Danish Energy Agency

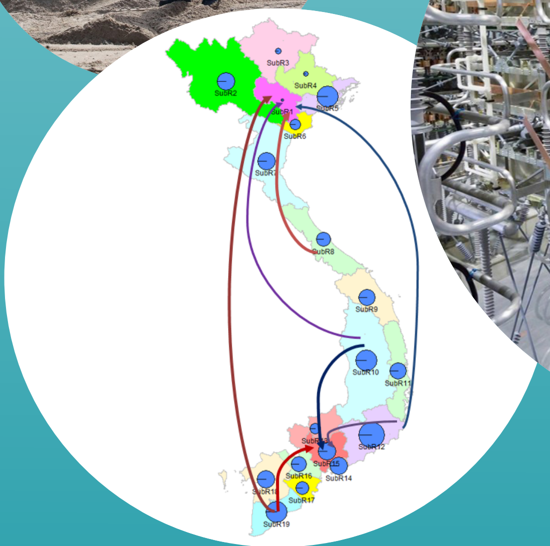
MOIT

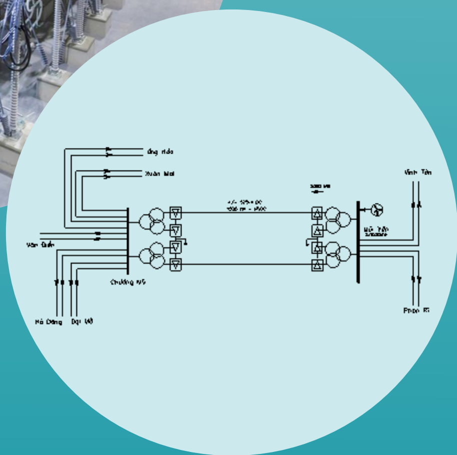
EREA
Electricity & Renewable Energy Authority

EMBASSY OF DENMARK
Hanoi

ANALYSIS OF HVDC FOR VIETNAM

High Voltage Direct Current analysis for PDP8





July 2020

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Appendix 1: Danish Experience with HVDC and Appendix 2: Calculation results are attached to this main report

ABBREVIATIONS

MOIT	Ministry of Industry and Trade
PPs	Power Plants
TL	Transmission Line
EVN	Electricity Corporation of Vietnam
NPC	Northern Power Company
NPT	National Power Transmission Corporation
PDP7	Master Power Development Plan for 2011-2025 period with view to 2030
HPP	Hydro Power Plant
TPP	Thermal Power Plant
CCGT	Combined Cycle Gas Turbin
NPP	Nuclear Power Plant

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FOREWORD

This study is conducted under the Danish Energy Partnership Programme with Vietnam (DEPP) as a part of Development Engagement 1: Capacity Building in Long Term Energy Planning. This study is a deliverable under the activity Analysis of HVDC for PDP8 support. The implementation group responsible for the programme activities consist of EREA, The Danish Embassy in Hanoi and the Danish Energy Agency. The study has been conducted by Institute of Energy of Vietnam with support from the Danish TSO Energinet.

The objective of Development Engagement 1 is capacity development for long-range energy sector planning to reach the goal "Vietnam's energy system is more sustainable through implementation of cost-optimised policy and planning." In Development Engagement 1 the Danish Energy Agency cooperates with EREA under MOIT, the agency responsible for the governmental energy planning in Vietnam. EREA (Planning Department) is the overall responsible for the development of the forthcoming National Power Development Plan 8 (PDP8). Comprehensive support to development of the PDP8 has already been delivered under DEPP. As one of the final preparations for the PDP8 EREA has expressed their interest in further support on the power transmission technology High Voltage Direct Current (HVDC).

The starting point for this activity is the modelling of the Vietnamese power system which was part of the Vietnam Energy Outlook Report 2019 (EOR19). Among other findings the analysis showed a big – and increasing – demand for transmission between the two load and production centers; the Hanoi area in the North and around the Ho Chi Minh City in the South. Today the backbone of the transmission system North-South is 2x 500 kV lines. Already as of today capacity on these lines are insufficient and regularly overloaded. A third line is under construction and is expected to be commissioned shortly. However, with the rapid growth in both demand for electricity as well as in the connection of RES generation the grid study mentioned above shows need to reinforce capacity on the North-South axis. Since the distance North-South is rather long it is mentioned in the EOR19 that an embedded HVDC line linking the North and South could be worthwhile investigating as an option to cope with the capacity constraint.

There are no HVDC lines in the Vietnamese power system, whereas Denmark commissioned its first HVDC interconnector in 1965. During the recent 50 years more interconnectors have been added including a link to the Netherlands commissioned in 2019. Today 5 HVDC interconnectors are in operation in the Danish power system. A new link to Germany is completed and expected to be commissioned shortly and finally a link to the UK is approved by authorities and expected to be commissioned by 2023. Therefore, the Danish TSO has comprehensive experience in design and operation of HVDC projects.

CHAPER 1. OVERVIEW OF VIETNAM POWER SYSTEM AND POWER DEVELOPMENT PLAN

1.1. Current status of power system in the whole country

1.1.1. Current status of the national electricity consumption

According to EVN's final report [1], total sale energy in 2019 was 209,42 billion kWh. The growth rate of electricity sale reached 8.64% compared to 2018. In which, electricity for industry – construction section accounted for 53.8%, increased by 10.9%; electricity for management – household accounted for 32.9%, increased by 9,3%; electricity for commerce – service accounted for 5.6%, increased by 9.3%; electricity for agriculture accounted for 3.1%, increased by 20.4%; other sector accounted for 4.6%, increased by 18.3%.

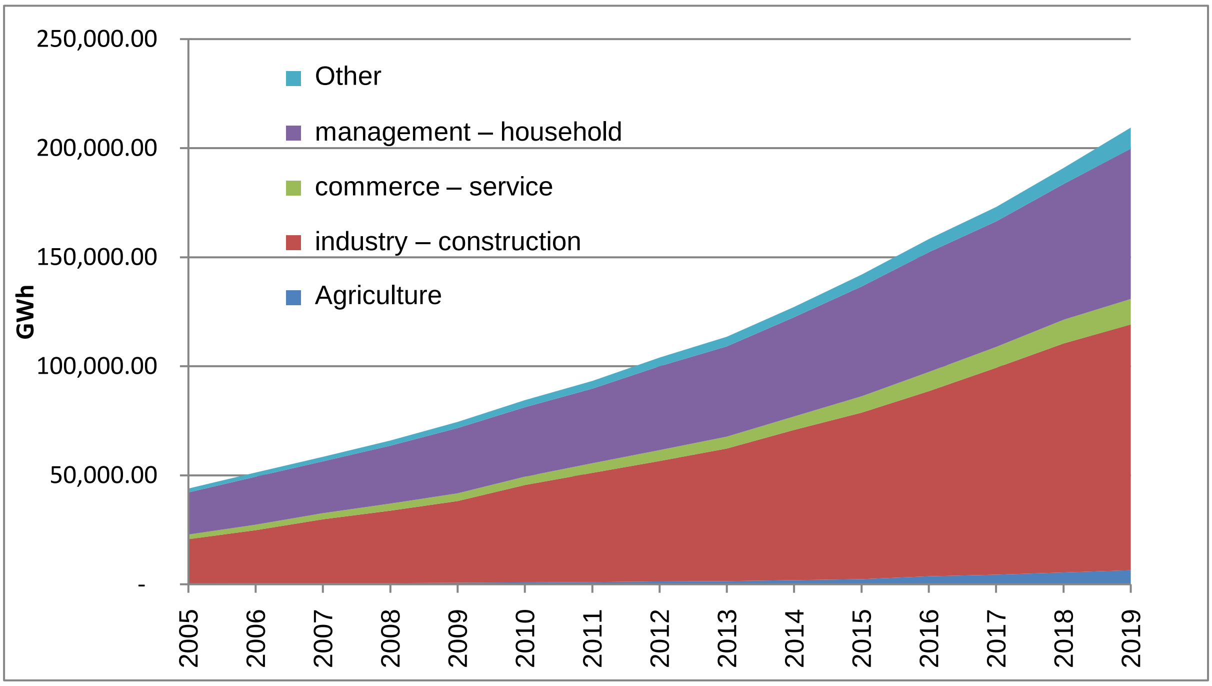


Figure 1-1 Electricity sale of Vietnam in period of 2005 - 2019

Total electricity sale of 231.1 billion kWh in 2019 is highest level ever. The growth rate of Viet nam’s electricity sale reached 11.6%/year in the period of 2005-2019.

In the period of 2005-2019, electricity consumption structure of Vietnam also changed slightly. Electricity demand for industry – construction sector increased from 45% in 2005 to 54% in 2019. Electricity for management – household sector decreased from 43% in 2005 to 33% in 2019. The commerce - service and agriculture - forestry - fishery sectors still accounted for a small proportion of 4-6%.

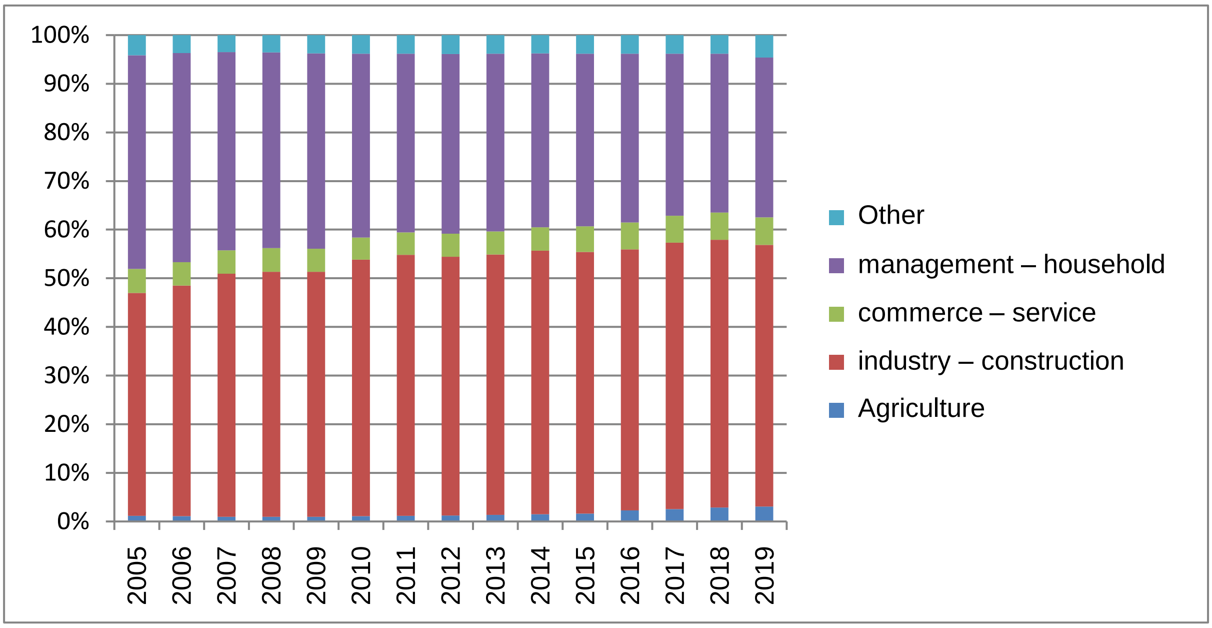


Figure 1-2 Electricity consumption structure of Vietnam in the period of 2005-2019

The growth rates of electricity sale by area in the period of 2006-2019 are shown in the figure below:

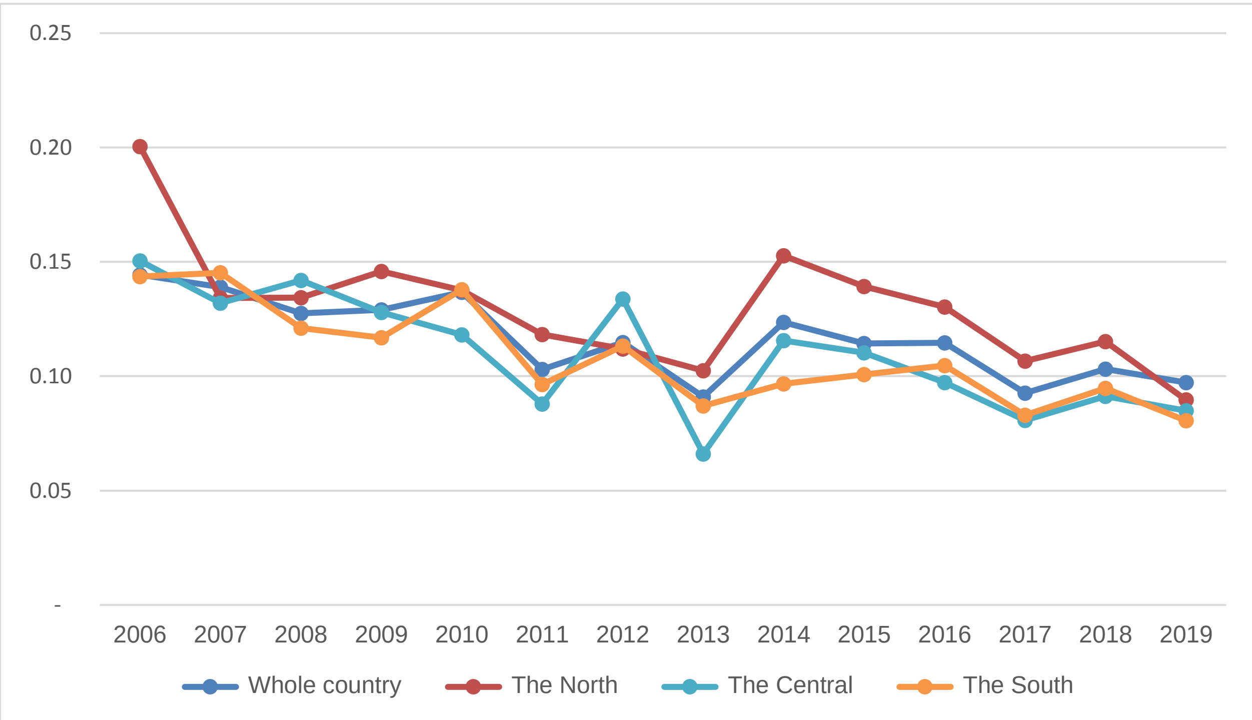


Figure 1-3 Growth rates of electricity sale by area in the period of 2006-2019

The growth rate of electricity sale in the last 13 years show that the trend of the growth rate of national commercial electricity is decreasing, from 14,5% in 2005-2006 to 10.3% in 2018. In 2019, the growth rate of electricity sale continues to decrease to 9.7%. The North has the highest average growth rate in all three areas, followed by the Central and the South.

The peak load (Pmax) in the whole power system in 2019 reached 38249 MW. This value is new record of Pmax in whole power system. Pmax occurred in June 2019.

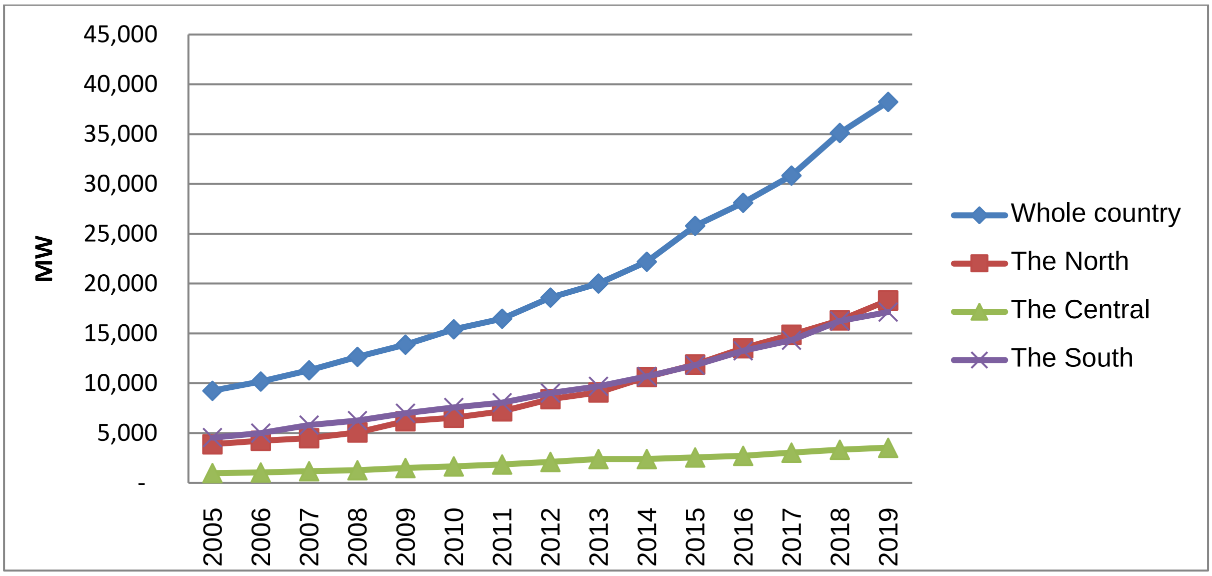


Figure 1-4 Pmax in the whole country and areas in the period of 2005-2019

Through peak load in the regions, it can be seen that Pmax of the North has exceeded Pmax of the South since 2015, although the electricity sale of the South is higher than that of the North. Pmax of the North reached 18313MW in 2019. This value is higher than Pmax in the South by 1174 MW. The Central region develops hydropower sources, but the local demand is quite low. Central peak load in 2019 reached 3535 MW, accounted for about 9.2% of the national peak load.

1.1.2. Current status of power sources in the whole country

Until 2019, the total installed capacity reached 54880MW[1]. The structure status of developing power sources nationwide in the period of 2010-2019 is shown in the figure below.

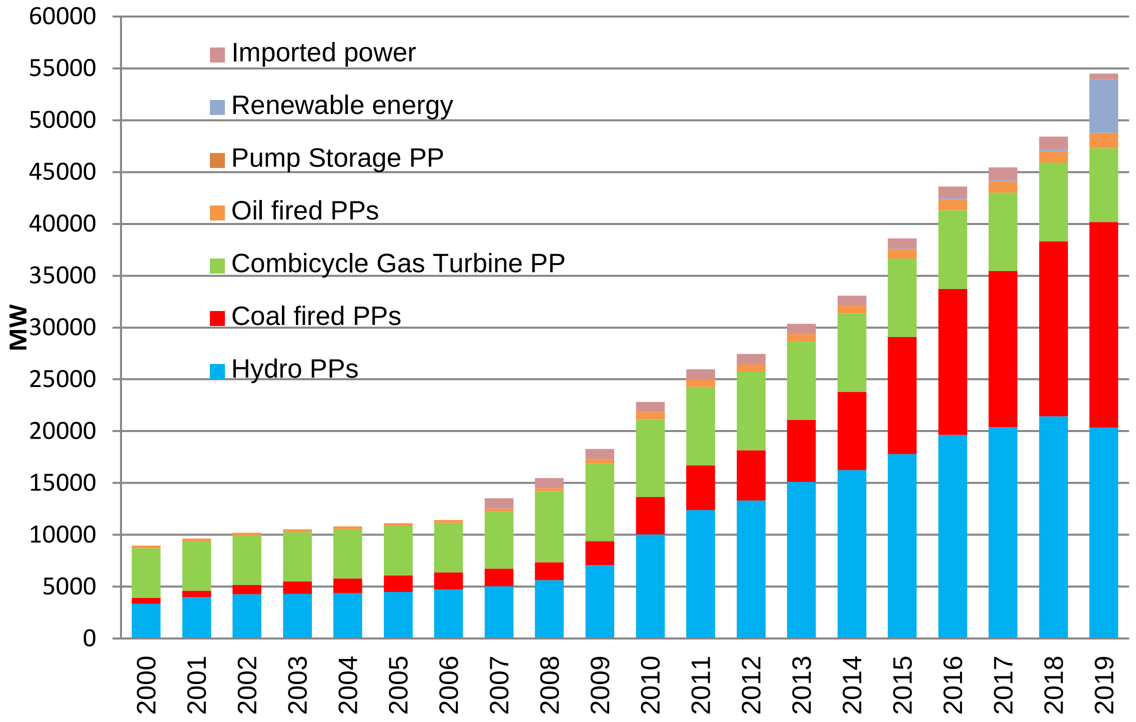


Figure 1-5 Structure status of developing power sources nationwide in the period of 2010-2019

Currently, in the source structure of the power system, the proportion of hydro and coal fired thermal power is high. Hydro power account for 36.65%, coal fired thermal power account for 36.61%. Hydro power that account for high proportion is mainly located in North west and highland. Gas Turbine power is mainly located in the South East and coal fired power is mainly located in the North East. Therefore, the seasonal and weather factors have a great influence on the operation of the power system in general and the operation of the transmission grid in particular.

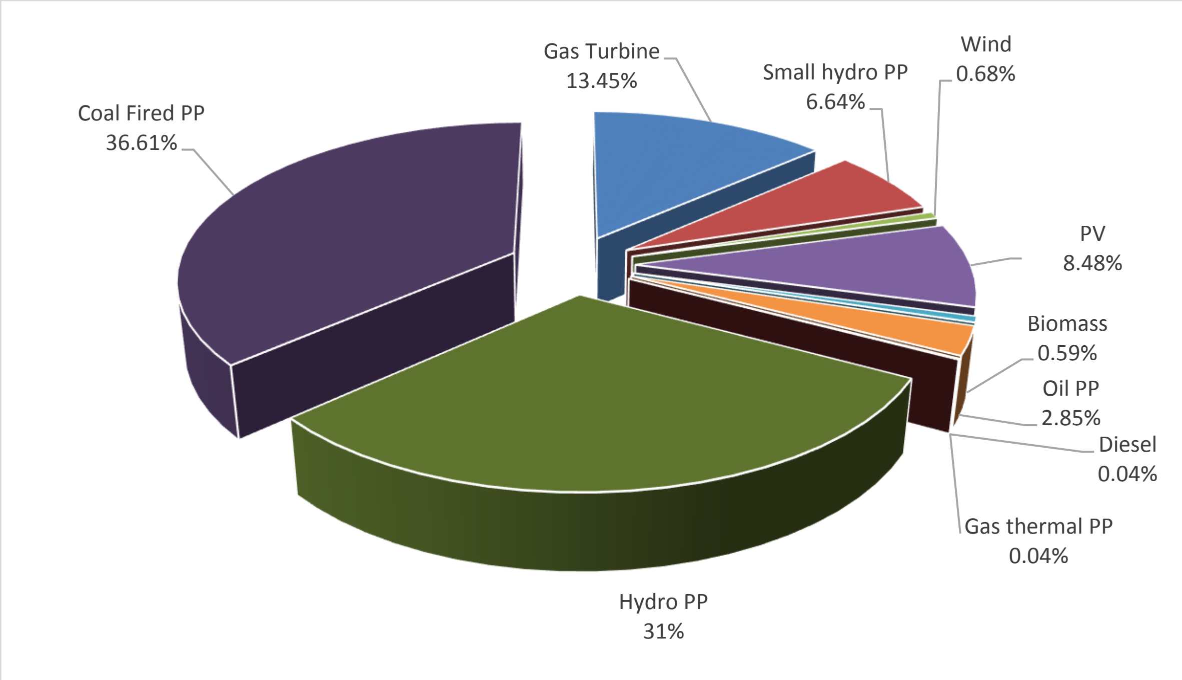


Figure 1-6 Structure status of power sources in Vietnam power system

The production of various types of power sources in recent years in shown in the figure below:

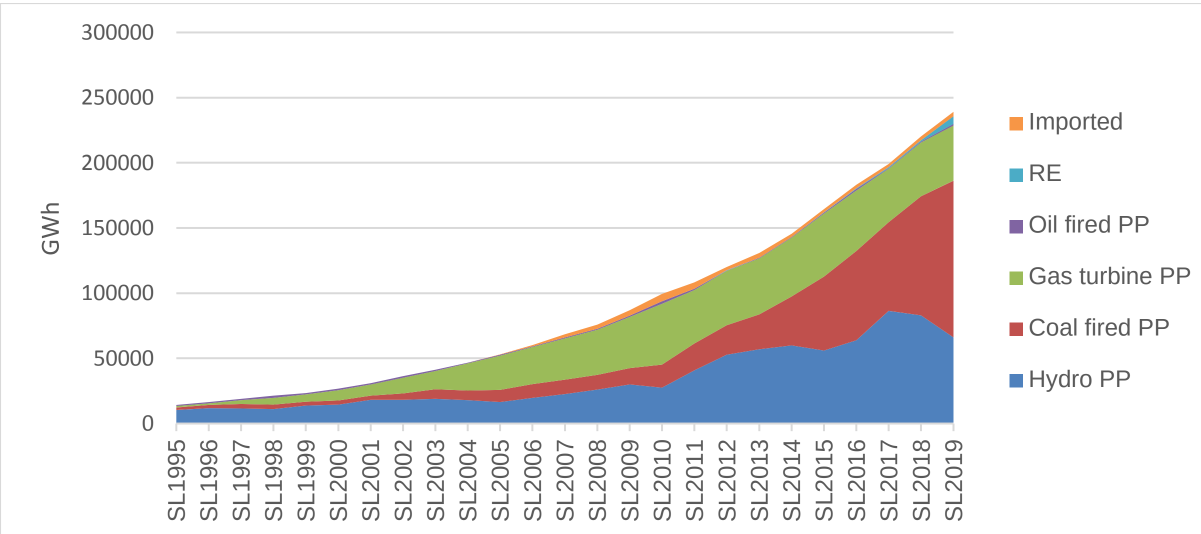


Figure 1-7 The production of various types of power sources in the period of 1995-2019

Compare to 2019, the electricity production of hydro power plants decreased in 2019, reached 66 billion kWh, account for 27.7%. The electricity production of coal fired power plants have a great development, reached 120 billion kWh, account for 50.25%.

In 2019, there is a big change in the source structure of Vietnam power system. The development of RE sources (mainly PV) with the total large scale will complement power source for the national power system. From the end of 2018 to December 2020, there are 87 PV power plants put into operation with total installed capacity of 4500MW (account for 8% of total installed capacity of Vietnam power system).

1.2. Development plan of power system

1.2.1. The national demand forecast

The national load forecast is updated according to "The Revised Power Development Master Plan for Vietnam's power system in the period of 2011-2020 with the vision to 2030" (Revised PDP7) approved by the Prime Minister by Decision No. 428/QD-TTg dated March 18, 2016.

