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Investigation into transmission options for cross-border power trading in ASEAN power grid

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ABSTRACT

This work is a feasibility study of high voltage AC (HVAC) and high voltage DC (HVDC) transmission option for the Association of Southeast Asian Nations (ASEAN) Power Grid (APG) interconnections. An optimal power flow, a minimum-cost power generation model, is developed in the MATPOWER simulation platform to perform this analysis. Electricity generation and consumption data are taken from the latest power development plans of individual ASEAN countries for the evaluation of optimal cross-border power flow through the interconnections. Results show that APG can enhance power generation from countries with abundant renewable resources to meet the growing demand at load centers in the ASEAN member nations. An annual cost is used as the output matrix for this study. The analysis results reveal that in some interconnections, implementing HVDC link instead of currently planned HVAC could be economically beneficial for the APG. The findings in this paper would serve as valuable references for the APG planners.

1. Introduction

The member countries in the Association of Southeast Asian Nations (ASEAN) comprise the world's third fastest-growing economy (IEA, 2015a). Due to high economic growth, this region has a high growth rate in electricity demand in the world context. Meeting this growth rate in a techno-economic and sustainable way is challenging for the ASEAN nations (Chang and Li, 2015; IEA, 2015a). The interconnection of the proposed regional market in ASEAN region may contribute to meet this challenge in a secure, sustainable, and cost-effective way. Hence, the ASEAN Power Grid (APG) development is being implemented in ASEAN member countries (ACE, 2010; Ibrahim, 2014). APG may increase the access to energy resources by reducing the cost of the development of energy infrastructure. Moreover, it will enable the more economic power transfer from a power surplus region to a power deficit region. Furthermore, APG may reduce the overall operation cost of the generation system by reducing inefficient generation units. If APG is fully built, it can contribute towards the development of the geographically distributed variable renewable power generation capacity enhancement of ASEAN countries.

At present, ASEAN countries are generating power by prioritizing the affordability and availability of fuel types rather than the environmental sustainability. As a result, conventional energy sources, mainly oil, coal, and gas, are the dominant fuel mix, which contributed 82% of electricity generation in 2013 (IEA, 2015b). Nonetheless, this region is rich in renewable energy resources (RESs). The RESs of this region can be utilized for electricity generation. However, the geographical distribution of RESs limits their eventual utilization (Huber et al., 2015; Lidula et al., 2007; Taggart et al., 2012). Moreover, the lack of transmission facilities among the RESs and load centers is one of the major barriers to RESs utilization (Das and Ahlgren, 2010). Power generation from RESs can be promoted by APG, which in turn expedites cross-border trade and free movement of green electricity within the ASEAN region (Sambodo, 2013). To implement cross-border trade, a comprehensive investigation is sought, especially on technical, economic, and environmental issues during the interconnection of the power systems of individual countries. Among the grid interconnection issues, selecting the transmission technology (i.e., HVAC and HVDC) is the most critical because a massive investment is associated with commissioning the long-distance regional transmission line. More advanced and robust planning of transmission grids is necessary for the justification of the investments and the efficient grid design during practical implementation (Ergun et al., 2012; Torbaghan et al., 2015).

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HVDC transmission technology is becoming more attractive over AC technology because of the bulk power transferring capability from both onshore and offshore locations (ADB, 2014; Bahrman and Johnson, 2007). Nonetheless, HVDC has some advantages such as cost-effectiveness, reduced size and weight, low power loss due to the use of two cables, reactive power management, and harmonics. Though, HVDC transmission options are commonly preferred for transmission systems above a certain distance, evaluation of the detailed cost and benefit when choosing transmission options is necessary because distance is not only the factor in selecting transmission options (Ahmed et al., 2017; Van Eeckhout et al., 2010; Wang et al., 2008).

Several studies evaluated the HVAC and HVDC transmission options in (Elliott et al., 2016; Hur, 2012; Meah and Ula, 2007; Sousa et al., 2012; Van Eeckhout, 2008; Van Eeckhout et al., 2010; Wang et al., 2008). However, most of the research focused on the transmission options for offshore wind power plants in Europe. Recently, a comparative study between HVAC and HVDC transmission options for connecting the offshore wind farm in Great Britain was presented by Elliott et al. (2016). The authors indicated that the HVDC option would be economically feasible than the HVAC in the large power transmission from the offshore wind farms.

