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Sustainable Power Plant Planning Using Pinch Analysis Approach

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Growing economic and population expansion has posed great stress in power plant planning as energy consumption is increased every year. Power plant expansion or new power plant construction require years of planning before implementation. Together with the aid of energy storage (ES) for improving power plant capacity factor, this work applied Electric System Cascade Analysis (ESCA) to identify the total power plants that are needed to fulfil energy demand in an on-grid power system. A hypothetical Case Study has created to consider the factors of ES charging and discharging efficiency, increment of energy demand, integration of existing with new power plant. The results obtained by ESCA are 929.22 MW of total power plants capacity, 1,073.44 MW of ES real capacity, and 2,614.39 MWh of ES energy capacity, as well as 298.98 MWh of initial content in the ES.

1. Introduction

Power plants planning is the upmost crucial tasks to ensure that the ever-increasing energy demand is met (Li et al. 2009). Many tools and techniques have been utilized to conduct power plant planning (Diamante et al., 2014). One of the promising techniques for planning sustainable power plants is via Power Pinch Analysis (PoPA) (Wan Alwi et al., 2012), a branch of Pinch Analysis (PA). PA was pioneered by Linnhoff and Flower(1978). The first representation of PA in a power system targeting was performed by Bandyopadhyay where Grand Composite Curve (GCV) were used for isolated renewable energy (RE) system sizing (Bandyopadhyay, 2011). With reference on Bandyopadhyay's work, Wan Alwi et al. (2012) presented two tools for PoPA technique: Power Composite Curve (PCC) and Continuous Power Composite Curve (CPCC) to determine the minimum outsourced electricity supply to be purchased and excess electricity available for the next day operation. Mohammad Rozali et al. (2012) extended application of PoPA by consider energy losses during power system conversion, transfer and storage. Ho et al. (2012) also proposes a stepwise numerical heuristics called the Electric System Cascade Analysis (ESCA) for designing a stand-alone Distributed Energy Generation (DEG) of biomass generator and energy storage (ES) systems. The technique suggested by Ho et al. (2012, is applicable to determine the optimal power capacity of the generator as well as the ES. Giaouris et al. (2014) proposed a systematic approach using Power Grand Composite Curve (PGCC) to identify optimum power management strategies. Since ES allows the balance between supply and demand to be achieved, suitable ES size is important. For example, chemical based ES (fuel cell and battery) are suitable for storing small size of energy, while mechanical energy based ES (pumped hydroelectric and compressed air) are suitable to store larger size of energy. This paper applied ESCA method to plan for the total power plant capacity that is required to meet future increasing energy demand. The configuration of the system consists of existing and new power plants that is integrated with a pumped hydroelectric ES to meet with the increased energy demand. A hypothetical case study is presented to demonstrate the application of the extended ESCA methodology in large scale power plant planning.

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2. Methodology

In the extended version of ESCA, an additional of two step is required prior to ESCA methodology (presented in Ho et al. (2012)'s work). Step 1, similar to ESCA methodology, data is collected, however in this case, additional data which include existing power plants capacity, soon to be shut down power plant, system configuration, and new energy demand profile (future energy demand) is required. Once the data is collected, in Step 2, a new energy profile (a combined profile of the future demand and the existing energy generation from existing power plants) is constructed. It is noted that, as the system now lacks of energy, it is assumed that the existing power plants will operate at its full capacity. Figure 1 summaries the flow of this paper methodology.

3. Case study

The Case Study presented in this paper begins with three power plants: Two coal fired power plant of 375 MW and 500 MW, and a natural gas (NG) power plant with capacity of 375 MW, supplying power to meet energy demands as shown in Figure 2. However, 20 y in to the future, energy demand is projected to increase by 35 %, and one of the coal-fired power plant (500 MW) will ceased from operation. With the increment in energy demand, the new load profile at year 2035 is shown in Figure 3. At this point, existing coal-fired power plant and NG power plant that still operate in year 2035 will operate at constant and full capacity with the total power of 750 MW. The new system configuration is shown in Figure 4. Figure 4 shows that the generation (Coal and NG power plant), ES (pumped hydroelectric ES) and demand are all alternating current and with no conversion loss from converting alternating current to direct current or direct current to alternating current. During low electricity demand period, the excess electricity is being utilised to pump the water to higher water reservoir (charging), whereas during high electricity demand, power is being discharged by releasing the water through turbine. The charging and discharging efficiency of ES is 88.3 % with the depth of discharge of 80 %. It is noted that the new power plants shown in Figure 4 can represent any type of power plants that generates alternating current and is not intermittent by nature. These power plants can be both fossil fuel based or renewable. After deducting 750 MW for each hour from the load profile (Figure 3), a new load profile that show surplus and deficit energy is shown in Figure 5. Figure 5 provides information of demand that is not fulfilled by existing power plant (positive values) and the excess energy produced by existing power plants (negative values) that can be stored in the ES. The excess energy is the energy that is not consumed by the demand at the time.

