A REVIEW OF IMPLEMENTATION OF GLOBAL ENERGY INTERCONNECTION IN INDONESIA: JAVA AND SUMATERA ISLANDS

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ABSTRACT

Indonesia is called an archipelago state because consists of land and sea territory with plentiful resources of renewable energy such as geothermal, hydro, solar, wind, and bioenergy. The optimization of local renewable energy needs to support the national demand for electricity in Java as the majority of industrial areas and Sumatera with the highest usage of renewable energy (hydro power plants). The Global Energy Interconnection (GEI) is a modern energy system purposed to achieve global power demand in renewable energy, especially in reducing the level of CO2 emissions. This study aimed to review the mechanism of global energy interconnection if applied in Java and Sumatera islands, Indonesia. This study also applied the descriptive qualitative method with secondary data derived from the results of references review, journal interpretation, and publications research. The data needed is collected by literature study of the collections of data, theory, and concepts from various research sources related. The results indicate that HVDC interconnection between Java and Sumatera islands are more feasible to be implemented to fulfill the high energy demand and to transfer power across the island with renewable energy to achieve Net Zero Emissions in the future. The interconnection grid designed based on the GEI concept at a high level of electrification, large scale of clean energy development, and grid interconnection across regions will increase the transition energy towards a modern energy system.

Keywords: *Global Energy Interconnection, Renewable energy, High Voltage Direct Current, Java and Sumatra Islands.*

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1. INTRODUCTION

Indonesia is called an archipelago state which consists of land and sea territory totaling 17,508 islands with 80 % of the power supplied by Indonesiastate-owned electricity company or Perusahaan Listrik Negara (PLN) and 20 % fulfilled by Independent Power Producers (IPPs) [1]. Fig-1 shows the territory of the Republic of Indonesia and its border countries in the Pacific Asean Field.

Fig-1. The territory Republic of Indonesia and its border area in Pacific Asean [2]

Indonesia's energy final consumption total in 2019 was dominated by industrial, commercial dan power plant sectors, predicted will increase by 3.5 % per year with the average growth rate while electricity will increase by 4.7 % per year in 2050 [3]. As an archipelago state, Indonesia is blessed with plentiful resources of renewable energy such as geothermal, hydro, mini-hydro, solar, wind, and bioenergy. According to [4] the potential and installed capacity for power plants with resources of renewable energy in Indonesia consists of geothermal, hydro, mini-hydro, solar, wind, and bioenergy. However, bioenergy which is CPO also used as fuel in the transportation sector as a substitute for diesel oil. Fig-2 showed the potential and installed capacity with resources of renewable energy to support Indonesia's demand.

The purpose of optimization of local renewable energy is to optimize regional's renewable resources in terms of fulfilling the demand for electricity so the development of the electrical system in Java and Sumatera islands are observed. While the supply model considers all the potential renewable resources in Indonesia including four electrical systems such as Sumatera, Southern Sulawesi, Maluku, and West Papua. Optimation scenario of renewable resources to each province also considering its regional development plan. Currently, to support the base load, Indonesian used fossil power plants (coal and gas) also renewable energy (hydro, geothermal, solar, wind and bioenergy. Besides that, the intermediate is supported by a power plant based on fuel oil, and lastly, the peak load is supported by hydro, diesel, and gas-based power plants.

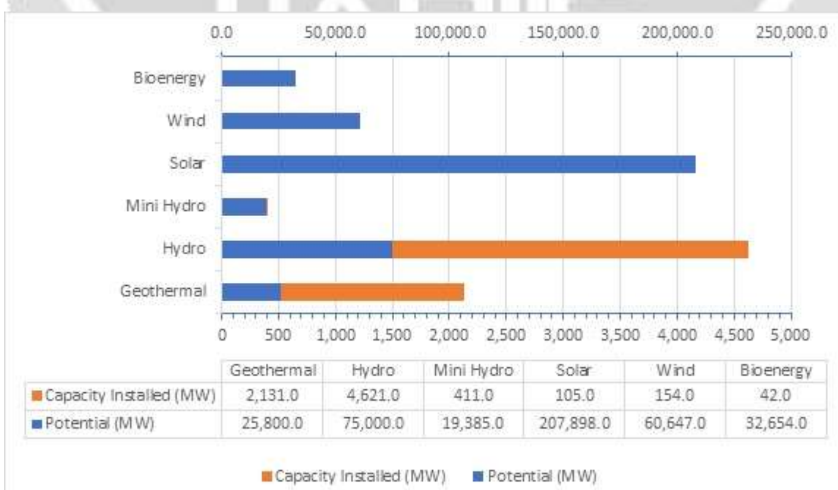

Fig-2. The potential and installed capacity of renewable energy power plants in Indonesia [3]

As per [5], North Sumatera has the highest usage in hydropower plants while Java Island is currently dominating support the national energy demand by fossil power plants. The primary energy usage in Java and Sumatera islands describe in Table-1.

