Danish Energy Agency

EMBASSY OF DENMARK

MOIT

EREA
Electricity & Renewable Energy Authority

Grid modelling of Net-Zero scenario

Background to

Viet Nam Energy Outlook Report Pathways to Net-Zero

Contents

ABBREVIATIONS

CCGT	Combined cycle gas turbine
DEPP III	Energy Partnership Program between Viet Nam and Denmark
DEA	Danish Energy Agency
EREA	Electricity and Renewable Energy Authority of Viet Nam
EOR	Energy Outlook Report
EVN	Vietnam Electricity
HC	Highest wind and solar Curtailment snapshot
HF	Maximum total interconnected transmission capacity snapshot
HG	Highest generation snapshot
HPP	Hydro power plant
HRD	Highest residual demand snapshot
HVDC	High voltage direct current
HVAC	High voltage alternative current
LG	Lowest generation snapshot
LF	Minimum total interconnected transmission capacity snapshot
LRD	Lowest residual demand snapshot
MOIT	Ministry of Industry and Trade
NZ	Net-Zero
PDP	Power Development Plan
RE	Renewable Energy
TPP	Thermal power plant

1. Introduction

This project is carried out as part of the Development Engagement 1: "Capacity Development for long-range energy sector planning with Electricity and Renewable Energy Agency of Viet Nam", currently being conducted under the Energy Partnership Program between Viet Nam and Denmark (DEPP III), a cooperation between the Danish Energy Agency (DEA), the Electricity and Renewable Energy Authority of Viet Nam (EREA) and the Vietnamese Ministry of Industry and Trade (MOIT).

The main purpose of this project is to contribute to the Energy Outlook Report, Pathways to Net-Zero (EOR-NZ) with a detailed analysis of the transmission grid in Viet Nam for the Net-Zero scenario under different conditions for the future power system.

In particular, the work herein reported aims at:

- **Verifying the Balmorel modelling with respect to the inter-regional transmission system**. The Balmorel model uses a simplified approach to the transmission grid modelling with eight transmission lines interconnecting seven transmission regions. The capacity of each of these (aggregated) lines must be the practical maximum capacity for secure operation. This capacity may be much smaller than the sum of the technical capacity of the lines between the transmission regions. The Balmorel model is verified and reviewed across three subjects:
  - The capacity between regions;
  - The losses of the transmission system;
  - The additional investment cost per transmission interface.
- **Verifying the grid operation of the local transmission network within regions**. The Balmorel model does not consider the local transmission network in the simulation. In the PSS/E study, the model operators assign power plants and load to nodes for the local transmission network and check the operation of the local network, considering the following aspects:
  - Voltage in all grid elements based on snapshots of selected hours, where demand and generation (per plant) are transferred from Balmorel to PSS/E. Over and undervoltage are reported and compared with planning values with +/- 5-10% deviations in relation to normal voltage.
  - Overloading of lines and transformers.
  - N-1 cases are computed: these represent the most critical errors that can occur in the operation of the power system.

2. Methodology

2.1. PSS/E model

Among the power system simulation software used for power development and planning in Viet Nam, the Power System Simulator for Engineering (PSS/E) is the most used. PSS/E was developed by Siemens PTI, integrating many modules, including: (i) Power flow of grid in static state; (ii)

Optimal power flow; (iii) Study of symmetric and asymmetrical incidents; (iv) Simulation of the process of electromechanical transition and stable analysis of the system [1].

The elements in the grid such as transmission lines, transformers, generators, capacitors, electric resistors, DC-AC, AC-DC converters, loads at the nodes, are mathematically modelled. PSS/E uses algebraic methods for equation solving, such as Fixed-Slope decoupled Newton-Raphson, Full Newton-Raphson, Gauss-Seiden, DC Solution to determine solutions of state equations. The set of solutions describe the state of the electrical systems, such as: phase angle and voltage at the bus; active power and reactive power run on branches (lines, capacitors, series resistance or transformers); power loss on each element and the whole power system. For the simulation of electromechanical transients occurring in the power system, PSS/E solves the system of consecutive equations with a short time frame of several milliseconds to observe the evolution of the mode parameters (voltage, frequency, phase angle) when grid incidents occur.

Due to the availability of grid simulation data as input to the PSS/E software in Viet Nam, along with the popularity of software, this study proposes to use PSS/E as a tool to simulate grid operation to verify generation development scenarios from Balmorel.

2.2. Grid modelling methodology in this study

The result from the Balmorel model provides two important inputs to PSS/E model including:

- The installed generation capacity and installed transmission capacity between regions in each simulation year. The power plants in each region and the inter-regional transmission system in PSS/E will be built based on this input from Balmorel.
- The generation dispatch snapshots: Balmorel optimizes the hourly output power of each power plant in each region (BB3 run). This "snapshot" is transferred to the PSS/E model. Some critical snapshots are selected to be simulated in grid operation, in order to check the response of the transmission system.

The connection between the Balmorel model and PSS/E is done on the basis of synchronizing data on the generating capacity of each unit (or group of power plants) and synchronizing the load in region.

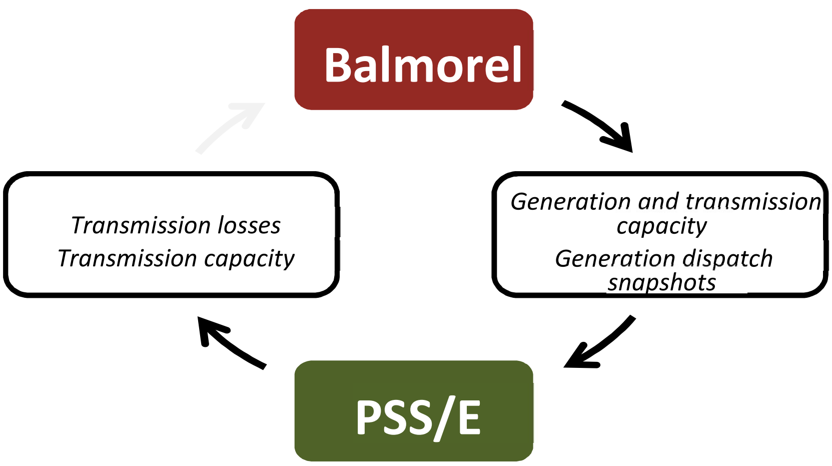

Figure 1. Methodology diagram of interaction between the Balmorel and PSS/E models.

After receiving input data from Balmorel, the main calculation steps in the power grid study are as follows:

<u>Step 1:</u> Data collection, prepare to build a calculation model

It is expected that the data to be collected includes the following main items (but not limited to):

- Data on the current status of Viet Nam's power sources and grid.

- Updated information on possible operation progress of various types of power sources.

- Updated information on possible operation progress of 500 kV and 220 kV transmission grid projects.

<u>Step 2:</u> Build a power transmission grid model

The scope of the power grid calculated in the project includes the nationwide 500 kV and 220 kV power transmission system. The calculation model includes main input parameters, such as: demand forecast, plans for the development of the power system and the transmission grid. Details of the assumptions are presented in Section 3. The calculation model was initially built on the basis of the power transmission grid structure according to PDP8. Then, based on the scale of Balmorel optimized power capacity mix in the Net-Zero scenario, the study calculates and checks the responsiveness of the power grid and propose transmission grid projects that need to be upgraded to meet Viet Nam's technical standards.

<u>Step 3:</u> Run load flow study for each snapshot from Balmorel

The load and power plants in each region are dispatched according to the snapshot from Balmorel. This is done using an automatic tool for PSS/E written in Python language, which creates the PSS/E case file for each regime.

- Run optimal power flow (OPF): Active power of power plants is set corresponding to Balmorel snapshots, but the reactive power control of power plants (through scheduled voltage) is set through OPF run that makes the calculation regimes be more convergent.

- Run Power flow for each PSS/E case file.

<u>Step 4:</u> Analysis of results

The study simulates the power grid to check the operating ability of the power system in normal operating mode and N-1 incidents for all snapshots, thereby proposing corrections and additions to the power grid, if necessary.

- The PSS/E model is used to calculate and check the power flow on the power system and identify the nodes with voltage or transmission capacity exceeding the allowed limit. For checking N-1 faults, the study uses a calculation module written in Python to check all N-1 fault cases on the 500 kV and 220 kV grid in all snapshots. It only scans N-1 incidents of line branches and transmission transformers, excluding generator set incidents and busbar incidents. The calculation program classifies N-1 incidents depending on the level of overload on the elements of the transmission grid: (i) Serious incidents (overload < 10%); (ii) Extremely serious incidents (overload 10% ÷ 20%); (iii) Emergency incidents (overload > 20%).

- Based on the results of analytical calculations, the study proposes the transmission grid projects that need to be newly built or renovated to transmit electricity from the power sources and supply power to load centers; avoid circuit congestion and overload; and ensure safe and reliable operation of the system. If an overloaded event is recorded, the study proposes the necessary transmission grid projects to overcome the overloaded events. The transmission grid projects proposed are based on the characteristics of the regional power system, with the best economic and technical criteria, such projects that could be increasing capacity because of overload or connecting of new power sources. After the addition of the transmission grid projects, the load flow program is re-run in order to check whether the power system is violated or not. Many loops are implemented until there is no overloaded event.

Step 5: Calculate power loss, estimate volume and investment cost of transmission grid (including inter-regional and intra-regional power grids)

- Power loss: Calculated by PSS/E, based on typical transmission distance between regions. Typical transmission distance is determined by the distance between the power center of one region to the load center of another region. This distance may be longer than the actual length of interface lines; however, this will more accurately reflect the nature of the transmission between the two regions.

- Volume and investment cost of transmission grid: Based on the analysis in step 4 and using the unit price of lines and substations according to PDP8.

3. Building simulation transmission grid for PSS/E

3.1. Scope of simulation

The simulation scope of Balmorel power system model is up to 2050. In order to provide an overall picture of power system operation, the transmission grid needs to be simulated and calculated up to 2050. However, this study focuses on analyzing power grid operations in the medium term, while the power grid structure after 2030 is still uncertain and lacks sufficient legal basis for its development. Therefore, the grid simulation only calculates operation for the years 2025 and 2030 with the following purposes:

- Check the feasibility of the proposed development plan in the Net-Zero scenario, for power grid operation according to the approved planning.
- Check the voltage and load level on inter-regional and intra-regional lines in different power operating modes, thereby making recommendations on upgrading and expanding the transmission grid.
- Estimate the investment cost for the transmission grid to meet the power development plan.
- Calculate the power losses on the inter-regional transmission grid as a basis for adjusting inputs to the Balmorel model.

Voltage level:

According to the Grid code [2], the transmission voltage level of Viet Nam's power system is 500 – 220 kV. According to PDP8, until 2030, plans are outlined for the transmission system of Viet Nam only at the 220 – 500 kV voltage level, while no plans are outlined for other voltage levels (e.g. 750 -

800 kV AC, 1000 kV AC, HVDC). Therefore, the level 500 – 220 kV is determined as the initial assumption for the simulation in PSS/E. In case the output from Balmorel shows that the power transmission between regions is large enough and if the transmission distance is far enough, higher–voltage transmission solutions (800 kV, 1000 kV) or HVDC will need to be considered in future planning.

The grid with voltages under the 110 kV voltage level is called distribution grid [3]. Most renewable energy (RE) sources, such as PV power, wind power etc., are connected to the distribution grid. In this study, the distribution grid will not be simulated in detail. Generation units and demands that are connected to the distribution grid will be equivalent to 220 kV bus bars in the transmission grid[1].

3.2. Demand forecast and distribution of load at nodes in the power system

Balmorel results only provide regional demand forecast. To calculate grid simulation in PSS/E, information about the load to each node in the power system is needed. Therefore, the study assumes that the load is assigned to nodes in each region, based on PDP8. The total load of each region is scaled up or down to match each snapshot's input data. Forecast of electricity consumption by region in 2025 and 2030 according to PDP8 and EOR-NZ is as follows:

Table 1 Annual demand forecast for electricity by regions in PDP8 and EOR-NZ (Unit: GWh).

