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Application of Electric System Cascade Analysis for Various System Configuration

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Ongoing primary reliance on conventional fossil fuel resources such as coal and natural gas (NG) for energy generation may be the most economical method but also the most damaging to the environment. Energy management of power plant via sizing is one of the energy and economical saving methods. In this paper, Electric System Cascade Analysis (ESCA), an analytical pinch method is used for optimally size the generation capacity of power plant and storage capacity of energy storage. Energy can be direct current or alternating current, which require rectifier or converter to convert the energy before transporting. Therefore, energy system configuration has various combination depending on the type of currents on each part of the system configuration. The usage of ESCA will be applied on eight types of system configuration. A hypothetical case study is used to demonstrate the application of ESCA. Results show that the least energy lost due to energy conversion is the system configuration with the same type of current input and output.

1. Introduction

World energy generation are still vastly relies on conventional fossil fuel resources: oil, coal and natural gas (NG) (Lee et al., 2015). These finite fossil fuel resources are not only depleting year by year, but are also the main contributor to climate change (Sharafi and ElMekkawy, 2015). Renewable energy (RE) resources is green and clean from emitting CO_2, such as solar and wind energy that exist in abundance (Theodosiou et al., 2015). However, the intermittency nature of RE sources is making integration of RE resources into the power generation system become challenging (Mohammad Rozali et al., 2014). However, energy storage (ES) can smooth these fluctuation, allowing RE generation easier to be deployed and integrated into the power grid (Barelli et al., 2015). This integration system or also known as distributed energy system (DES) offer a quick fix and more environmental friendly options in power supply system (Belderbos et al., 2017). DES has gained growing interest due to the main three categories advantages: technical benefits, economic benefits, composite of technical and economic benefits as described by Ho et al. (2012).
Pinch analysis is an effective analysis method for optimisation process (Foo et al., 2014). Pinch Analysis was pioneered by Linnhoff and Flower (1978) and first applied for Heat Integration in the early application and after considerably extended (Klemeš, 2013). Following that, Pinch Analysis has been applied in the field of water network (Wang and Smith, 1994), gas network (Alves and Towler, 2005), and production planning (Singhvi et al., 2004). In 2011, Bandyopadhyay (2011) introduced Pinch Analysis for power system analysis. Both space design approach and Pinch Analysis were implemented in the work of Bandyopadhyay (2011) for designing an optimal isolated energy system. Wan Alwi et al. (2012) developed the Power Pinch Analysis (PoPA) tool, called as Power Composite Curve (PCC) with reference on Bandyopadhyay work to determine the minimum outsourced electricity supply to be purchased and excess electricity available for the next day operation for

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hybrid power system. In Wan Alwi et al. (2012) work, the power transfer and battery efficiency is considered 100 %. Ho et al. (2012) proposes a stepwise numerical heuristics called the Electric System Cascade Analysis (ESCA) for designing a stand-alone DES and storage systems with reference on Bandyopadhyay's work as well. The suggested technique by Ho et al. (2012), is applicable to determine the optimal power capacity of the generator as well as the energy storage. Ho et al. (2013) then extended ESCA to optimise solar photovoltaic (PV) system and subsequently incorporate load shifting to improve the power demand curve of an off-grid DES system. However, both Application of PoPA was further extended with another tool, Storage Cascade Table (SCT) which is able to consider the energy losses in the energy system design (Mohammad Rozali et al., 2014). With the consideration of energy losses due to conversion to direct current (DC) and alternating current (AC), this paper presents the guideline of using ESCA in sizing the DES with various system configuration.

2. Method

Figure 1 illustrates the new ESCA flowchart. With reference to the work of Ho et al. (2012), the method starts with data collection. Then the type of system configuration is determined. As shown in Figure 2, in DEG system, power generator, energy storage and load has various combination of AC or DC input and output. Figure 3 is presented to provide a step by step guidance on performing Cascade Analysis of ESCA.