Table-1. The primary energy usage in Java and Sumatera island [5]

Locations	Primary Energy							
	Oil Fuel		Natural Gas		Coal		Renewable Energy	
	(TOE)	%	(TOE)	%	(TOE)	%	(TOE)	%
Java	6348	69.4	82	0.9	2092	22.9	629	6.9
Sumatera	4184	78.9	488	9.2	72	1.4	561	10.6

Since the Indonesian government has agreed on Intended Nationally Determine Contribution (INDC) to reduce emission carbon in 2030 by 29 % and 41 % if helped by international also to achieve Net Zero Emission (NZE) in 2060, therefore interconnection will increase both the availability and reliability on the power supply to minimize the environmental impacts because of fossil fuel [1] [6]. To achieve this goal, the government has released several main regulations between *Peraturan Pemerintah* No. 79 in 2014 about National Energy Policy *or Kebijakan Energi Nasional* (KEN) and *Peraturan Presiden* No. 22 in 2017 about National Energy General Plan or *Rencana Umum Energi Nasional* (RUEN) [3].

However, according to [4] there are several challenges regarding energy issues in Indonesia such as :

1. Domestic consumption depends on gas dan coal fuels
2. Energy access to power plants and city gas networks centered on a densely populated island
3. Difficulties in determining feed-in tariff in renewable energy for business entities
4. The lack of renewable energy technology
5. Require energy substitution in industry and households
6. Minimummun of budget allocation for science and technology research
7. Require the government's commitment to greenhouse gas emission reduction
8. Require energy buffer management and fuel operational reserve

Studies to forecasting models of future energy systems have been done with almost 180 research articles on renewable energy system design that demonstrate technical and economic feasibility [7]. Previous studies focused on Cost-benefit analysis through the calculative device used to study the energy flows with and without interconnectors [8], while [9] analyze the important aspects of Global Energy Interconnection, and [7] study the future cone concept to define the scope and purpose of foresight compared to forecasting method. Despite having limited scope and divergences due to an active and dynamic environment, future energy design is one research field that required many techniques to achieve future energy concepts [7]. The interconnection grid was designed based on the GEI concept at a high level of electrification, large-scale clean energy development, and grid interconnection across regions believed to be one way of the energy transition. This study analyzes the potential of resources of renewable energy in the implementation of interconnection to support Indonesia's energy security.

2. MATERIALS AND METHODS

This study applied the descriptive qualitative method with secondary data derived from the results of references review, journal interpretation, and publications research. The data needed is collected by literature study of the collections of data, theory, and concepts from various research sources related. A case study is an exploratory process related to systems, events, activities, or various cases from time to time with complex sources of information. The characteristics of the study cases include: (1) identifying a case as a study, (2) Case is a system bounded by time and place, (3) Case study use complex and in-depth data to provide an overview of events, and (4) Researchers are considered to spend plenty of time to draw related the context or setting for a case. While the analysis process refers to qualitative data that has been analyzed to get an explanation of the problems.

According to [10] “Scenarios are stories about what could happen in the future—not what will happen (predictions) or what should happen (proposals)— but what could happen over the coming years …”. For optimization scenarios using special assumptions as follows:

- The existing renewable energy potential is only used to meet the needs of electricity supply.
- The electrical systems have 3 types of loads such as base, intermediate, and peak load.
- The renewable energy potential is used to support the base load and peak load of the existed electricity system.