	Base scenario - PDP8		**High scenario - PDP8**		**EOR-NZ**	
	2025	*2030*	*2025*	*2030*	*2025*	*2030*
North	143,868	215,394	142,752	214,143	110,457	154,892
North Central	21,767	34,456	21,767	34,455	16,676	24,752
Center Central	17,481	26,853	17,508	26,922	13,415	19,290
Highland	9,015	14,459	9,015	14,458	6,781	10,006
South Central	175,35	28,929	17,524	28,900	13,456	20,781
South East	168,655	246,901	169,755	248,114	97,231	132,502
South West					32,839	45,198
Whole country	378,321	566,991	378,321	566,991	290,857	407,422

From the above tables, it can be seen that the location of load is unevenly distributed among regions. Power consumption is mainly concentrated in the two extremities of the country. The North accounts for 38% and the South accounts for 44% of the total consumption. However, the favorable locations for the development of coal, gas, LNG, wind and solar power plants are concentrated in low load

[1] If generation nodes under 220 kV voltage do not supply enough power to the demand nodes, the power flow will go down from transmission grid (220 kV) to distribution grid via 220kV transformers. If generation nodes under 220 kV voltage can supply enough power to demand nodes and have excess power, the power flow will go up from distribution grid to transmission grid via 220 kV transformers. We simulate under a 220 kV grid by flow through 220 kV transformers. The power flow on the 220 kV – 500 kV grid will be relatively similar to full distribution grid simulation through 220 kV transformers. The power flow on the 220 kV – 500 kV grid will be relatively similar to full distribution grid simulation.

regions such as North Central, Highlands and South Central. This can put pressure on investments to improve the transmission capacity between regions.

3.3. Locating power sources in the simulation of the transmission grid

- Large power sources include coal power plants, gas power plants, medium and large hydro power plants.

The Balmorel model input defines large power sources as individual candidates up to the plant or unit size. The large power sources in the Balmorel model are updated based on the current power sources and detailed list of projects in Decision No. 500/QD-TTg dated May 15, 2023 approving PDP8[1]. Power plants have clear locations; therefore, these can be easily and accurately identified in the PSS/E model. The study reviews the large power sources proposed for development according to the results of the Balmorel model and applies them to the corresponding nodes in PSS/E.

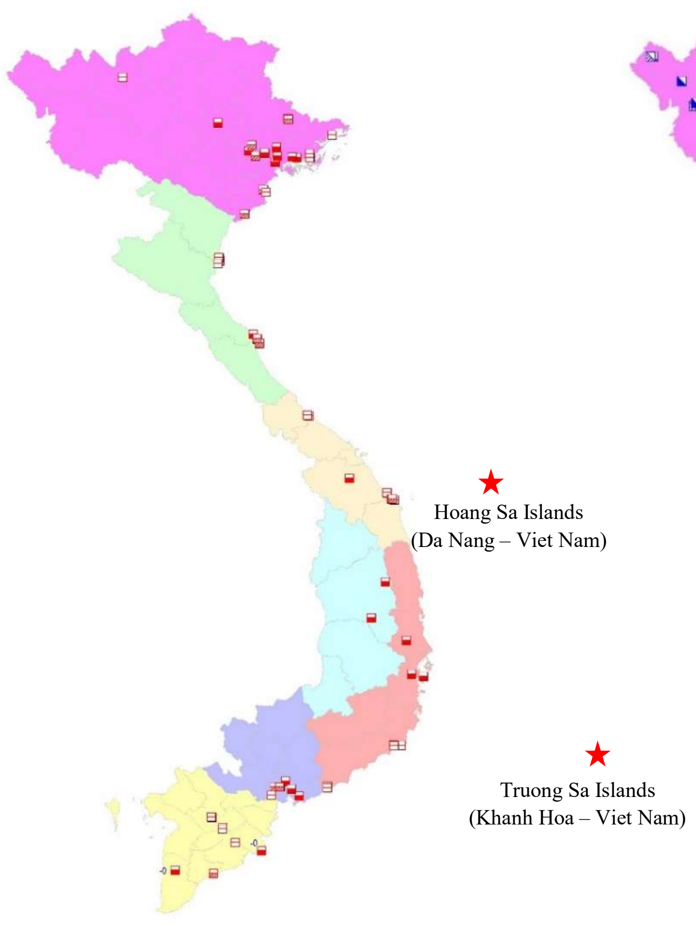

Figure 2 Location of thermal power plants.

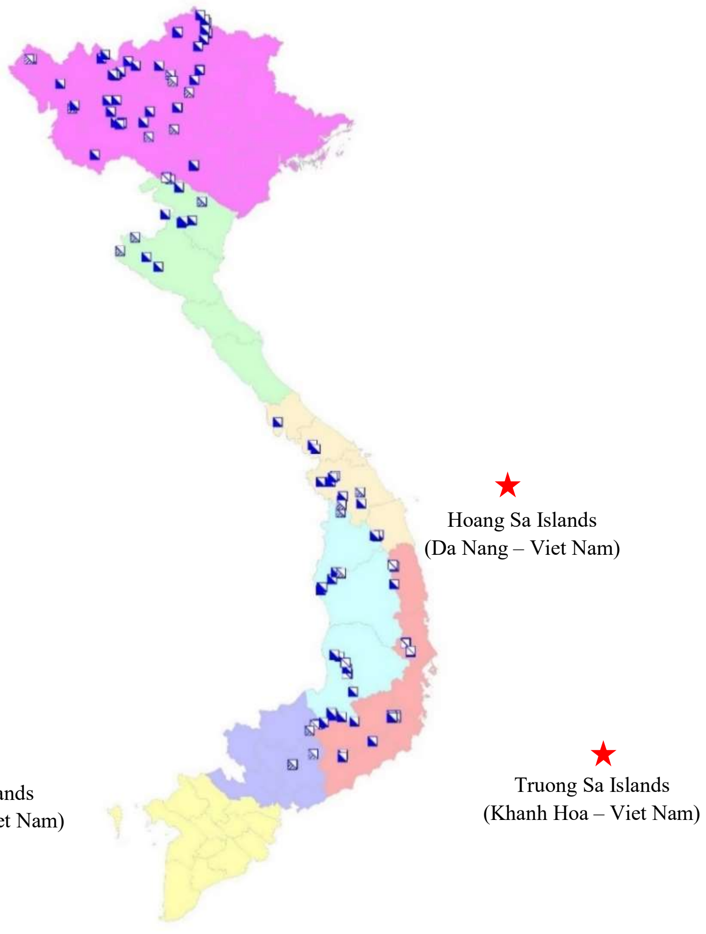

Figure 3 Location of hydro power plants.

Source: PDP8

[1] The power system development in EOR-NZ do not commit to developing the entire power system according to PDP8. Depending on each scenario, appropriate types of source commitments are selected. However, the list of large power sources is still based on PDP8.

According to PDP8 [4], in the period to 2030, Viet Nam is expected to develop about 6 GW of coal-fired thermal power sources, 22.5 GW of LNG gas-fired thermal power sources, 7.2 GW of domestic gas thermal power sources and 2.6 GW of medium and large hydro power sources. In particular, coal-fired thermal power sources are concentrated mainly in the North East, North Central and South Central regions; LNG thermal power sources are concentrated in the Central and South regions; domestic gas-fired thermal power sources are concentrated mainly in the South region; hydropower sources are concentrated mainly in the North West, Center Central and Highlands. It can be seen that different types of power sources are unevenly distributed across the country due to obvious differences in natural characteristics between regions.

- ❖ Renewable energy sources include solar power plants, offshore wind power plants, onshore/near-shore wind power plants, biomass power plants, waste power plants, small hydro power plants.

To accurately simulate power grid operations, it is necessary to determine the relative locations of power generation and demand points, that is, power centers and load centers. In particular, determining the relative location of power sources is very important. As stated in the previous section, for large power sources, such as coal thermal power, gas thermal power, medium and large hydropower in the Balmorel model, it is relatively close to the project list according to PDP8. The location and capacity scale of these types of sources are relatively clear. However, for renewable energy sources such as onshore/near-shore wind power, solar power, biomass and waste power, small hydropower, determining the detailed location of each project in the planning stage can be more challenging. Balmorel results only show the total capacity of each type of renewable energy source in 7 regions. This study determines the relative locations of these types of sources according to regional clusters and allocates them to appropriate 220 kV nodes in the power grid. This assumption still ensures accuracy in assessing the operation of the transmission grid because in reality, in each area with favorable characteristics for developing renewable energy sources, substations that collect the capacity of many projects are often placed and connected to the national power system.

For offshore wind power sources, potential development locations are taken according to Report of C2WIND “Vietnam Offshore Wind- Country screening and Site selection” [5]. From these potential locations, the onshore substation is determined on the principle of being close to the coast and having the smallest distance from the offshore wind turbine to the land to reduce the cost of sea transmission cables. Onshore substations collecting offshore wind power are located in the provinces of Quang Ninh, Hai Phong, Thai Binh (Northern Viet Nam), Ninh Thuan, Binh Thuan (South Central Viet Nam), etc. These locations are suitable for development orientation in PDP8 [4].

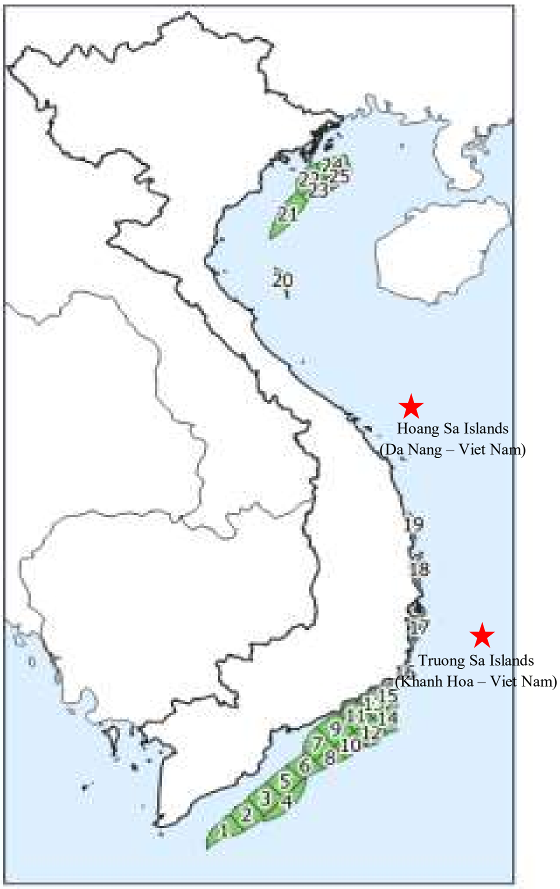

Figure 4 Feasible areas for fixed bottom projects according to C2Wind [5].

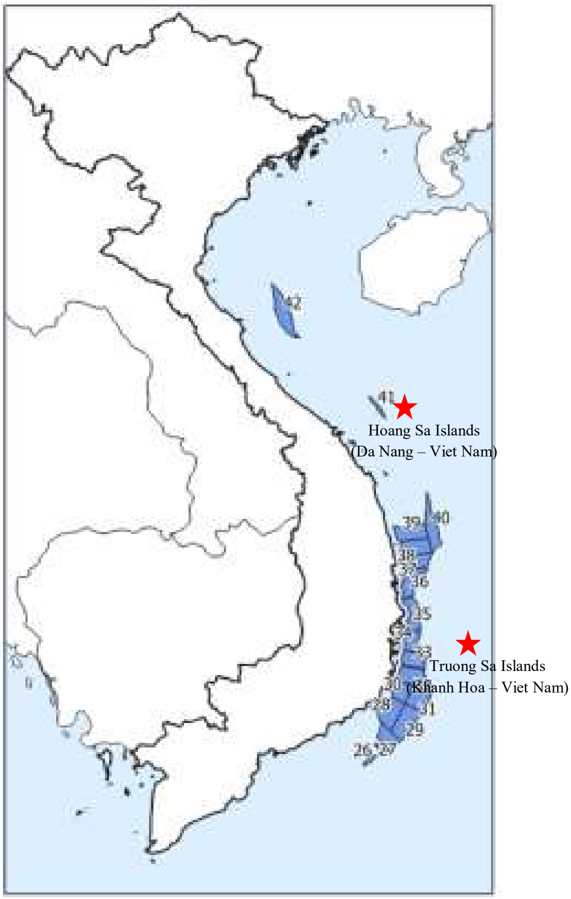

Figure 5 Feasible areas for floating bottom projects according to C2Wind [5].

3.4. Other input assumptions

Power factor at load nodes (Cosφ):

The voltage on the grid depends on the power factor (Cosφ) at load node. Cosφ usually ranges from 0.9 to 1.0. The lower the Cosφ, the more reactive power the load consumes. This can lead to lower voltage. Since the power grid simulated in this project only represents equivalent electrical load at 220 kV nodes, it is assumed that Cosφ = 0.98 – i.e. the average compared to the present (0.95 - 1.0).

Generator terminal voltage:

Traditional generators and modern inverters for wind and solar power can act as voltage control elements on the grid, by controlling the amount of emitting reactive power. However, the output voltage of the generators cannot be set too high or too low and must meet the requirements of the grid code. In the grid simulation, it is assumed that the terminal voltage of generators varies within +/- 5% of the rated voltage.