In the base scenario, the national electricity sale is expected to reach more than 234 million kWh by 2020 and 506 million kWh in 2030. The peak load (Pmax) is forecasted to reach 42000 MW in 2020 and 90600 MW by 2030.

The demand forecast of the whole country up to 2030 are summarized in the figure and table below.

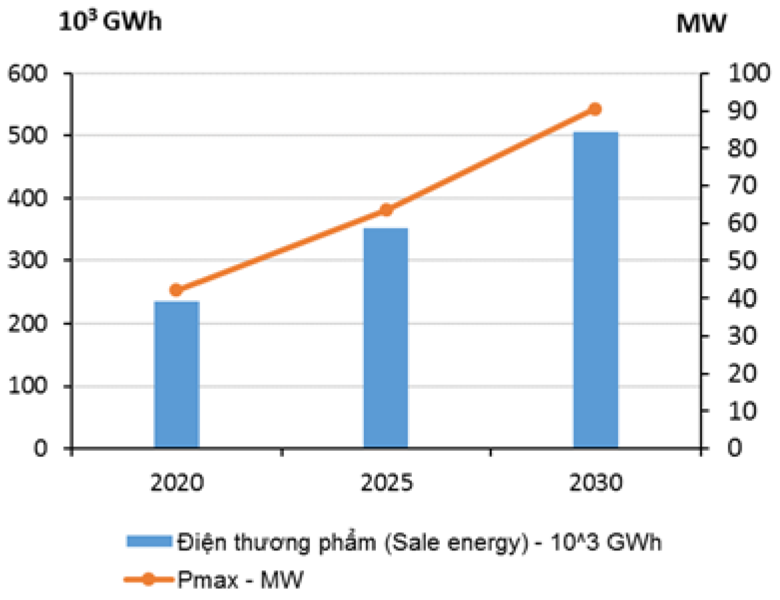


Figure 1-8 National demand forecast in years 2020, 2025, 2030 – Base case

Table 1-1 The demand forecast of the whole country up to 2030

Categories	Unit	2020	2025	2030
Electricity Sale				
The whole country	GWh	234558	352288	506001

Categories	Unit	2020	2025	2030
The North	GWh	95222	145833	210163
The Central	GWh	22230	35056	48603
The Soutt	GWh	116105	171398	247235
Peak load (Pmax)				
The whole country	**MW**	**42080**	**63471**	**90651**
The North	MW	18891	28663	40704
The Central	MW	4644	7236	9858
The South	MW	19717	29415	42521

According to the demand forecast, the total electricity sale nationwide is expected to grow about 11.0%/year in the period up to 2020; 8.5%/year in 2021-2025 and 7.5%/year in 2026-2030. In particular, the North and the South will have similar growth rates and reach about 210 billion kWh and 247 billion kWh electricity sale in 2030. The Central region will have lower growth and reach nearly 49 billion electricity sale in 2030. Peak load is forecasted to grow rapidly and reach over 90600 MW in 2030 nationwide.

In the total electricity sale nationwide, the South will account for nearly 50%, the North will account for about 40% and the share of the Central region will be 10%.

❖ **Demand center location forecast**

According to revised PDP VII, Northern load will be concentrated in Hanoi and neighbouring areas, Quang Ninh - Hai Phong - Hanoi triangle area and North Central Coast provinces (Thanh Hoa - Ha Tinh).

Southern load will be concentrated in the Southeast region, especially in Ho Chi Minh City and the provinces of Binh Duong, Dong Nai, Ba Ria - Vung Tau.

Central load will be concentrated in Central Coast region, including provinces from Da Nang to Khanh Hoa. In particular, the load centre will be the provinces of Da Nang, Quang Nam and Quang Ngai with large industrial zones such as Dung Quat and Chu Lai Industrial Zones.

1.2.2. Power sources development plan

The progress of power source projects up to 2030 are updated according to sources below:

- Decision No 428/QD-TTg dated March 18, 2016 of Prime Minister approving "The Revised Power Development Master Plan for Vietnam's Power system in the period 2011-2020 with the vision to 2030".
- Report about overall revision of PDP VII rev prepared by the Institute of Energy in February 2020 at the request of Electricity and Renewable Energy Department - Ministry of Industry and Trade;
- Report of MOIT in 2019 about the status of implementation of electricity projects in Revised PDP7 dated 31/01/2020 (document reporting to the National Steering Committee on power development).
- Decision No. 1725 / TTg-CN dated December 19, 2019 of the Prime Minister approving the addition of Bac Lieu LNG Power plant to the National Electricity Development Planning;
- Document No. 58/BC-BCT dated June 4, 2019 of the Ministry of Industry and Trade (MOIT) on the implementation of power projects in Revised PDP7;

According to updated data, power source projects expected into operation in the period up to 2025 are likely to be delayed, especially power sources in the South. This affects supply-demand balance in the whole country. With the delayed progress of the power sources in the South (the region with the largest load in Vietnam), the burden continues to be placed on the transmission grid in the period up to 2025. The installed capacity structure of national power sources up to 2030 is as follows:

Table 1-2 Installed capacity of national power sources up to 2030 (updated to 03/2020)

Type of power sources	**2020**		**2025**		**2030**	
	MW	**%**	**MW**	**%**	**MW**	**%**
Hydropower (≥ 30 MW)	17768	30%	19118	18%	19213	14%
Coal-fired thermal power plants	19637	33%	38522	37%	47162	34%
Gas + Oil thermal power plants	8716	15%	15831	15%	27956	20%
Small hydro power plants (< 30 MW)	3800	6%	4620	4%	5900	4%
Renewable energy (wind power, solar power, biomass power…)	8314	14%	20114	19%	29724	21%
Energy storage (hydroelectricity storage + battery storage)	0	0%	2100	2%	3600	3%
Imported (from China, Laos)	920	2%	3520	3%	5256	4%
Total installed capacity	**59155**	**100%**	**103895**	**100%**	**138811**	**100%**

The national installed capacity in 2030 is expected to reach about 138 GW (including renewable energy sources). Of which, coal-fired thermal power plants account for the highest proportion in the structure of national power sources in 2030 (respectively 34%), Renewable energy account for 21%, gas and oil thermal power plants account for 20%, hydro power plants account for 14%. The remaining components only account for 11%.

The period of 2019-2025 marks the restructuring of different types of power sources. Before 2019, hydro power plants accounted for the highest proportion (over 35%), but the installed capacity of coal-fired thermal power plants will gradually increase and reach the highest proportion of power sources structure in the period of 2019-2025. The main reason for the investment orientation in coal-fired thermal power plants is because the hydropower potential in Vietnam is almost fully exploited and cannot meet the growth rate of the power demand of the economy. The period of 2019-2025 is also expected to mark the explosive growth of renewable energy sources after policies and support mechanisms issued by the government. The share of small hydropower and renewable energy sources also increased rapidly from 9% in 2018 to about 21% in 2030.

Currently, solar power projects are entitled to development incentives under Decision No.11/2017/QD-TTg dated April 11, 2017 of the Government. The period of 2019-2025 promises the booming development of solar power sources. To March 2020, 140 solar power projects with total installed capacity of 13600 MWp (equivalent 10900 MWAC) were approved by Vietnam's Government and Prime President. These projects concentrate mainly in some provinces such as Ninh Thuan, Binh Thuan, Dak Lak, Tay Ninh, Binh Phuoc, Khanh Hoa. Most projects are expected into operation in 2020, the rest will operate after 2020.

1.2.3. Power transmission system development plan

❖ **500 kV grid:**

✓ ***The period up to 2020:***

According to Revised PDP7, 500 kV grid linking regions in this period will not change much:

- Between the North and the Central region: There are two 500 kV circuits from Nho Quan to Da Nang. Series compensation capacitors on 500 kV transmission lines linking the North and Central region were upgraded the rated current from 1000 A to 2000 A. This enhanced the transmission capacity to meet the high transmission from the North to the South in the context of delaying Southern power sources.

- Between the Central region and the South: 500 kV transmission grid were upgraded to four 500 kV circuits from Pleiku to Cau Bong and Tan Dinh. In this period, there will be not many new power sources in the Central region, therefore developing Central - Southern transmission grid is mainly to ensure the safe operation when transmitting more power from the North to the Central and to the South.

  ✓ ***The period of 2021-20230***

- The North: Considering to upgrade 500 kV Nho Quan - Vung Ang transmission line from single circuit to double circuit to improve transmission capacity of the North-Central interface; completing 500 kV cycle around Ha Noi city; constructing 500 kV double-circuit transmission line from thermal power cluster in the North Central region to the South of Red River.
- The Central region and the South: Constructing 500 kV transmission lines from the Central CCGT (using Ca Voi Xanh gas field) to the South; constructing 500 kV transmission grid to connect thermal power plants in the Southwest.

❖ **220 kV grid:**

  ✓ ***The North:***

- Improving power supply ability for Hanoi city by adjusting 220 kV transmission lines from Hoa Binh - Ha Dong, Hoa Binh – Chem, Ha Dong – Chem, Thuong Tin – Ha Dong; upgrading some 220 kV substation such as Tay Ha Noi, Son Tay, Van Tri…; building new 220 kV substations: Me Linh, Van Dien, Hoa Lac, Dai Mo…

  ✓ ***The Central:***

- Up to 2020: Completing 220 kV double-circuit line along the central coast linking all provinces. This 220 kV line is from Vung Ang to Dong Hoi - Dong Ha - Hue - Hoa Khanh - Da Nang - Tam Ky - Doc Soi - Quang Ngai - Phuoc An - Tuy Hoa - Nha Trang – Thap Cham. It is expected to upgrade the single-circuit lines up to double-circuit lines to ensure the reliability of electricity supply for regional load such as: the second circuit of some 220 kV lines such as An Khe – Pleiku, An Khe - Phuoc An, Nha Trang – KrongBuk. In addition, some 220 kV transmission lines will be built to connect hydro power plants from Southern of Laos to Pleiku;
- 2021-2030 period: Developing power grid to supply for regional load.

  ✓ ***The South:***

- Up to 2020: Building 220 kV lines from Vinh Tan and Song May to supply electricity to Central-South load; building 220 kV lines from 500 kV Duc

Hoa, Tan Uyen substations and 220 kV underground cable lines to supply electricity to Ho Chi Minh city; building 220 kV lines to transmit capacity from thermal power plants in the South West to power system.

- In the period of 2021-2030: Completing 220 kV backbone for the Central - South coastal area, 220 kV cycle to supply to load centers such as Ho Chi Minh City, Ba Ria – Vung Tau, Binh Duong... and 220 kV lines to transmit capacity from thermal power plants in the South-West region.

1.3. Potential and location of power sources

1.3.1. Gas power

➢ *Gas supply capacity and fuel conversion*

Gas supply capacity for power production in base scenario in periods following:

- Total gas supply capacity for power production increase from 7.7 billion m^3/year in 2020 to 14.6 billion m^3/year in 2025.
- After 2025, gas supply capacity decreases gradually. Until 2030, gas supply capacity reach 9.2 billion m^3.

Because the domestic gas in the Southeast will decline after 2023, PM3_CAA gas that be supplied to Ca Mau thermal power plant will decline in 2020. Therefore, in the coming time, the current gas-fired thermal power plants could be lack of gas fuel to keep the balance of the power system.

According to revised PDPVII, Ca Mau gas power plant will be fueled from Block B gas. However, the Ministry of Industry and Trade is currently planning to buy gas from Malaysia to supply gas for Ca Mau 1 & 2 thermal power plant in the period of 2020-2031[1].

Total installed capacity of gas power plant that switch to use LNG fuel is about 4500 MW in the period of 2024-2030. This value will increase by 2700MW after 2030. Existing gas power plants have been built since the 2000s. Therefore, in the period after 2035, necessary for upgrade capacity scale to meet the demand. In the south, Oil and gas thermal power plants (including Can Tho PP – 165MW – since 1999, Thu Duc PP – 290 MW – since 1990, Hiep Phuoc – 375 – since 1999, Ba Ria GT – 46 MW – since 1991) expected to retire in 2025. Because these power plants have been operation for a long time, the equipment is old, and the system has enough peak power sources.

In the Southwest, in B Block, gas fuel expected to supply to O Mon power center (total installed capacity of 3800MW (because O Mon II, IV, III are approved to upgrade installed capacity of 1050 MW by Ministry of Industry and Trade). The volume of gas

Notice No. 459 / TB-VPCP dated 13/12/2018 about the conclusions of the Prime Minister at the meeting on the policy of buying gas from Malaysia..

that be exploited in B Block reach 4.06 billion m3/year and provide 0.7 billion m^3/year to non-electric sectors.

In the central, the study that develop petrochemical project using Cá Voi Xanh gas field of PVN has not much progress. So that, MOIT approved to construct Dung Quat III LNG power plant project (In decision NO 2612/QĐ-BCT dated July 25, 2018 about approving and adjusting the planning of the Central Gas Center - Location of Dung Quat Power Center). Therefore, LNG power plants in Quang Nam, Quang Ngai provinces with total capacity of 3800 MW and demands non-electric will ensure the gas consumption from CVX gas field (4.2 billion m^3/year).

Total installed capacity of gas thermal power plants that expected to construct until 2030 (approved in PDP VII revised) is about 6500MW.

- *Ability to construct LNG thermal power sources*

Domestic coal and gas sources are almost impossible to increase the scale of exploitation in the coming period. The development of other power sources (PV and Wind) can mitigate fuel import but is expected to take time to scale up. Therefore, the fuel imported is needed to meet electricity consumption. According to study of Institute of Energy (Planning of LNG storages and ports facilities – IE 2017[2]), Vietnam could import LNG fuel from Australia, Quata, USA (these countries have highest LNG potential and expected to increase gas exploitation output). In long term, considering to import LNG fuel from Russia and Middle East countries. Creating more LNG import sources is needed to improve fuel supply security. However, the gas reserves of the world are not large. They can only be exploited in 50 years with the current consumption. While the world gas demand is increasing. Early construction of LNG import infrastructure and sources of electricity using LNG is necessary to be able to build the LNG market in Vietnam in the long term. Potential locations for building LNG-using power plants and LNG import ports in Vietnam:

- North: Hai Phong, Quang Ninh, Thai Binh, Nam Dinh, Ninh Binh;
- North Central: Thanh Hoa, Ha Tinh;
- Center Central: Quang Nam, Hue;
- South Central: Binh Dinh, Ninh Thuan, Khanh Hoa, Quang Ngai;
- South: Dong Nai, Kien Giang, Bac Lieu, TP. HCM, Ba Ria – Vung Tau, Ca Mau, Ben Tre.

Currently, total installed capacity of LNG power sources that is approved in PDPVII revised in the period until 2030 is 12400MW. These power plants are located in the South and South Central. In which, the installed capacity of LNG power sources that certainly operate in the period of 2021-2025 is 1500 MW (Nhon Trach 3&4 thermal power plants).

The total potential of the construction site of LNG power source according to the preliminary evaluation of the project is very large, about 104GW nationwide, of which many projects in the Southern region are proposing additional planning.

In addition to large-scale LNG power centers, considering the potential to develop flexible power plants that use LNG fuel such as single cycle gas turbines (SCTG), internal combustion engines (ICE). These are flexible technologies, suitable for the integrated power system with large amount of renewable energy. These can be installed with small scale from 20MW, large scale to 500MW. These plants can be located at the load center to participate in peak coverage.

1.3.2. Coal fired power

- *Domestic coal supply capacity*

According to study of Institute of Energy (IE 2019: Report of power system balance up to 2030)[3], total domestic coal for power production in periods following: about 35 million ton in 2020, 36,3 million ton in 2025, 39.8 million in 2030.

Based on reports of adjusting coal supply for thermal power plants until 2020, with orientation toward 2030. It is expected that coal plants will be put into operation in the North such as Thai Binh 2 and Hai Duong, Nam Dinh I had to use blended coal. Because there is not enough domestic coal.

The total number of thermal power plants that use domestic coal and blended coal in the PDP7D is expected to put into operation in the period of 2021-2025 is about 4400MW. Total capacity of potential and new construction is 1800MW in the period of 2026-2030

- *Ability to construct thermal power source using imported coal*

According to a study on coal import capacity, Vietnam can import coal from Indonesia, Australia, South Africa and Russia. Coal reserves are long-term (can be exploited for 130 years with current consumption), while the growth rate of world coal demand in the coming period is quite low, not as high as gas demand. Several coal exporting countries like Australia are interested in processing coal to reduce the environmental impact of this type of fuel..

Currently, there are about 4800 MW of imported coal fired power plants (using Bituminous coal has a calorific value of about 6000kcal / kg, mainly imported from Indonesia). Including Ha Tinh Formosa thermal power plant (TPP), Formosa TPP, Vinh Tan 4 TPP, Duyen Hai III TPP, Vinh Tan I TPP, Vedan TPP.

Preliminary results show that the total potential of the location to build more imported coal power plants nationwide can be up to 76 GW. The South remains the region with the greatest potential for construction. The total scale of the imported coal thermal power projects that is approved to the PDPVII revised is 33,330MW. The total scale of coal thermal power projects that committed to operate in the period of 2020-2025 is 15680MW. Projects already approved in the plan but expected to put into operation after 2025 and potential projects are considered as the potential for further development of each region.

1.3.3. Renewable energy

➢ *Wind power*

Currently, total capacity of wind power sources is not large (500MW). However, due to the impact of the price support mechanism, there are many projects that have been implementing investment and construction procedures to put into operation before November 2021. Total capacity of wind power that is approved to supplement the plan is about 5 GW. Due to the effect of Covid 19 pandemic, it is hard to reach 5 GW additional wind farms to put into operation on time (November 2021).

Total potential capacity of onshore wind is quite large. However, this is mainly low (4.5-5.5m/s) and average (5,5-6m/s) speed wind potential. The high-speed wind potential is small.

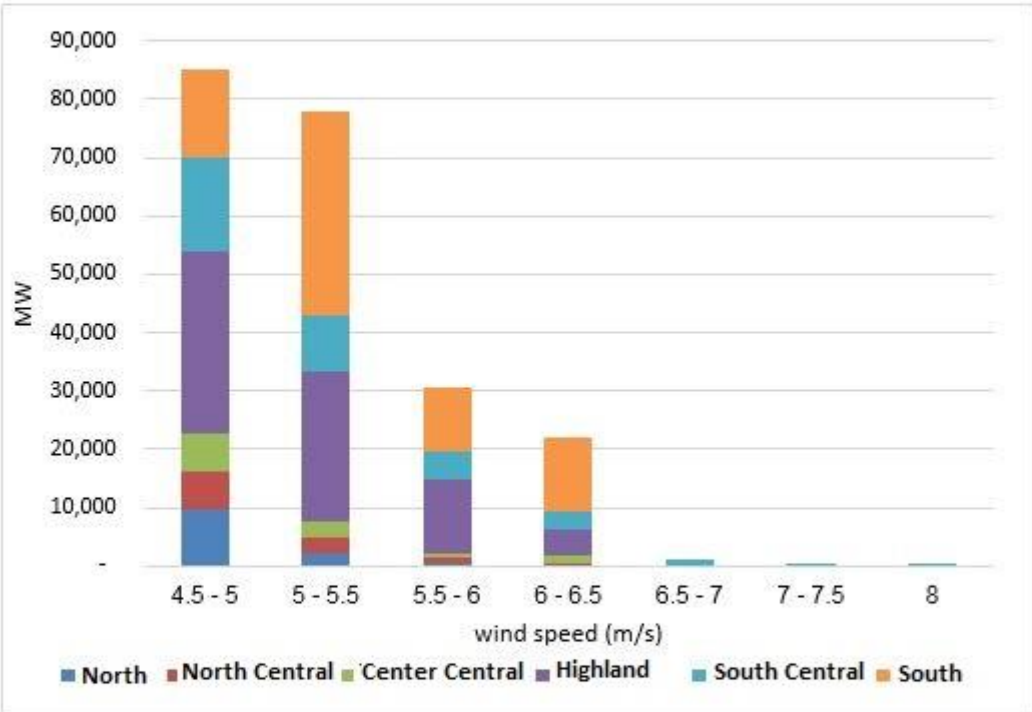


Figure 1-9 Capacity potential of offshore wind power

South: Renewable development plan until 2035 (October 2018, Institute of Energy).

Currently, there are many investors who register to construct in South Central region with total registered capacity is about 15GW. In which, Thang Long offshore wind project (3.4GW in Ke Ga, Binh Thuan province) was approved to study by Prime Minister. Total potential capacity of offshore wind power is about 160 GW (COWI 2020, offshore wind resource potential and costs in vietnam). This capacity is classified by regions as follows:

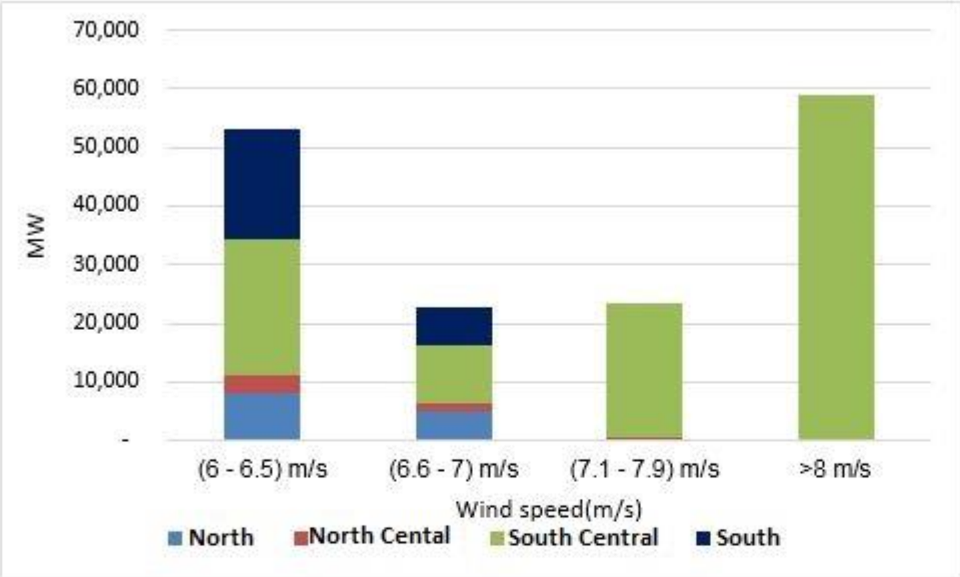


Figure 1-10 Offshore wind technology potential in Vietnam

The region which have largest potential offshore wind power is South Central. Most of the potential can be built as a fixed foundation. There are only about 57GW of floating foundation potential (4GW in North Central and 53 GW in South Central GW).

➢ *Solar PV power*

Due to the effect of price support mechanism, solar power has boomed in recent years in Vietnam. Particularly in 2019, there is 5GW of solar power has been put into operation (mainly in Ninh Thuan and Binh Thuan - over 2 GW). Total capacity scale of the solar power projects that is approved to the plan is over 10 GW (8GW before 2020 and 2GW after 2020). The total capacity of PV power that registered construction but has not been approved is 25GW (12.3 GW before 2020 and 12.9 GW after 2020), specifically:

There is large PV power potential in the South. The average radiation intensity is from 1705 to 1910 kWh/m2/year in the South, much higher than the North (only about 1200 kWh/m2/year). Total technical potential capacity of PV solar power is large (up to 1646 GW - 1569GW on land potential and 77GW on water surface potential). However, this value is calculated based on the same criteria for all provinces, not yet considered for some provinces with difficult conditions for construction (high mountains, far from roads). There are some small areas not eligible for large-scale solar power development in some provinces. Accordingly, the total potential capacity of large-scale PV solar power is about 386 GW, mainly in the South, South Central and Highlands.

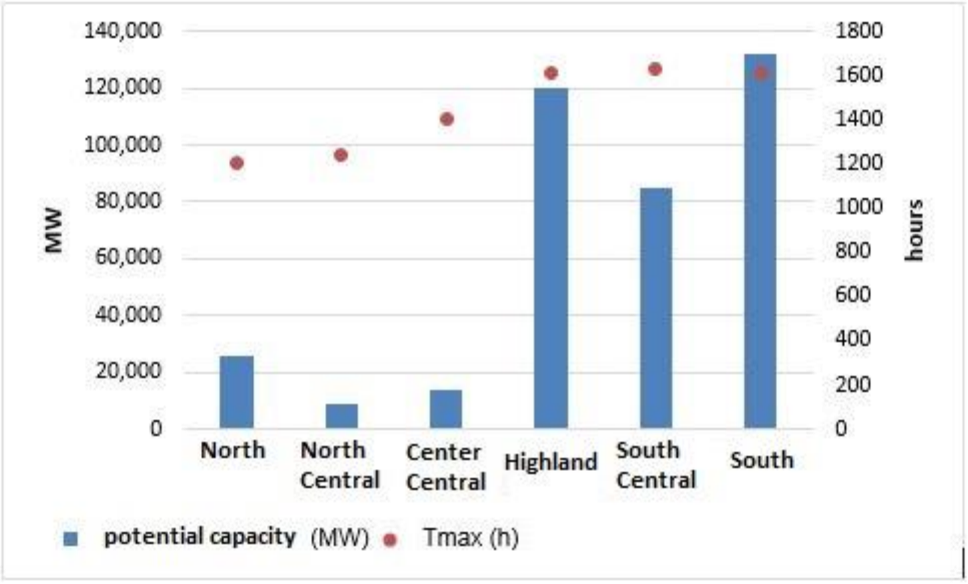


Figure 1-11 The potential development of large-scale solar power and Tmax

About rooftop solar PV power, according to final report of EVN, until 2019, total capacity of rooftop PV power reached 340MWp (about 272 MW). In which, there is about 11 MW in the North, about 5 MW in North Cental, about 12 MW in Center Central, about 30 MW in Center Central, about 70 MW in South Central, about 140 MW in the South. According to EVN's assessment, if the electricity price mechanism of 9.35 Uscent / kWh is maintained, it is possible to encourage the development of about 2000MW of rooftop solar PV in the period to 2025. The total potential of rooftop solar PV is up to 48GW, mainly located in the the South of 22GW.

- *Hydro power*

In the period to 2025, there will be about 2600MW of hydro power with installed capacity over 30MW that expected to be put into operation. Total capacity of small hydro power projects that being built in this period is about 3200MW, the remaining small hydro potential is about 2800MW.