Sumatera and Java Islands were chosen as the case study for the implementation of renewable energy in the interconnection scenario since North Sumatera has the highest usage in hydropower plants while currently Java Island is dominated by fossil power plants to support national energy demand. To conduct the analysis. There are four main steps to be followed :

1. Current situation analysis, starts with identifications of potential renewable energy data in Indonesia.
2. Supply-demand analysis, the identification of potential renewable data used to analyze the opportunities and generate the feasibility of development in the future.
3. Set a target for renewable energy usage as an action plan. The development of renewable energy implemented in public service, for example, investment in energy sectors, or institutional settings for implementation of renewable energy to support its load.

3. RESULTS AND DISCUSSION

3.1 GEI’s Concept

Global warming and climate change awareness had became a serious matter globally since affected all aspects of natural and human systems also causing extreme events and disasters economically [11]. The Paris agreement is one of the methods agreed upon by countries to limit the global average temperature below 2 °C as in the pre-industrial era. Fossil fuel is alleged as the dominant contributor to CO_2 emissions in fossil fuel combustion. Lately, mass campaigns and utilization of renewable energy such as solar, wind, hydro, geothermal, and nuclear energy alongside Carbon Capture Storage (CCS) and bioenergy wildly spread across nations to set awareness toward global citizens. The modern energy system will be dominated by low-carbon to zero-carbon energy sources and mass-produced electrification tools in households, transportation, and industry sectors since represent cost-efficient and environmentally friendly [11].

The Global Energy Interconnection (GEI) is a modern energy system that used smart grids, ultra-high voltage (UHV) grids, and renewable energy to supply energy demand across the world [11]. A smart grid is used to connect and distributed various energy resources for efficient utilization. The UHV grid is the GEI’s key component which transmitted alternating current (AC) up to 1000 kV and direct current (DC) at voltages of ± 800 kV. Renewable energy with related technologies is expected to demonstrate stability and efficiency will replace fossil fuels and will be dominantly used in the future [11].
The GEI these days received enthusiastic responses across the countries such as North & South Asia, Africa, and Emirate of Arab, etc [12]. The main elements of GEI according to [13] are presented below :

1. Energy Transaction, the GEI as the energy transmission of various primary energy in electricity needs to be transmitted to its end-user properly.
2. Resource Allocation, the GEI despite intermittent uncertainty of renewable energy resources (RESs) needs to balance the load and generation considering time and season among the countries.
3. Information Interaction, the GEI collects and analyzes data in real-time communication between suppliers and customers.

3.2 The Implementation of Interconnections Around the World

Europe is one of the countries that is committed to the low carbon energy transition. Interconnectors that link the electricity system to EU markets with total capacities of 4 GW such as Brexit (UK-EU), BritNed (Netherlands), IFA (France), Moyle (Northern Ireland), EWIC (Ireland), and Nemo interconnector in Belgium. Interconnectors believed can help reduce carbon emissions by 80 % in 2050 as well as Europe’s renewable energy uses target which is 15 % by 2020 since interconnectors are considered as low carbon, low cost, and secure the electricity system by increasing their flexibility, decarbonizing the electricity security supply, and reduce the electricity prices [14]. The existing and proposed interconnectors in Europe countries are shown in Fig-3.

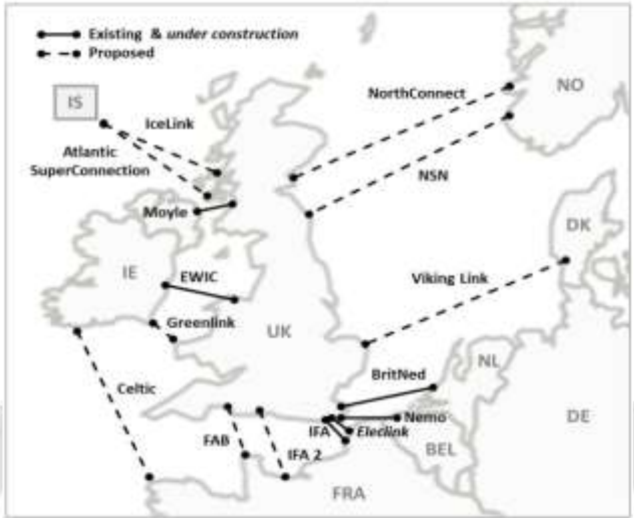

Fig-3. The existing and proposed interconnectors in Europe countries [14]

The result of the Cost-Benefit Analysis by Viking Link showed that alternative energy systems potentially integrate renewable energy and increase public acceptance. On the other side, the transition energy by Viking Link could be an excellent example of a new economic perspective to achieve a sustainable transition [8]. The Viking Link's design of cable construction was examined to show corresponding thermal emissions of submarine cable installation in German's AWZ [15]. The principle of High Voltage Direct Current (HDVC) interconnector under the sea is illustrated in Fig-4 as shown below.