Limitation capacity of transmission lines: In this project, the thermal limit of transmission line is used (except for lines over 300 km using the limit capacity according to the condition of power system stability).

Limit capacity of 500/220 kV transformers: It is set according to the rated power of the transformer.

Resistor, resistance of line and transformer parameters (R0, X0, B0): Typical parameters on the current transmission grid are used.

4. Scenarios in the transmission grid modeling

The Net-Zero scenario in EOR-NZ is selected to simulate the power grid operation. In the Net-Zero scenario, the net-zero target in 2050 is achieved in a cost-optimal way, assuming policies and efforts ensuring that important barriers and inertia for the transition are overcome. The purpose of the study is to test the ability to operate the power grid and propose renovation and new construction grid projects (if necessary) for an open power development, which is less binding than PDP8 in order to minimize system-wide costs.

There are 8760 hours of generation in one year, corresponding to 8760-time steps of load (with approximate hourly accuracy). Therefore, in theory, it would be necessary to observe 8760 hours of power grid simulations in a year to test the ability of the grid to match dispatching and load at any point in time. However, not all 8760 grid operation modes are critical. In grid simulation, it is often only some of the most critical operation modes that are interesting to analyze in order to reduce the number of simulations. If the most critical operation modes are satisfied, the grid can respond well to the remaining operation cases. The Balmorel model calculates the generation mix of the power system in the years 2025 and 2030 at full 8760 h, among which a number of typical snapshots for analysis in PSS/E are selected.

The interesting operation snapshots for the simulation of the load flow in the power system are as follow:

- Highest generation (HG)
- Lowest generation (LG)
- Highest residual demand (HRD)
- Lowest residual demand (LRD)
- Maximum total interconnected transmission capacity (HF)
- Minimum total interconnected transmission capacity (LF)
- Highest wind and solar Curtailment (HC)

Highest generation (HG)

It is usually in the period 10:00-14:00 or 19:00-21:00 and is used to check the capability of transmission lines in the heaviest load condition.

Lowest generation (LG)

The LG snapshot is the lowest load condition (usually the first days of the lunar year - New Year holidays). In LG snapshot, voltage in the transmission grid is often high, therefore the LG snapshot is used to check the voltage in the grid. In some other calculations, the LG snapshot is considered locally to check the possibility of dispatching power from coal thermal plants and wind power plants, as this snapshot represents the heaviest operation condition for transmission lines.

Highest residual demand (HRD)

At the period 19:00-21:00 in the evening in summer, the load is high while the output power from

PV solar is zero. This is the HRD snapshot. This snapshot is used to check the possibility of dispatching power from traditional power plants (coal-thermal, LNG, hydro power plants).

Lowest residual demand (LRD)

The LRD snapshot represents the condition with maximum output from wind and solar PV power. This snapshot is used to check grid operation when dispatching of traditional sources is lowest; supply grid for battery is in charge mode; and the possibility of dispatching power from wind and PV solar power plants when the output power of these sources is high.

Maximum total interconnected transmission capacity (HF)

HF is usually a condition where sources in one region have high output power and transmit to other regions over a large transmission distance.

Minimum total interconnected transmission capacity (LF)

The LF snapshot shows minimum level of transmission between regions to achieve the lowest system cost.

If the HF and LF are both high on transmission load for certain lines, this indicates high transmission over a long distance, leading to large transmission losses in the power system. This requires large investments in transmission lines.

Highest wind and solar Curtailment (HC)

The HC snapshots correspond to the highest curtailment of renewable energy, i.e. wind and solar power. This usually happens in the low load or high wind and solar regime, and this snapshot is used to assess whether curtailment is caused by local congestion in transmission system or excess power in whole system.

- **Snapshot result in 2030 from Balmorel:**

Highest generation (HG)

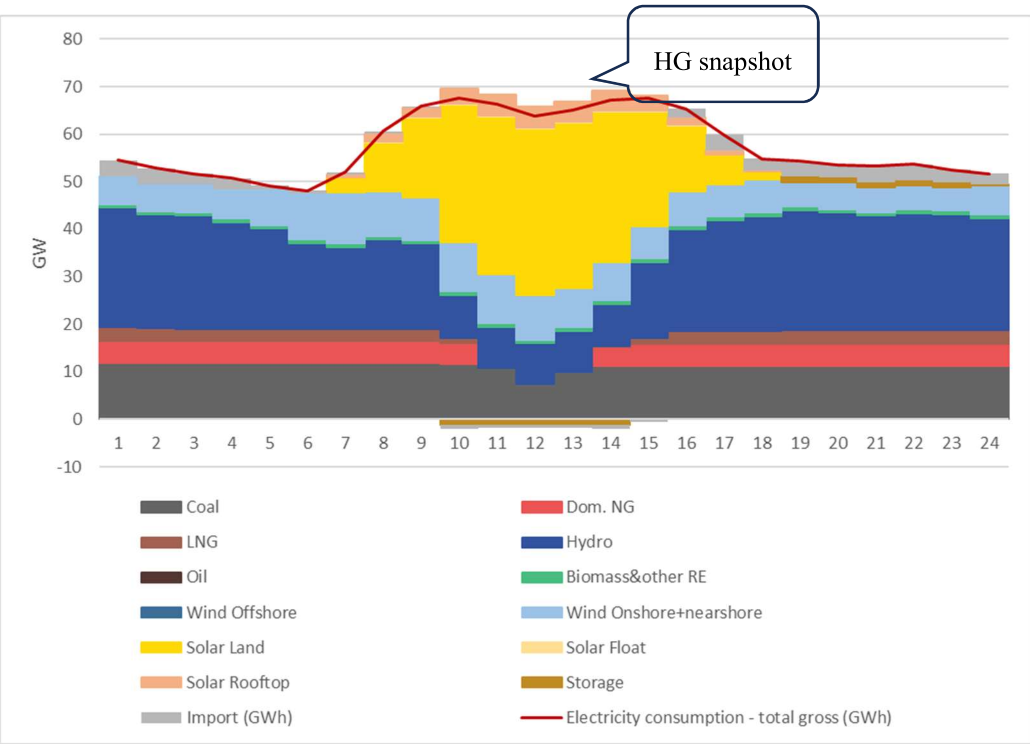

Figure 6. Power generation dispatch on day with HG in 2030.

The day with the largest power generation output from power plants (corresponding to the largest load) in 2030 falls around July, which is the time when the demand for cooling equipment increases. In particular, the output of power plants reaches the largest at around 3 pm. Coal and hydro power sources have to increase generation output on this day.

Lowest generation (LG)

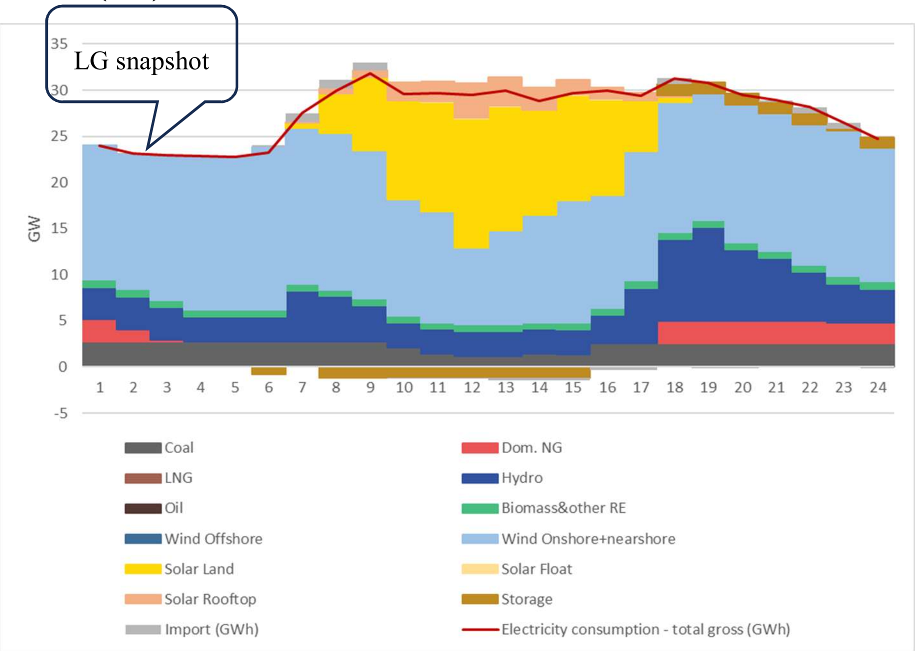

Figure 7. Power generation dispatching on day with LG in 2030.

The day with the smallest power generation output from power plants (corresponding to the smallest load) in 2030 falls around the end of January, the time of Viet Nam's Lunar New Year. In the LG snapshot at around 4 am, solar power is not generating, LNG thermal power sources are not dispatching due to high fuel costs, coal and hydro power sources have reduced generating output.

Highest residual demand (HRD)

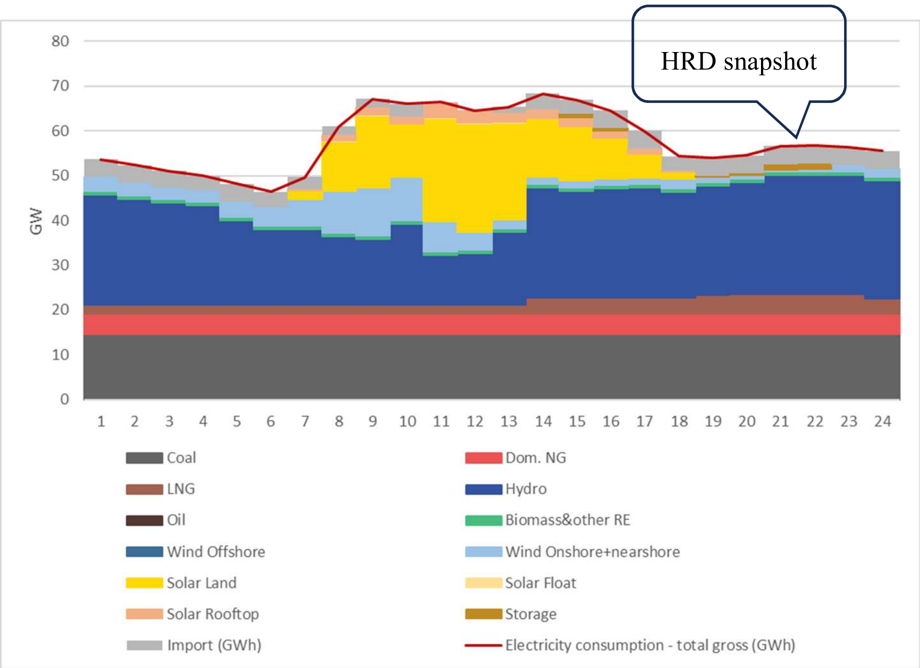

Figure 8. Power generation dispatch on day with HRD in 2030.

HRD snapshot falls at about 10 pm on a day in July. When there are not many renewable energy sources and the demand is relatively high, the power system needs to increase the output of hydro power sources and import electricity. It can be seen that with the high uncertainty of wind and solar power sources, Viet Nam's power system still depends heavily on regulated hydro power sources.

Lowest residual demand (LRD)

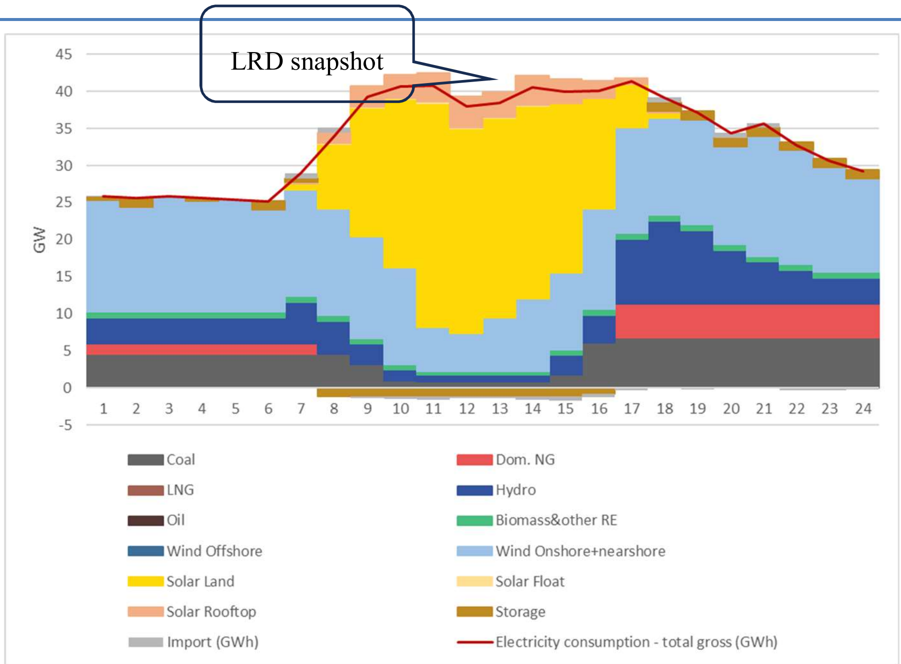

Figure 9. Power generation dispatch on day with LRD in 2030.