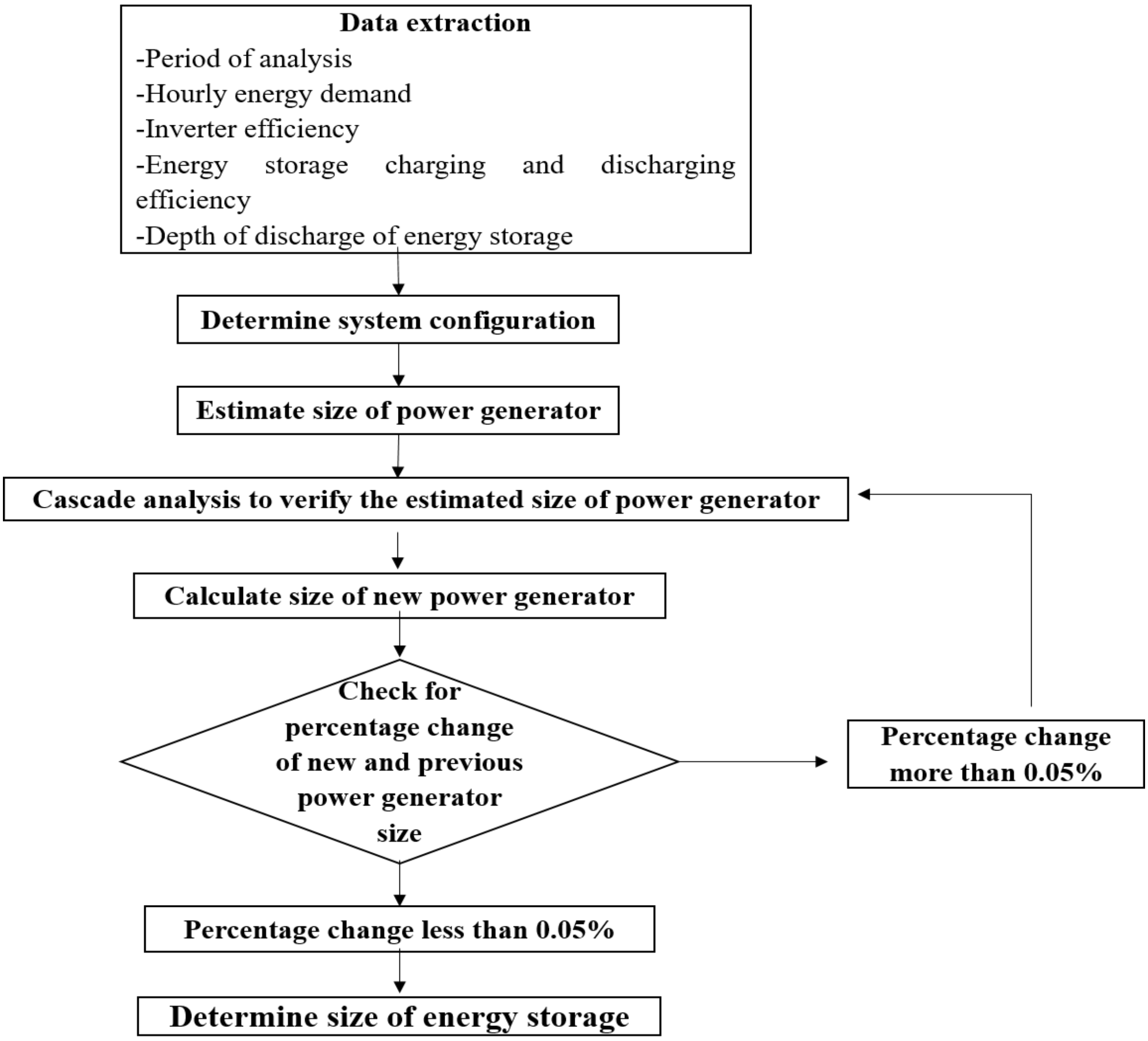

Figure 1: New ESCA flowchart

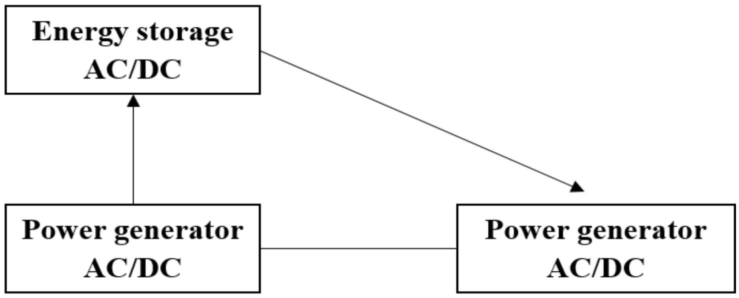

Figure 2: Basic representation of distributed energy generation system

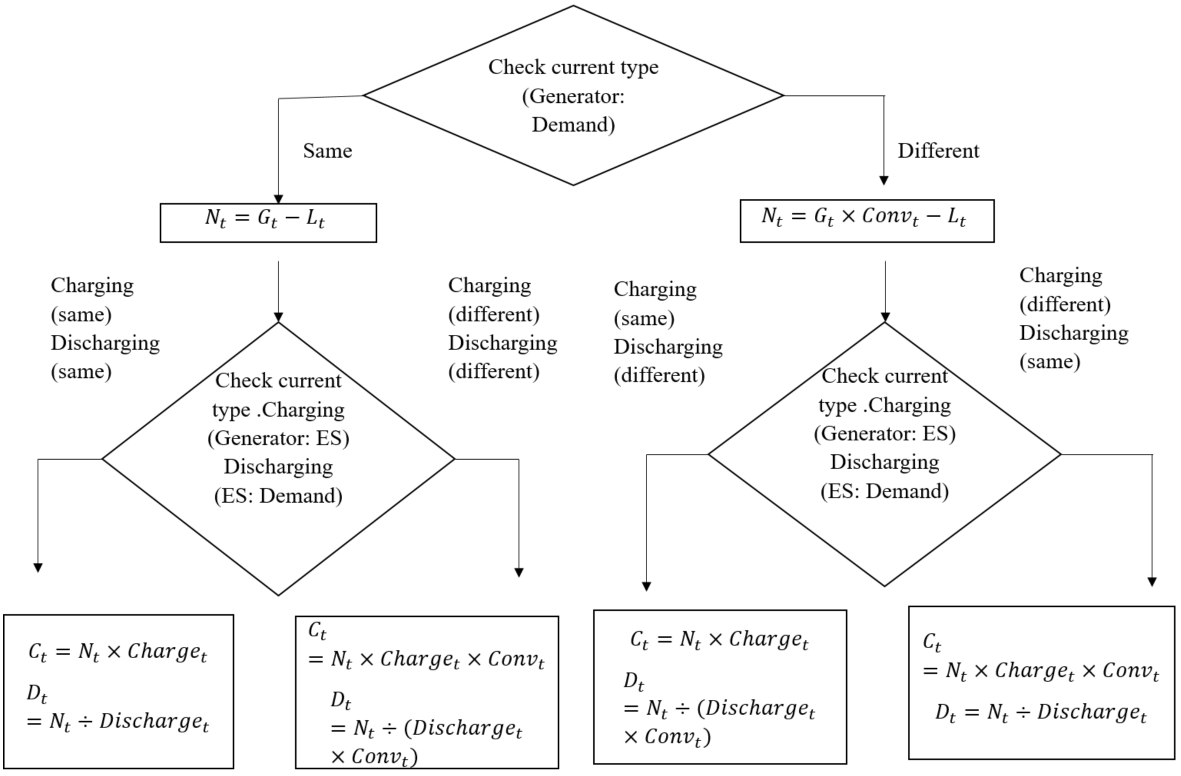

Figure 3: Guideline of ESCA on various system configurations

3. Case Study

A hypothetical case study with the daily load profile as shown in Figure 3 is conducted. As described in earlier section, each DEG part can have various input and output, a total of eight systems configurations can be presented:

Configuration 1: AC generator-DC ES-DC demand

Configuration 2: AC generator-AC ES-AC demand

Configuration 3: DC generator-DC ES-DC demand

Configuration 4: AC generator-DC ES-AC demand

Configuration 5: AC generator-AC ES-DC demand

Configuration 6: DC generator-DC ES-AC demand

Configuration 7: DC generator-AC ES-DC demand

Configuration 8: DC generator-AC ES-AC demand

The result of each configuration, followed with the guideline is shown in Section 4. Efficiency of inverter (converting DC to AC), rectifier (converting AC to DC), charging rate and discharging rate of energy storage are 90 %, 95 %, 88.3 % and 80 %. Depth of discharge of energy storage is assumed to be 80 %. The rest of the assumptions are similar with the work of Ho et al. (2012).