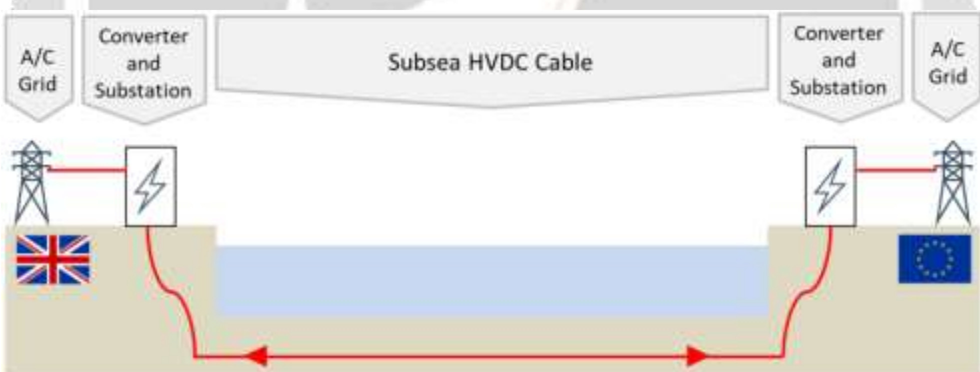

Fig-4. Illustration of HDVC interconnector under the sea [14].

Interconnections between UK and Denmark, known as Viking Link is a project of submarine transmission line by National Grid Viking Link Limited (NGVL) and Energinet. DK crosses the territorial water of the Netherlands and Germany with a total voltage of 525 kV and a maximum load of 1.400 MW. Viking Link consisted of approximately 760 km cables (submarine and onshore) in length which were divided according to their area such as the offshore part to transmit direct current crossing the exclusive economic zone (AWZ) of the UK, Netherlands, Germany, and Denmark need 630 km. Also, the onshore area needs approximately 55 km in the UK and 75 km in Denmark [15]. Fig-5 illustrates the route of the Viking Link that connects between United Kingdom, Netherlands, and Denmark.

Fig-5. The Illustration of Viking Link's route that connects between United Kingdom, Netherlands, and Denmark [15]

3.3 Electrical Power System in Indonesia

Generally, the electrical power system is divided into three main parts: power plant, high voltage transmission grid, and distribution system to transmit power to the final consumers which are usually to coverage area for example Jawa Bali Electrical Power System or *Sistem Tenaga Listrik Jawa Bali* (STLJB) otherwise called as Jawa Bali System *Sistem Jawa Bali* (SJB) that covers the Jawa islands, Madura and Bali [16, 17]. To achieve the purpose of the power system's operation, the following three points must be considered :

a. Economy, meaning that the electricity needs to be operated as economically but still considering the security and its quality.
b. Security, meaning the level of system security.
c. Quality, meaning that the quality is measured by the fixed level of voltage and frequency.

The purpose of the electrical power system's operation can be seen as shown in Fig-6. However, the electrical power system could perform normal, standby, emergency, and recovery conditions. The normal condition occurs when the security system is approved, operational failures handled and consumers are well served. Standby condition occurs when operational failures and consumers are well served but system security can't be obtained. The emergency condition occurs when consumers and operational failures can't be obtained. Lastly, recovery condition occurs when electricity's emergency transition is measured by the quality of voltage and frequency kept as per some agreed level. These conditions lead to various problems that happened during the electrical power system's operations such as frequency setting, operational and maintenance cost, system development, system disruption, and voltage in the system.

Fig-6. The purpose of the electrical power system's operation [17]

According to [17] the electrical power system's operation of the unit of power plants categorized into three types which are :

1. Base load power plant, with capacity factor > 57 % and the average operations 5000 hours per year. This power plant has great output power, high capital cost, and low operational cost usually formed by coal and geothermal power plants.
2. Medium load power plant, with a capacity factor of 23-57 % and the average operations around 2000-5000 hours per year. A combined cycle and gasses power plant could be used as a medium load power plant.
3. peak load power plant, operated to support peak load with the average operations less than 2000 hours per year and the capacity factor < 23 %. Peak load power plant less in capital cost but high operational cost so usually use pump storage, oil, water, and diesel-based power plant.

