of transmission lines. A transformer is required within the power distribution process to step-up or step-down the voltage, suitable to be used by multiple end-users such as residential, commercial and industrial consumers. The vast majority of power grid network uses centralised energy generation (CEG) where electricity is generated in a large scale from centralised facilities. CEG are usually operated based on coal, gas and nuclear power plants. Some are generated from hydropower plants, wind and solar farms. Normally CEG are suitable for high-demand urban areas; however the facilities are usually located far away from end-users. Transmission losses of the centralised power plants becomes a concern.

During the electricity transmission, some energy is “lost” from the transmission system to the surrounding. Power distribution sector is considered the least efficient in the entire power producing and supply sector, with the distribution losses approximated as 50 % [1]. While for transmission losses, it is approximated as 17–22.5 %, depending on the network characteristics and operation mode. These losses are usually in the form of heat. The technical losses occurred in the transmission lines are mainly due to the transmission medium/wires or long distance of power transmission up to several hundred kilometres [2]. As a result, the power available to the end users has been reduced. The overall transmission systems must be designed properly to maximize the power generated from the central utilities.

The generation trend has becoming more localised via decentralised energy generation (DEG) system. DEG refers to a small-scale energy generation; the capacity ranges between 1 kW to 250 MW [3]. Compared to the conventional centralised generation, DEG is located at the vicinity near to electricity consumers. It is not directly connected to the bulk transmission system and is not centrally dispatched. Some advantages of DEG are, its localised characteristic can be used in remote areas where the main grid extension is difficult to access. In this case, it reduces the dependency from the centralised power system because it can self-generate and self-sustain. As the access to efficient energy sources from local is increasing, DEG becomes a more popular and practical type of energy generation system. For instance, the concept of Hybrid Power System has been introduced as one form of DEG, which utilizes two or more renewable energies as the power generation source. However the application of DEG especially those that operate on solar and wind power cannot be reliable on its own. RE may possess an issue of intermittency, which affect the electricity security at times of low resource availability. For instance, solar energy can be harnessed during the day but not the night; wind energy is accessible according to seasons.

According to Kursun et al. [4], complementing centralised grid with decentralised power systems improves energy reliability and independence. The power transmission and distribution losses in current CEG also contributes significantly to the overall performance and efficiency of the energy generation and distribution network, therefore it is a critical parameter to be improved on. In this work, the integration the current centralised and decentralised energy generation systems as a new form of energy system is proposed. This study applies Power Pinch Analysis to design and target the new integrated energy system at its optimal capacity. The methodology discussed in this paper is a combination of two existing Power Pinch Analysis namely Power Pinch Analysis (PoPA) [5] and Electric Cascade System Analysis (ESCA)
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