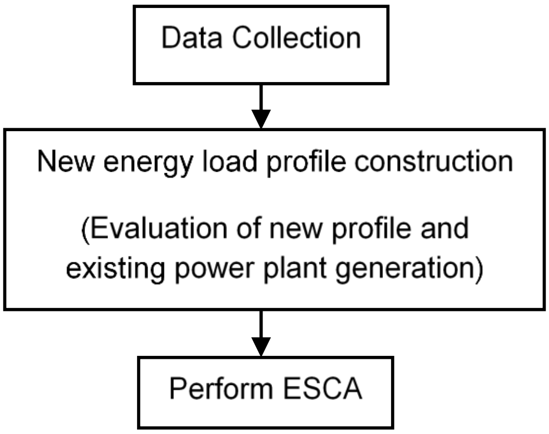

Figure 1: Summary of methodology

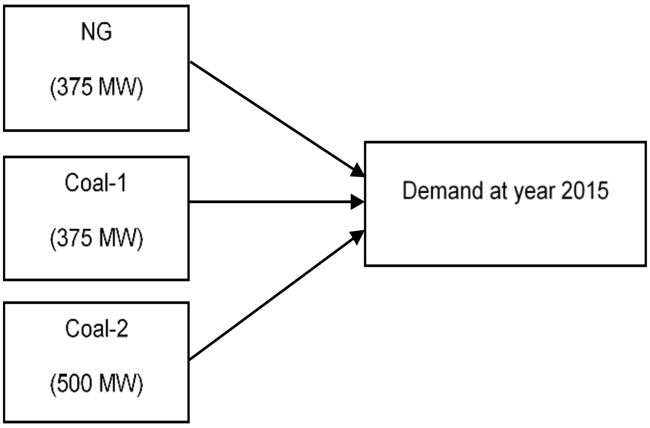

Figure 2: Year 2015 supply and demand configuration

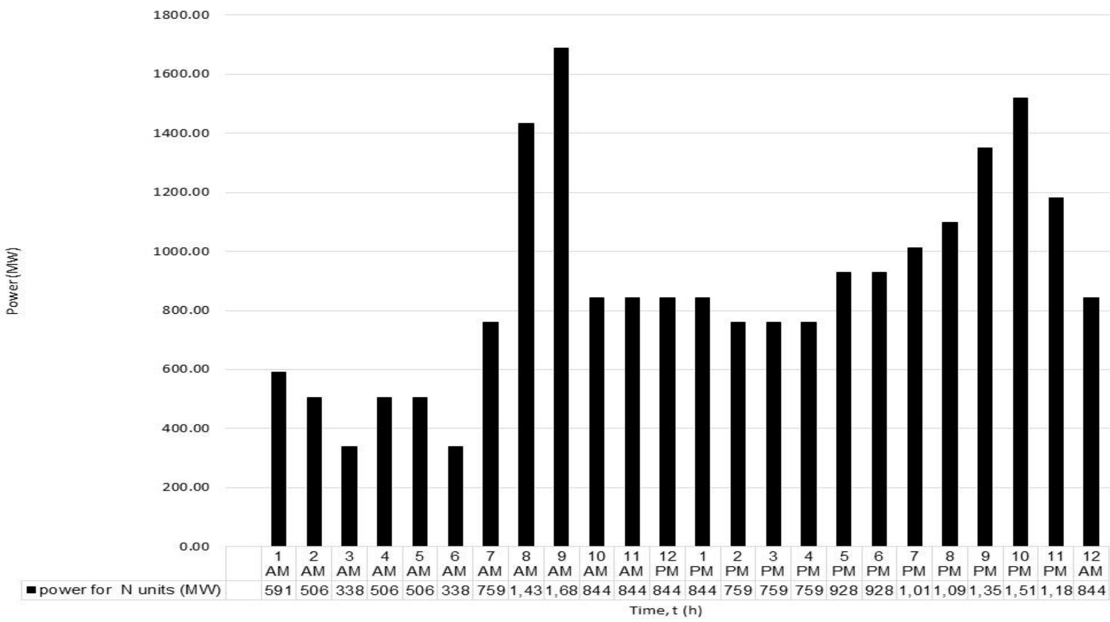

Figure 3: Year 2035 projected residential load profile

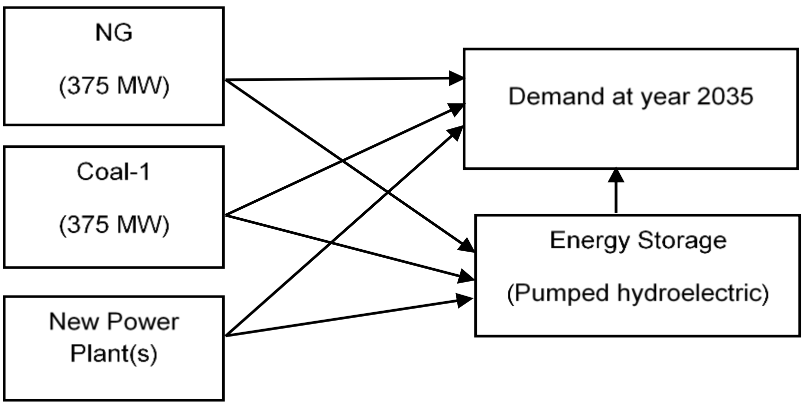

Figure 4: Year 2030 supply and demand configuration

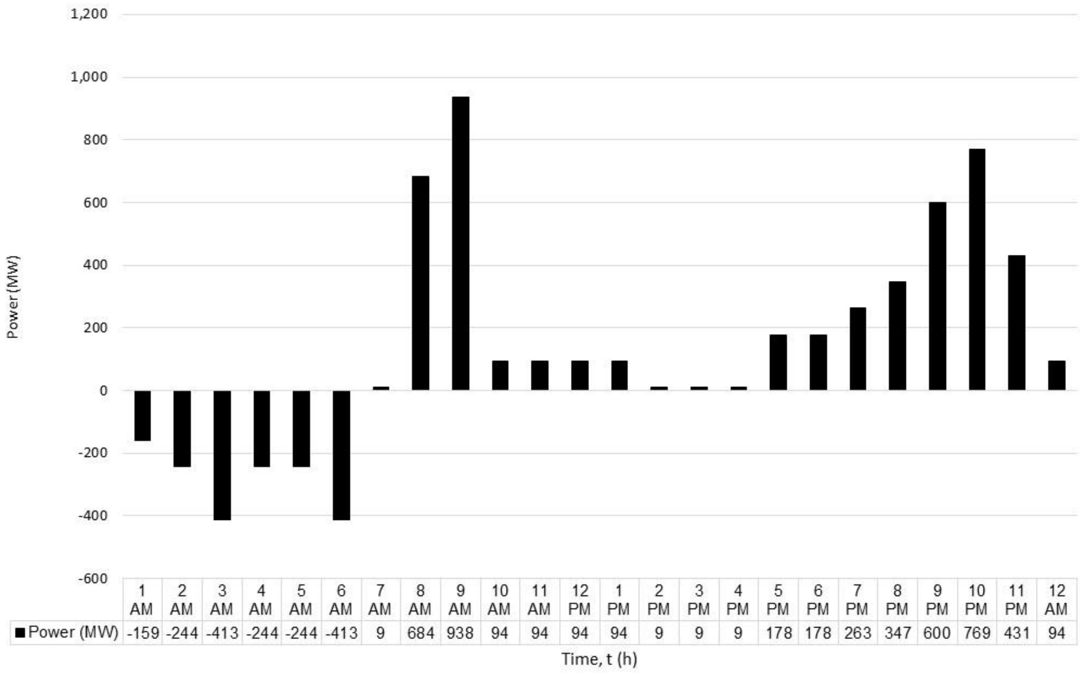

Figure 5: Year 2035 surplus-deficit based load profile

4. Results and discussion

Table 1 depicts the iteration results. The ESCA iteration is started by assuming 200 MW of total power plant capacity. Table 2 depicts the results for final iteration. From Table 2, the information that can be extracted are the optimized total capacity of new power plants combined (value in column 3), ES power (largest negative value in column 6) and ES energy capacity (largest positive value in column 7), as well as initial content of ES (the initial value in column 7). The result shows that the new optimized power plant capacity is 179.22 MW. Since the iteration is based on the new load profile as shown in Figure 3, the total capacity of existing power plants (375 MW + 375 MW = 750 MW) should be added to the value generated in Table 2. In other words, the total capacity of power plants that is needed to fulfil the energy demand in year 2035 is 929.22 MW (750 MW + 179.22 MW). The optimized battery power and energy