At times when the load is low while renewable energy sources, especially solar power, generate high output, hydro power sources have to minimize their generation output to make room. Even coal and gas thermal power sources need to reduce generating output to match demand.

Maximum total interconnected transmission capacity (HF)

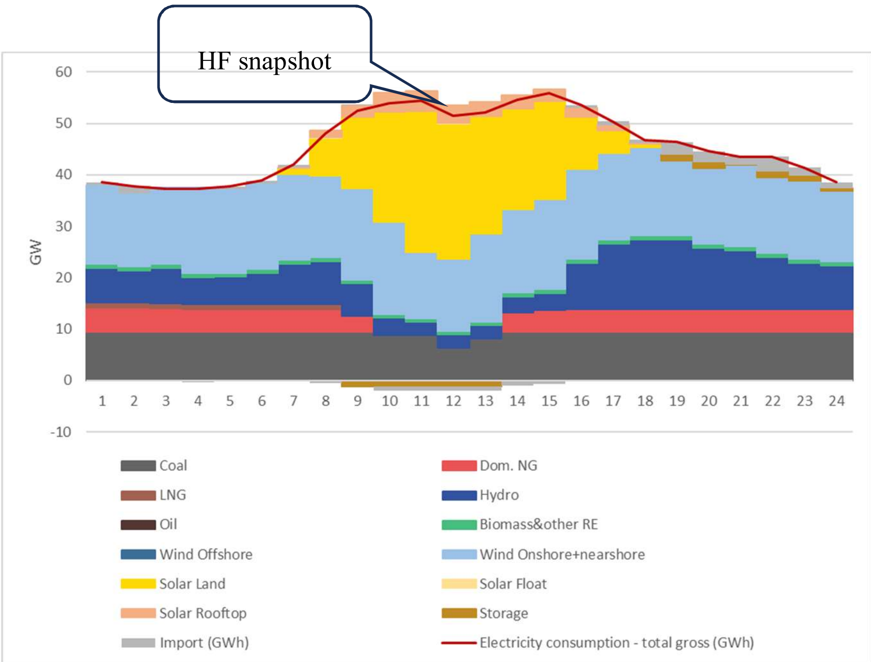

Figure 10. Power generation dispatch on day with HF in 2030.

Due to the development characteristics of wind and solar power sources located far from load centers, the high transmission snapshot is the time when wind and solar power sources generate high output, while demand decreases like at the noon peak. In this snapshot, it is necessary to check power grids that distribute wind and solar power sources.

Minimum total interconnected transmission capacity (LF)

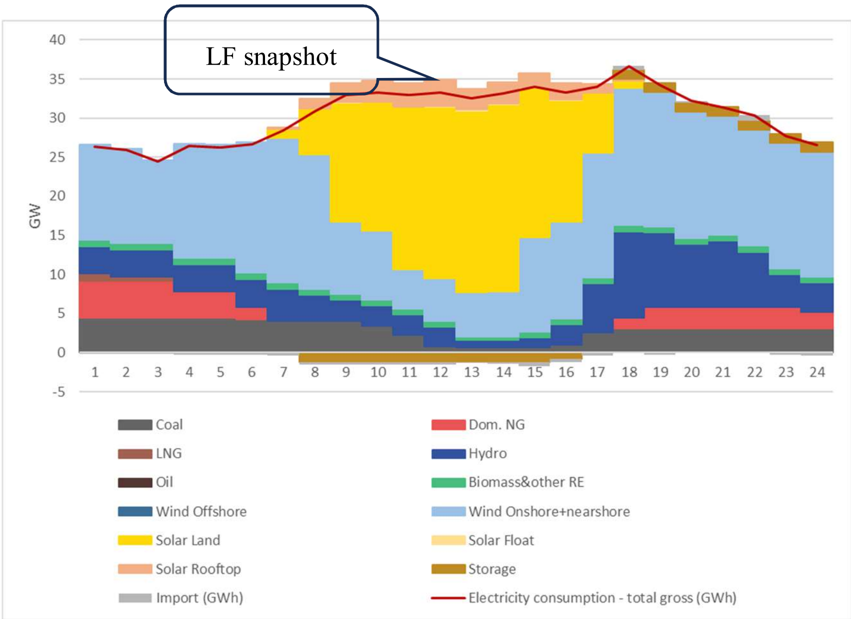

Figure 11. Power generation dispatch on day with LF in 2030.

LF snapshot is potentially less dangerous than HF snapshot, but still requires observation of specific areas to evaluate power system operation.

Highest wind and solar Curtailment (HC)

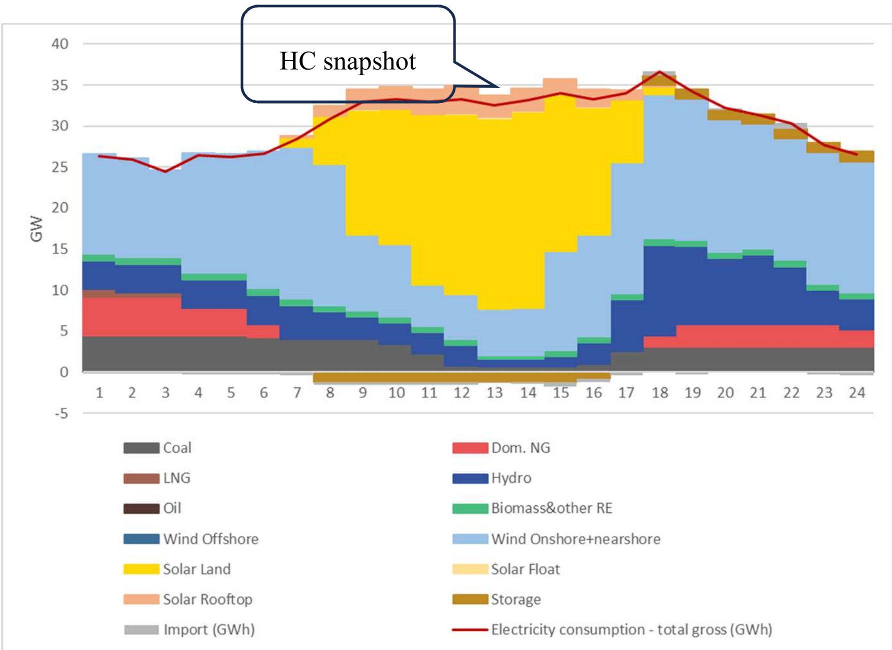

Figure 12. Power generation dispatch on day with HC in 2030.

In 2030, the maximum curtailment of wind and solar power sources is about 24 GWh. At the time of low load at noon on a holiday at the end of January, despite using power dispatching measures, such as reducing hydro power output and not dispatching coal thermal power sources, domestic gas and LNG, it is necessary to reduce the amount of wind and solar power to balance the demand.

5. Results of grid simulation corresponding to power generation scenarios

5.1. Results of grid simulation in 2025

Simulating the power transmission grid in 2025 has limited meaning in terms of planning, because the power grid projects that want to operate in 2025 must currently take steps to prepare for investment and start construction. New construction projects proposed at the present time to be operational in 2025 are not feasible. The simulation of the transmission grid in 2025 is based on a relatively clear power grid structure, compiled according to EVNNPT's Investment Plan information. However, the simulation of 2025 can therefore be seen as an evaluation of the Balmorel results and the current plans. The study still provides recommendations on potential bottlenecks, thereby providing reference information in regulating operations and taking short-term remedial measures.

5.2.1. Inter-regional transmission system in 2025

In 2025, the inter-regional transmission interfaces will not be much different from the current status, except for the construction of two additional 500 kV circuits of Quang Trach - Thanh Hoa - Nam Dinh I - Pho Noi (North - North Central interface) and build additional Duc Hoa - Cau Bong 500 kV line and Duc Hoa - Phu Lam 500 kV line (South East – South West interface).

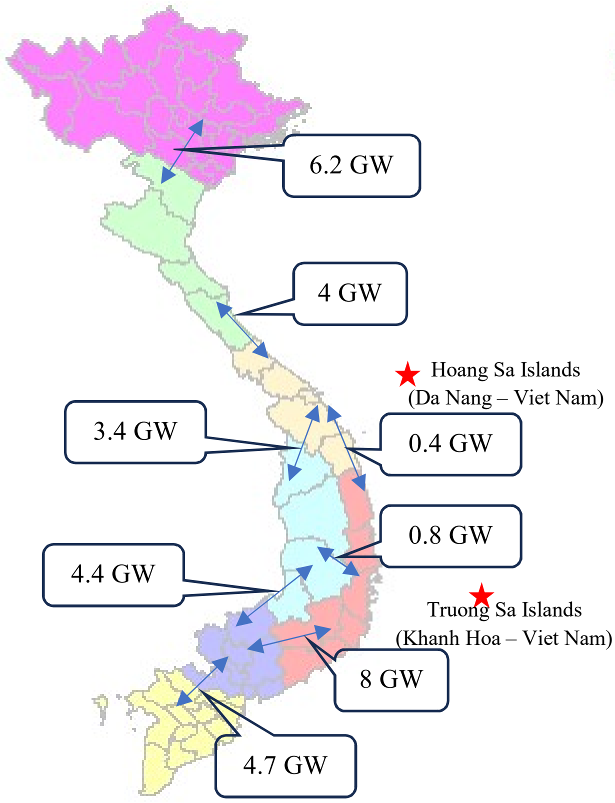

Figure 13 Installed capacity of interfaces in 2025.

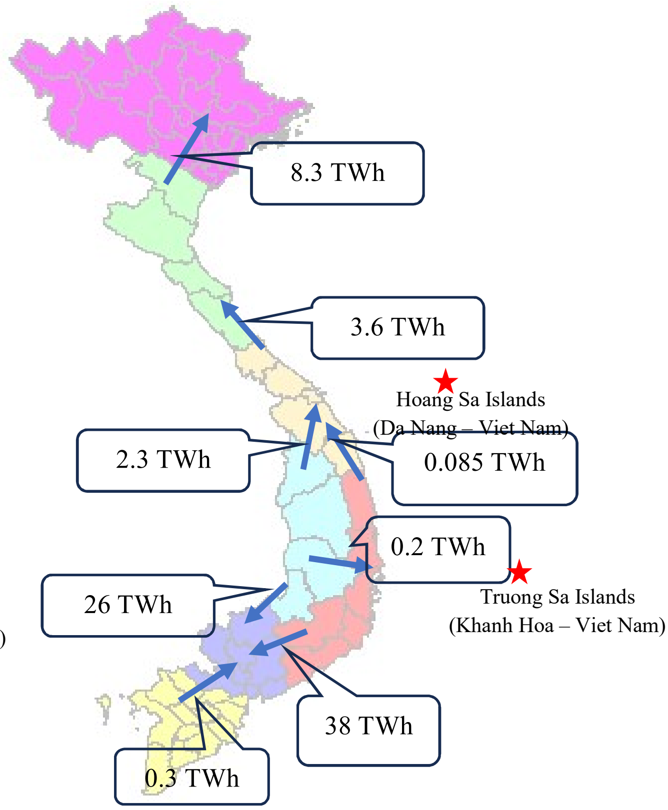

Figure 14 Electricity transmission among interfaces in 2025.

In general, the transmission limit on inter-regional interfaces in 2025 ensures the transmission of the amount of power according to Balmorel results. The operating time (Tmax) of the transmission interfaces is relatively low, about 1000 h – 3800 h, except for the case of the Highlands – South East interface with Tmax transmission up to 6000 h. Therefore, careful attention should be paid to transmission on lines belonging to this interface in snapshots.

The results of calculating the power flow in the snapshots of interest in 2025 do not record overload elements in normal operating mode (N-0) as well as N-1 contingency mode. Therefore, the power grid configuration of inter-regional interfaces in 2025 according to PDP8 ensures operation in some extreme snapshots of the Net-zero power scenario in the EOR-NZ, without the need for additional renovation and upgrade measures.

5.2.1. Intra-regional transmission system in 2025

a. Normal operation condition (N-0)

In normal operating mode, the voltage at the 500 kV and 220 kV nodes in typical snapshots is within the allowable limits specified in Circular No. 25/2016/TT-BCT and Circular No. 30/ 2019/TT-BCT of the Ministry of Industry and Trade regulating power transmission systems.