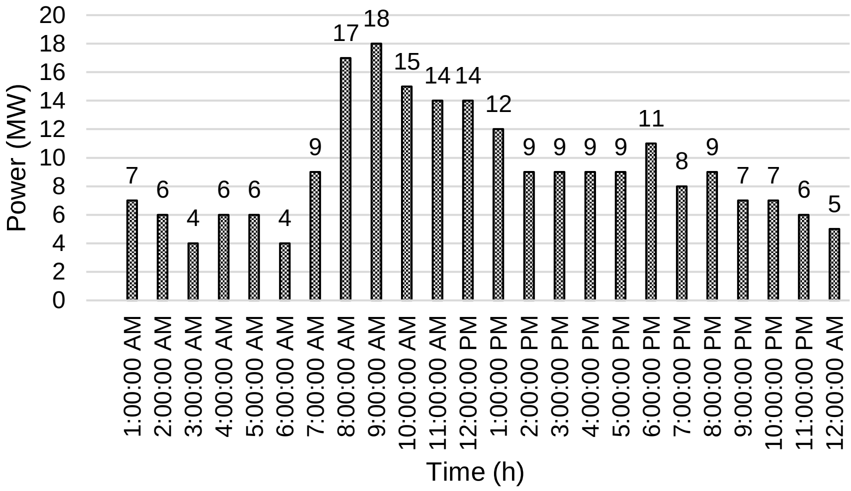

Figure 4: Load profile

4. Results and Discussion

The cascade analysis begins with configuration 1 (AC generator-DC ES-DC demand). Table 1 shows the number of iteration conducted in order to obtain a percentage change less than 0.05 %. In the configuration 1, 4 iterations are needed to achieve the criteria. Table 2 summarises the result obtained from the final iteration of configuration 1 to configuration 8. From Table 2, it is clear that configuration 2 (AC generator-AC ES-AC demand) and configuration 3 (DC generator-DC ES-DC demand) are the most energy and financial saving as they only need the smallest size of energy storage and generator. This is credit to no energy losses during the conversion of AC to DC and vice versa, as configuration 2 and 3 have similar input and output type. The most energy and financial consuming is configuration 6 (DC generator-DC ES-AC demand), as converting DC into AC incur more energy loss as compared to converting AC into DC. Table 3 shows the final iteration of configuration 1 using ESCA cascade analysis.

Table 1: Iteration results

No. of iteration	Generator size (MW)	Percentage Change (%)
1	10.00	-
2	10.35	5.0
3	10.38	2.9
4	10.38	0

Table 2: Result summary of all eight systems configuration

Configuration number	Generator size (MW)	Energy storage size (MW)	Energy storage energy capacity (MWh)	Initial content of energy storage (MWh)
1	10.38	10.17	46.35	14.41
2	9.77	10.28	67.40	30.60
3	9.77	10.28	67.40	30.60
4	10.05	11.05	48.86	15.33
5	10.48	11.17	50.14	15.67
6	11.06	11.17	50.15	15.67
7	10.05	10.47	45.26	14.53
8	11.06	10.06	45.14	14.11

Table 3: Final iteration results

Time (h)	Demand (MWh)	Generator size (MWh)	Net energy demand (MWh)	Energy Charging (MWh)	Energy Discharging (MWh)	Cumulative energy (MWh)	New cumulative energy (MWh)
							14.41
1:00:00 AM	7.00	10.38	2.86	2.40	0.00	2.40	16.81
2:00:00 AM	6.00	10.38	3.86	3.24	0.00	5.64	20.05
3:00:00 AM	4.00	10.38	5.86	4.92	0.00	10.56	24.97
4:00:00 AM	6.00	10.38	3.86	3.24	0.00	13.79	28.20
5:00:00 AM	6.00	10.38	3.86	3.24	0.00	17.03	31.44
6:00:00 AM	4.00	10.38	5.86	4.92	0.00	21.95	36.36
7:00:00 AM	9.00	10.38	0.86	0.72	0.00	22.67	37.08
8:00:00 AM	17.00	10.38	-7.14	0.00	-8.92	13.75	28.16
9:00:00 AM	18.00	10.38	-8.14	0.00	-10.17	3.57	17.98
10:00:00 AM	15.00	10.38	-5.14	0.00	-6.42	-2.85	11.56
11:00:00 AM	14.00	10.38	-4.14	0.00	-5.17	-8.02	6.39
12:00:00 PM	14.00	10.38	-4.14	0.00	-5.17	-13.20	1.21
1:00:00 PM	12.00	10.38	-2.14	0.00	-2.67	-15.87	-1.46
2:00:00 PM	9.00	10.38	0.86	0.72	0.00	-15.15	-0.74
3:00:00 PM	9.00	10.38	0.86	0.72	0.00	-14.43	-0.02
4:00:00 PM	9.00	10.38	0.86	0.72	0.00	-13.70	0.71
5:00:00 PM	9.00	10.38	0.86	0.72	0.00	-12.98	1.43
6:00:00 PM	11.00	10.38	-1.14	0.00	-1.42	-14.41	0.00
7:00:00 PM	8.00	10.38	1.86	1.56	0.00	-12.84	1.57
8:00:00 PM	9.00	10.38	0.86	0.72	0.00	-12.12	2.29
9:00:00 PM	7.00	10.38	2.86	2.40	0.00	-9.72	4.69
10:00:00 PM	7.00	10.38	2.86	2.40	0.00	-7.32	7.09
11:00:00 PM	6.00	10.38	3.86	3.24	0.00	-4.08	10.33
12:00:00 AM	5.00	10.38	4.86	4.08	0.00	-0.01	14.40

5. Conclusion

ESCA was shown for two specific cases for non-intermittent AC system coupled with a DC ES and AC demand and for intermittent DC system coupled with a DC ES and AC demand. As power systems are evolving and involving several combinations of AC and DC components, this work has managed to illustrate the applicability of ESCA to design and optimise for various possible combination of power systems to cater for current and future needs in optimisation of power systems.

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