Nevertheless, limited research on transmission expansion planning has been reported for the ASEAN context, in particular, for APG establishment. Developing optimal power generation to meet the growing power demand of ASEAN countries by prioritizing renewable generation integration was presented by Chang and Li (2013). The benefits of different amounts of cross-border electricity transmission by considering the macroeconomic data of power generation and transmission, as well as the cost of losses and emission pricing, were also discussed by Chang and Li (2013). However, the availability of renewable sources (e.g., solar and wind) and the feasibility of transmission options are not considered by Chang and Li (2013). The financial sustainability of interconnecting cross-border power system for the ASEAN+2 (China and India) was presented in the study of Li and Chang (2014), where the benefits of different amounts of cross-border power transmission were analyzed. Matsuo et al. (2015) conducted a quantitative assessment of a future APG (ASEAN + Yunnan Province of China + North East India) interconnection based on the optimum power generation planning model and the supply reliable evaluation model for 2010–2035. This study considered maximum peak power demand, power generation cost, transmission loss, and transmission cost for optimal design of APG. The cost and benefit of various interconnection routes interconnecting Vietnam, Lao PDR, and Thailand were analyzed in this study. However, this study only considered hydropower as a potential candidate for power exchange instead of optimal generation. Huber et al. (2015) proposed an optimal sustainable power system development for the ASEAN region by considering all possible renewable generation resources. Cost–benefit analysis for three specific routes of APG was conducted by Fukasawa et al. (2015). However, the comparison between HVAC and HVDC transmission options for the selected routes was not presented by Fukasawa et al. (2015). Operation and maintenance costs were also not considered for cost calculation. Another evaluation study was conducted by ADB (2014) for the Borneo and Mindanao power systems. ADB (2014) concluded that the HVDC transmission options are suitable for certain routes for this part of the APG; however, more evaluation studies are required.

Based on research gaps, this study aims to compare the HVAC and HVDC transmission options for the point-to-point transmission interconnections toward the development of APG for the 2030 generation and demand scenarios. This study also analyzes the ASEAN electricity transmission network and the future needs of additional cross-border power transmission for a low-cost generation by considering the available power generation options of individual countries. The APG model for the 2030 scenario was developed to evaluate the HVAC and HVDC options. However, the developed APG model characterizes the representative APG based on publicly available data for the ASEAN region. This work considers all the proposed potential routes projected in the ASEAN Interconnection Master Plan Study (ACE, 2010; Ibrahim, 2014). The developed APG network represents a minimum-cost power dispatch model for the ASEAN power transmission network, which was developed for analyzing HVAC and HVDC options.

The rest of this paper is organized as follows: Section 2 presents the methodology of APG modeling and the scenario assumptions. Section 3 presents results and discussions of energy market simulation and economic feasibility between the HVDC and HVAC transmission options, as well as a sensitivity analysis on total annual costs and transmission distances. Section 4 summarizes the major conclusions, contributions, and implications of this work.

2. Methodology

2.1. Overview of the APG model

The APG model is developed here to analyze the economic characteristics of HVAC and HVDC connection options for all cross-border interconnections by considering the maximum requirements for cross-border transmission capacity under 2030 scenarios. This model also focused on minimum-cost power generation options to meet the growing electricity demand. Accordingly, all types of generation portfolios and maximum peak demands of 10 ASEAN countries are considered in this analysis. The variable generation costs of each type of generation are considered during the calculation of the optimal cross-border power flows among the interconnections. However, the model does not consider optimal cross-border transmission routes toward APG establishment.

The individual power transmission networks of APG are considered as a single node; the internal network constraints are not considered here. The reasons for this consideration are the lack of publicly available data (e.g., transmission line capacity, electricity consumption, and generation time series) on the entire ASEAN transmission network and the computational complexity associated with a large geographic transmission network. In addition, the unavailability of detailed demand and generation data for ASEAN countries compels the representation of large geographical countries, such as Myanmar, Thailand, Vietnam, and Laos, by only one single region in this model. Nevertheless, the results could give the idea about the future cross-border power transmission scenario for the ASEAN region to the investors and policy makers.

2.2. APG network

APG network is represented in this study by 15 nodes because of the presence of 15 isolated Transmission System Operators (TSOs) in the interconnection project. Myanmar, Thailand, Laos, Cambodia, Vietnam, Singapore, Brunei, and Philippines (i.e. Luzon grid) are represented by a single node. Malaysia is represented by three nodes, namely, Peninsular Malaysia, Sarawak, and Sabah. Indonesia is represented by four nodes, namely, Sumatra, Batam, W. Kalimantan, and E. Kalimantan. These 15 nodes are interconnected by cross-border transmission links (ACE, 2010; Ibrahim, 2014). In this model, no capacity limit is considered for the cross-border transmission links.

The transmission network is parameterized by publicly available data in the given transmission voltage level for the power flow and optimal power flow (OPF) modeling. The typical single-circuit reactance value used in this model is 0.31 Ω/km for 380 kV lines at 50 Hz during the DCOPF modeling (Say, 1973). Resistance and shunt admittance have been ignored in the DC power flow model for simplicity (Zhou and Bialek, 2005). Only distances of the cross-border interconnections are considered to model the APG (ADB, 2014; Energy Commission, 2016; Fukasawa et al., 2015). In countries where more