Calculation results of checking the power grid in 2025 in snapshots almost do not record the event of overloading grid elements in normal operating mode (N-0), Except for the case of Binh Dinh 500 kV substation overloading for about 2% in the HF snapshot. Therefore, it is recommended to increase the capacity of the 500 kV Binh Dinh substation with a capacity of 2x900 MVA from 2025 instead of 900 MVA to ensure operation.

b. N-1 contingency cases (N-1)

When an element on the transmission grid has a problem and is separated from the grid, the remaining elements will have to carry a heavier load, and in some cases may be overloaded. Cases of N-1 faults that overload the remaining elements in the power grid are considered not to meet the N-1 criterion.

In 2025, the study examined a total of 1290 N-1 faults, which only scanned N-1 faults of line branches and transmission transformers, excluding generator set and busbar faults.

Statistics of N-1 incident cases causing overload of remaining elements on the grid of 7 Balmorel snapshots are as follows:

- HG: 18/1290 (1,40%).
- LG: 5/1290 (0,38%).
- HRD: 18/1290 (1,40%).
- LRD: 11/1290 (0,85%).
- HF: 10/1290 (0,78%).
- LF: 8/1290 (0,62%).
- HC: 19/1290 (1,47%).

Therefore, the regime that meets the lowest N-1 criteria (highest violation rate) is the HC period with 19 violations (accounting for 1.47%). Ranked second are HG and HRD with 18 cases, accounting for 1.40% (these 2 snapshots correspond to the same timestep). Calculation results show that cases of violation of the N-1 criterion mainly occur in the power grid releasing power capacity.

HG snapshot

The HG snapshot is analyzed further, since it is the most violated snapshot. Some of the critical areas and violations will be examined.

For the Northern power grid:

- Muong Te - 500 kV Lai Chau 220 kV line is overloaded by about 65% when a single circuit fails because Lai Chau province is developing many small hydro power sources in the period up to 2025. Therefore, it is recommended to accelerate the construction of Muong Te transit on 220 kV Phong Tho - 500 kV Lai Chau from the period 2026 - 2030 according to PDP8 to the period 2021 - 2025 to ensure the use of capacity of small hydro power sources in Lai Chau province. In case this line circuit cannot be built in time, it is necessary to consider regulating the operation of regional small hydropower sources in case of N-1 incident.

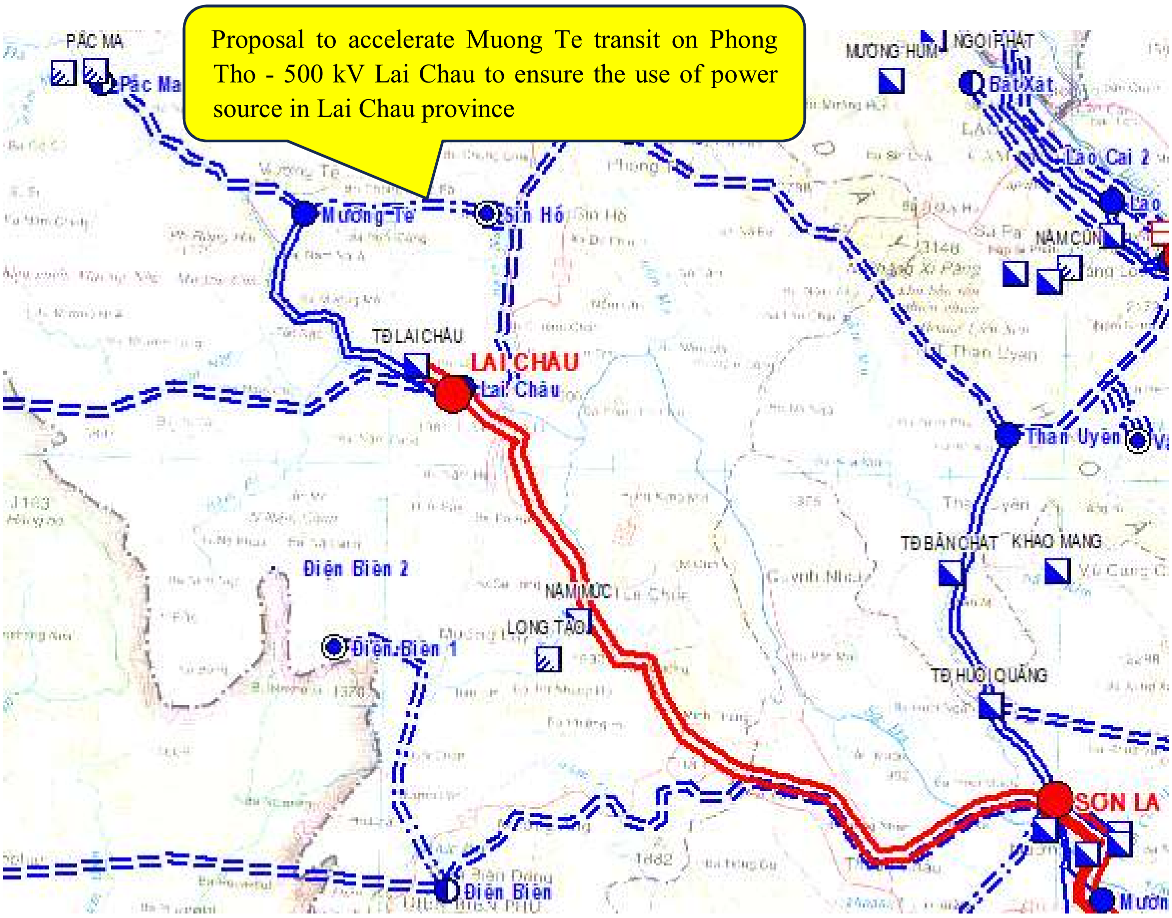

Figure 15 Transmission grid map in North West.

- The Hoa Binh - Tay Hanoi 220 kV line is overloaded by about 8% when one circuit fails because in this mode, hydro power sources in the North West region generate high power to increase power supply to Hanoi load center. To ensure operation according to N-1 criteria, it is recommended to renovate and replace the thermal conductor for this line section. According to Vietnamese regulations, the power grid supplying load power to important load centers, such as Hanoi and Ho Chi Minh City, needs to ensure N-1 criteria.

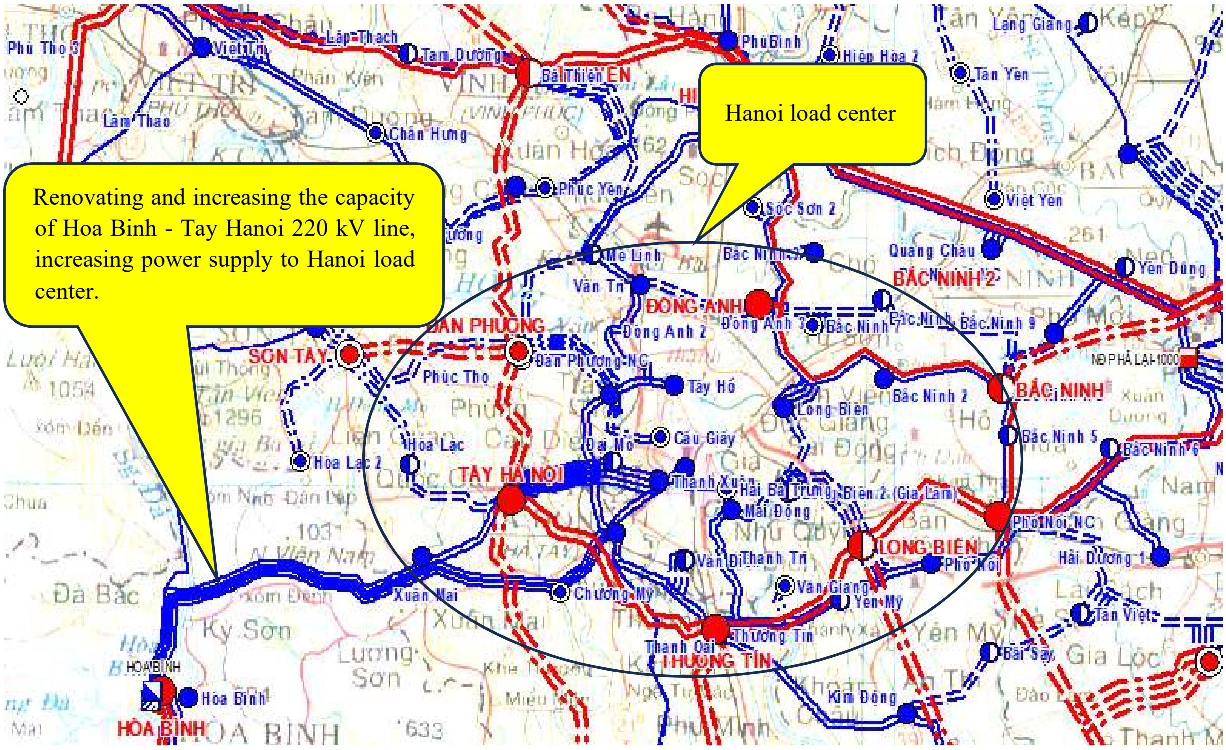

Figure 16 Transmission grid map in Hanoi.

For the Central power grid:

- The Quang Ngai - Nuoc Long HPP - Kon Plong HPP - Thuong Kon Tum HPP - Dak Lo HPP 220 kV line is overloaded when one circuit fails due to relatively many power sources connected on the small conductor size line (load capacity of each circuit is about 300 MW). The proposal is to renovate and replace the thermal conductor line for this section to enhance the ability to distribute capacity from small hydropower sources and regional wind power.

- The Pleiku - Sesan 3 - Sesan 3A 220 kV line is overloaded by about 12% when one circuit fails. Teh proposal is therefore to renovate and increase the load capacity and replace the thermal conductor for this line section to ensure N-1 criteria.

- The Krongbuk – Krong Ana and Krongbuk – Serepok 4 220 kV line overloads when one circuit fails. The proposal is to renovate and increase the load capacity and replace the thermal conductor for this line section to ensure N-1 criteria.

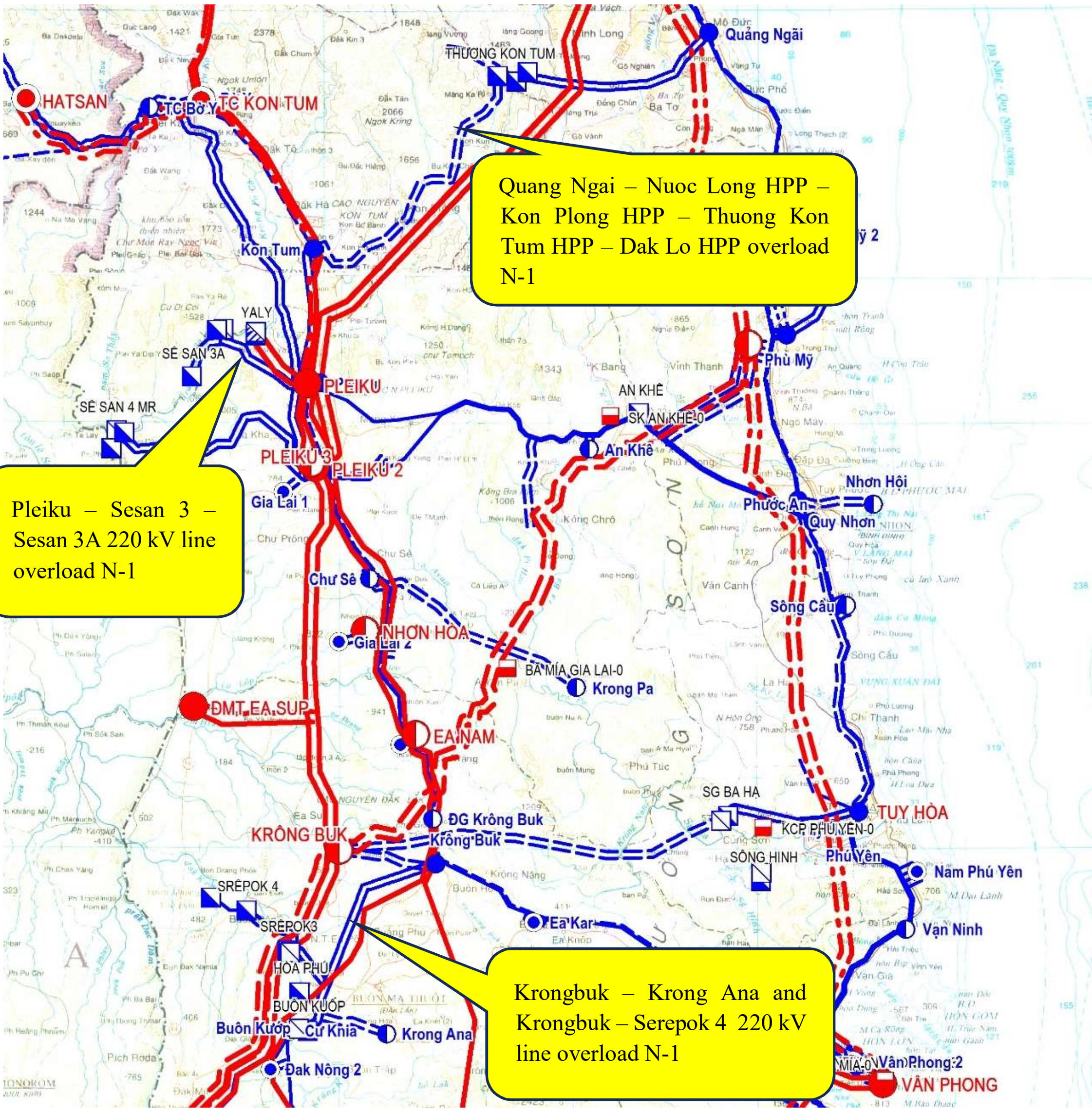

Figure 17 Transmission grid map in South Central – Highlands.