capacity are 858.75 MW and 2614.39 MWh. Since the depth of discharge of ES is 80 %, the real ES capacity is 1,073.44 MW (858.75 MW ÷ 0.8) with the initial content of the battery in the beginning of the day is 298.98 MWh. The large size of the ES is due to the large demand requirement during off-peak and on-peak period. To ensure that energy is optimally utilize, a large portion of energy is charged into the ES during off-peak period to provide during on-peak period. However if no ES is installed, a total of 338 MW in capacity of power plants is required. By incorporating ES, 45.1 % capacity reduction from the total power plant capacity can be achieved.

Table 1: Iteration results

No. of iteration	Total Capacity of Power Plants (MW)	Percentage Change (%)
1	200.00	-
2	180.90	9.55
3	179.36	0.86
4	179.23	0.06
5	179.22	0.03

Table 2: Final iteration results

Time, t (h)	Demand, L_t (MWh)	Generation by new power plant, G_t (MWh)	Net energy demand, N_t (MWh)	Energy charging by pumping the water to reservoir, C_t (MWh)	Energy discharging through turbine, D_t (MWh)	Cumulative energy, E_t (MWh)
1 AM	-159.38	179.22	338.60	298.98	0.00	298.98
2 AM	-243.75	179.22	422.97	373.48	0.00	672.47
3 AM	-412.50	179.22	591.72	522.49	0.00	1,194.96
4 AM	-243.75	179.22	422.97	373.48	0.00	1,568.44
5 AM	-243.75	179.22	422.97	373.48	0.00	1,941.93
6 AM	-412.50	179.22	591.72	522.49	0.00	2,464.42
7 AM	9.38	179.22	169.85	149.98	0.00	2,614.39