- *Biomass and other types of renewable energy*

At present, biomass power has about 378MW of bagasse power which is operating to co-generate for sugar factory and generate power to the grid (about 100MW). In additional, there are about 70MW of Wood fired power are in the stage of investment preparation.

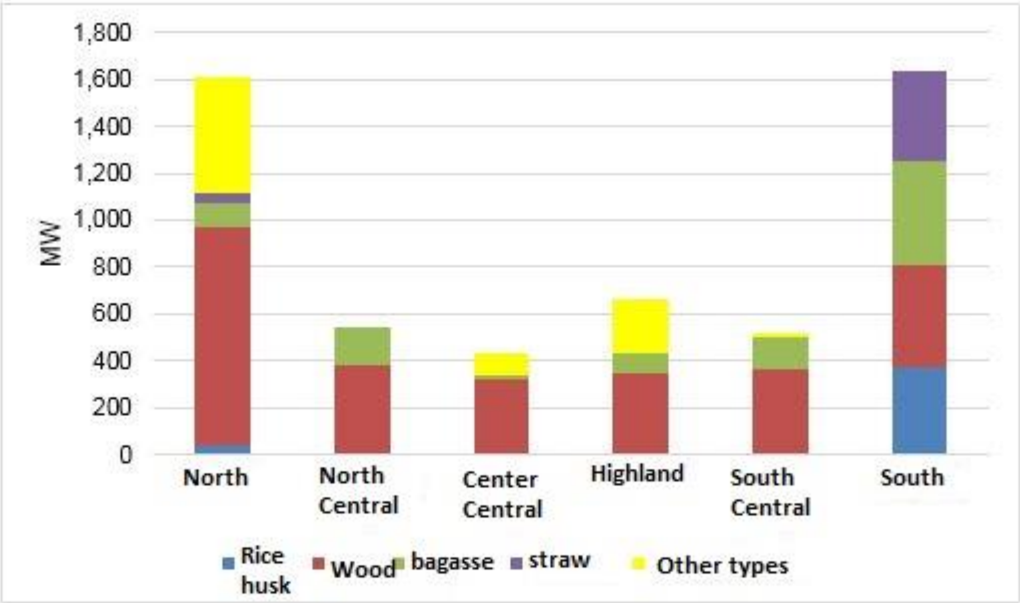


Figure 1-12 Potential of biomass types

The total capacity of biomass power potential nationwide is quite large (equivalent to 13.7 GW). The South-Central region has the greatest potential. However, the ability to collect biomass is difficult to develop biomass plants.

Despite the great potential, the ability to collect biomass to develop biomass power plants is difficult. So, according to the assessment of the possibility of developing biomass power sources, the scale of biomass power potential is only about 5 - 6GW.

There are 10MW of garbage power plants that are operating. However, total capacity of garbage power potential is up to 1500 MW, mainly in the South (about 1000MW). The remaining types of renewable energy such as geothermal, biogas, and tides are now in the research period.

REFERENCE

[1] EVN, “Báo cáo kết quả thực hiện kế hoạch năm 2019. Mục tiêu, nhiệm vụ kế hoạch năm 2020,” 2019.

[2] IE, “Quy hoạch phát triển ngành công nghiệp khí Việt Nam đến năm 2025, định hướng đến năm 2035,” 2017.

[3] IE, “Báo cáo cân đối cung cầu điện giai đoạn 2020-2030,” 2019.

CHAPER 2. CALCULATION OF TECHNICAL-ECONOMIC INDICATORS AND POTENTIAL APPLICATION OF HVDC POWER TRANSMISSION TECHNOLOGY IN VIETNAM

This chapter will analyze, calculate and compare the economic and technical indicators between the two transmission technology HVDC and HVAC in Vietnam, under the technical support of ENERGINET Eltransmission (Denmark), under a cooperation program between the Embassy of Denmark and the Ministry of Industry and Trade of Vietnam. The calculation results will be an important reference source for the transmission grid design of the National Power Development Plan for the period 2021-2030, with a vision to 2045 (PDP VIII) being built by the MOIT.

2.1. Potential locations for HVDC transmission in Vietnam

The potential locations for application of HVDC transmission technology are determined based on power development potential and load forecasting in regions and areas throughout the country.

According to the draft of PDP 8, the distribution of Peak region load by 2045 is as follows:

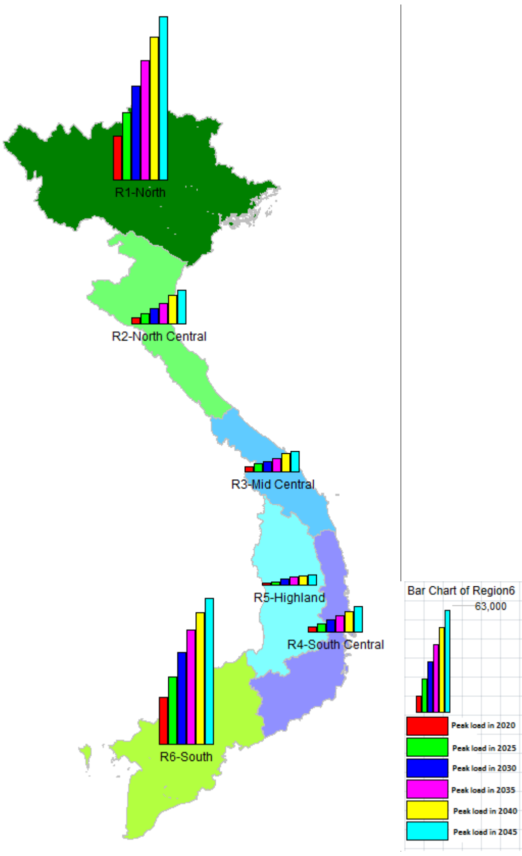


Figure 2-1 Distribution of Peak region load from 2020 to 2045

Currently, the North and the South region are the two load centers of Vietnam with the respective peak capacity of 2020 reaching about 18.3 GW and 17.8 GW. In the long term, these two regions are forecasted to continue to grow highly and remain the two load centers at both ends of the country. The peak load capacity of 2045 for each region can reach in the range of 60-70 GW. The appearance of long transmission grid projects (such as HVDC or HVAC) is often related to the supply of electricity to these two load centers.

The remaining regions of Central Vietnam (North Central, Central, South Central and Central Highlands) have relatively low load, only accounting for about 18% in 2020 and about 16% in 2045. However, these areas are high renewable energy potential such as onshore wind power, solar power and offshore wind power. Therefore, large-scale power transmission systems often originate from these regions.

The identification of potential locations for application of HVDC technology is also based on the potential of developing power sources by geographical regions.

According to the Vietnam Energy Outlook Report 2019 (EOR19)[4], coal-fired power sources will tend not to develop strongly, instead the trend of increasing more environmentally friendly power sources such as wind power, solar power and gas turbines. By this time, there are many investors registering and looking for investment opportunities in the field of power generation development in Vietnam. According to statistics, the volume of new power source registration has now reached 159 GW, including wind power of 34 GW, solar power of 30 GW and LNG of 40 GW. The location of the power source depends on the natural conditions, so the power sources could be distributed at locations far from the load center.

The figure below shows the size of the total installed capacity of power sources that are being requested for investment and added to the national power source development planning, divided by 6 geographical regions.

From the figure below, when comparing the peak load (P20) with the installed power (G20) in 2020, it is realized that the Southern region is short of power. Therefore, it is necessary to receive electricity from other areas. However, in the future, the picture of the power source may be very different when the amount of registered capacity (G45) in the regions is very large, which may lead to different power development scenarios.

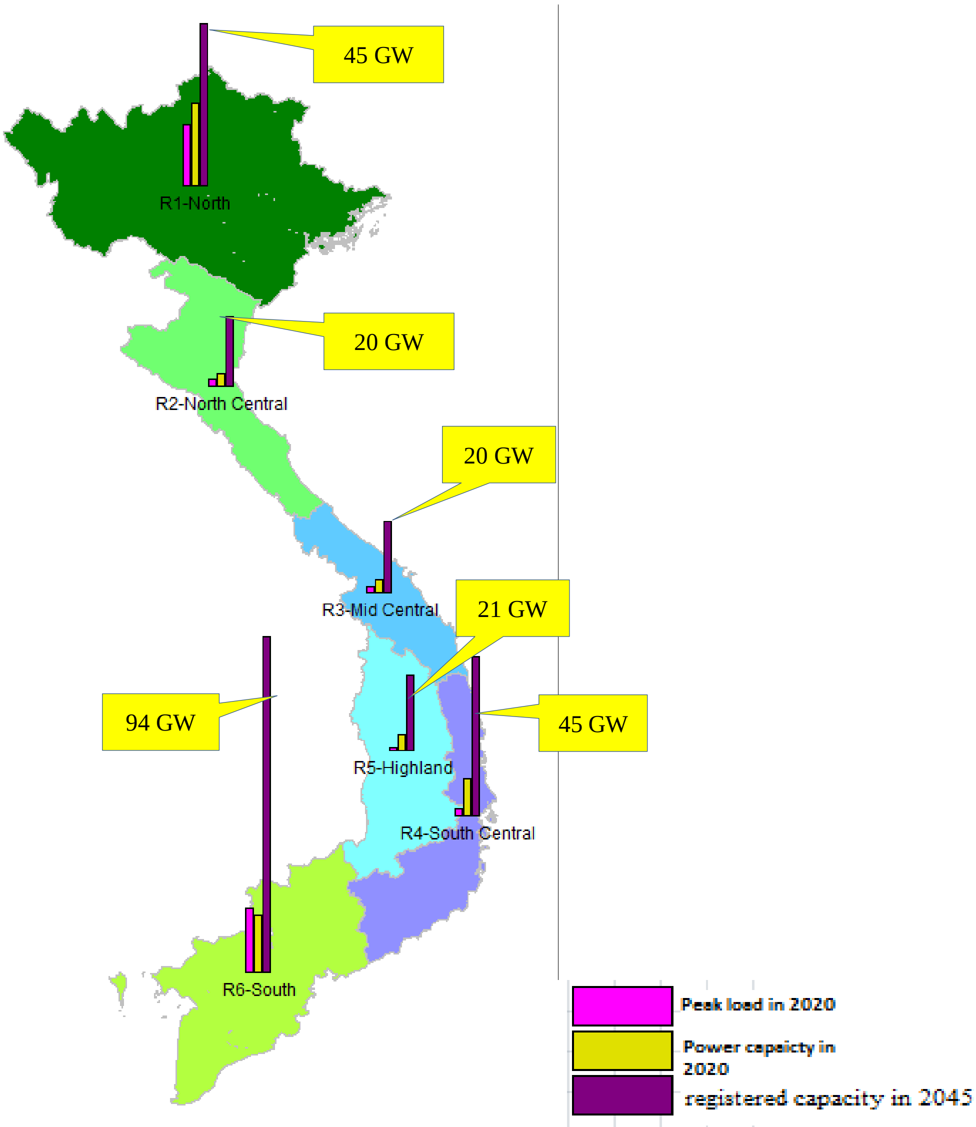


Figure 2-2 The distribution of power sources takes into account registered projects

From the picture above, it is noticed that many power source investors want to build wind power plants and wind farms in the South, South Central and Highland region. The registered source capacity in these 3 regions is up to 94 GW, 45 GW and 21 GW.

To better understand the potential of applying HVDC to power transmission, the study team of IE also analyzed the load forecast and power potential in smaller subregions based on geographical and electrical system characteristics. From 63 provinces and cities, there are 19 sub-regions can be classified. The forecast of maximum load (Pmax) in 2030 (P30) and the registered power capacity of each sub-region (G30) is shown in the following figure.

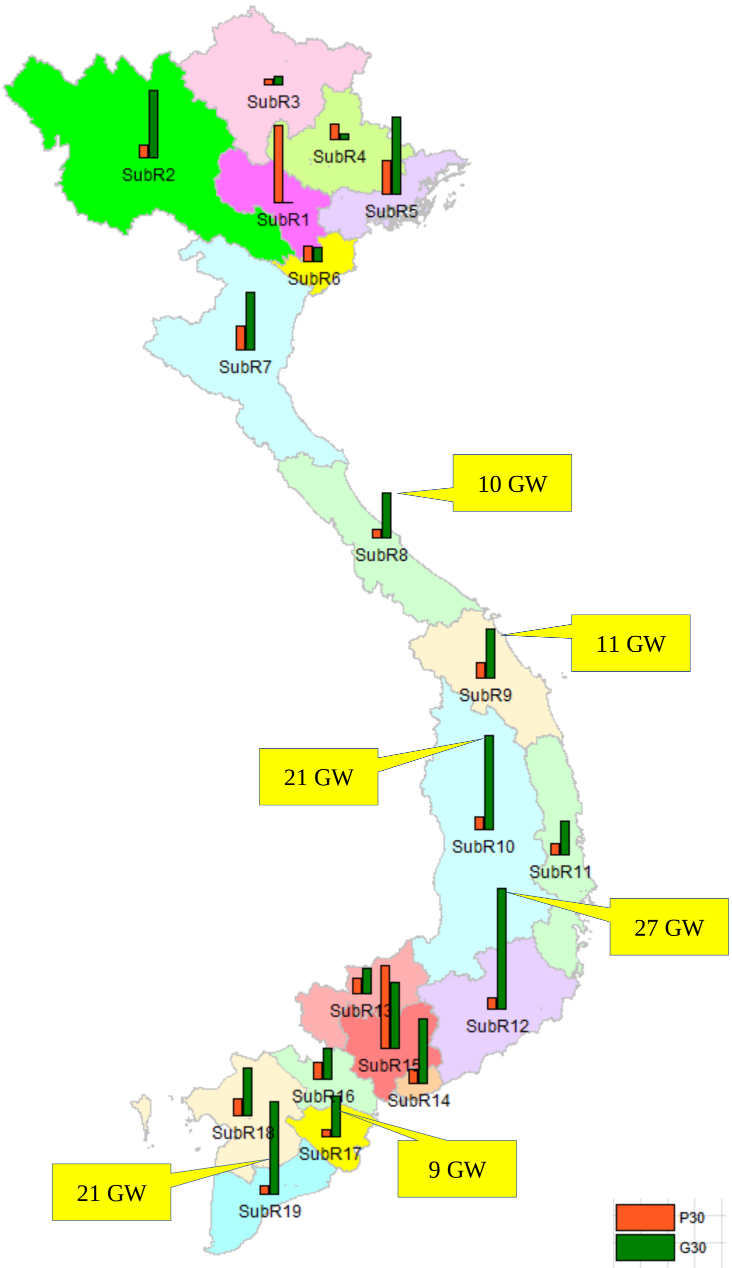


Figure 2-3 Peak load in 2030 and registered source capacity in the subregions

Many sub-regions have low electricity demand such as SR12, SR19, SR10, SR8, but the potential for building a huge power source, from 10 GW to 27 GW. The power generation capacity of the SR 12, SR 17 and SR 19 areas could be much larger considering future Off-shore wind power. These may be the starting points of the HVDC system in the future.

Based on the load distribution and potential power distribution in the system, potential HVDC transmission routes can be located as shown below.

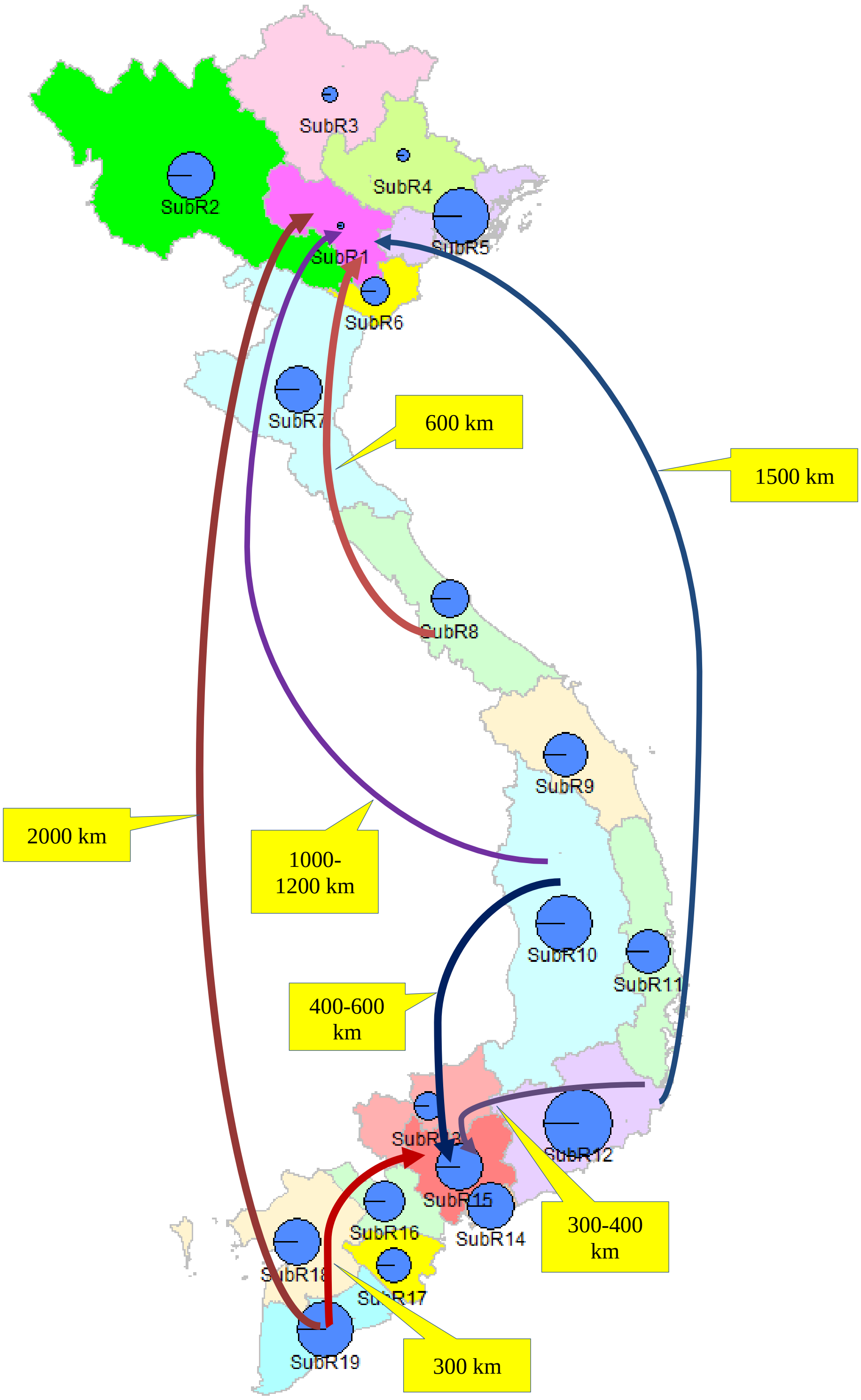


Figure 2-4 Locate potential positions of application of HVDC technology in Vietnam transmission system

Whether or not the HVDC system will appear depends primarily on the policy of power development. If the high concentration of the power source at one location leads to very long distances to the load center, then the HVDC transmission option should be considered.

Due to the large scale of power source registration in some sub-regions, there are many development source scenarios. Corresponding to each source scenarios are transmission options. The power expansion program of PDP 8 is still in the process of being developed with many different scenarios and requires consultation from many parties. Therefore, inter-regional and inter-areas transmission plans are still open.

To support the grid design of PDP 8, this study will look at most potential locations of HVDC application in Vietnam Power System, compared with traditional solutions using HVAC technology for different transmission power levels. When the option of source development is selected for the PDP 8, this research result will be an important reference source in proposing transmission solutions.

The following section will calculate the economic and technical comparison between the two transmission options for HVDC and HVAC for different transmission capacity scale scenarios in Vietnam conditions. Calculate the investment cost (capex), power loss and the net present value (NPV) cost of transmission options. The calculation cases are shown as follows:

Table 2-1 Cases of calculation and comparison of HVDC and HVAC technology in Vietnamese power systems

Scenarios	1000 MW	2000 MW	3000 MW	4000 MW	5000 MW	6000 MW
300 km	X	X	X	X	X	X
400 km	X	X	X	X	X	X
600 km	X	X	X	X	X	X
1000 km	X	X	X	X	X	X
1200 km	X	X	X	X	X	X
1500 km	X	X	X	X	X	X
2000 km	X	X	X	X	X	X

Calculation results will then be made into graphs and tables, becoming a database in the design of transmission grid of the PDP 8.

2.2. Overview of Danish grid planning and experiences of Danish side about HVDC

2.2.1. The Danish transmission system

This part introduces the Danish transmission system. Key figures and operation of the system as well as the planning procedure are described.

2.2.1.1. *The Danish power system at a glance*

The Danish power system, like other power systems worldwide, is undergoing a transformation from a system dominated by centralized thermal power plants to a system incorporating different power generation sources of various sizes and technologies, such as wind power and photovoltaics.

While the power system is being transformed, the laws of physics that determine electrical power flows do not change. To maintain a reliable and economically efficient system, a range of interdependent technical and operational fundamentals must be fulfilled at all times.

The 400 kV transmission grid serves as the backbone of the power system, allowing transportation of large quantities of energy across the country. Major power plants, major consumers, interconnectors and offshore wind power plants are connected to the transmission grid.

Regional sub-transmission grids (132 kV and 150 kV) take power from the 400 kV transmission grid and move it to load-serving substations that serve distribution grids. Major urban centres can have concentrated 132-150 kV grids comprising several load-serving substations in a relatively small geographic area. Alternately, regional sub-transmission grids can serve sparsely populated areas with significant distances between substations. The planned transmission grid at year-end 2024 is shown in below figure

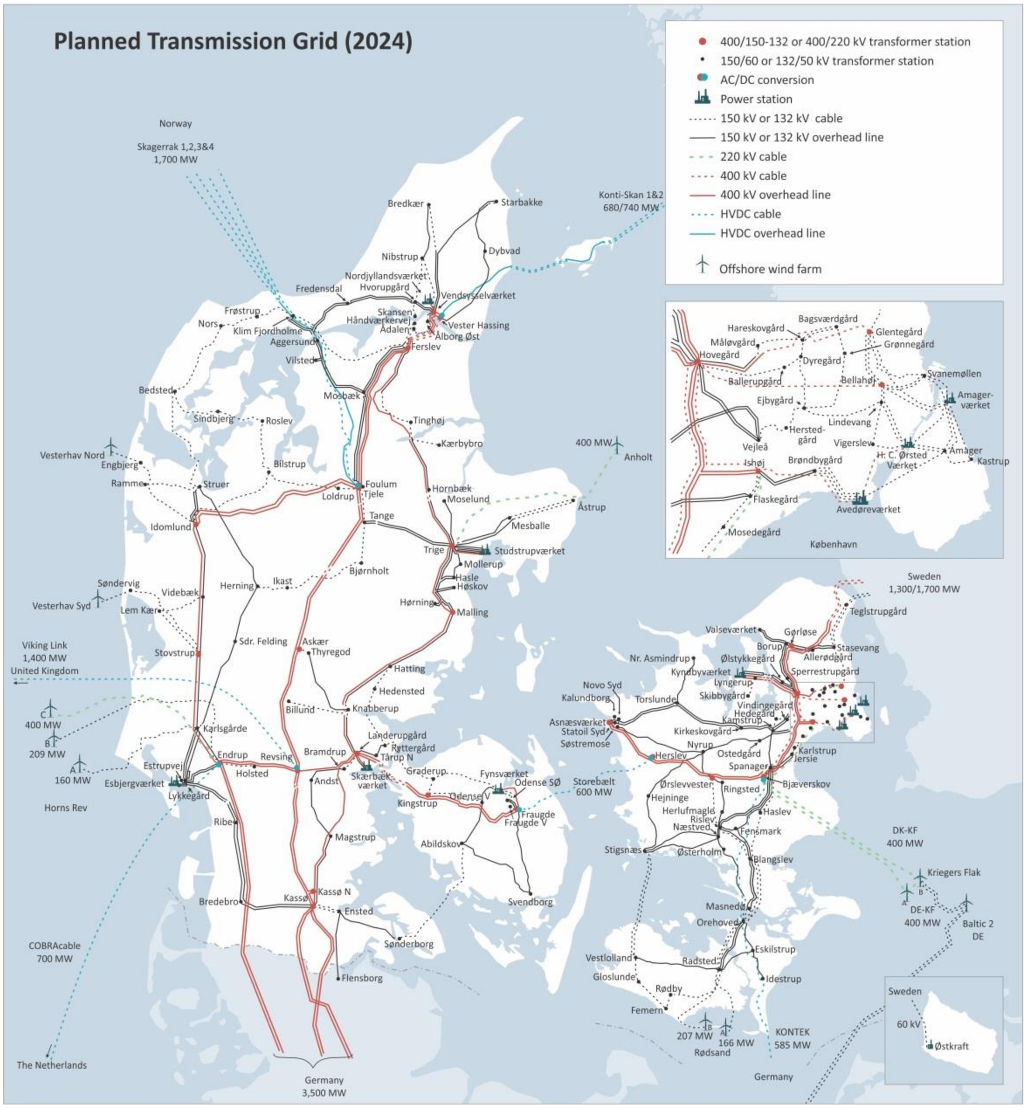


Figure 2-5 Planned transmission grid – as at year – and 2024

Distribution grids are planned and operated by distribution system operators (DSOs). Energinet and DSOs cooperate in operating the power system and have several interface agreements and joint operating procedures.

The overall power system, including both the transmission- and distribution grids, serves electricity generators and consumers by facilitating the electricity market to ensure that supply of and demand for electricity are physically matched.

The transmission grid is designed and operated according to international standards[2] to ensure sufficient transmission capacity to transfer power from areas of generation to

[2] More information in ENTSO-E grid codes: https://www.entsoe.eu/network_codes/

areas of demand. Limiting factors on transmission capacity include thermal current ratings, voltage constraints and dynamic stability limitations.

For historical reasons, the Danish transmission grid is operated as two separate synchronous systems but at the same frequency. Eastern Denmark is part of the Nordic synchronous system, while Western Denmark is part of the continental European synchronous system. The below figure shows the present European synchronous systems. Being part of two synchronous systems, Denmark is interconnected via several HVDC and HVAC interconnectors.