- After a period of accelerated development of wind and solar power in the Ninh Thuan - Binh Thuan area, the area has been supplemented with the Thuan Nam 500 kV substation and increased capacity of Ninh Phuoc and Thap Cham 220 kV substations and connection line. The ability to distribute generation output of regional power grid has been significantly improved and no cases of incidents have been recorded in the mode of high generation power sources. However, attention should be paid to ensuring the progress of Ninh Son - Chon Thanh 500 kV double-circuit line into operation by 2025, increasing the evacuation of regional power sources towards the South East load center. This line section is relatively long, about 300 km, so there may be many difficulties in determining route direction and site clearance.

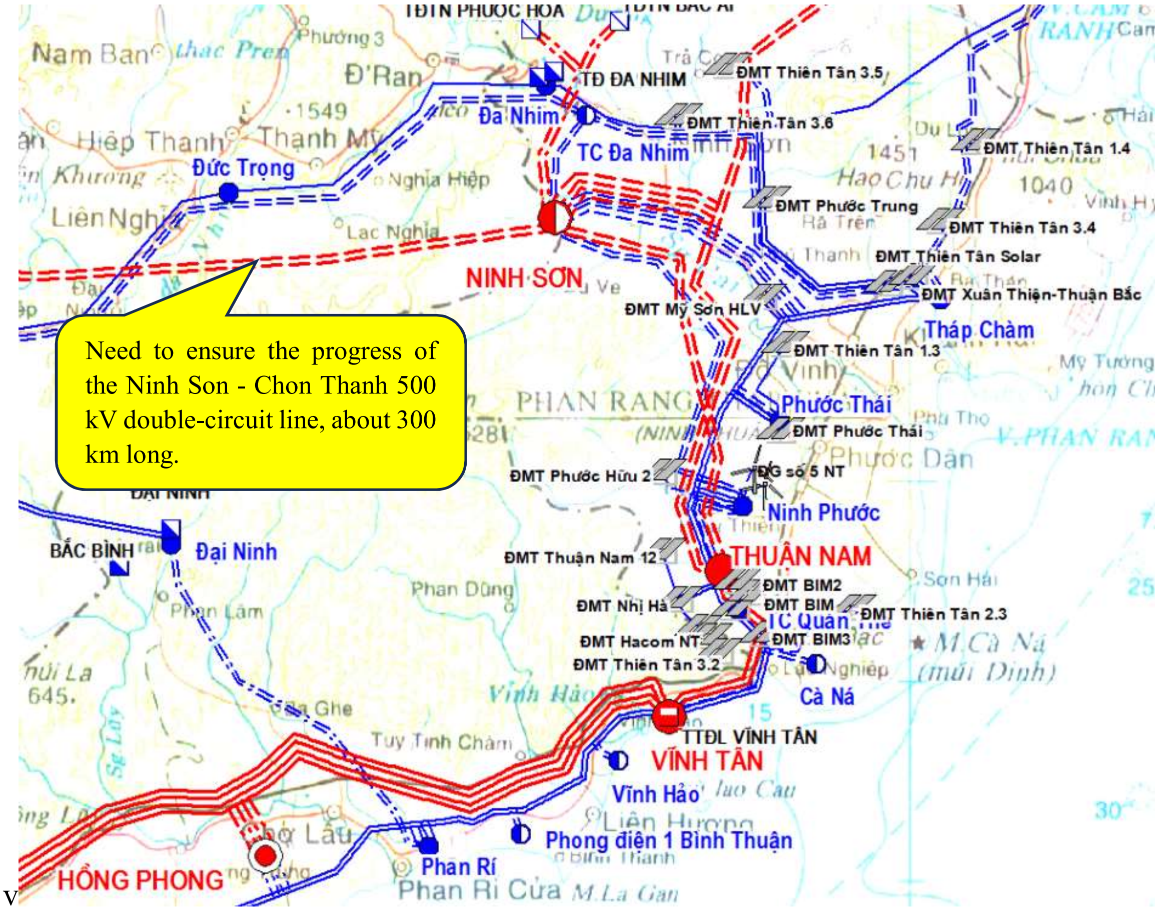

Figure 18: The power transmission system at Ninh Thuan – Bình Thuan area (South Central region).

For the Southern power grid:

- CCGT Phu My – My Xuan 220 kV transmission line is the most critical element of Southern power grid. The busbar of CCGT Phu My is also separated to reduce the short circuit current, similarly as for CCGT Nhon Trach. Although this transmission line uses thermal resistant conductor with capacity limit increase to nearly 800 MVA/circuit, the load distribution between the two circuits is uneven, causing overload in N-1 fault regime. Therefore, it is necessary to separate the busbar more suitably to avoid N-1 overload.

Overload elements at N-1 failure in snapshots LG, HRD, LRD, HF, LF, HC are as follows:

- Series capacitors on 500 kV lines Da Nang - Doc Soi, Da Nang - Quang Tri, Da Nang - Thanh My are overloaded when N-1 faults occur in high inter-regional transmission modes, such as snapshots HF and LRD. Currently, these lines are being installed with series capacitors to improve stability on inter-regional lines with large length distances. Series capacitors use 30.5 Ohm type, with a thermal load capacity of 2000 A, corresponding to about 1700 MVA, much lower than the thermal limit of the ACSR4x330 line (thermal load capacity about 2390 MVA). Therefore, it is proposed to consider the option of replacing capacitors of about 2500 - 3000 A for these lines to nearly reach the line's thermal limit. This proposal is also consistent with the calculations in PDP8.

- Da Nang - Doc Soi 500 kV line was overloaded in some neighboring line incidents. According to PDP8, Da Nang - Doc Soi 500 kV line will be built the new second circuit in the period up to 2030.

Currently, this project has not been assigned project management by EVN, so the operation schedule in 2025 is not realistic. In case the Da Nang - Doc Soi 500kV line cannot be renovated in time by 2025, it is necessary to pay attention to implementing power dispatching measures to avoid high inter-regional transmission, leading to overloading of this line.

- Some inter-regional 220 kV lines have notable operating conditions such as:

+ Phu Ly - Nho Quan 220 kV line is overloaded by about 14% when a circuit fails, due to increase in the transmission between the Central and North regions. Currently, this line is operating a circuit with a relatively small conductor size of ACSR330 (carrying a load of about 290 MW). The second circuit of Phu Ly - Nho Quan is expected to come into operation in 2025 with conductor size ACSR2x330. Therefore, to ensure operation according to N-1 criteria, it is proposed to renovate and increase the existing circuit of Phu Ly - Nho Quan to conductor size ACSR2x330.

+ Binh Dinh - An Khe - Yang Trung - Pleiku 2 220 kV line carries high load in normal operating mode and overload occurs when one of the segments fails. This is the connecting line between the South Central and the Highlands. It is recommended to build a new circuit to ensure N-1 criteria.

- Regarding the load supply to the power grid, some double circuit lines are overloaded when one circuit fails such as Tay Hanoi - Hoa Binh 220 kV line in HRD snapshot, Cat Lai - Thu Duc 220 kV line in LG snapshot, The proposal is to renovate and replace thermal conductor for these line sections, because according to Vietnamese regulations, the transmission grid supplying power to important load areas, such as Hanoi or Ho Chi Minh City, needs to be given priority to ensure N-1 criteria.

- Regarding the power grid distributing power sources, some 220 kV lines such as Thai Binh - Thai Thuy, Cat Lai - Nhon Trach, Thai Binh - Thai Thuy, Soc Trang - Bac Lieu, Binh Dinh - An Khe - Yang Trung– Pleiku 2 are overloaded when incident N-1 occurred. The proposal is to renovate and replace thermal conductor line or build a new circuit for these line sections.

- 500 kV substation needs to install a new transformer to increase the ability to distribute power generation output in the South Central region, such as Binh Dinh.

According to the simulation and summary results, by 2025, to ensure N-1 criteria and avoid overload, it is necessary to build about 100 km of 500 kV line, 550 km of 220 kV line, 1800 MVA of 500 kV transformer; and renovate about 400 km of 220 kV line compared to PDP8.

In addition, through preliminary estimates, with the increased development of wind and solar power sources by 2025, it is necessary to newly build about 1800 MV of 500 kV transformer, 6500 MVA of 220 kV transformer, 800 km of 220 kV line and 100 km of 500 kV line.

5.2. Results of grid simulation in 2030

Similar to 2025, the study conducted calculations to check the operation of the power grid according to the power generation scenario calculated in Balmorel at 7 notable snapshots: HG, LG, HRD, LRD, HF, LF, HC in 2030. The results of simulating the power flow from PSS/E illustrates bottlenecks and overloads, helping to make recommendations and solutions to improve the power grid, ensuring the distribute the generated power and ensuring transmission capacity on regional link lines. The power grid will be renovated and newly built to meet the technical conditions in normal operation mode N-0 and N-1 contingency cases. The main results are presented in the following sections.

5.2.1. Inter-regional transmission system in 2030

According to PDP8, in the period up to 2030 the inter-regional transmission capacity will continue to be strengthened, especially the North Central - North and South Central - South interfaces. Inter-regional transmission lines by 2030 are expected to be as follows:

- North Central – North interface: Including 7 of 500 kV line circuits, specifically: 1 existing circuit line Vung Ang - Nho Quan line, newly built 2 circuit line Quang Trach - Quynh Luu - Thanh Hoa - Nam Dinh (2021 - 2025), renovate 1 circuit line Vung Ang - Nghi Son - Nho Quan into 2 circuit line (2026 - 2030), build 2 circuit line connecting the North Central LNG source to the North.

- Center Central - North Central interface: Including 4 of 500 kV line circuits, specifically: 2 circuit line Da Nang - Vung Ang, 2 circuit line Doc Soi - Quang Tri - Quang Trach (operated in 2022).

- Highlands - Center Central interface: Including 5 of 500 kV line circuits, with the existing Pleiku - Doc Soi single circuit line and the existing Pleiku 2 - Doc Soi double circuit line and the renovation of the Pleiku - Thanh My from single circuit line to double circuit line (2026 - 2030).

- South Central - Center Central interface: Including 2 of 500 kV line circuits: double circuit Thuan Nam - Van Phong - Binh Dinh - Dung Quat CCGT, completing the entire route in the period of 2026 - 2030.

- South Central - Highlands interface: Including 3 of 500 kV line circuits: existing single circuit Pleiku - Di Linh and double circuit Krong Buk - Binh Dinh.

- South Central – South interface: Including 7 of 500 kV line circuits. Specifically: existing single circuit Di Linh - Tan Dinh, 2 circuits of 500 kV Vinh Tan - Dong Nai - Song May line, 2 circuits of 500 kV Ninh Son - Chon Thanh newly built in the period 2021 - 2025.

- Highlands - South interface: Including 5 of 500 kV line circuits: existing Pleiku - Chon Thanh double circuit, existing Dak Nong - Tan Dinh single circuit and new Krong Buk - Tay Ninh 1 double circuit built in 2021 - 2025.