8 AM	684.38	179.22	-505.15	0.00	-572.09	2,042.30
9 AM	937.50	179.22	-758.28	0.00	-858.75	1,183.55
10 AM	93.75	179.22	85.47	75.47	0.00	1,259.03
11 AM	93.75	179.22	85.47	75.47	0.00	1,334.50
12 PM	93.75	179.22	85.47	75.47	0.00	1,409.97
1 PM	93.75	179.22	85.47	75.47	0.00	1,485.44
2 PM	9.38	179.22	169.85	149.98	0.00	1,635.42
3 PM	9.38	179.22	169.85	149.98	0.00	1,785.39
4 PM	9.38	179.22	169.85	149.98	0.00	1,935.37
5 PM	178.13	179.22	1.10	0.97	0.00	1,936.34
6 PM	178.13	179.22	1.10	0.97	0.00	1,937.30
7 PM	262.50	179.22	-83.28	0.00	-94.31	1,842.99
8 PM	346.88	179.22	-167.65	0.00	-189.87	1,653.13
9 PM	600.00	179.22	-420.78	0.00	-476.53	1,176.59
10 PM	768.75	179.22	-589.53	0.00	-667.64	508.95
11 PM	431.25	179.22	-252.03	0.00	-285.42	223.53
12 AM	93.75	179.22	85.47	75.47	96.80	395.80

5. Conclusions

A great reduction in total capacity that is needed to fulfil the energy demand in the future can be achieved, with the aid of ES by using ESCA. This provides a valuable insight for power system planning that considers soon to be shut down power plant and increased energy demand in the future. However, it does not reveal the selection of new power plant(s) to be operated in the future. By considering power plant selection factors such as economic or environment, improved and more detail insight of power system planning can be done in future works.

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