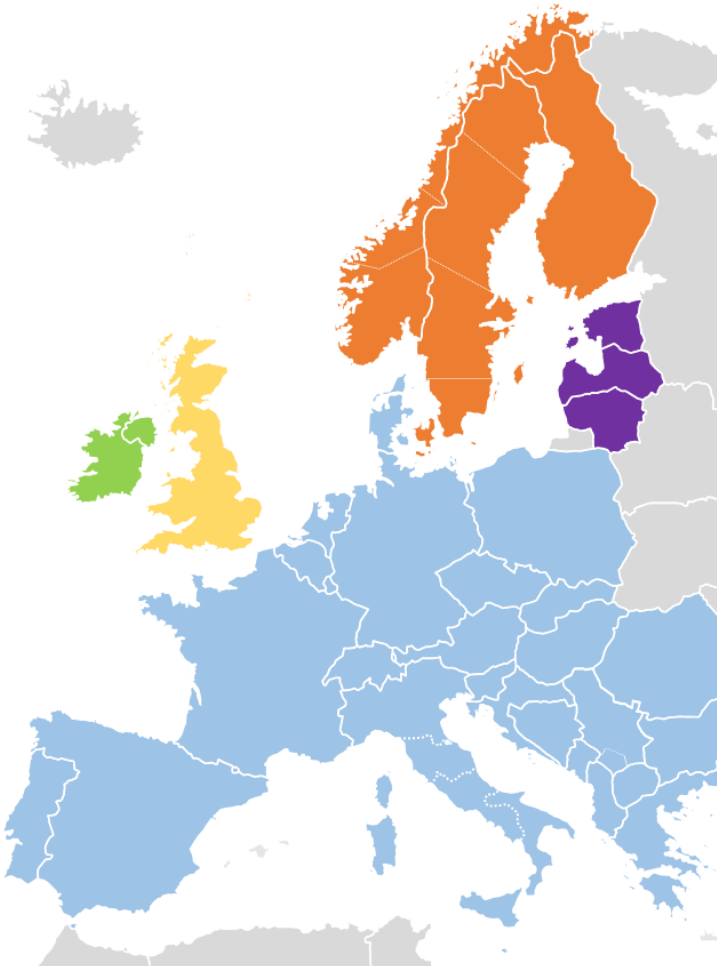


Figure 2-6 European synchronous systems (ENTSO-E)

The Western part of the Danish transmission grid has high voltage alternating current (HVAC) connections to the synchronous continental European system. Specifically, the connection to Germany consists of four HVAC connections. Export capacity is 1,780 MW, and import capacity is 1,500 MW. By 2023, a total of six 400 kV HVAC connections are planned to be in operation, increasing transmission capacity to 3,500 MW in both directions.

In addition, the Western part of the Danish transmission grid is connected to Sweden and Norway by high voltage direct current (HVDC) connections. The Konti-Skan connection to Sweden consists of two HVDC connections with a total export capacity of 740 MW and an import capacity of 680 MW. The Skagerrak connection to Norway consists of four HVDC connections with a total two-way capacity of 1,700 MW.

A 700 MW HVDC link between Western Denmark and the Netherlands (COBRAcable) has been commissioned in 2019. The 1,400 MW HVDC link between Western Denmark and Great Britain (Viking Link) is planned to be commissioned in 2023.

The eastern part of the Danish transmission grid is connected by HVAC to the synchronous Nordic system. The resund Link between Zealand and Sweden consists of four HVAC connections with a total export capacity of 1,700 MW and an import capacity of 1,300 MW.

The Eastern part of the Danish transmission grid is connected to Germany by an HVDC connection, Kontek, which has a capacity of 600 MW. Moreover, Eastern Denmark and Germany will become interconnected via the world's first offshore electricity grid as part of the grid connection concept for the Kriegers Flak offshore wind power plant. This Kriegers Flak combined grid solution (CGS) has a capacity of 400 MW in both directions with commissioning planned for 2019. The connection's export and import capacities will be limited by the power generation levels of the Kriegers Flak offshore wind power plant.

Western Denmark and Eastern Denmark are interconnected by a HVDC link, the Great Belt Link, which has a capacity of 600 MW. The connection is obviously not an actual international connection as it interconnects two Danish market areas. However, it is operated in the same manner and is included in the market on the same terms as other interconnectors.

Denmark has the largest interconnector capacity in Europe relative to domestic electricity consumption and has considerable energy exchange with neighboring countries. These interconnections have a major impact on the interaction between generation and demand in the interconnected systems. The connections with neighboring systems are essential parts of balancing a power system with a large share of renewable generation while they also serve to facilitate a competitive electricity market. Present and future Danish interconnectors are shown in the below figure.

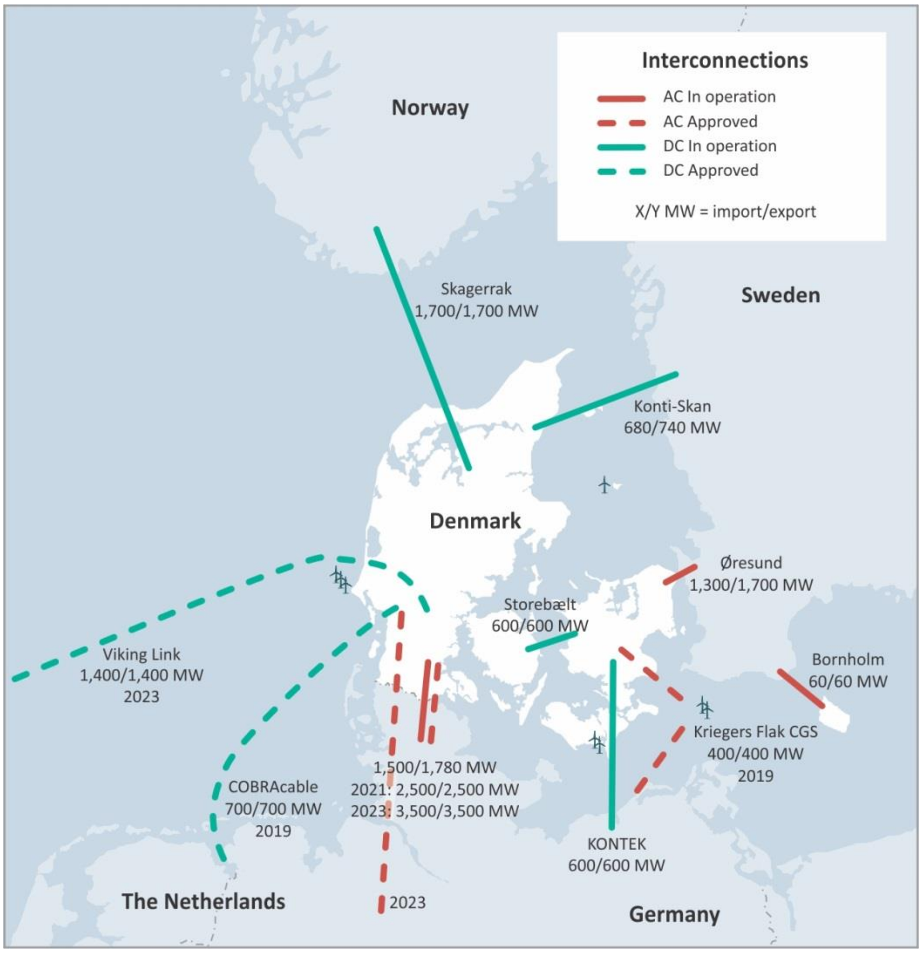


Figure 2-7 Present and future interconnectors

The Danish transmission system mainly consists of OHLs and air-insulated outdoor substations. However, the use of gas-insulated (GIS) substations in the transmission grid has increased in recent years. Worldwide, UGCs are rarely used for 400 kV transmission lines and only over short distances because of the related technical challenges and high costs due to the high transmission capacity requirements necessitating the installation of several parallel cable circuits.

UGC installations operated at the 132-150 kV voltage level do not introduce similar technical challenges and high costs as with 400 kV UGCs and have therefore been the reference technology at the 132-150 kV voltage level for several years in accordance with the national principles for the establishment of transmission lines. The cable share at this voltage level makes up about half of the transmission lines operated at the 132-150 kV voltage levels.

2.2.1.2. *Energinet's obligation*

Energinet is an independent, state-owned company and is the statutory transmission system operator (TSO) in Denmark.

The responsibilities of Energinet include:

- To operate a reliable and economically efficient transmission grid;
- To plan and develop grid infrastructure, including interconnectors;
- To facilitate integration of renewable energy in Denmark; and
- To facilitate market development.

Development of the transmission grid is one of the central tasks of Energinet as the TSO responsible for planning and operating the main grid in Denmark. Long-term planning and development ensure that the transmission grid and the overall power system fulfil the requirements defined by national and international regulations.

2.2.1.3. *Energinet's grid development procedure*

The transmission grid must be expanded through a coherent, long-term, controlled development, maintaining the security of supply and supporting optimal electricity market functionality. Moreover, expansions must take into account the continued technological development, environmental impact, including landscape considerations, and the socio-economic impact.

As part of the grid development procedure, transmission alternatives are evaluated against a number of key performance objectives, which must be achieved regardless of the particular technology. The objectives for any proposed grid expansion are:

- To comply with system operation guidelines (ENTSO-E, 2017) and planning standards (Energinet, u.d.);
- To provide an environmentally acceptable and cost-effective solution;
- To provide the required transmission capacity;
- To enable future expansions of the transmission grid; and
- To enable future grid connections of renewable generation.

Planning standards are defined and measured in terms of performance of the transmission grid under various contingencies, e.g. a single contingency (N-1) or a double outage contingency (N-1-1). Prediction of the transmission grid contingency performance is established using the results of simulated power flow scenarios, including different load and generation profiles as well as different patterns of interconnector energy exchange.

In addition, system stability must be maintained and power oscillations adequately damped when subjected to severe disturbances such as a three-phase short circuit of a vital transmission line or a three-phase bus bar fault.

2.2.1.4. *Operational guidelines*

The operation of the interconnected continental European synchronous system is founded on the principle that each TSO is responsible for its own system. Within this context, the *N-1-principle* is a well-established practice among European TSOs, which ensures the operational security by foreseeing, that any predefined contingency in one area must not endanger the operational security of the interconnected operation. *Normal* and *exceptional* types of contingencies are considered in the contingency list.

The operational framework covers, for instance, operational procedures, which are important for the operation of the interconnected synchronous continental European system.

- *Active power reserves*

Energinet is obligated to rectify any contingency in the Danish power systems and bring the affected system back into a secure operational state within a limited period of time, including bringing interconnector energy exchange back on schedule. A key enabler in this respect is the active power reserves that must be held at a sufficiently high level to ensure that contingencies do not lead to violation of operational security limits.

The dimensioning contingency is defined as the greatest loss of generation or loss of infeed from HVDC interconnectors that the power system must be able to withstand. In Western Denmark, the dimensioning contingency is the loss of 700 MW.

Manual active power reserves are spread throughout the power system. Energinet has limited knowledge of the locations of the reserves when activating them. As such, no manual power reserves can be assumed to be available to handle grid-related contingencies. Energinet therefore generally only activates reserves to correct for loss of generation or loss of infeed from HVDC interconnectors.

Energinet estimates that it is socioeconomically optimal to design the transmission grid to ensure sufficient transmission capacity to handle any normal grid related contingency without the need to adjust interconnector power flows or generation. Consequently, Energinet has decided not to maintain manual active power reserves to handle grid-related contingencies, such as tripping of a transmission line. Only in the event of a second contingency occurring within the same 24-hour "market period" will it be necessary to change interconnector power flows in line with operational guidelines.

2.2.1.5. *Energinet's grid development procedure*

Energinet's grid development plan, *The RUS plan* (Energinet, 2017), presents an overall and long-term development plan for the transmission grid, establishing and coordinating reinvestment, expansion and reconfiguration needs. The plan covers the next 10 years and defines the projected long-term structure of the transmission grid in Denmark.

Energinet's RUS plan has been prepared in accordance with the Danish national principles for the establishment of transmission lines. According to the revised principles, new 400 kV transmission lines are to be built as overhead lines with the possibility of partial underground cabling as well as underground cabling of 132-150 kV overhead lines in the vicinity of new 400 kV overhead lines.

New 132-150 kV transmission lines are to be established with UGCs. Furthermore, the revised principles stipulate that the 2009 Cable Action Plan (Energinet, 2009) no longer applies; however, the possibility of underground cabling of 132-150 kV overhead lines in selected urban areas and areas of particular environmental interest still exists to some extent.

2.2.2. High voltage direct current (HVDC)

High voltage direct current (HVDC) is a well proven technology for transmitting power efficiently and reliably over long distances. The benefits of long-distance transmission with low losses, combined with features like the ability to connect unsynchronized power systems, have opened up new opportunities for this versatile technology. HVDC has been used in Denmark since 1965, interconnecting Sweden and Jutland (the Konti-Skan link).

2.2.2.1. *AC vs DC*

Advantages with DC compared with AC

- Connection of two AC grids which are not synchronous
- No problems with long cables (e.g. long sea cables)
- Effective for very long transmission systems with very high power
- Cables for DC are cheaper than for AC
- Complete control of power flow
- A fault in the AC grid will not be transferred to the other AC grid

Disadvantages with DC compared with AC

- Change of voltage level is complicated compared to transformers for AC
- Converters for conversion from AC to DC or vice versa are complicated, very expensive and require more maintenance than AC equipment
- Special fault cases e.g. commutation failure

2.2.2.2. *General*

Two technologies are used for HVDC-transmission:

- Line-commutated converters (LCC) based on thyristors;
- Voltage source converters (VSC) based on transistors.

Today, LCC technology is mainly built for very high-power transmission with ultra-high DC voltages (800 kV and above) and overhead DC lines. All HVDC projects under construction in Europe are based on the VSC technology and, being considered the new standard.

Table 2-2 Comparison of VSC and LCC

Technology	LCC	VSC
Power electronic component	Thyristor	IGBT (transistor)
Transformers	Special HVDC due to DC-offset	Standard transformer
AC-filters	Several. To be switched depending on power	Nil or small filter that is always connected
Commutation failure	Yes. Specially in weak AC grids	No. No requirements to the AC grid
Black net start	No	Yes
Reactive power	Stepwise by switching filters	Adjustable. Capability is dependent on active power
Minimum active power	Normally 10% of nominal power (3% can be specified)	0 MW
Losses	0.6 – 0.7% per converter	0.8 – 1.2% per converter
Power reversal	Change of polarity of DC voltage	Change of DC current direction
Cables	Mass impregnated cables (oil impregnated paper insulation)	Normally XLPE cables
Multi-terminal (DC grid)	Possible but very complicated	Feasible, but as long as there is no DC breaker available the whole DC grid has to be disconnected when a fault occurs
Weak grid operation	Needs a strong grid to form the voltage around. Commutation errors are likely	Can be grid forming

In the following only VSC technology will be described.

2.2.2.3. *Voltage source converters*

The VSC technology is based on transistors, mainly insulated-gate bipolar transistors (IGBTs). The state-of-art technology is the Modular Multi-Level Converter (MMC) configuration where the converter comprises a large number of IGBTs connected in series within each leg of the three phases.

The reactive power exchanged between a HVDC VSC link and the HVAC grid can be controlled independently at both ends of the link and within the rating of the link, independent of transferred active power. A HVDC VSC link can support steady state voltage regulation but, more importantly, also provide dynamic voltage support during and after disturbances in the surrounding transmission grid.

Several HVDC VSC links use DC voltages of 320 kV, but links are currently under construction utilizing XLPE cables with DC voltages of up to 525 kV. The DC current is limited by the maximum current allowed by the IGBTs and typically lies in the range of 1,200-2,000 A.

Electrical loss in each converter typically amounts to 0.9-1.1 % of the transferred active power. In addition, losses in the HVDC cables must be considered.

2.2.2.4. *Configuration of HVDC links*

A HVDC VSC link can be configured in several ways. Many VSC links are symmetrical monopoles where two HVDC cables for plus and minus voltages are used (e.g. +/-320 kV on the 700 MW COBRAcable between Denmark and the Netherlands). To increase power rating, a bipolar configuration is commonly used, like a rigid bipole (as planned for Viking Link) or a bipole with metallic return or ground return. The different options are shown in below firgures

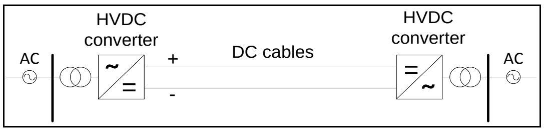


Figure 2-8 Symmetrical monopole.

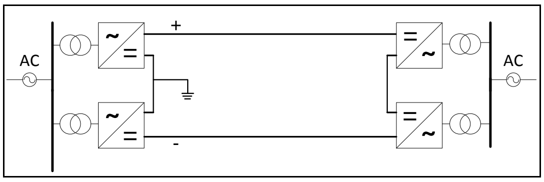


Figure 2-9 Rigid bipole.

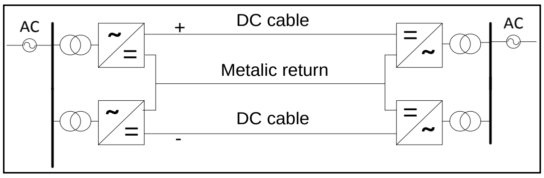


Figure 2-10 Bipole with metallic return.

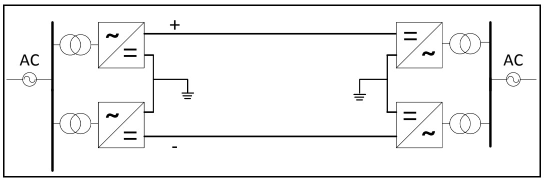


Figure 2-11 Bipole with ground return.

❖ *Rigid bipole*

The rigid bipole only uses two HVDC cables and no ground return conductor (e.g. +/-525 kV for Viking Link). The drawback is that full transmission capacity is lost in case of a cable fault. In the case of a fault in one of the converters, the full transmission capacity is lost until the HVDC cables are reconfigured for monopole operation with one set of converters. If the DC switchyard is equipped with switching devices, half of the transmission capacity can be re-established within a few seconds.

❖ *Bipole with metallic return*

The bipole with metallic return requires two HVDC cables and a medium voltage return cable. The advantage is that half of the transmission capacity can be maintained in case of a fault on a cable or in a converter. A disadvantage is the additional cost of the third cable. During maintenance of the converters, monopolar operation is possible without any special DC switching devices.

❖ *Bipole with ground return*

The bipole with ground return requires two HVDC cables and an electrode station in each end of the link. During normal operation, no current flows to the ground. During a cable or converter fault, however, monopole operation will require that the full DC current returns through the ground. For long HVDC links, the ground return solution is cheaper than using a metallic return cable but long-lasting ground currents may result in corrosion of metallic pipelines near the electrode stations.

❖ *Multi-terminal HVDC*

There is growing interest in VSC-based multi-terminal HVDC schemes due to the advantages they offer over LCC-based multi-terminal HVDC schemes, e.g.:

- The ability to control the power flow through each of the interconnected converter stations and the capability to reverse power flow through a converter station without the need for mechanical DC switches; and
- The advantages inherently offered by VSC over LCC converters such as the ability to connect to passive grids and lower harmonic generation.

The major drawback of VSC-based multi-terminal HVDC schemes is the very limited operational experience with its implementation and operation. Due to this, credible and reliable data regarding expected challenges during installation and operation of a multi-terminal HVDC scheme is sparse due to the very limited number of installations in operation.

One of the benefits of an HVAC transmission line is its flexibility in providing connection points for future generation and consumption along its route. A multi-terminal HVDC link can to some extent be used similarly, thereby enabling the fulfilment of the technical objective of a transmission line between Endrup and Idumlund. The configuration in below figure**Error! Reference source not found.** exemplifies the grid connection of two offshore wind power plants (WP) with the advantage of feeding generation from the HVAC substation Stovstrup (STS) to different AC substations, in this case EDR (Endrup) and IDU (Idomlund).

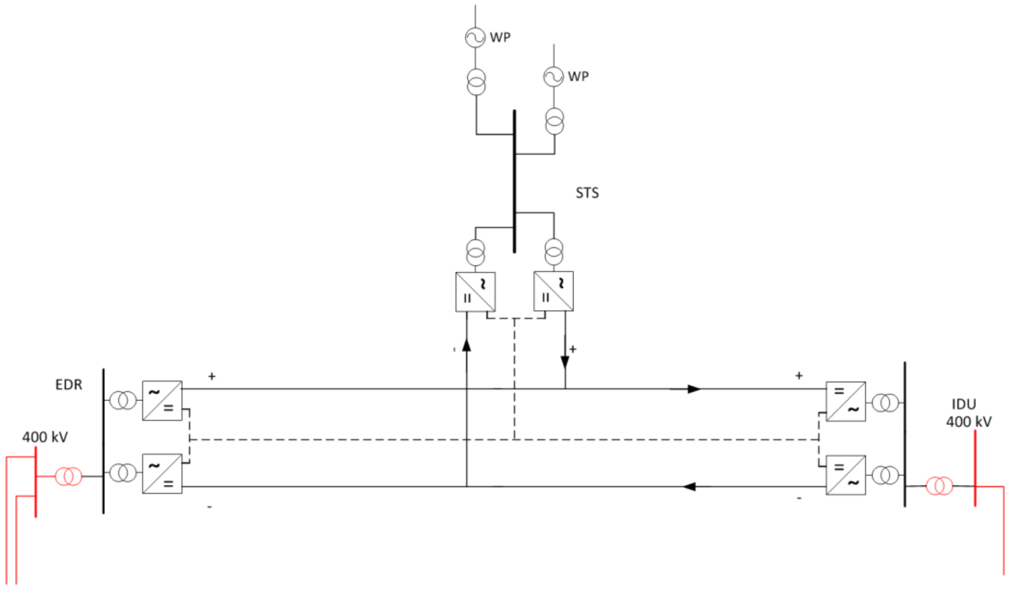


Figure 2-12 Two three-terminal HVDC links configured as bipoles exemplified using the Endrup-Idomlund transmission line.

The dimensioning contingency in the Danish transmission grid is loss of 700 MW, meaning that any internal fault in an HVDC link used to connect generation to the transmission grid must not lead to a momentary loss of power of more than 700 MW at any time. This limitation must be observed for a multi-terminal HVDC link as an alternative to the HVAC transmission line between Endrup and Idumlund, and, thus, the rating of converters in Stovstrup must not exceed 700 MW.

2.2.2.5. *Control functions*

By nature, a HVDC VSC link will not react to the loss of a parallel HVAC transmission line by automatically adjusting its flow of active power as would be the case with an HVAC transmission line. Fast control of active and reactive power to support the grid can be achieved with the application of special control functions. There are a few HVDC links around the world where the control systems are designed to emulate an HVAC transmission line, but operational experience is limited.

2.2.2.6. *Usability*

HVDC links are used in special cases in the transmission grid and the main reasons for selecting HVDC are:

1. Interconnection of two asynchronous power systems;
2. Long distances (including long submarine cables where OHLs are not possible); and

3. Very high levels of power transmitted over very long distances where HVDC is more cost-effective than HVAC transmission.

For power transmission applications other than these three, and particularly over relatively short distances, HVAC rather than HVDC transmission links are normally more economic due to the high cost of converter stations.

The HVDC link across the Great Belt is an example of item 1 above. For other interconnections between the Nordic synchronous system and the Central Europe synchronous system (e.g. Skagerrak), both items 1 and 2 are relevant. In Germany, HVDC links are used to connect large offshore wind power plants located far from shore. This has not been implemented in Denmark to date. In China, for example, several HVDC links have been built to accommodate high levels of power transported over very long distances (item 3).

HVDC transmission does not naturally integrate with HVAC systems and does not impart to the grid the natural resilience of HVAC transmission lines. HVDC is inherently more complex than HVAC in all respects from design, construction, testing, and maintenance to operation. Thus, a meshed HVAC transmission grid with embedded HVDC links will add complexity to future grid planning and expansion.

For these technical reasons, HVDC transmission is normally only used in EHV grids in cases where technical or economic reasons rule out HVAC transmission.

2.2.2.7. *Reliability*

The reliability of HVDC links is affected by the frequency and duration of both unplanned and planned maintenance. Unplanned maintenance is a forced outage due to a fault or the failure of an item of equipment. Planned maintenance is typically part of an annual or biannual maintenance schedule or simply a need to do repairs outside normal maintenance plans.

Planned maintenance has a lower impact on the power system as this can be timed to occur when demand is low or reduced transmission requirements are expected. Unplanned maintenance can occur at any time and may have a significant impact on the power system.

ENTSO-E publishes an annual Nordic HVDC Utilisation and Unavailability Statistics (entsoe) in which availability and utilisation of HVDC links connected to the Nordic and Baltic power system are presented with an emphasis on forced outages. The definitions of the abbreviations used to describe reliability are listed in below figure.

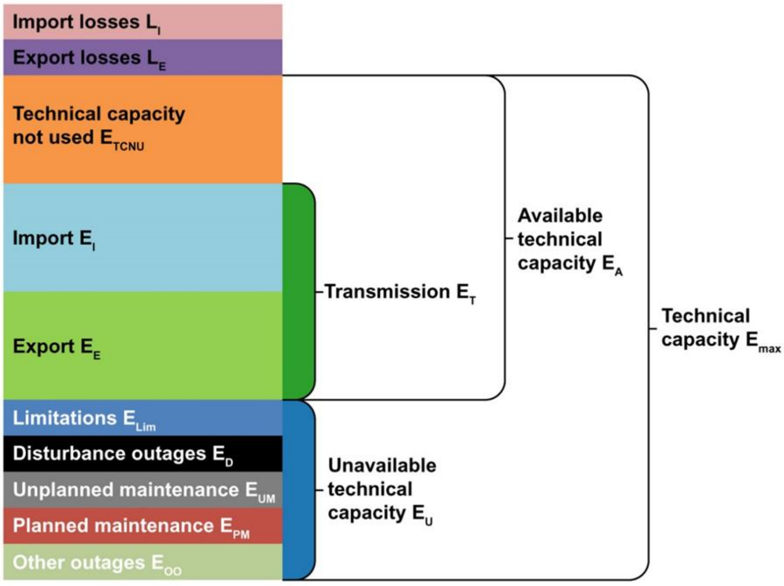


Figure 2-13 Availability and utilisation categories used in ENTSO-E's HVDC statistics.

In below figure, statistics for 2016 is presented. Values used are energy values and represent part of the technical capacity.