The load capacity between transmission interfaces considering the N-1 criterion used in PSS/E calculation is determined according to PDP8, as follows:

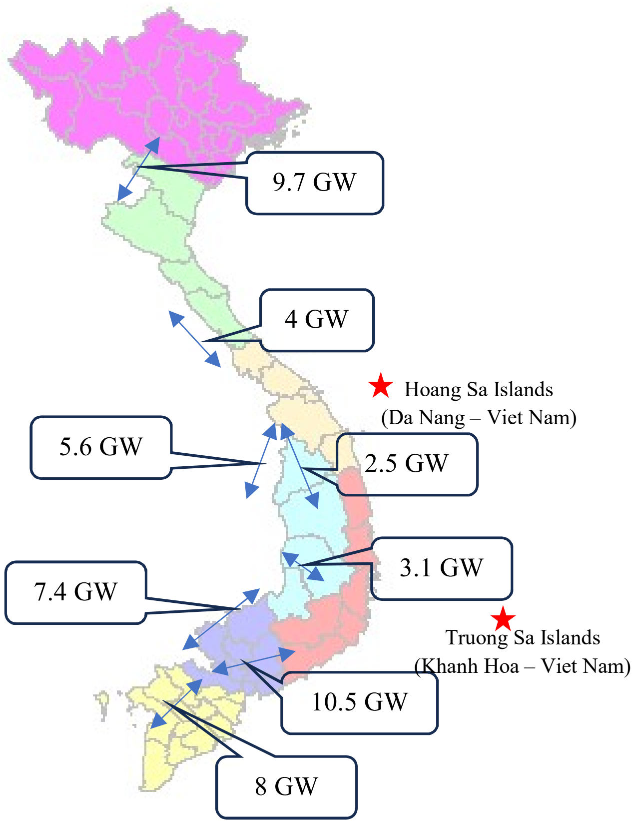

Figure 19: Load capacity of interfaces in 2030.

The results of load flow calculations show that inter-regional transmission grid elements almost ensure the technical conditions of load carrying level and voltage according to Viet Nam's regulations in the snapshots. However, some inter-regional transmission lines of the North Central - North and Highlands – South East regions have installed series capacitors to improve stability. These series capacitors usually use 30.5 Ohm type, with thermal limit of 2000 A, corresponding to about 1700 MVA, much lower than the thermal limit of ACSR4x330 line (thermal limit of about 2390 MVA). Therefore, it is proposed to consider the option of replacing series capacitors of about 2500 - 3000 A for these lines to nearly reach the line's thermal limit. This proposal is also consistent with the calculations in PDP8.

In addition, with the plan to develop power sources according to the Net-Zero scenario, it will be necessary to build a high-voltage direct current power transmission system (HVDC) with capacity of about 1 GW of from the Center Central to the North, with a transmission length of more than 1000 km.

5.2.1. Intra-regional transmission system in 2030

a. Normal operation condition (N-0)

In normal operating mode, the voltage at the 500 kV and 220 kV nodes in the typical snapshots are within the allowable limits specified in Circular No. 25/2016/TT-BCT and Circular No. 30/ 2019/TT-BCT of the Ministry of Industry and Trade regulating power transmission systems.

In normal operating mode (N-0), there is a need for increasing capacity of some overloaded 500 kV substations with the role of utilizing renewable energy sources, such as in Binh Dinh, Krongbuk and Bac Lieu.

Compared to PDP8, the Net-Zero scenario in EOR-NZ does not propose to develop offshore wind farms, so the volume of grid connecting these power sources will be reduced. However, this scenario proposes to develop more than 35.5 GW of solar power by 2030, so it is necessary to build more gathering substation to connect to the National Power System. For example, 500 kV Yen Bai Renewable Energy Substation, 500 kV Son La Renewable Energy Substation, 500 kV Dien Bien Renewable Energy Substation in the North region, 500kV Thanh Hoa Renewable Energy Substation in the North Central region, Renewable Energy South Central 1 substation in Ninh Thuan - Binh Thuan provinces.

With onshore wind power, although the total installed capacity in 2030 is equivalent to PDP8, the regional distribution is different, focusing on development in two areas with good wind potential: the Highlands and the South West. Through power grid research, it is found that it is necessary to consider building about 2-3 additional 500 kV substations in each area to utilize onshore wind power capacity.

With LNG power sources, the Net-Zero scenario in EOR-NZ only proposes to develop about 7 GW, while PDP8 proposes to develop about 22 GW in the period up to 2030. In particular, only developing LNG sources that are being under construction includes LNG Hiep Phuoc, LNG Nhon Trach 3+4 and fuel conversion of existing power sources that are running on domestic gas but do not have enough fuel. Since LNG sources are not developed as in PDP8, the volume of 500 kV connection lines will decrease by about 125 km. However, lines that play an inter-regional transmission role, such as LNG Nghi Son - Hung Yen, LNG Ca Na - Binh Duong, LNG Bac Lieu - Thot Not, are still necessary to build to ensure inter-regional transmission. But instead, it will be connected from the regional renewable energy center to the load center.

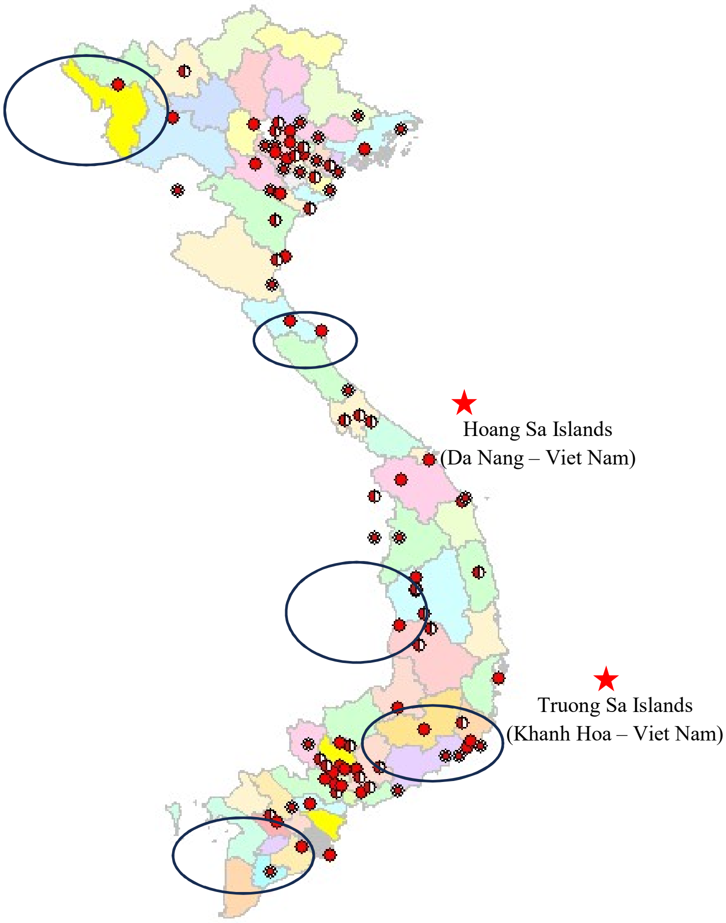

Figure 20: Areas that need to consider building more 500kV substations to transmit renewable energy generation compared to PDP8.

b. N-1 contingency cases (N-1)

In 2030, the study examined total of 1708 N-1 faults, which only scanned N-1 faults of line branches and transmission transformers, excluding generator set faults and busbar faults.

Statistics of N-1 incident cases causing overload of remaining elements on the grid of 7 Balmorel snapshots are as follows:

- HG: 46/1708 (2.69%).
- LG: 41/1708 (2.40%).
- HRD: 36/1708 (2.11%).
- LRD: 30/1708 (1.76%).
- HF: 64/1708 (3.75%).
- LF: 24/1708 (1.41%).
- HC: 24/1708 (1.41%).

Therefore, the mode that meets the lowest N-1 criterion (highest violation rate) is the HF period with 64 violations (accounting for 3.75%). Ranked second is HG snapshot with an N-1 violation rate of

2.69%. Calculation results show that cases of violation of the N-1 criterion mainly occur in the power grid that has responsibility for transmission of the generated power.

<u>HF snapshot</u>

HF snapshot is analyses further, since it is the most violated snapshot. Some of the critical areas and violations will be examined.

For the Northern power grid:

- After proposing to build a number of additional 500 kV substations to evacuate the capacity of solar power and small hydro power sources in the North West region as mentioned, the power grid in the Northern region ensures N-1 criteria.

For the Central power grid:

- For the power grid to utilize the capacity of renewable energy sources, it is possible to consider looking at the flexible N-1 criterion. For example, when one circuit of line/transformer fails, the remaining circuits/transformer are only allowed to operate below 100% load and the operator can curtail renewable energy to ensure operation of power grid within allowed range. If the curtailment of renewable energy sources is lower than the number of rotating reserves of the power system (equal to the largest power plant unit), the power system is considered to meet the flexible N-1 criterion. Therefore, when designing the grid for integration of wind and solar power, it is possible to consider flexibly the N-1 criterion (not N-1 criterion like other large power plants) in order to reduce the amount of grid investment without greatly affecting the power supply security.

- DZ 220 kV Doc Soi - Quang Ngai 2 - Quang Ngai is overloaded by about 25% in 1-circuit fault mode. Therefore, it is recommended to renovate and increase the load capacity and replace the thermal conductor for this transmission line.

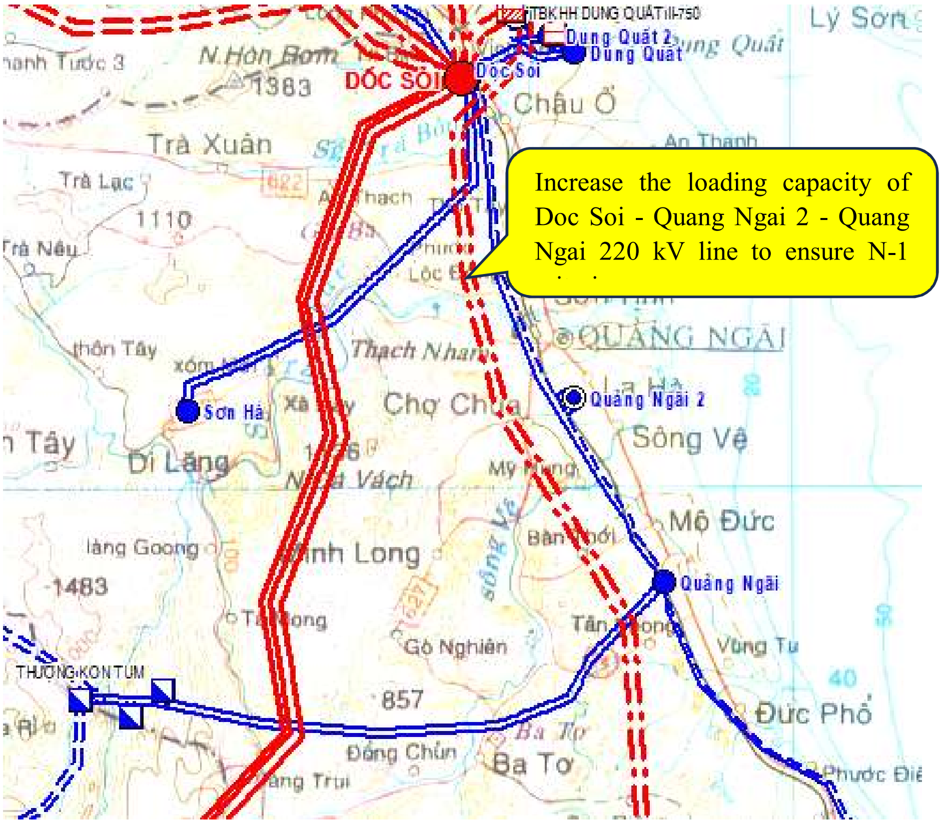

Figure 21: The power transmission system at Quang Ngai area (Center Central region).

For the Southern power grid:

- Some 220 kV lines in the South West region that play a role in utilizing renewable energy sources are overloaded during the N-1 incident mode. It is necessary to take measures to improve and increase load capacity such as Soc Trang. – Chau Thanh, O Mon – Chau Thanh, Ca Mau – Ca Mau thermal power plant,

Overload elements at N-1 failure in snapshots HG, LG, HRD, LRD, LF, HC are as follows:

- Nam Dinh - Hai Hau - Truc Ninh 220 kV line is overloaded when a circuit failure in case of high transmission in North - Central interface. Therefore, it is proposed to renovate and replace the thermal conductor for this line.

- Some 220 kV lines to evacuate the capacity of small hydro power sources and wind power sources in the Highlands region are overloaded when one circuit fails, such as: Pleiku - Sesan 3 - Sesan 3A, Thanh My - Dak Mi and Krongbuk - Krongana - Serepok 4. Therefore, it is recommended to improve load capacity and replace thermal conductor for these lines.