Indonesia's electricity system is currently only able to accommodate electricity production from renewable energy plants to meet the needs of the base load and peak load. In the Province of Naggroe Aceh Darussalam (Sumatera) the base load demand is predicted to keep increasing until 2024 with 43-65 % support by the coal power plant and 5-24 % supported by the geothermal power plant. The Government of the Province of Naggroe Aceh Darussalam plan to maximize the potential of geothermal energy to meet the base load needed in the Sumatra region. For other renewable energy generators such as hydro (run-off river), solar, and bioenergy the tendency to support base load is considered still inadequate, in the future hydro generators used to run off river could supply the power of Sumatera's electricity system for 1-5 % out of total base load demand which is 19,023-58,783 GWh. The simulation model showed that hydro and fuel power plants could support the peak load demand until 2024 with hydro continuing to increase while fueling degradation after 2021. As per mentioned before Indonesia's electricity system couldn't afford to support medium load demand so technical readiness especially frequency and demand projection with valid certainty needed to support the demand for renewable energy in the future. The reverse margin that portrays the power reserve of peak load power plants in the national electricity system showed 25-35 % and we need to set awareness of the reverse margin's drop potential in Sumatera due to the lack of balance in renewable energy power plants [10].

To transfer the power from Java – Sumatera will take a transmission line approx 400 km in length, a submarine cable approx. 40 km in length across in Sumatera and transmission line approx. 300 km in length in Java so basically the total line length of the interconnector is about 700 km length. To operate 450 kV in voltage level that transfer 2,400 MW power, a submarine cable is used as the type of cable selected by the global experience for DC system since filled with oil and mass impregnated. From the cable terminal, the parallel two cables for each pole will be divided into the smaller amount of high voltage configurations. The losses due to overhead lines and cables will contribute about 122 MW and since High Voltage Direct Current (HVDC) is a modern technology this scenario is predicted to cost 922,70 MUSD with transfer price up to 0,73 cent/kWh [1]

3.4 Interconnections As Future Energy System

HDVC interconnection has fewer effects on electromagnetic and static fields, less audible noise, and radio interferences around conductors in the environment. Determine the structure of future energy systems that lead to transition energy into low carbon energy need support from policymakers (government) and ensure its development will be completed in the short-term to 2050 and beyond. Regardless, the outcome of interconnectors is a "regret-free" option for contributing to decarbonizing the energy system and as a part of future government policy [14]. The cooperation on energy issues in the Brexit interconnection's case will impact the other country since related to the natural environment and physical infrastructure between UK and EU, furthermore it is also useful to maximize synergies among those countries. The UK is well-known as a leader of "real economy diplomacy" when several countries collect their ideas to support each other in redesigning the energy sectors, economies, and society as happened in the Powering Past Coal Alliance. A political declaration on the development of a North Sea grid-connected across the region has been agreed upon by ten North European countries called as North Seas Countries Offshore Grid Initiative (NSCOGI) as a way to ensure a low carbon future energy as well as deliver the benefits of economic and energy security to participants. The EU plans to expand interconnector capacity by installing generator electricity capacity to 10 % by 2020 and 15 % by 2030 [14].

3.5 Mechanism of CO_2 Emission Reduction by Global Energy Interconnection

The reduction of fossil fuels by utilizing resources of renewable energy as final energy consumption forms a general pattern of the global interconnection power grids across regions, countries, and continents so basically GEI is called a modern energy system [11]. International Renewable Energy Agency showed that the total primary energy supply provided by renewable energy in 2015 is 15 % and is predicted to increase by 66 % in 2050 [18]. Electricity production and the industrial sector are required to reach a zero-emission level in 2050. The advancement of electrical devices, as well as the development of zero-carbon buildings, will enhance the domination of energy sources by electrification in advance to achieve the 2 °C temperature limitation by the IPCC. Clean energy as the interconnection grid to distributed across the world despite its intermittent and volatile need to be integrated into a macro-power grid on a large scale. By 2017, China has been developed 25 UHV projects that covered 37,000 kilometers of transmission lines and 210 GW of transmission capacity making China the largest country with integrated power capacities for hydro, wind, and photovoltaic energy sources in the world [11]. By around 2050, the fossil fuels production of energy reach its peak and begin to decline the next years from 67 % to 31 % from 2015 to 2050 while the production of clean energy will expand every year [11]