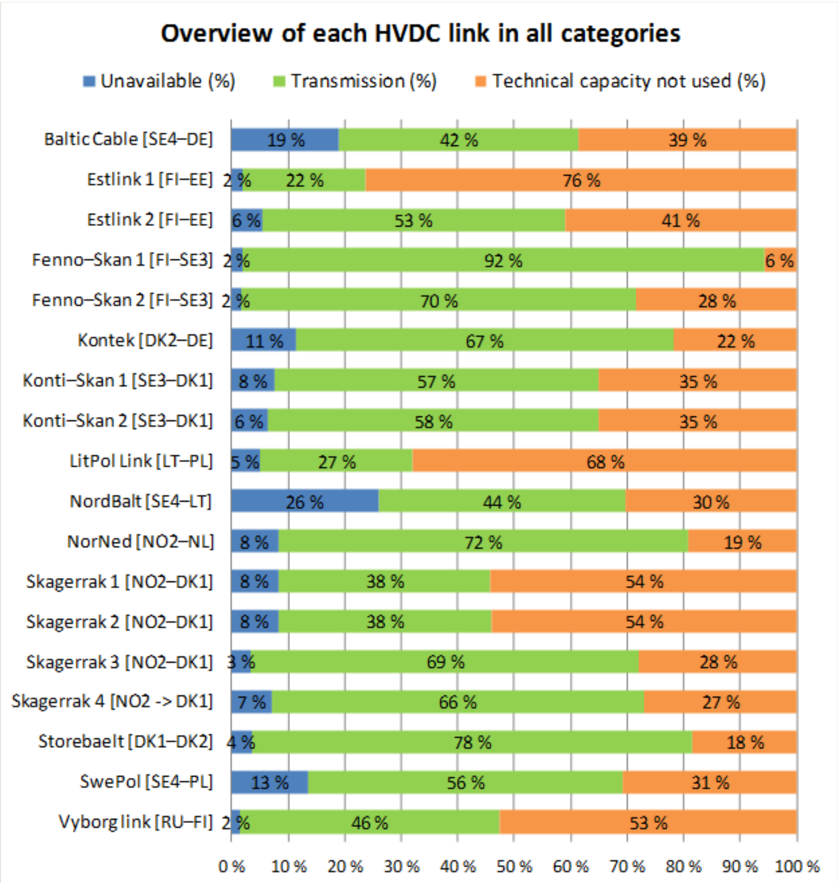


Figure 2-14 Utilization of Nordic HVDC installations

2.2.2.8. *Environmental impact*

The HVAC switchyard of a HVDC link is comparable in character to existing 400 kV substations within the transmission grid. However, the land area of this part of the converter station varies significantly, depending on the HVDC technology employed and the transmission capacity of the HVDC link.

Analyses from the planning phase of the Viking Link project show that the technical installation would cover an area of 42,000 m^2. The below figure shows a converter station with a 210 x 200 m^2 footprint.

In total, the substation would cover 20 hectares, or approximately 200,000 m^2, to include necessary parking, rainwater accumulation and shielding planting etc.

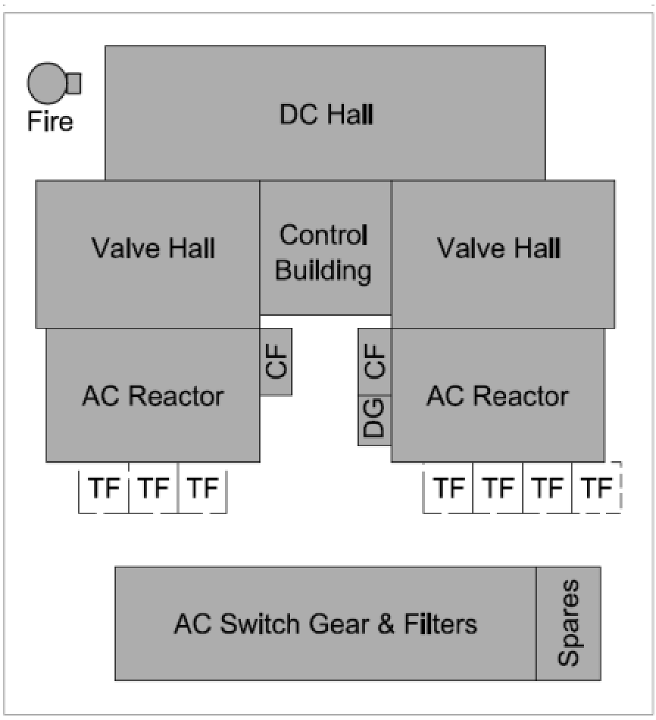


Figure 2-15 Conceptual layout of a 1,400 MW bipole

Figure 2-16 Visualization of 400 kV Revsing substation after Viking Link's completion.

2.2.2.9. *Summary*

HVDC is a proven technology and primarily used for bulk power transmission over long distances or for interconnecting asynchronous power systems. The introduction of HVDC VSC technology offers improved technical performance. The application of embedded HVDC links as part of the transmission grid in Western Jutland will introduce considerable complexity with regards to the operation and future development of the transmission grid compared to an HVAC solution.

Some HVDC cases that have been implemented in Denmark will be shown in the ***appendix 1***

2.2.3. HVDC Offshore Wind

In addition to interconnection of syncroneous areas and embedded lines in AC-systems as already described HVDC is also emerging as a technology for connection of large-scale offshore windfarms. The first connections are recently installed in Europe. Currently Denmark does not have any HVDC offshore wind. For the Kriegers Flak project which is a combined interconnector[3] and offshore wind farm the initial idea was to build it as a HVDC solution but due to bad experience in Germany with offshore HVDC the prices were high and confidence in the solution was low. The solution ended up with a 150/220 kV offshore AC grid with a back-to-back converter in Germany. The amount of offshore AC cables and the combination of different technologies and voltages has made it a very complicated system to analyze, energize and operate, so with longer distances it would be even more difficult to connect offshore wind via AC. Normally 100-150 km offshore cables are expected to be maximum length for AC to be the technical and economical optimal solution. One of the issues for longer distances are that the reactive power production in AC cables will take up a lot of the capacity limiting the capacity for active power.

[3] The combination of offshore windfarms and interconnectors are often referred to as a Hybrid Project

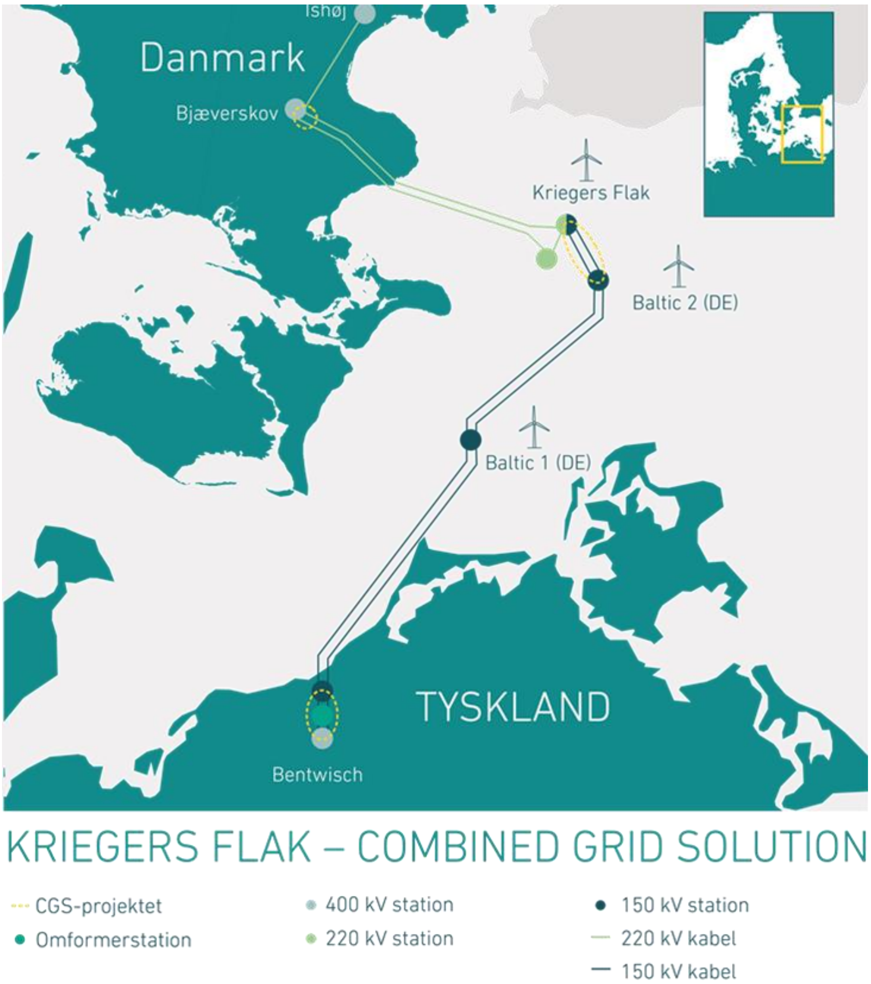


Figure 2-17 Kriegers Flak Combined Grid Solution.

Today the HVDC offshore technology has matured and the need to find wind locations further offshore and to ensure a more flexible integration to the existing transmission system, HVDC will probably be the recommended solution for connecting offshore wind with a greater distance than 100 km. Currently Denmark and neighboring countries are developing wind energy island projects that can combine large amounts of offshore wind with interconnectors and local consumption (like power to gas).

HVDC offshore wind has been used with success in Europe especially in Germany, but there has been a lot of difficulties in the beginning, so it is recommended to study the relevant projects[4].

[4] https://www.offshorewind.biz/2014/06/26/tennet-working-to-power-up-borwin-1/

Figure 2-18 Energy Island

2.3. Economic and technical calculations for HVDC and HVAC transmission systems

The economic-technical comparison between the HVDC and HVAC transmission options in this study is based on the following assumptions.

Comparative voltage: HVAC 500 kV and HVDC +/- 525 kV (based on the popularity of the standard and the commercialization of equipment, overhead lines and 525 kV DC power cables).

Conductor: 4 bundles wires for both 500 kV and HVDC 525 kV HVAC technologies. The wire cross section is selected between 4xACSR400 - 4xACSR500 with thermal capacity of about 2200 MW to 3100 MW / circuit for HVAC and from 1436 MW to 1984 MW / circuit for HVDC. The calculation applies to overhead lines (OHL).

Series Capacitor compensation and reactance compensation: the HVDC line does not need to install 2 devices. However, for the long HVAC lines, series capacitor should be installed to ensure stability and reactors compensation to keep the voltage in limitation. The level of series capacitor compensation is about 75%. For each 300-400 km line segment, it is required to install reactors at both ends with a capacity of 128 MVAr on each end. OHL 500 kV transmission with a length of 600 km or more need to build intermediate switching stations to install series compensation capacitor and reactors.

To ensure fairness when comparing economic - technical, it is assumed that the generation side of both HVAC and HVDC options are at the same 220 kV AC voltage. It is assumed that the power system at the two ends of the line has a short-circuit capacity strong enough to enable the use of LCC technology (Line Commutated Converter) for the HVDC option.

The HVAC option uses 500/220 kV transformers with a capacity of 900 MVA / unit. The transformers carry approximately 75% of the load in normal operating mode.

HVDC option: using LCC technology to compare with HVAC, the input and output of the HVDC system are 220 kV alternating current. The 220 kV bus bar of the AC-DC, DC - AC converter stations is connected to the regional 220 kV grid. VSC technology (Voltage Source Converter) will be considered when calculating the transmission plan for specific projects, the investment cost of VSC will be higher than LCC technology.

Investment cost for 500 kV AC system:

+ Investment cost for substation 500/220 kV: 0.065 mil. USD / MVA.

+ Investment cost for 500 kV double circuit transmission line: 0.966 mil. USD / km.

+ Investment cost for 500 kV single circuit transmission line: 0.7 * double circuit investment cost.

Investment cost for HVDC system of 525 kV:

+ Investment cost for OHL bipole +/- 525 kV: 0.773-0.927 mil. USD / km

+ converter station investment cost: ranges from 0.111 Mil. USD / MW to 0.083 Mil. USD / MW.

Calculation life of transmission grid project: 40 years.

Transmission Load factor: 0.479.

With the above input assumptions, the following section calculates the comparison between the two HVDC and HVAC transmission options with transfer power levels ranging from 1000 MW to 6000 MW.

2.4. Calculation of economic-technical comparison between HVDC and HVAC technologies with Vietnam conditions

In this section, the study team will compare the economic and technical between HVDC and HVAC transmission alternatives for different transmission scenarios with consideration of Vietnam conditions in terms of transmission capacity (1000 MW - 6000 MW) and transmission distance (300 - 400 - 600 - 1000 - 1200 - 1500 - 2000 km). Calculate the investment cost (capex) and the power loss of the transmission options.

2.4.1. Comparison of investment costs between HVDC and HVAC transmission technologies

Investment scope of transmission system: including 500/220 kV step up / step down substations, 500 kV transmission line between 2 stations (excluding 220kV transmission lines that connecting to other transformer stations and power plants).

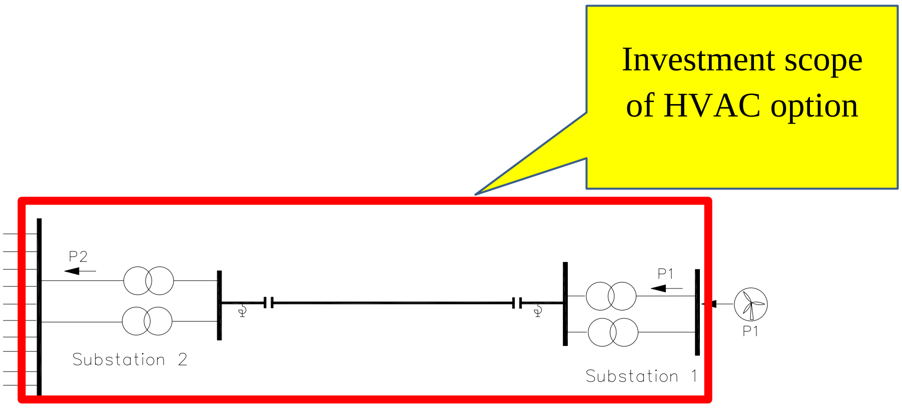


Figure 2-19 Investment scope of HVAC option

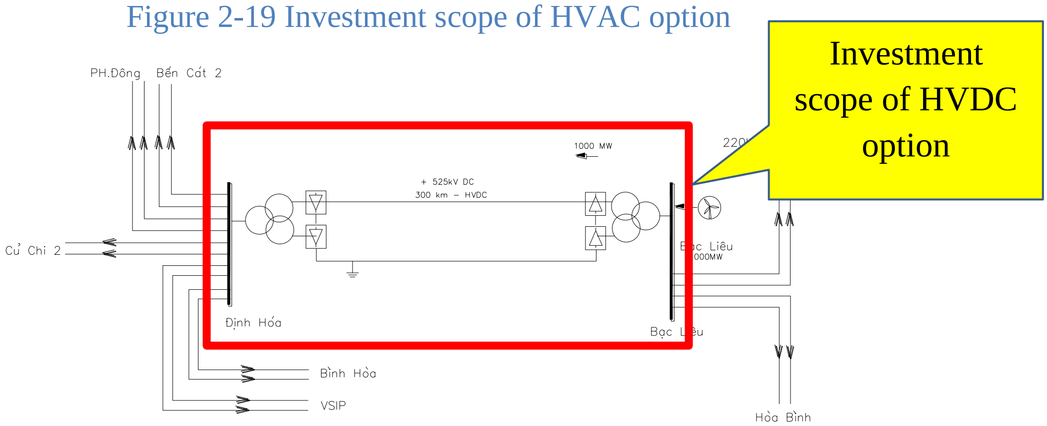


Figure 2-20 Investment scope of HVDC option

The detail of CAPAX calculation for 84 cases (HVAC and HVDC transmission technology) are shown in the appendix. The following sections show some typical single line diagrams and CAPEX calculation for the transmission system.

- *Power transfer 1000 MW – 300 km:*

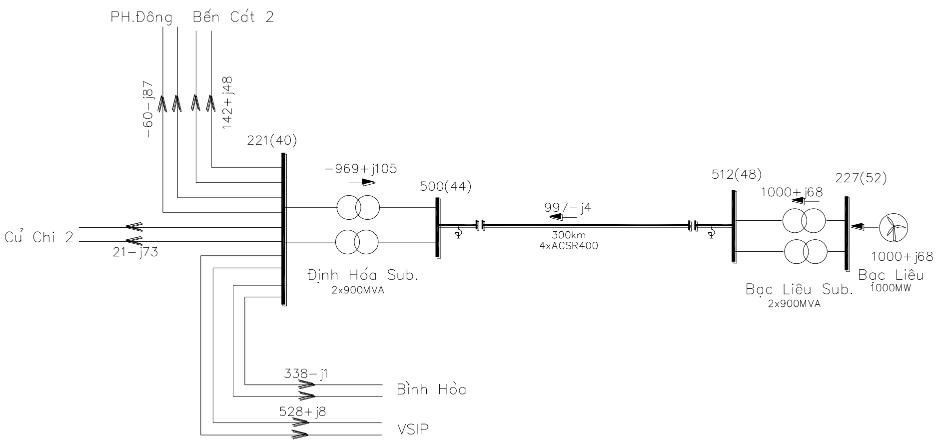


Figure 2-21 Single line diagram and load flow simulation results in 500kV HVAC alternative – 300 km – 1000 MW

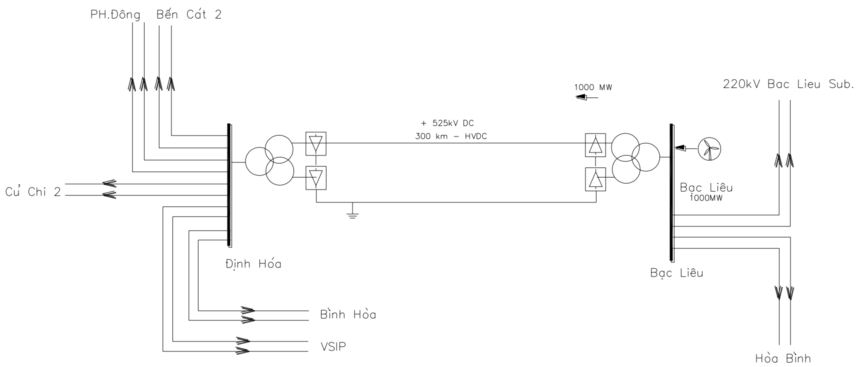


Figure 2-22 Single line diagram for 525kV HVDC alternative – 300 km – 1000 MW

Table 2-3 Total investment cost in HVAC alternative – 300 km – 1000 MW

No.	Elements	Type	Unit	Value	Unit cost (mil. USD/km or Mil. USD/MVA)	Cost (mil. USD)
A	**Transmission lines**					**202.9**
1	500 kV TL 1	Single circuit, 4xACSR400	km	300	0.676	202.9
B	**Substation**					**234.0**
1	500/220 kV Sub. No. 1 (from source)	2x900 MVA	MVA	1800	0.065	117.0
2	500/220 kV Sub. No. 2 (To load)	2x900 MVA	MVA	1800	0.065	117.0
C	**Total investment cost**					**436.9**

Table 2-4 Total investment cost in HVDC alternative – 300 km – 1000 MW

No.	Elements	Type	Unit	Value	Unit cost (mil. USD/km or Mil. USD/MW)	Cost (mil. USD)
A	**Transmission lines**					**231.8**

1	+525 kV Monopole TL	4xACSR400, Ground conductor return	km	300	0.773	231.8
B	**Substation**					**220.0**
1	AC-DC Converter Sub. (from source)	1000 MW	MW	1000	0.11	110.0
2	DC-AC Converter Sub. (to load)	1000 MW	MW	1000	0.11	110.0
C	**Total investment cost**					**451.8**

- *Power transfer 1000 MW – 600 km:*

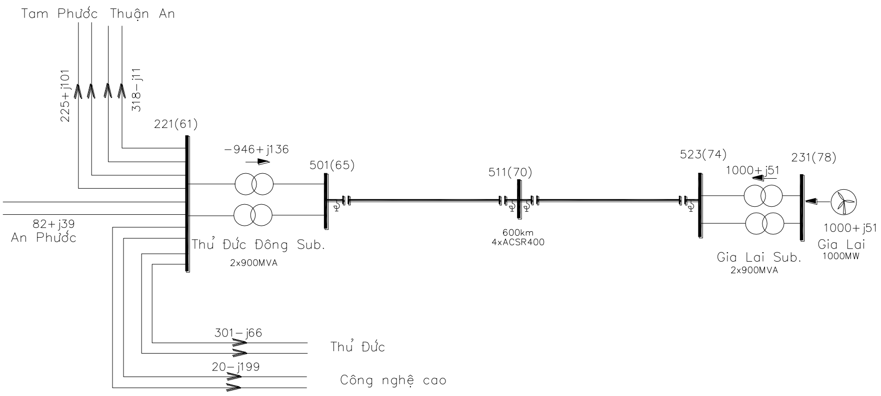


Figure 2-23 Single line diagram and load flow simulation results in 500kV HVAC alternative – 600 km – 1000 MW

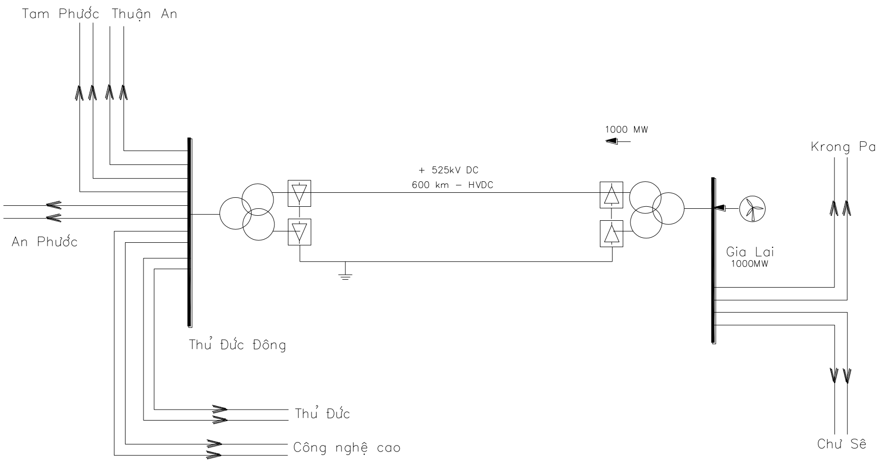


Figure 2-24 Single line diagram and load flow simulation results in 500kV HVAC alternative – 600 km – 1000 MW

Table 2-5 Total investment cost in HVAC alternative – 600 km – 1000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MVA)	Cost (mil. USD)
A	**Transmission line**					**405.7**
1	500 kV TL 1	Single circuit, 4xACSR400	km	600	0.676	405.7
B	**Substation**					**244.5**
1	500/220 kV Sub. No. 1 (from source)	2x900 MVA	MVA	1800	0.065	117.0
2	500/220 kV Sub. No. 2 (To load)	2x900 MVA	MVA	1800	0.065	117.0
	Compensation Sub. No1					
1	500 kV TL Bay	Bay		2	1.644	3.3
2	Reactance	128 MVAr		2	3.587	7.2
C	**Total investment cost**					**650.2**

Table 2-6 Total investment cost in HVDC alternative – 600 km – 1000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MW)	Cost (mil. USD)
A	**Transmission line**					**463.7**
1	+525 kV Monopole TL	4xACSR400, Ground conductor return	km	600	0.773	463.7
B	**Substation**					**220.0**
1	AC-DC Converter Sub. (from source)	1000 MW	MW	1000	0.11	110.0
2	DC-AC Converter Sub. (to load)	1000 MW	MW	1000	0.11	110.0
C	**Total investment cost**					**683.7**

- *Power transfer 2000 MW – 400 km:*

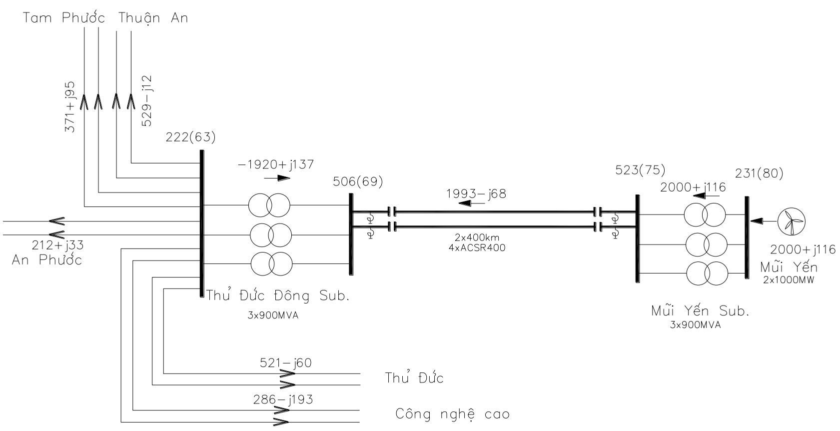


Figure 2-25 Single line diagram and load flow simulation results in 500kV HVAC alternative – 400 km – 2000 MW

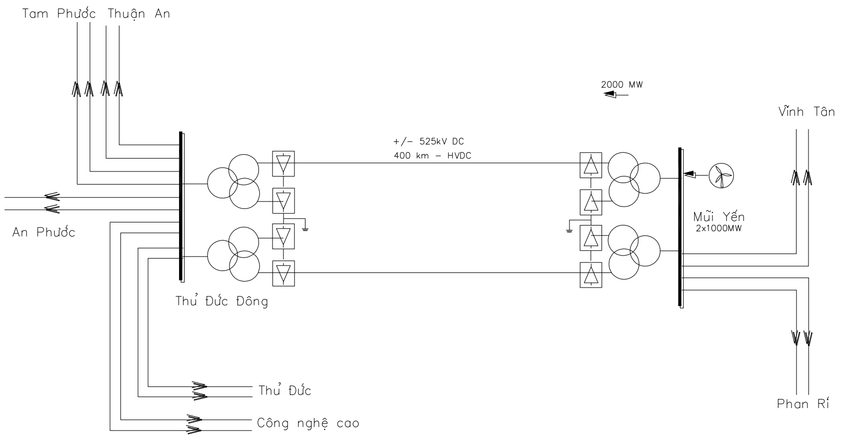


Figure 2-26 Single line diagram for 525kV HVDC alternative – 400 km – 2000 MW

Table 2-7 Total investment cost in HVAC alternative – 400 km – 2000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MVA)	Cost (mil. USD)
A	**Transmission line**					**386.4**
1	500 kV TL 1	Double circuit, 4xACSR400	km	400	0.966	386.4
B	**Substation**					**351.0**
1	500/220 kV Sub. No. 1 (from source)	3x900 MVA	MVA	2700	0.065	175.5
2	500/220 kV Sub. No. 2 (To load)	3x900 MVA	MVA	2700	0.065	175.5
C	**Total investment cost**					**737.4**

Table 2-8 Total investment cost in HVDC alternative – 400 km – 2000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MW)	Cost (mil. USD)
A	**Transmission line**					**309.1**
1	+525 kV Bipole TL	4xACSR400	km	400	0.773	309.1
B	**Substation**					**440.0**
1	AC-DC Converter Sub. (from source)	2000 MW	MW	2000	0.11	220.0
2	DC-AC Converter Sub. (to load)	2000 MW	MW	2000	0.11	220.0
C	**Total investment cost**					**749.1**

- *Power transfer 2000 MW – 1500 km*

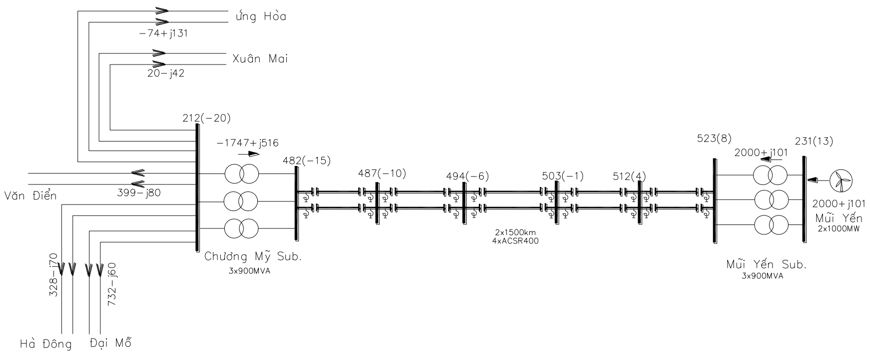


Figure 2-27 Single line diagram and load flow simulation results in 500kV HVAC alternative – 1500 km – 2000 MW

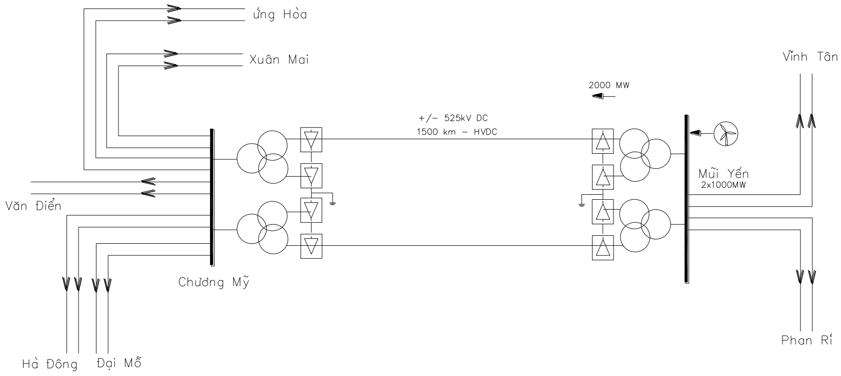


Figure 2-28 Single line diagram for 525kV HVDC alternative – 1500 km – 2000 MW

Table 2-9 Total investment cost in HVAC alternative – 1500 km – 2000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MVA)	Cost (mil. USD)
A	**Transmission line**					**1449.0**
1	500 kV TL 1	Double circuit, 4xACSR400	km	1500	0.966	1449.0
B	**Substation**					**434.7**
1	500/220 kV Sub. No. 1 (from source)	3x900 MVA	MVA	2700	0.065	175.5
2	500/220 kV Sub. No. 2 (To load)	3x900 MVA	MVA	2700	0.065	175.5
	Compensation Sub. No1					
1	500 kV TL Bay	Bay		4	1.644	6.6
2	Reactance	128 MVAr		4	3.587	14.3
	Compensation Sub. No2					
1	500 kV TL Bay	Bay		4	1.644	6.6
2	Reactance	128 MVAr		4	3.587	14.3
	Compensation Sub. No3					
1	500 kV TL Bay	Bay		4	1.644	6.6
2	Reactance	128 MVAr		4	3.587	14.3

	Compensation Sub. No4					
1	500 kV TL Bay	Bay		4	1.644	6.6
2	Reactance	128 MVAr		4	3.587	14.3
C	**Total investment cost**					**1883.7**

Table 2-10 Total investment cost in HVDC alternative – 1500 km – 2000 MW

No.	Elements	Type	Unit	Value (km)	Unit cost (mil. USD/km or Mil. USD/MW)	Cost (mil. USD)
A	**Transmissions line**					**1159.2**
1	+525 kV Bipole TL	4xACSR400	km	1500	0.773	1159.2
B	**Substation**					**440.0**
1	AC-DC Converter Sub. (from source)	2000 MW	MW	2000	0.11	220.0
2	DC-AC Converter Sub. (to load)	2000 MW	MW	2000	0.11	220.0
C	**Total investment cost**					**1599.2**

Summary of correlation between investment cost and transmission distance in HVDC - HVAC technologies are shown in the following figures:

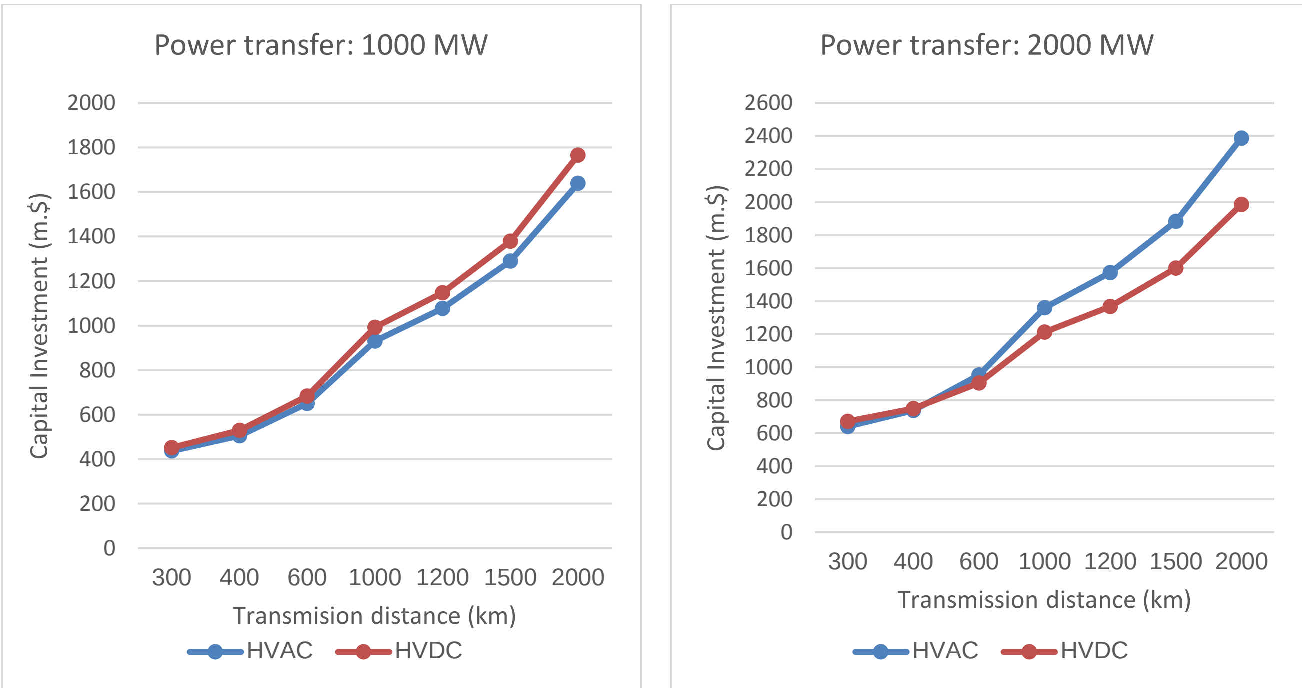


Figure 2-29 CAPEX of HVAC and HVAC alternatives in the power transfer scenario of 1000 MW and 2000 MW

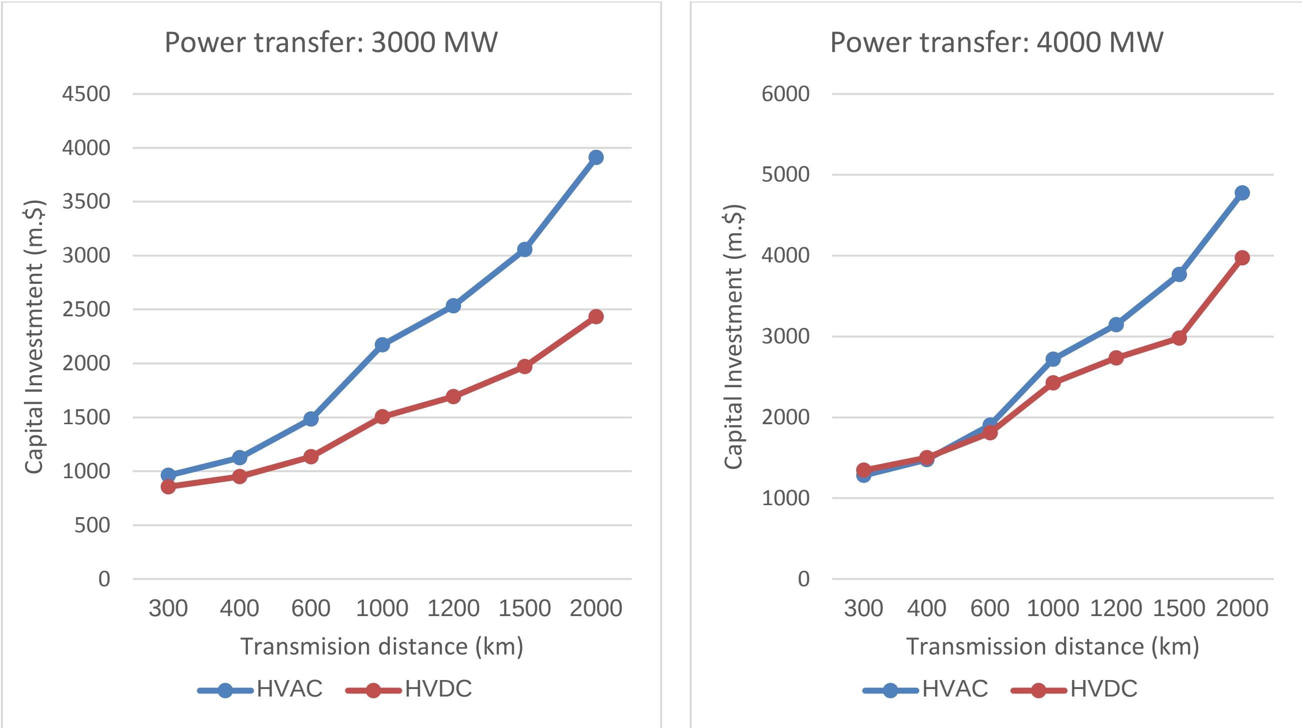


Figure 2-30 CAPEX of HVAC and HVAC alternatives in the power transfer scenario of 3000 MW and 4000 MW

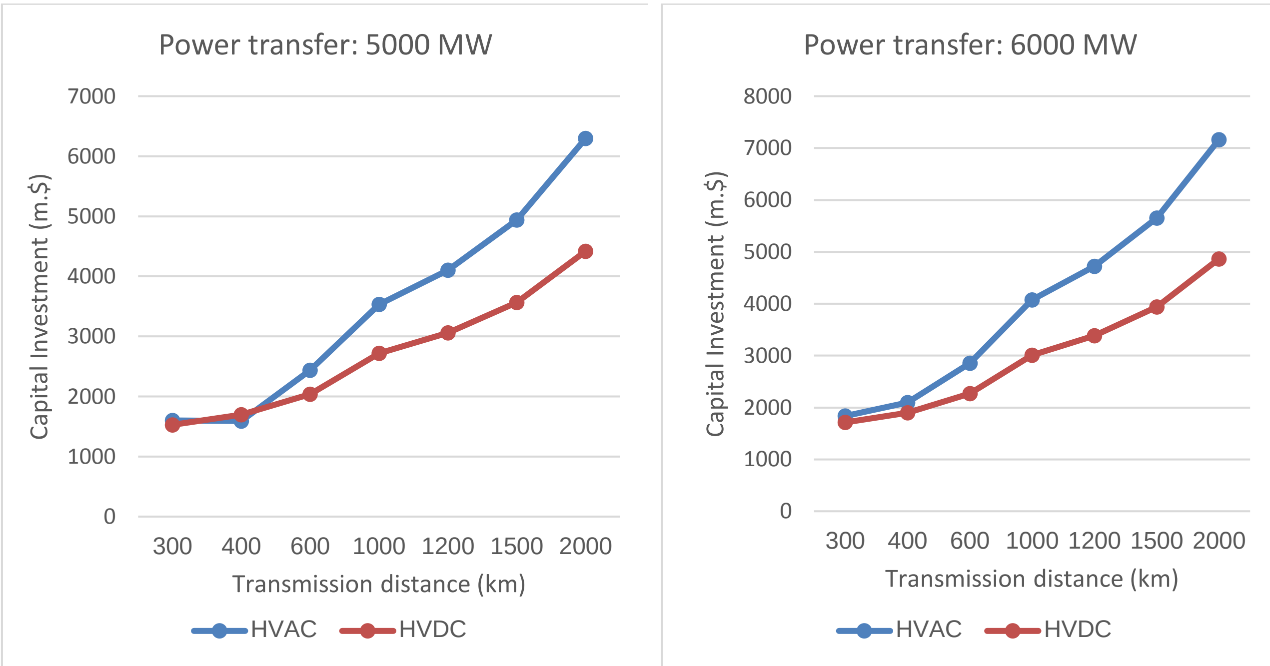


Figure 2-31 CAPEX of HVAC and HVAC alternatives in the power transfer scenario of 5000 MW and 6000 MW

<u>Comments:</u>

Investment costs in HVAC and HVDC alternatives show that:

- For low power transfer scenario (1000 MW), the investment cost in HVAC alternative is lower than HVDC alternative in all cases of transmission distance (300 – 2000 km). However, the difference of investment cost in two alternatives is not large. Investment cost of HVAC transmission alternative is about 3-8% lower than that of HVDC.
- For higher power transfer scenarios (2000 – 6000 MW), the transmission investment cost is similar in low transmission distance cases (300 – 400 km). In larger transmission distance cases (600 - 2000 km), the investment cost of HVAC transmission alternative is quite greater than that of HVDC (12-61%).

2.4.2. Comparison of power loss in HVDC and HVAC alternatives

In this part, consultancy calculate and analyzed power loss in HVAC and HVDC alternative in difference scenarios of power transfer and transmission distance.

Power loss results in HVAC and HVDC transmission alternatives are shown in figures below:

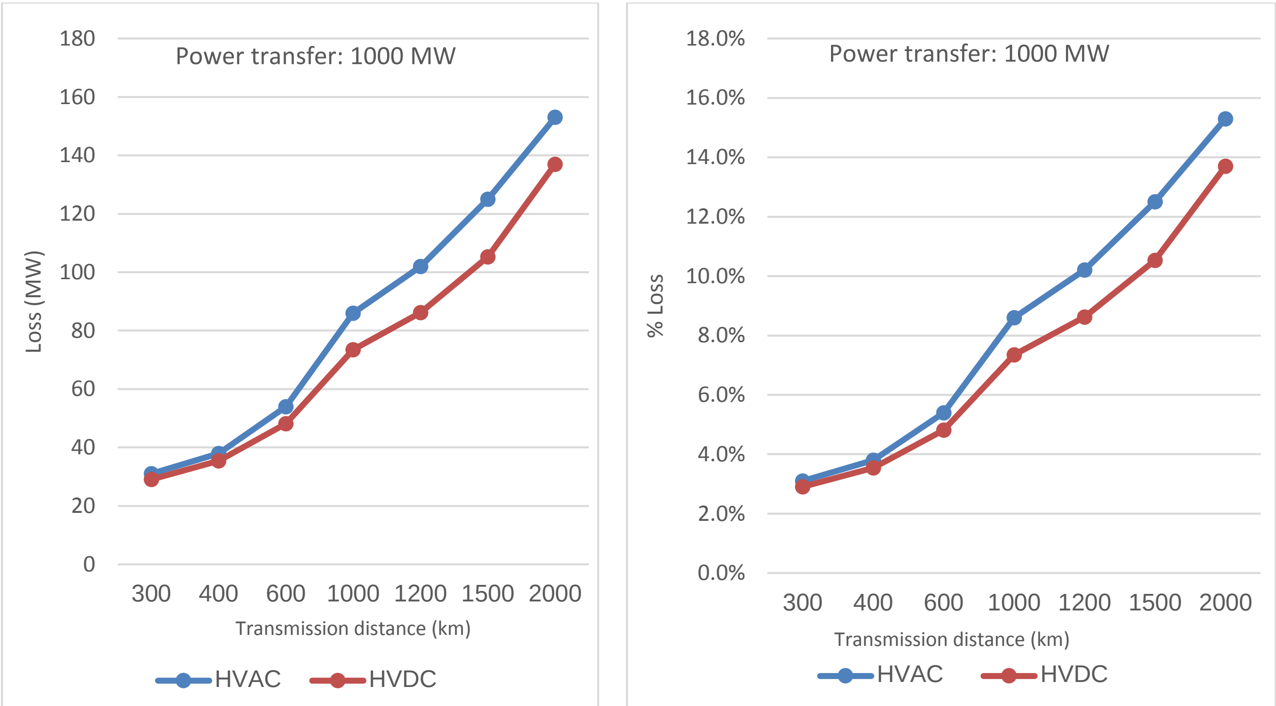


Figure 2-32 Power loss in HVAC and HVAC alternatives – 1000 MW of power transfer

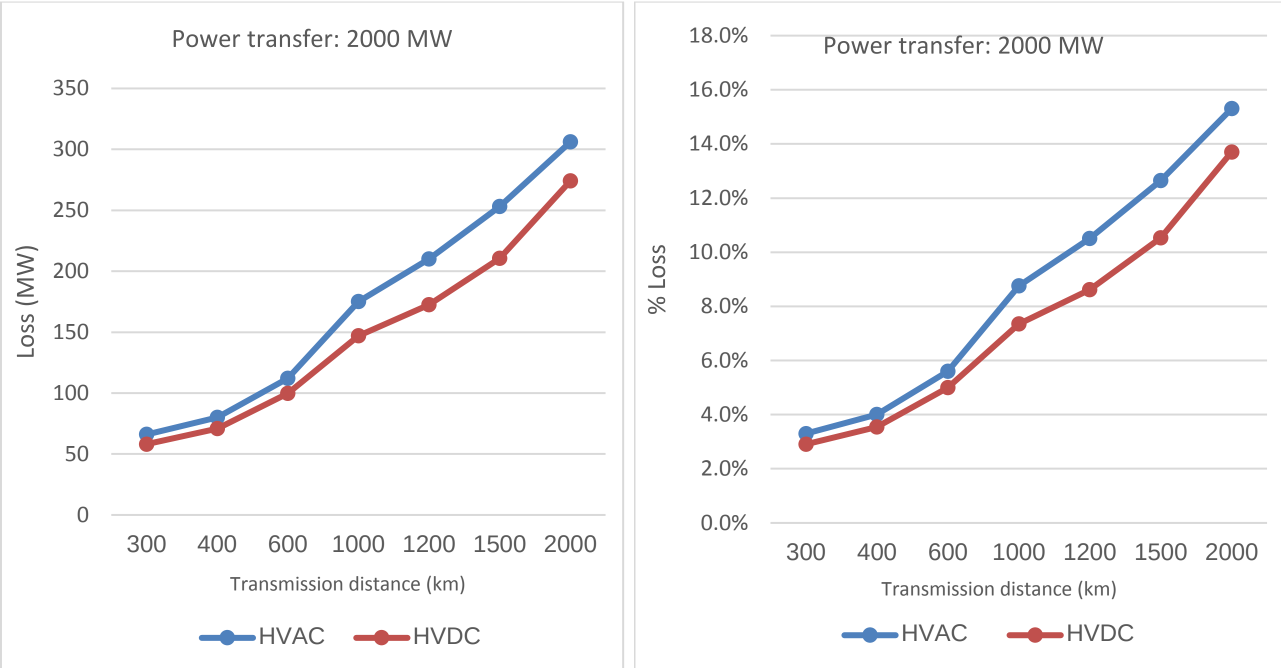


Figure 2-33 Power loss in HVAC and HVAC alternatives – 2000 MW of power transfer

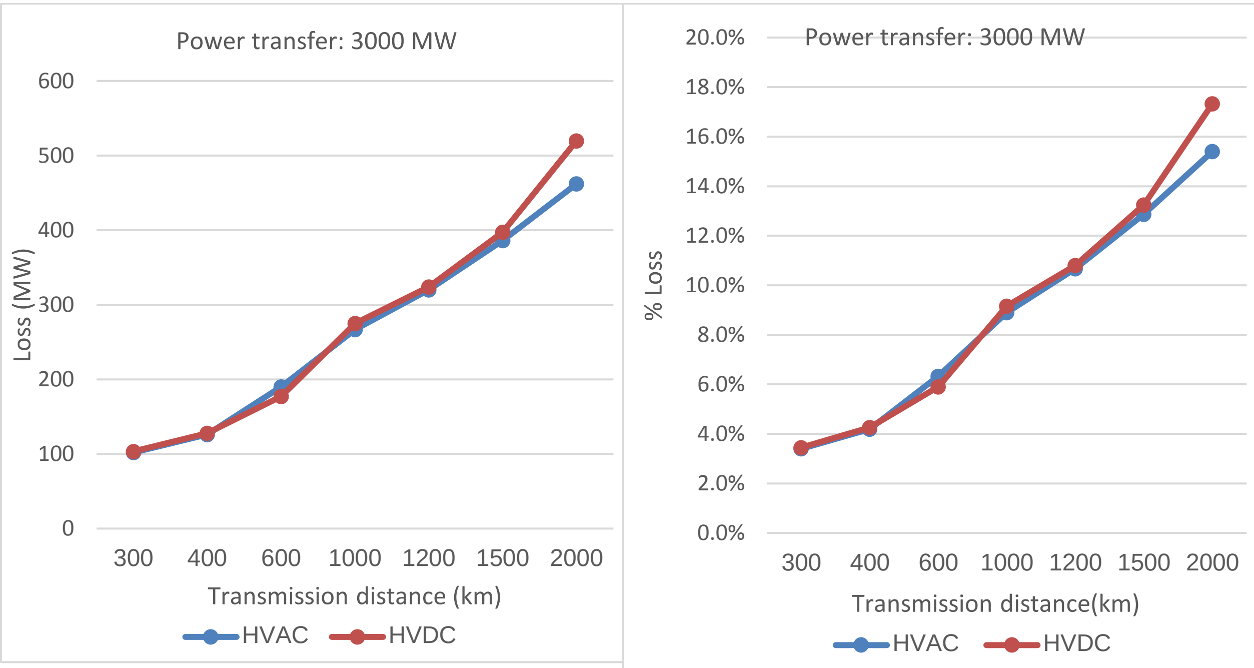


Figure 2-34 Power loss in HVAC and HVAC alternatives – 3000 MW of power transfer

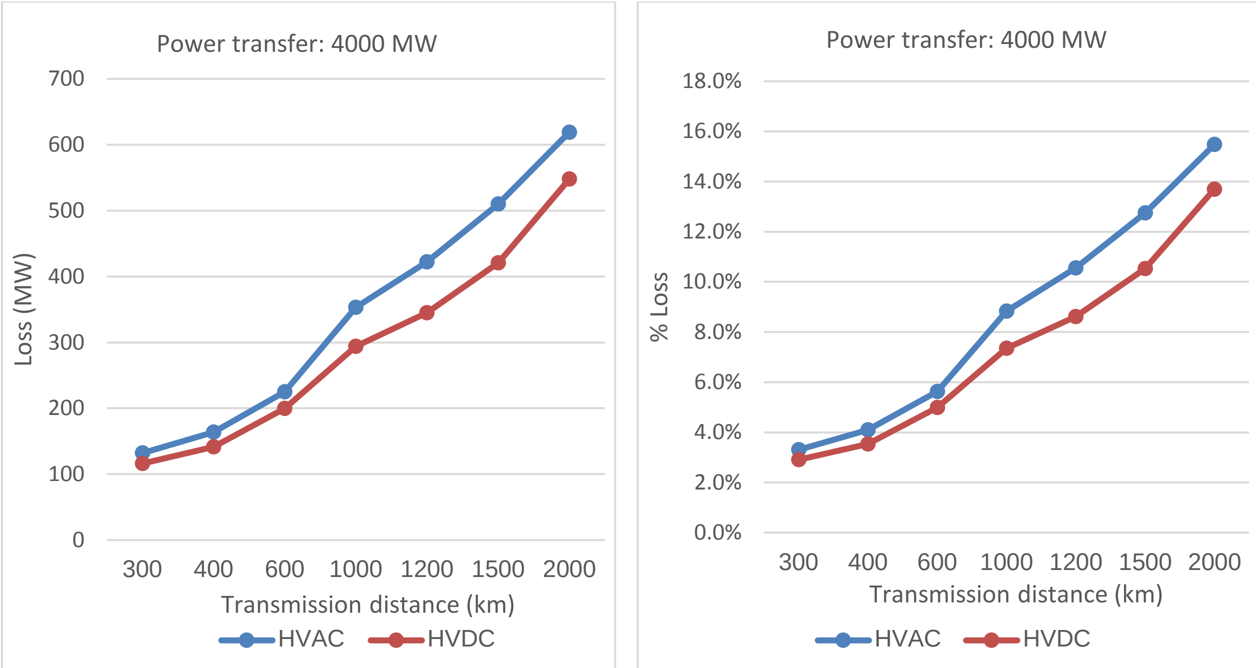


Figure 2-35 Power loss in HVAC and HVAC alternatives – 4000 MW of power transfer

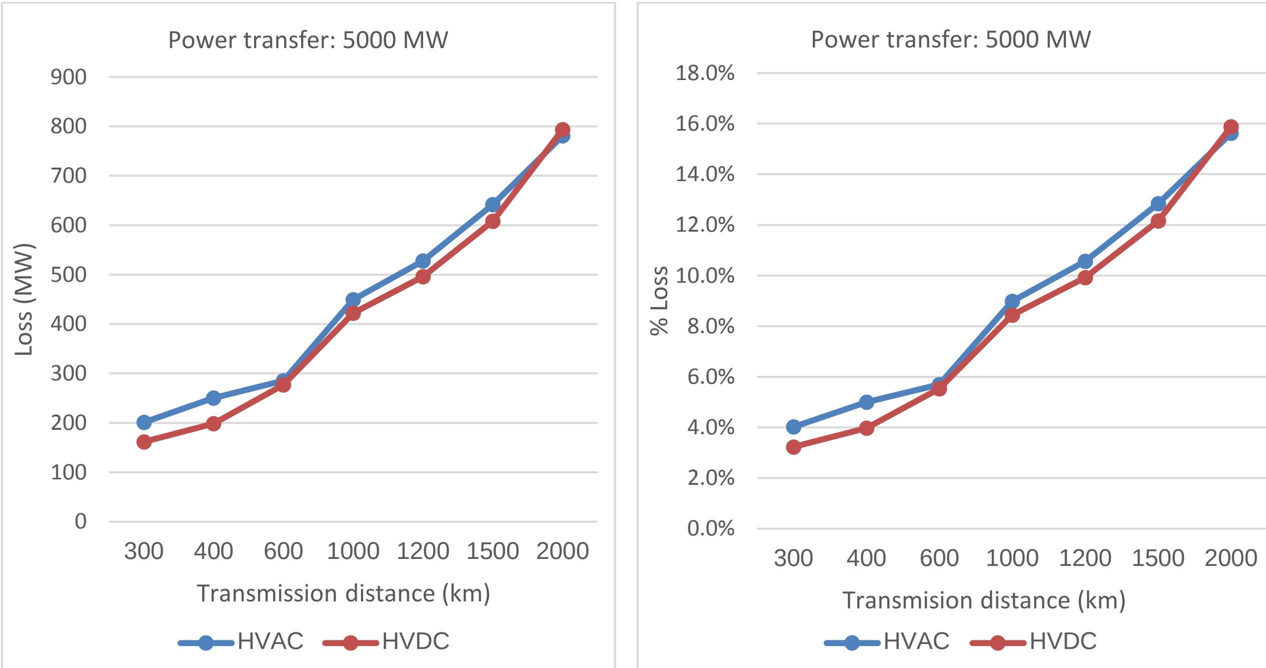


Figure 2-36 Power loss in HVAC and HVAC alternatives – 5000 MW of power transfer

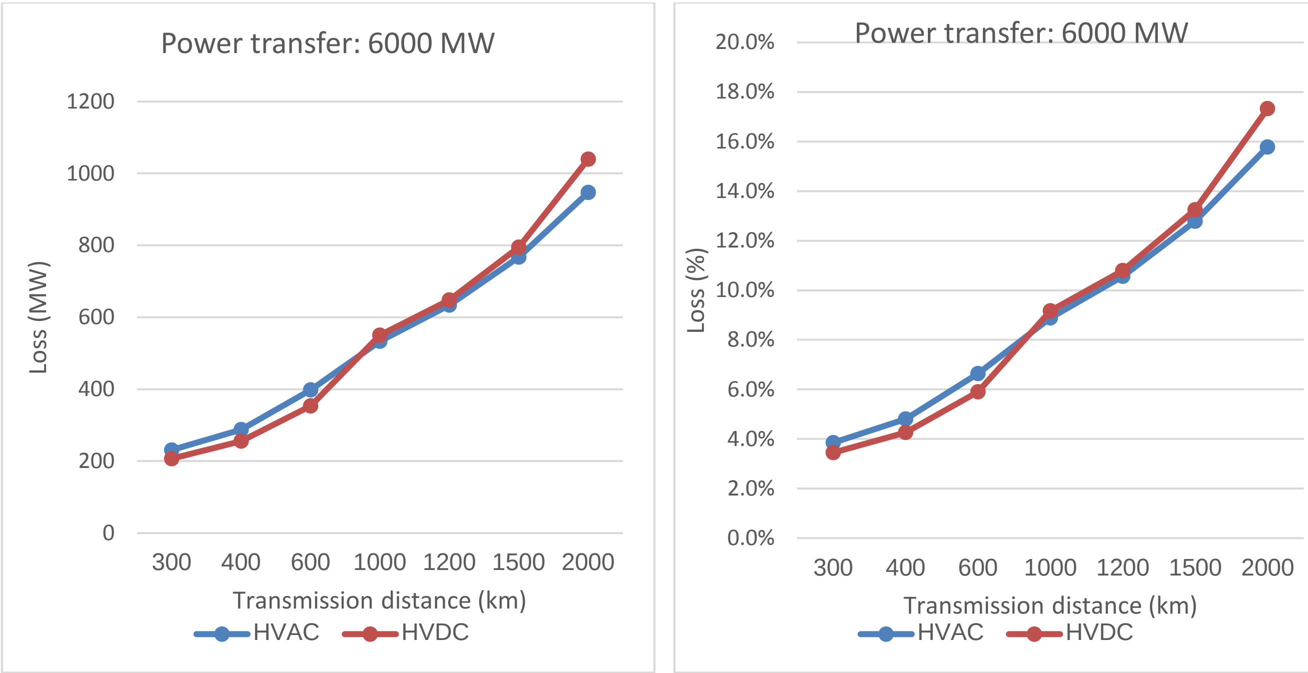


Figure 2-37 Power loss in HVAC and HVAC alternatives – 6000 MW of power transfer

Comments:

Results of power loss in HVAC and HVDC transmission alternatives show that:

- In low power transfer (1000 – 2000 MW) and low transmission distance (300 – 400 km) cases, power loss is similar in two transmission alternatives. In low power transfer and higher transmission distance (600 – 2000 km) cases, power loss in HVAC alternative is about 1 – 2% larger than that of HVDC.
- In high power transfer (5000 – 6000 MW), and low transmission distance (300 – 400 km) cases, power loss in HVAC alternative is larger than that of HVDC. In contrast, in high power transfer with a large transmission distance (1000-2000 km) cases, power loss in HVAC alternative is lower. However, the difference of loss between the two transmission alternatives is not large (about 0.2-1.5%).

2.4.3. Comparison of net present value in HVDC and HVAC alternatives

In this part, HVDC and HVAC transmission alternatives are compared against each other based on net present value (NPV) in over the lifetime of project (40 years). The values are discounted to the year of investment preparation with the discount factor of 2% (in USD).

Total cost of each alternative includes:

- ***Investment cost:*** Including investment cost for the transmission lines and transformer substations in HVAC and HVDC transmission alternatives;

- ***Annual maintenance and operation costs***: 2% of investment capital;
- ***Cost of electricity losses:*** *Based on cost power production costs that calculated in the daft of PDP8.*

NPV of HVAC and HVDC alternatives in difference of transmission scenarios are summarized in the following figures:

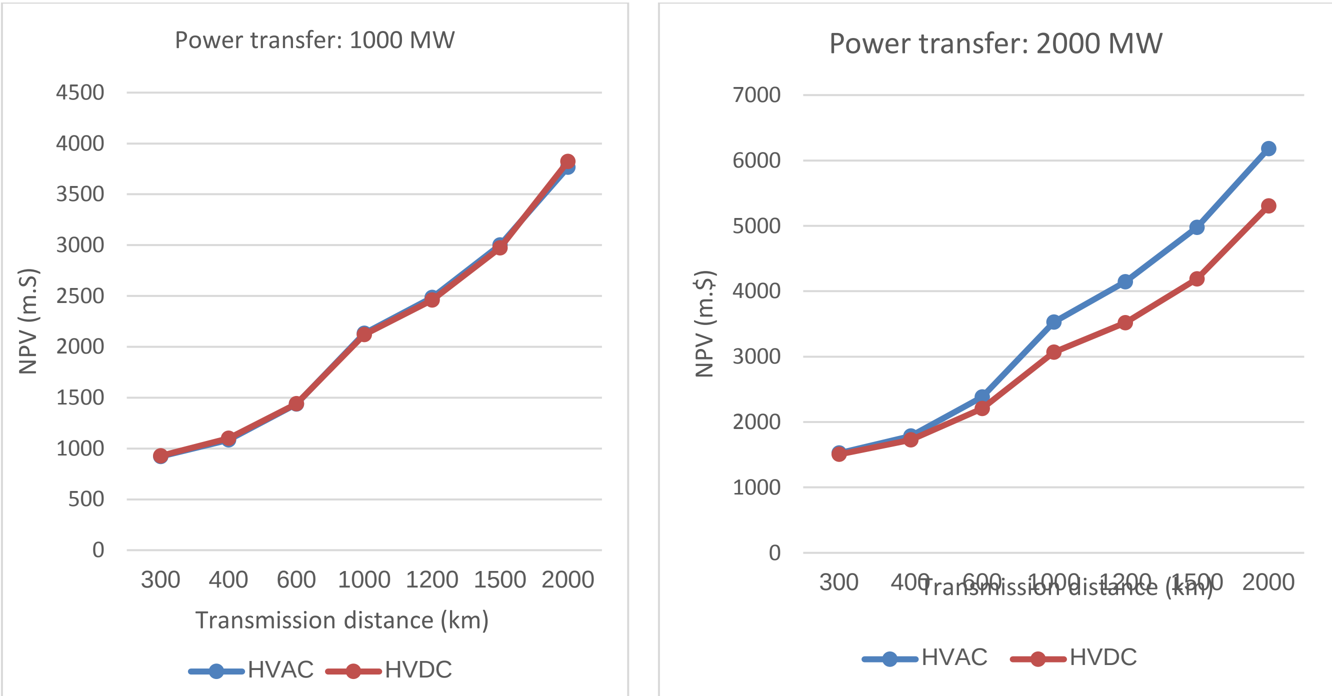


Figure 2-38 Net present value of HVAC and HVDC transmission alternatives in the power transfer scenario of 1000 and 2000 MW

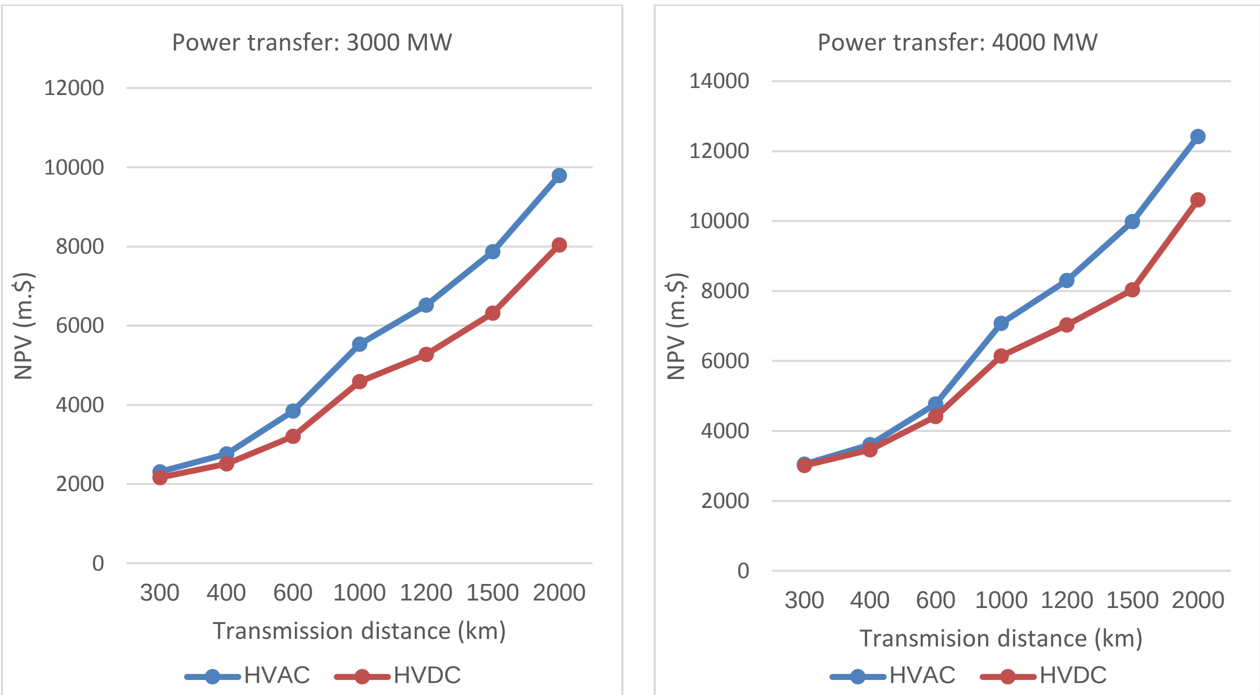
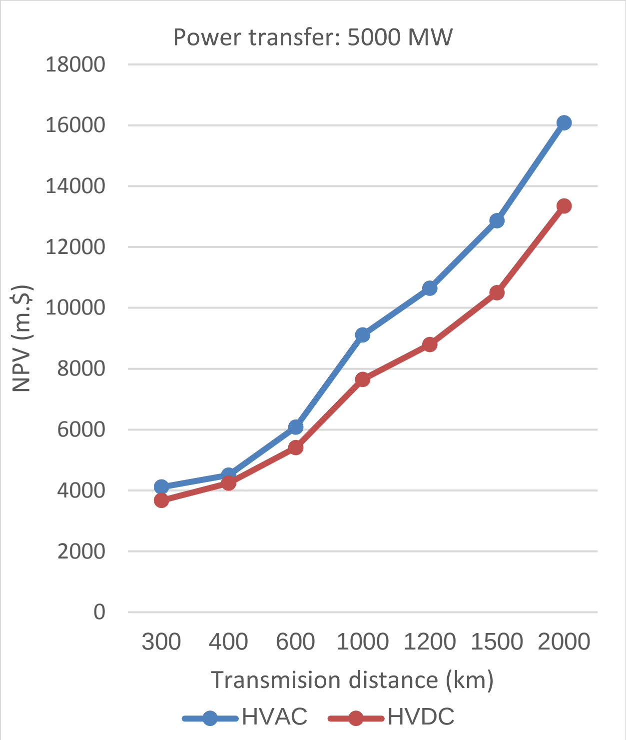


Figure 2-39 Net present value of HVAC and HVDC transmission alternatives in the power transfer scenario of 3000 and 4000 MW



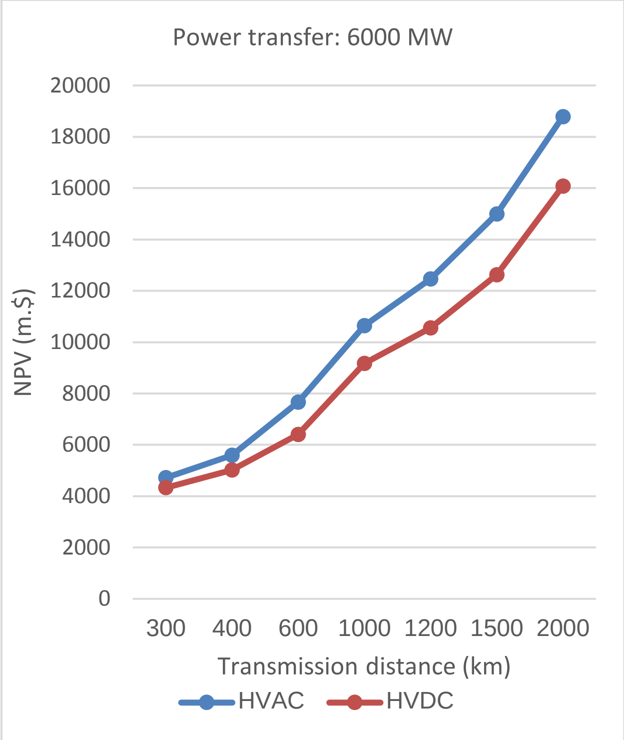


Figure 2-40 Net present value of HVAC and HVDC transmission alternatives in the power transfer scenario of 5000 and 6000 MW

Comments:

Results of NPV in HVAC and HVDC transmission alternatives show that:

- Because the difference of power loss between the two alternatives is not large, the NPV is highly influenced by the CAPEX.
- In low power transfer scenario (1000 MW), NPV is similar in two transmission alternatives. Because the difference of investment cost and power loss are not large between two alternatives.
- For higher power transfer scenarios (2000 – 6000 MW), in low transmission distance (300 – 400 km), NPV is similar in two alternatives. In higher transmission distance (600 – 2000 km), NPV of HVAC transmission alternative is higher than that of HVDC (about 8-27%). The difference of NPV between two alternatives increase increases gradually with the transmission distance.

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CHAPER 3. LONG-TERM POWER SOURCE EXPANSION SCENARIOS AND POSSIBILITY OF HVDC APPLICATION IN INTER-REGIONAL POWER TRANSFER

3.1. Long-term power development scenarios

Compared to the power development program of the PDP7 (Build in 2014-2015)[5], up to this point, the government has adjusted the scale and progress of many large power projects, especially coal fired thermal power plants. At the same time, there are many mechanisms and policies to encourage RE development [6],[7],[8],[9].

In the period of 2019-2021, many renewable energy sources such as wind and solar power have been added to the PDP, which have been and are being built. With the current incentive policies, a large amount of RE resources is being proposed for investment. The change of the power source structure (in the direction of increasing the proportion of renewable energy) will substantially change the characteristics of electricity transmission compared to the PDP 7R, making the backbone transmission grid may not meet the Grid code requirements. Therefore, the program of developing long-term power sources until 2030 or beyond (as of 2045) has not been clearly defined.

In order to find the optimal power source development structure in the long term and develop a suitable transmission grid development program, the Ministry of Industry and Trade of Vietnam is implementing the National Power Development Plan for the period 2021-2030, taking into account 2045. The power generation expansion program in PDP 8 needs to ensure a harmonious balance between regions, openness, flexibility and rational development of RE resources [10].

Source development scenarios under consideration in PDP 8:

The source development scenarios will be related to the promulgated policy goals and a number of presumptive policies to fully consider the potential development of future power sources.

+ Scenario 0 - Normal development scenario (KB0A_BAU): This is a planning calculation scenario in accordance with the approved PDP7R. The type of power source chosen for future development is entirely based on cost competitiveness and does not take into account external costs. This scenario is called the baseline scenario, with the aim to evaluate the effectiveness of the proposed policies in other scenarios.

+ Scenario 1 - Scenario of renewable energy target based on RE development strategy No. 2068 and Resolution 55-NQ / TW (KB1A_RE, KB1B_RE): This scenario is added with additional constraints on renewable energy targets, created in accordance with Vietnam's Renewable Energy Development Strategy for the period from 2030 to 2050 (Decision 2068 / QD-TTg dated 25/11/2015). Accordingly, the proportion of electricity produced from renewable energy sources (including large hydroelectricity) in the total electricity generation capacity of the whole country will reach 38% in 2020, 32% in 2030 and 43% in 2050. The KB1A_RE version does not take into account the external costs which are the costs due to emissions during the generation of electricity (External Cost); The scenario KB1B_RE is taking into account the external costs, which are the costs incurred to the emissions of the power generation process.

+ Scenario 2 - RE target is higher than 0268 strategy (KB2A_RE, KB2B_RE): This scenario considers the RE target to increase gradually: 38% in 2020, 38.5% in 2025, 39% in 2030, 40% in 2035, 41% in 2040, 42% in 2045 and 43% in 2050. KB2A_RE, KB2B_RE are the NO and YES scenarios considering exogenous costs.

+ Scenario 3 - High Renewable Energy Goal (KB3A_RE, KB3B_RE): is a scenario with RE targets much more ambitious than the Renewable Energy Development Strategy 2068. Expected percentage of electricity produced from Renewable energy will reach 40% in 2025, 42% in 2030, 44% in 2035, 46% in 2040, 48% in 2045 and 50% in 2050. KB3A_RE, KB3B_RE are the WITHOUT and WITH scenarios that take into account the external costs.

+ Scenario 4 - Target to reduce greenhouse gas (KB4A_CO2, KB4B_CO2): this scenario considers the change in source structure when reducing 25% of greenhouse gas emissions compared to the normal development scenario. KB4A_CO2, KB4B_CO2 are WITHOUT and WITH scenarios taking external costs.

+ Scenario 5 - No new coal thermal-power plants construction after 2030 (KB5B_Nonewcoal): This is a scenario combining the policy of renewable energy development under scenario 1 and the policy of not developing additional new coal power plants after 2030, taking into account the external costs.

+ Scenario 6 - Development of nuclear power in the period after 2035 (KB6B_Nuclear): This is a scenario combining the policy of targets of renewable energy development under scenario 1 and the policy of assuming nuclear power development after 2035.

Therefore, there is total of 11 main scenarios were calculated. The objective function is the least cost.

3.2. Calculation results of long-term power expansion program

The results of calculating the scale of the power source and the power capacity structure from the Balmorel model over the years for 11 scenarios are as follows:

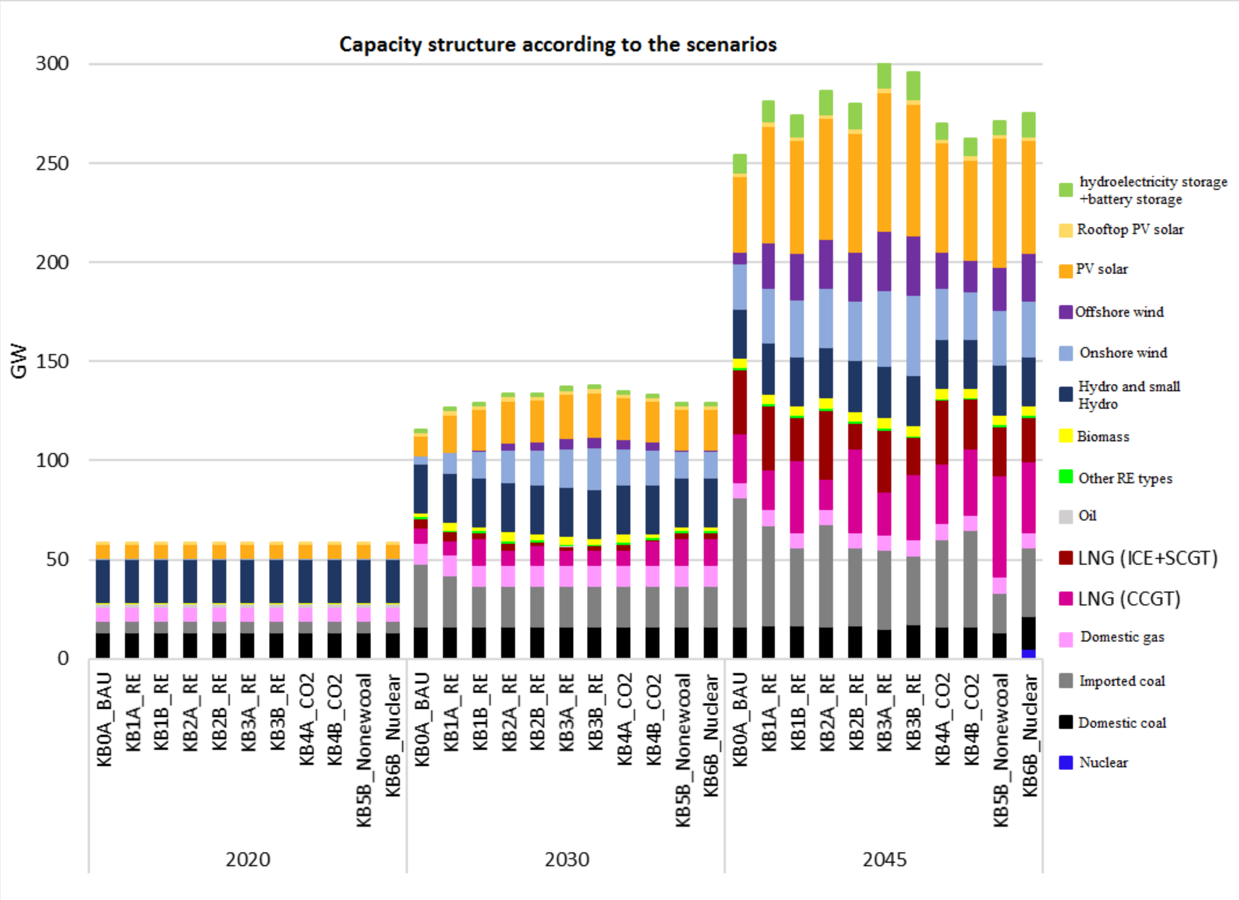

Figure 3-1 Capacity structure according to scenarios

The results show that renewable energy will be selected for large-scale development in the future, especially wind and solar power. Coal and gas are the fossil fuel sources that will continue to be used in all scenarios, and oil fuel will not be used to peak after 2025. Nuclear power is not selected to develop in the conventional scenario, scenarios using renewable energy policies and targets to reduce CO2 emissions.

Under the normal development scenario, coal thermal power will continue to be developed on a fairly large scale from 19.5GW in 2020 to 48GW in 2030 and 81GW in 2045, accounting for 33% of the electricity structure in 2020 to 41% in 2030 and 32% in 2045. LNG thermal power plant will also increase in capacity scale by 2045 due to limitations in the potential construction location of coal thermal power source in large load areas (North, South) and require only the development of improved supercritical technology for coal-fired power after 2035. However, most of the gas power capacity using LNG is a flexible source to cover the peak load and ensure system redundancy. Therefore the electricity produced from LNG will not be high. Renewable energy sources, especially wind and solar, are still selected to develop on a fairly large scale (wind of 29GW and solar of 40GW in 2045). In terms of capacity structure, renewable energy (including large hydroelectricity) will reach 37% in 2030 and 39% in 2045.

In renewable energy target scenarios, renewable energy sources are put into development to ensure the set goals, renewable energy capacity depending on the scenario will be higher from 1.4 -1.8 times the normal development scenario. Coal power plants capacity will be lower and gas thermal power will be higher when taking into account external costs of different types of emissions. In the scenarios without external costs, the selected gas thermal power plants are mainly developed with flexible sources with large scale to cover peak time load and ensure system redundancy. In scenarios taking into account external costs, CCGT was chosen to develop more with a higher amount of electricity generated from LNG.