4. CONCLUSIONS

HVDC interconnection between Java and Sumatera islands are feasible to be implemented to fulfill the high energy demand and to transfer power across the island with renewable energy in order to achieve Net Zero Emissions. The interconnection grid technologies as global production, allocation, and utilization of clean energy resources believed can reduce CO_2 emissions. In addition, the CCS component helps eliminate emissions from power generation-based fossil fuels. By increasing interconnection grid coverage and outreach the optimization of global allocation of renewable energy sources will be able to supply national energy demand. The interconnection grid designed based on the GEI concept at a high level of electrification, large scale of clean energy development, and grid interconnection across regions, countries, and continents, will increase the transition towards the modern energy system.

5. REFERENCES

1. Sudarmadi, D., et al., *DC Interconnection between Java and Sumatera, in Indonesia*. IEEE, 2006. **X**(06): p. 1210-1214.

2. Texas, U.o. *The Perry-Castañeda Library (PCL) Map*. 2021; Available from: https://maps.lib.utexas.edu/maps/middle_east_and_asia/indonesia_pol_2002.jpg.

3. BPPT, *OUTLOOK ENERGI INDONESIA 2021 (Perspektif Teknologi Energi Indonesia : Tenaga Surya untuk Penyediaan Energi Charging Station)*. 2021, Badan Pengkajian dan Penerapan Teknologi: Tangerang. p. 1-84.

4. Nazara, S., *Energy Transition Policy In Indonesia*. 2020, Kementerian Keuangan Republik Indonesia: Jakarta.

5. Winarno, O.T., Y. Alwendra, and S. Mujiyanto, *Policies and Strategies for Renewable Energy Development in Indonesia*, in *5th International Conference on Renewable Energy Research and Applications*. 2016, IEEE: Birmingham, UK. p. 270-272.

6. Indonesia, P.R., *Peraturan Presiden Republik Indonesia Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional*. 2017, Sekretariat Kabinet RI: Jakarta.

7. Gilmore, N., et al., *Clean Energy Futures: An Australian Based Foresight Study*, UNSW, Editor. 2021: Australia. p. 1-30.

8. Hasberg, K.S., *Constructing Viking Link : How the Infopower of Cost-benefit Analysis as a Calculative Device Reinforces the Energopower of Transmission Infrastructure*. Open Edition Journals, 2020. **10**(3): p. 555-578.

9. Voropai, N., S. Podkovalnikov, and K. Osintsev, *From Interconnections of Local Electric Power Systems to Global Energy Interconnection*. Global Energy Interconnection, 2018. **1**(1): p. 4-10.

10. Resources, M.O.E.A.M., *Prakiraan Penyediaan dan Pemanfataan Energi Skenario Optimalisasi EBT Daerah*. 2016, Pusat Data dan Teknologi Informasi Energi dan Sumber Daya Mineral KESDM: Jakarta.

11. Zhou, Y., et al., *Mechanism of CO2 Emission Reduction by Global Energy Interconnection*. Global Energy Interconnection, 2018. **1**(4): p. 409-419.

12. Ding, T., et al., *Zonally Robust Decentralized Optimization for Global Energy Interconnection: Case Study on Northeast Asian Countries*. IEEE Transactions On Automation Science And Engineering, 2020: p. 1-10.

13. Liu, Z., *Global Energy Interconnection*. 2015, China: Elsevier Inc.

14. Dutton, J., *UK-EU Electricity Interconnection :The Uk's Low Carbon Future And Regional Cooperation After Brext*, E3G, Editor. 2019. p. 1-12.

15. Brakelmann, H. and J. Stammen, *Thermal Emissions of the Submarine Cable Installation Viking Link in the German AWZ*. 2017: Rheinberg und Neukirchen-Vluyn.

16. Lasseter, R.H., *Distributed Generation*. Power Systems Engineering Research Center, 2003.

17. Wikarsa, M.T., *Studi Analisis Program Percepatan 10.000 MW Tahap 1 pada Operasi Sistem Tenaga Listrik Jawa Bali*, in *Fakultas Teknik*. 2010, Universitas Indonesia: Depok.

18. BNEF, B., *Electric Vehicle Outlook 2018*. 2018.