In the CO2 reduction target scenario, CO2 emissions will be reduced by 25% compared to the normal development scenario. Although using a different policy, the model still chooses to increase the scale of renewable energy, increase gas thermal power and reduce coal thermal power to reduce CO2 emissions. Nuclear power has not yet been selected for development in the planning period if only 25% of CO2 emissions are reduced compared to the conventional scenario. In 2030, the selected renewable energy scale is higher than the strategic renewable energy target scenario (KB1A_RE, KB1B_RE), and is equivalent to the scenario of increasing renewable energy target in 2030 (KB2A_RE, KB2B_RE). However, in the period until 2045, the scale of RE is lower than the target scenario of RE according to the strategy 2068.

Scenario KB5B_Nonewcoal does not develop new coal PP and still maintains strategic renewable energy target policy. Coal thermal power source will not be further developed after 2025, scale of coal thermal power capacity in 2030 will reach 37GW and by 2045 it will reach 34GW. The scale of gas PP in 2030 in this scenario does not increase compared to the strategic renewable energy target scenario (KB1B_RE). However, 2045 has the highest scale of thermoelectricity in all scenarios, reaching more than 83GW by 2045 (higher than the normal development scenario of 20GW and higher than the strategic renewable energy target scenario of 17GW). Regarding the structure of the power source, in 2030 the scenario KB5B_Nonewcoal has the same structure as the target scenario of renewable energy according to the KB1B_RE strategy. However, by 2045, coal thermal power will reach only 12%, gas thermal power will reach 31%, and renewable energy will reach 54% in terms of capacity structure. Because the development of more thermoelectricity is more flexible, solar power in scenario KB5B_Nonewcoal is more developed, wind power is lower than scenario KB1B_RE. The scale of solar power developed in this scenario is equivalent to the high RE development scenario (KB3B_RE). Scenario 5B_Nonewcoal will have a low emission target, however, the structure of electricity source until 2045 is unbalanced, depending heavily on imported LNG.

In the scenario KB6B_Nuclear, nuclear power is introduced in the period of 2040-2045 with the scale of 5000MW in 2045. The capacity structure of this scenario is different from the strategic renewable energy target scenario (KB1B_RE) in in 2040 and 2045 when more nuclear power is put into operation. Therefore, the power structure in 2045 of KB6B_Nuclear scenario is more diverse than other scenarios.

3.3. Calculation results of electricity transmission needs between regions in the electricity system

Corresponding to each source development scenario, the demand for inter-regional transmission will change accordingly. The results of calculation of transmission capacity requirement between regions in 2030 and 2045 are presented as the following sections.

3.3.1. Power transfer requirement for inter-regional transmission up to 2030

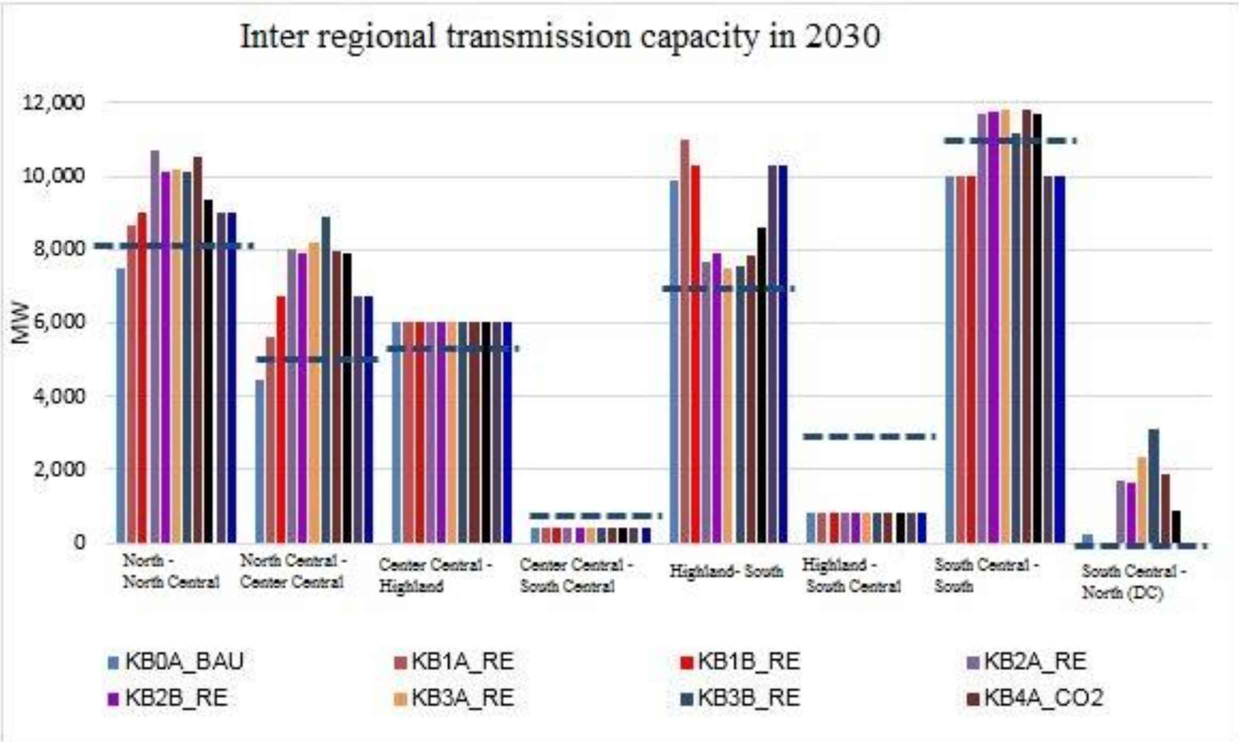

Figure 3-2 Inter-regional transmission capacity according to 2030 scenarios

Legend: -------- inter-regional transmission capacity limit in PDP 7R

Under the normal development scenario, the increase in transmission scale is quite consistent with the approved and additionally approved orientations for the PDP7R, only the Central Highlands - Southern link should be considered to add about 3000MW.

The medium, high renewable energy target scenarios and greenhouse gas reduction targets all have higher transmission increases on the links than the approved grid development plan. Especially when simulating more 1500 km long link from South Central to North, there is a ~ 2000-3000MW transmission capacity in scenarios KB2A_RE, KB2B_RE, KB3A_RE, KB3B_RE, KB4A_CO2, KB4B_CO2.

3.3.2. Power transfer requirement for inter-regional transmission up to 2045

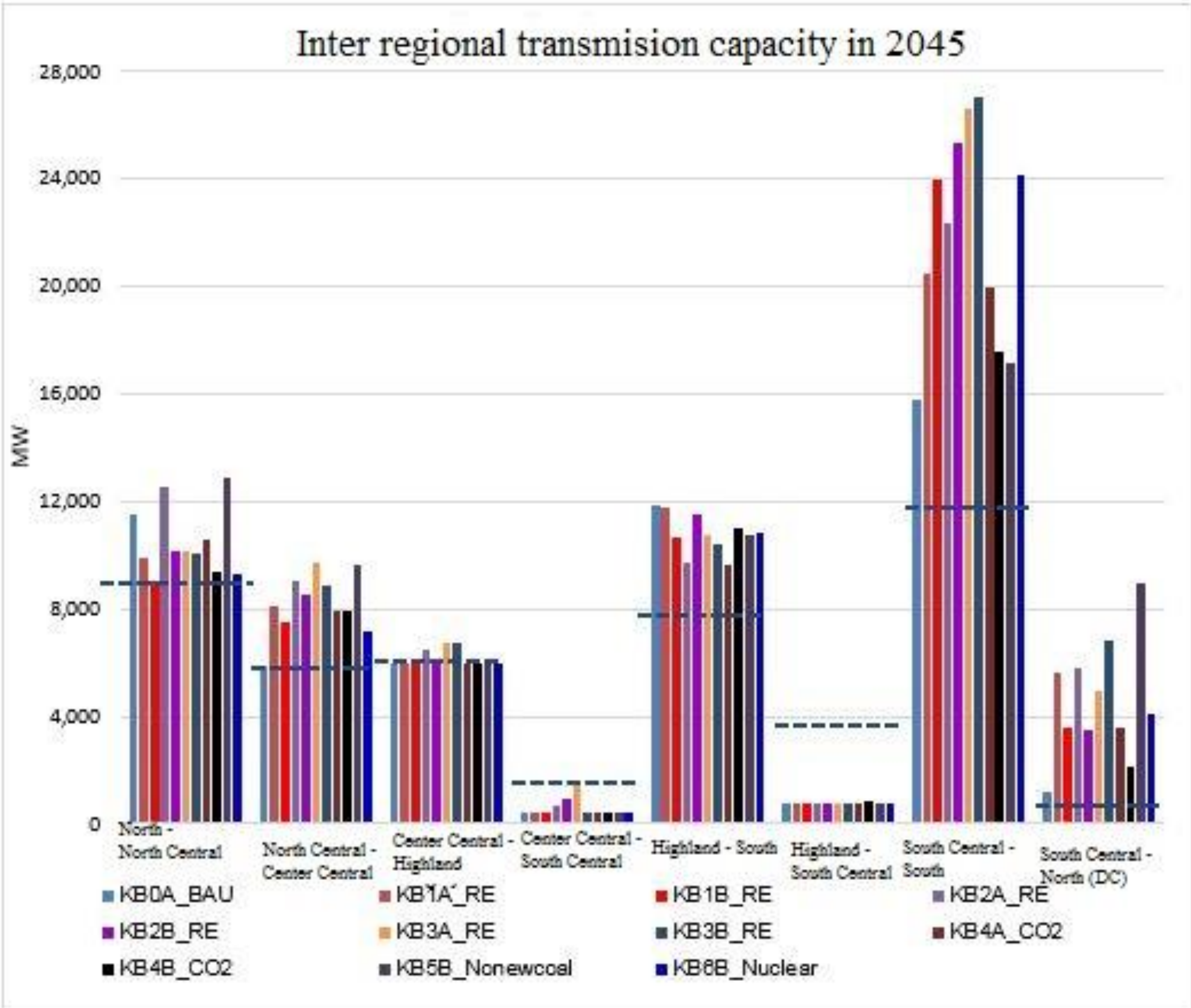

Figure 3-3 Inter-regional transmission capacity according to 2045 scenarios

Legend: - - - - - - - - inter-regional transmission capacity limit in PDP 7R

In the period to 2045, the linkage will be strengthened by the most from South Central to South Vietnam due to the development of offshore wind power.

The simulation results also show that the HVDC linkage system from the South Central to the North will appear with a large transmission scale, which can reach 10GW in the scenario KB5B_Nonewcoal, reaching about 7 GW in scenario KB3B_RE, reaching 6 GW. In the scenarios KB1A_RE, KB2A_RE, KB3A_RE, only about 4 GW in the scenarios KB1B_RE, KB2B_RE, KB4A_CO2 and KB6B_Nuclear.

3.4. Potential projects of HVDC transmission corresponding to long-term power development scenarios up to 2045 in Vietnam

Based on calculations of inter-regional transmission demand from the source simulation program, long-term HVDC projects in Vietnam can be considered as follows:

By 2030:

Power Scenario: KB0A, KB1A_RE, KB1B_RE, KB5B, 6B: Transmission increases about 2000 MW from the Central Highlands to the South on a distance of 400-600 km (compare to PDP7R in 2030). According to chapter 2, the NPV cost of the HVDC +/- 525 kV option may be 25% lower than the HVAC 500 kV at a distance of 600 km.

Table 3-1 Increased transmission capacity in Highland – South link – in 2030 - KB0A, KB1A_RE, KB1B_RE, KB5B, KB6B scenarios

Scenario	Increased transmission capacity (MW) Highland - South
KB0A_BAU	3023
KB1A_RE	4127
KB1B_RE	3454
KB5B_Nonewcoal	3454
KB6B_Nuclear	3454

Source scenario: KB2A_RE, KB2B_RE, KB3A_RE, KB3B_RE, KB4A_CO2, KB4B_CO2, the additional transmission capacity is about 2000 MW from the South Central Coast to the North over a distance of 1500 km. According to calculations in chapter 3, the NPV cost of the HVDC +/- 525 kV alternative is about 15.5% lower than the HVAC 500 kV.

Table 3-2 Increased transmission capacity in South Central – North link – in 2030 - KB2A, KB2B,KB3A,KB3B,KB4A,KB4B scenarios

Scenario	Increased transmission capacity (MW) South central – North
KB2A_RE	1688

KB2B_RE	1635
KB3A_RE	2320
KB3B_RE	3091
KB4A_CO2	1849
KB4B_CO2	890

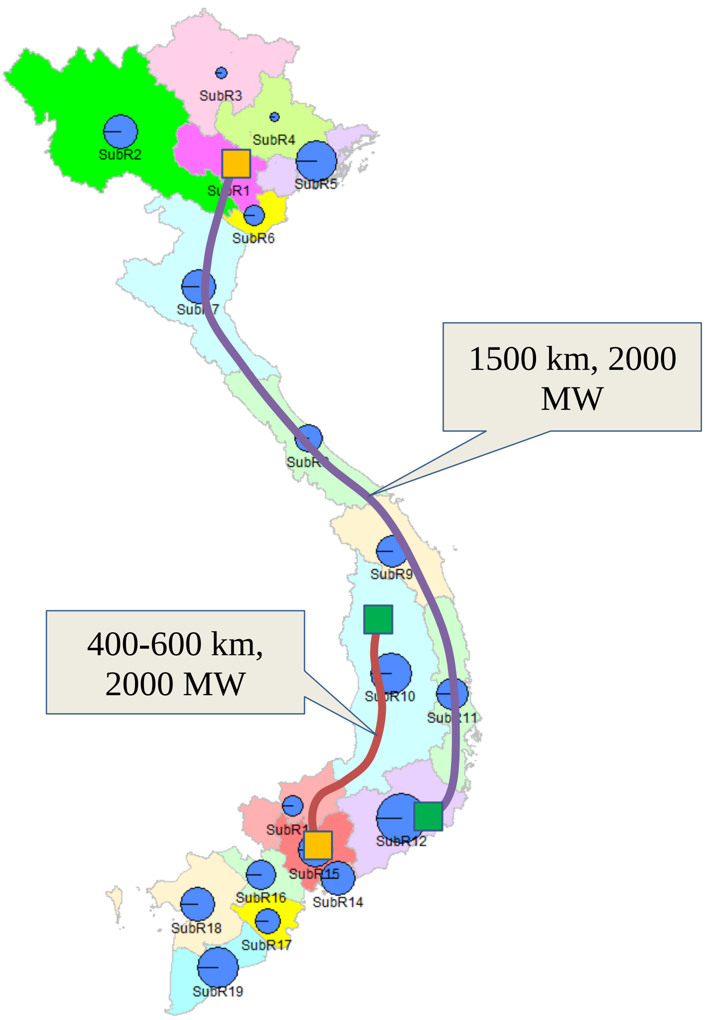

Figure 3-4 Potential HVDC projects by 2030

By 2045:

Source scenario: KB2A_RE and KB5B_Nonewcal, the Central power source can transfer to the North about ~ 2000 MW of additional capacity over a distance of 600 km. According to chapter 3, with this capacity scale and transmission distance, the current cost of modernization for the HVDC +/- 525 kV system may be 25% lower than the HVAC 500 kV.

Table 3-3 Increased transmission capacity in North Central – North and Center Central – North Central links – in 2045 - KB2A,KB2B,KB3A,KB3B,KB4A,KB5B scenarios

Scenario	Increased transmission capacity (MW)	
	North Central – North	Center Central – North Central
KB2A_RE	4395	4121
KB2B_RE	2010	3634
KB3A_RE	2037	4788
KB3B_RE	1971	3941
KB4A_CO2	2419	3010
KB5B_Nonewcoal	4767	4697

In all source scenarios, by 2045, the source from the Highland need to be transmitted to the South to increase (compare to Grid of PDP7R in 2030) by about 3 GW to 5 GW over the transmission distance from 400 km to 600 km. According to calculations in chapter 3, the cost of modernizing the HVDC system will be lower than HVAC 500 kV by about 14% - 20%.

Table 3-4 Increased transmission capacity in Highland - South link – in 2045

Scenario	Increased transmission capacity (MW)
	Highland - South
KB0A_BAU	3071
KB1A_RE	4964
KB1B_RE	3564
KB2A_RE	2918
KB2B_RE	2472
KB3A_RE	1285
KB3B_RE	1120
KB4A_CO2	2824
KB4B_CO2	2859
KB5B_Nonewcoal	3920
KB6B_Nuclear	3564

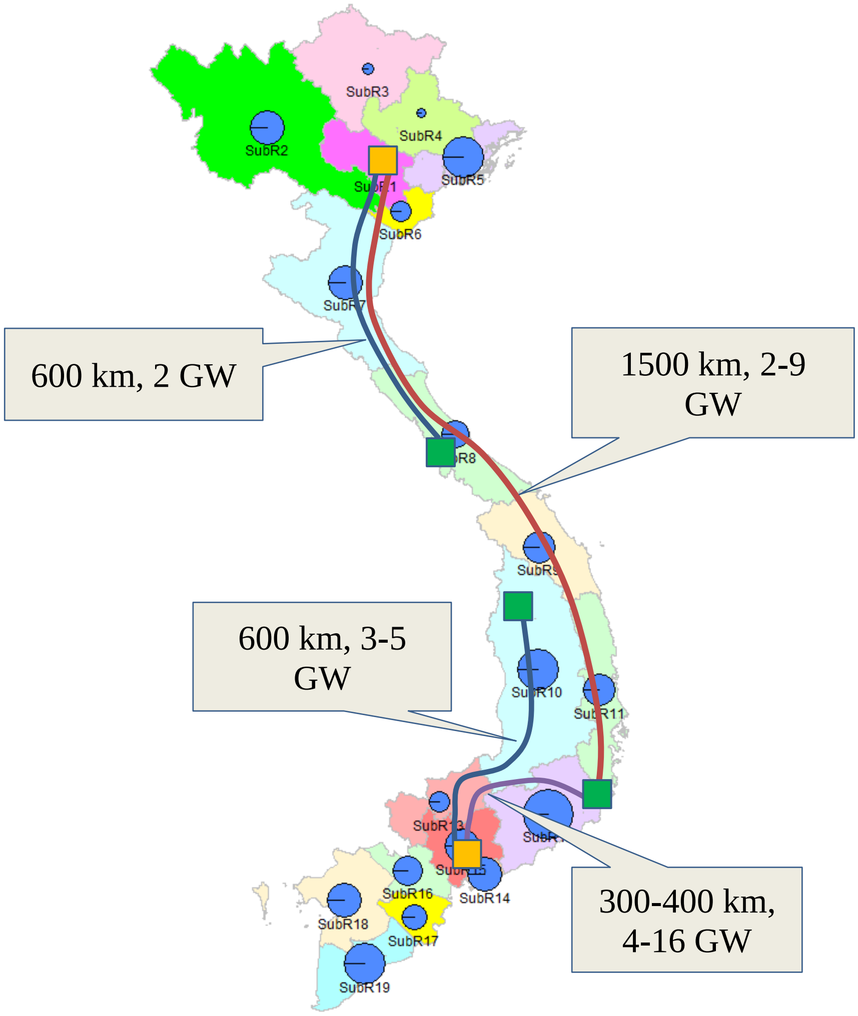

Figure 3-5 Potential HVDC projects by 2045

The need to increase transmission capacity from the South Central Coast to the South increases in all scenarios. According to PDP 7R, by 2030, the transmission capacity on this interface can reach about 11 GW. Calculation results in 2045 show that the transmission capacity on the interface needs to increase from about 4 GW to 16 GW depending on the source development scenario. According to the calculation in chapter 3, for the transmission distance of 300-400 km on this interface, HVDC technology will be significantly more efficient than 500 kV HVAC starting from 3000 MW or more (NPV cost is lower from 9% to 11%).

Table 3-5 Increased transmission capacity in South Central - South link – in 2045

Scenario	Increased transmission capacity (MW) South Central - South
KB0A_BAU	4061
KB1A_RE	8808
KB1B_RE	12264

KB2A_RE	10702
KB2B_RE	13610
KB3A_RE	14907
KB3B_RE	15382
KB4A_CO2	8253
KB4B_CO2	5896
KB5B_Nonewcoal	5451
KB6B_Nuclear	12467

The transmission power over 1500 km from South Central Coast to the North is also high in many scenarios, from 2 GW to 9 GW (KB5B_Nonewcoal). According to calculations in chapter 3, at a distance of 1500 km and a transmission capacity of 2-6 GW, the NPV cost of HVDC +/- 525 kV technology is 16% to 22% lower than that of HVAC 500 kV.

Table 3-6 Increased transmission capacity in South Central – North link – in 2045 - KB5B scenario

Scenario	Increased transmission capacity (MW) South Central – North
KB5B_Nonewcoal	8994

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CHAPER 4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

HVDC transmission technology is increasingly interested and widely applied in the world. Compared with HVAC transmission technology, HVDC technology has several advantages when applying long distance transmission and large transmission capacity. The outstanding advantages include: the investment cost for HVDC is lower than HVAC with the same voltage; low loss; There is no reactive power generated on the line so there is no restriction on the transmission length; ... HVDC is applied a lot in electrical systems linking countries and regions; submarine cable lines or areas where AC is difficult to build.

The size of Vietnam's power system has grown at an average of 11% per year in the last 10 years and is expected to continue to grow at a high level in the next 10-25 years. The electricity system still needs to be invested and constructed to provide enough electricity for production and social life. Corresponding to the development of power sources, the transmission grid system is also invested accordingly to ensure smooth, safe, reliable and stable power transmission. Due to the long and narrow topography from the North to the South, the power sources are distributed far from the load center, so in the transmission expansion plans with large capacity (over 1,000 MW), the use of HVDC technology should be considered compared to the traditional HVAC transmission option.

This study is one of the supplementary studies for the design of the transmission grid of the National Power Development Plan for the period 2021-2030, taking into account 2045 (PDP 8). The project has calculated the economic and technical comparison of 84 HVDC and HVAC transmission scenarios corresponding to different transmission power levels (1000 MW to 6000 MW) and different distances (300 km to 2000 km) in the context of Vietnam.

After analyzing and calculating the investment cost for the 525 kV HVDC system (LCC technology) and the 500 kV HVAC, power loss and current cost, the conclusions were made as follows:

Regarding the investment capital for construction of transmission system:

- At the transmission distance of 300-400 km, the HVDC option of 525 kV and HVAC 500 kV have the same investment capital.
- The larger the transmission capacity scale, the greater the distance, the more HVDC shows the advantage of investment capital. At a distance of 1000 km,

the investment capital for HVDC transmission systems is only 70% -80% compared to HVAC. At distance of 2000 km, the rate is only 62-70%.

About transmission loss:

- Transmission losses on the HVDC system are basically lower than the HVAC. However, this difference is not large, only about 0.2% to 2.1%.
- At the transmission distance of less than 600 km, the difference of HVAC and HVDC loss is negligible, from 0.2% to 0.6%.
- In some cases, for long-distance transmission lines (over 1000 km), the loss on the 525 kV HVDC system is higher than the HVAC 500 kV from 0.1% to 0.9% (if series capacitor are installed, reasonable reactor compensation installed).

Regarding the NPV cost:

When considering investment capital, power loss and 40-year project life, the NPV costs of HVDC and HVAC technology are similar in the transmission distance of 300-400 km. For transmission distances of 600 km or more, HVDC technology has significantly lower NPV costs, from 11% to 25% compared to HVAC technology.

Potential HVDC transmission projects:

The study also analyzes the outputs of the long-term power development program for 11 different scenarios. Based on the capacity of transmission capacity that needs to be strengthened on regional links, the HVDC transmission option may be considered for comparison and selection at some potential locations:

By 2030:

Source Scenarios: 0A, 1A_RE, 1B_RE, 5B, 6B: Consider the option of transmitting 2000 MW from the Central Highlands to the South on a distance of 400-600 km. According to calculations, the NPV cost of the HVDC +/- 525 kV option may be 25% lower than the HVAC 500 kV.

Source scenario: 2A_RE, 2B_RE, 3A_RE, 3B_RE, 4A_CO2, 4B_CO2, considering the option of transmitting 2000 MW from South Central to the North over a distance of 1500 km. According to calculations, the NPV cost of the HVDC +/- 525 kV option is about 15.5% lower than the HVAC 500 kV.

By 2045:

Source scenario: 2A_RE and 5B_Nonewcal, it is necessary to enhance the central-central power transmission line to the North with the scale of ~ 2000 MW over a distance of 600 km. The NPV cost of the HVDC +/- 525 kV system in this case may be approximately 25% lower than the HVAC 500 kV.

In all source scenarios, by 2045, the source from the Highland need to be transmitted to the South to increase by about 3 GW to 5 GW over the transmission distance from 400 km to 600 km. Constructing HVDC system will be lower than HVAC 500 kV by about 14% - 20%.

The need to increase transmission capacity from the South Central region to the South increases in all scenarios. Calculation results in 2045 show that the transmission capacity on the interface needs to increase from about 4 GW to 16 GW depending on the source development scenario. According to calculations, for the 300-400 km transmission distance on this interface, HVDC technology will be significantly more efficient than the 500 kV HVAC starting from a transmission capacity of 3000 MW or more (NPV cost lower from 9% to 11%).

The transmission capacity over 1500 km from South Central Coast to the North is also high in many scenarios, from 2 GW to 9 GW (KB5B_Nonewcoal). For a distance of 1500 km and a transmission capacity of 2-6 GW, the NPV cost of HVDC +/- 525 kV technology is 16% to 22% lower than that of HVAC 500 kV.

4.2. Recommendations

The choice of HVDC or HVAC transmission technology depends greatly on RE development goals and the philosophy of power development in Vietnam. HVDC technology is a new technology in Vietnam, it takes a lot of time to research and develop, develop standard systems and specialized regulations. Therefore, the decision to use HVDC technology should be made in a stable development roadmap for pursuing the government's targets of RE development and consistency in power development strategy. Lessons of sudden changes in policies for new technologies, such as policies for developing nuclear power technologies in Vietnam, should be avoided, leading to a waste of training, research and development resources over many years.

This research is only the first step in determining the applicability of HVDC in developing backbone transmission network in Vietnam. Given the posetive prosepcts for HVDC in this first step study, it is recommended to conduct more in-depth studies are needed to clarify the feasibility of HVDC technology, the choice voltage level is +/- 525 kV or may be lower (like +/- 320 kV) or higher (like + / - 600 kV, +/- 800 kV). LCC technology or VSC technology also needs to be analyzed at some specific transmission projects.

The technical in-depth aspects also need to be further investigated such as the effect of the HVDC system on the stability of the power system, short-circuit current, voltage, power supply reliability, ...