- The South West region develops many wind power sources but has relatively low load, leading to overload of some 220 kV lines in N-1 fault mode, such as: Soc Trang - Chau Thanh, O Mon - Chau Thanh, O Mon - Rach Gia and Ca Mau - Ca Mau thermal power plant. These lines need to be renovated and increase the load capacity to ensure operation according to N-1 criteria.

- Some 500 kV substations to transmit renewable energy sources recorded overload in N-1 mode such as Binh Dinh, Krongbuk, Bac Lieu, Ninh Son, etc. Therefore, it is necessary to consider renovating and installing additional transformers for substations or build new substations in the area to support transmission.

According to the simulation and summary results, by 2030, to ensure N-1 criteria and avoid overload, it is necessary to build about 110 km of 220 kV line, 3600 MVA of 500 kV transformer; renovate about 600 km of 220 kV line, 800 km of 220 kV line compared to PDP8.

In addition, through preliminary estimates, with the increased development of wind and solar power sources by 2030, it is necessary to newly build about 22500 MV of 500 kV transformer, 42750 MVA of 220 kV transformer, 4200 km of 500 kV line and 2300 km of 220 kV line.

5.3. Transmission loss

Transmission loss between regions is an input to the Balmorel model to simulate the inter-region transmission in the power system. In addition, transmission loss and investment capital of lines on the interface can affect the decision to invest in building new inter-regional lines or building power plants to meet local demand.

Transmission loss is calculated according to the formula:

$$Transmission\ loss\ in\ interface\ k\ (\%) = Average\left(\frac{Transmission\ loss\ in\ interface\ k\ in\ year\ i}{Energy\ transmission\ in\ interface\ k\ in\ year\ i}\right).100$$

The PSS/E model simulates the power system at a certain snapshot. Therefore, to calculating approximately energy transmission loss in interface k in year i, the study calculates the power loss of power system in snapshot HG (as it is the peak load) by PSS/E, then multiplied by experience factor Γ:

$$\Delta A_{year} = \Delta P_{Peak\ load}\ x\ \Gamma$$

Where:

ΔA_{year}: Energy transmission loss in year i

$\Delta P_{Peak\ load}$: Power loss in peak load regime in year i

Γ: Equivalent maximum power loss time, (Γ=(0.124+Tmax/10000)^{2}x8760)).

Based on the calculation selected in the load flow calculation, the report uses the simulated grid data in 2025 years and 2030 to calculate the transmission loss in the PSS/E software.

On each inter-region transmission interface, perform power loss calculations on hypothetical lines with lengths corresponding to the transmission distance between the two regions. Transmission distance is determined by the distance between the power center of one region to the load center of another region. This distance may be longer than the actual length of interface lines but will more accurately reflect the nature of the transmission between the two regions. The load carrying level of the line to calculate power loss is about 1100 MW/circuit (corresponding to the recommended transmission level on EVN NLDC's inter-regional 500 kV lines).

Summary of typical transmission distances on interfaces in the following table:

Table 2: Typical transmission distances on interfaces.

Interface	Length (km)
North – North Central	330
North Central – Center Central	450
Center Central – Highlands	200
Center Central – South Central	420
Highlands – South East	300
South Central – South East	250
Highlands – South Central	300
South East – South West	300

The results of the transmission loss are as follows:

Table 3: The results of the transmission loss in inter-regional grid.

Interface		2025	2030	Average power loss (%) (1)	Current power loss in Balmorel[1] (2)	Difference (1) - (2)
		Power loss (%)	Power loss (%)			
North	North Central	4.14%	4.62%	4.38%	3.20%	1.18%
North Central	Center Central	3.67%	4.75%	4.21%	3.60%	0.61%
Center Central	Highland	2.42%	2.78%	2.60%	2.50%	0.10%
Center Central	South Central	3.92%	4.67%	4.30%	3.80%	0.50%
Highland	South East	3.66%	3.91%	3.79%	3.50%	0.29%
South Central	South East	3.02%	3.38%	3.20%	3.00%	0.20%
Highland	South Central	2.39%	2.59%	2.49%	2.40%	0.09%
South East	South West	3.40%	3.69%	3.55%	3.20%	0.35%

Using the loop between the two programs Balmorel and PSS/E to determine transmission loss will help to evaluate more accurately the loss value put into Balmorel, because PSS/E is a specialized tool to calculate and simulate the power grid. The results show that the calculated transmission loss value in PSS/E software differs from transmission loss value included as input into the Balmorel model by about 0.1%-1.2% depending on the interface.

[1] Power losses in Balmorel are assumed the same for all years.

5.4. Estimated total volume and cost of power transmission system for Net-Zero scenario in EOR-NZ

The estimated volume of additional HVAC substation and transmission lines based on grid simulations for 2025 and 2030 in order to meet the requirements of the Grid code (in both inter-regional and intra-regional grid) is shown below:

Table 4: Estimated volume of additional HVAC substation and transmission line in NZ scenario compared to PDP8 in 2025 and 2030.

Region	500kV transformer (MVA)	500kV line (km)	220kV transformer (MVA)	220kV line (km)
2025				
North				159
North Central				0
Center Central		108	500	324
Highland	1,800	100	3,500	650
South Central	1,800		1,500	360
South East			1,000	157
South West				84
Total 2025	**3,600**	**208**	**6,500**	**1,734**
2030				
North	9,000	1,198	11,250	781
North Central	2,700	40	10,500	560
Center Central	0	580	0	158
Highland	7,200	120	7,500	766
South Central	5,400	80	7,500	400
South East	0	0	3,750	201
South West	4,500	80	2,250	270
Total 2030	**28,800**	**2,098**	**42,750**	**3,136**

We also need to construct a high-voltage direct current power transmission system (HVDC) with capacity of about 1 GW of from the Center Central to the North, with a transmission length of more than 1000 km in 2030.

For estimating the investment cost, the unit price of lines and substations according to PDP8 [4] are used. From the results of the grid analysis, the estimated total investment cost for the transmission grid in the Net-zero scenario in the period 2021 - 2030 is summarized in

Table 5. These costs include both the internal grid costs and the reinforcements of the interfaces between regions.

Table 5: Total investment cost for the transmission grid in Net-Zero scenario in the period 2021 - 2030.

	Investment cost for PDP8 (mill USD)	**Additional investment cost for NZ scenario (mill USD)**	**Total investment cost for NZ scenario (mill USD)**
HVDC			
HVDC Center Central – North	0	1,508	1,508
HVAC			
North	5,621	1,539	7,159
North Central	1,771	865	2,635
Center Central	1,626	442	2,068
South Central	2,292	548	2,840
Highlands	1,031	895	1,926
South East	3,039	-35	3,004
South West	1,214	372	1,586
Total	**16,593**	**6,133**	**22,726**

It can be seen that the investment cost of the transmission grid for the power system development in the Net-Zero scenario is significantly higher than that of PDP8 (about 1.4 times higher). To develop towards net-zero with minimal costs, ignoring current policy constraints, it will require more investment in the transmission grid than in PDP8, about 6,100 million USD. In particular, the North region needs to invest about 1,500 million USD more than PDP8 due to developing more solar power sources. Next, the Highlands and North Central need to invest about 900 million USD more. The South East region has a negative additional investment cost, because the increased investment costs of this region are smaller than the reduced investment costs due to not developing LNG and offshore wind power sources. The cost of investing in the HVDC transmission system from the Center Central to the North is about 1500 million USD. In general, developing many renewable energy sources will save fuel costs and protect the environment, but can increase the need for investment in power transmission networks.

It can be noted that this study has some limitations. Firstly, the additional cost for the Net-Zero scenario in this study is not the optimal cost. In reality, Viet Nam power grid is very huge with more than 700 nodes and more than 1500 branches/transformer in 2030. It is hard to find the optimal least-cost solution for transmission grid expansion. Therefore, we often find a suboptimal solution to design the grid. Secondly, this study only simulated PSS/E in 2025 and 2030 for Net-Zero scenario. On the other hand, the cost does not include the discount rate and is not assessed in the same way as in the EOR. Therefore, this study only gives an indication of the cost and can be used as an evaluation of the model results. It should not be used as a direct comparison to the EOR results.

6. Conclusions

The main purpose of this study are: (i) Check the feasibility of the proposed source development plan for power grid operation according to the approved planning; (ii) Check the voltage and load level on inter-regional and intra-regional lines in different power operating modes, thereby making recommendations on upgrading and expanding the transmission grid; (iii) Estimate investment cost for transmission grid to meet the source development program; (iv) Calculate power loss on inter-regional transmission grid as a basis for adjusting input to the Balmorel model.

The study simulated the operation of Viet Nam's power transmission grid using PSS/E software corresponding to the power development program according to the Net-Zero scenario in the years 2025 and 2030. In the Net-Zero scenario, the net-zero target in 2050 is achieved in a cost optimal way, assuming policies and efforts ensuring that important barriers and inertia for the transition are overcome. Through analyzing the operating characteristics of the power system, 7 snapshots were selected for studying including: Highest generation (HG); Lowest generation (LG); Highest residual demand (HRD); Lowest residual demand (LRD); Maximum total interconnected transmission capacity (HF); Minimum total interconnected transmission capacity (LF); Highest wind and solar Curtailment (HC).

Simulation results show that, for inter-regional power grids, the configuration according to PDP8 basically ensures operation in extreme snapshots of the Net-Zero scenario in EOR-BZ, without the need to carry out additional renovation and upgrades in 2025 and 2030. However, some inter-regional transmission lines currently have series capacitors installed to improve stability. These series capacitors usually use 30.5 Ohm type, with a thermal limit of 2000 A, corresponding to about 1700 MVA, much lower than the thermal limit of ACSR4x330 lines (thermal limit of about 2390 MVA). Therefore, it is proposed to consider the option of replacing capacitors of about 2500 - 3000 A for these lines to nearly reach the line's thermal limit. This proposal is also consistent with the calculations in PDP8. In addition, with the plan to develop power sources according to the Net-Zero scenario, it will be necessary to build a high-voltage direct current power transmission system (HVDC) with capacity of about 1 GW of from the Center Central to the North, with a transmission length of more than 1000 km.

Because the Balmorel model is a power planning model, the power grid is simplified, simulating only the connections between different areas. The cost of renovating and upgrading the transmission grid from the Balmorel model only includes inter-regional lines, not considering the intra-regional lines. Checking load flow and proposing measures to renovate and upgrade intra-regional lines and then calculate costs is useful information that this supplementary report provides in EOR-NZ. In 2025, it is necessary to build about 100 km of 500 kV line, 550 km of 220 kV line, 1800 MVA of 500 kV transformer; and renovate about 400 km of 220 kV line compared to PDP8. To connect additional renewable energy sources, it is necessary to build about 1800 MVA of 500 kV transformer, 6500 MVA of 220 kV transformer, 800 km of 220 kV line and 100 km of 500 kV line. In 2030, it is necessary to build about 110 km of 220 kV line, 3600 MVA of 500 kV transformer; and renovate about 600 km of 500 kV line, 800 km of 220 kV line compared to PDP8. To connect additional renewable energy sources, it is necessary to build about 22,500 MVA of 500 kV transformer, 42,750 MVA of 220 kV transformer, 4,200 km of 500 kV line and 2,300 km of 220 kV line. Most of power transmission grid renovation projects have increased compared to PDP8 to connect renewable energy sources.

Regarding investment costs for the transmission grid, it is necessary to invest about 23 billion USD to meet the power system development set out in the Net-Zero scenario in the period up to 2030. Of which, in addition to about 16.5 billion USD to build power grid projects already in PDP8, an additional investment of about 6.1 billion USD is needed. In general, developing many renewable energy sources will save fuel costs and protect the environment, but can increase the need for investments in power transmission networks.

APPENDIX

Appendix 1. Additional HVDC works for the NZ scenario compared to PDP VIII

No	Project	Scale (km/MW)
1	Bipole HVDC from Center Central to North	2x1000
2	Converter station in Center Central	1000
3	Converter station in North	1000

Appendix 2. Estimated list of additional 500 kV substations for the NZ scenario compared to PDP VIII

No	Project	Capacity according to PDP VIII (MVA)			Capacity according to NZ scenario (MVA)			Note
	North							
1	Dien Bien	-			3	x	900	New build
2	Son La	-			3	x	900	New build
3	Yen Bai	-			3	x	900	New build
4	Than Uyen	-			1	x	900	New build
	North Central							
1	RE Thanh Hoa	-			3	x	900	New build
	Center Central							
	South Central							
1	Binh Dinh	1	x	900	3	x	900	Upgrade
2	Solar South Central 1	-			2	x	900	New build
3	Solar South Central 2	-			2	x	900	New build
	Highlands							
1	Krongbuk	2	x	900	3	x	900	Upgrade
2	Wind Highlands 1	-			3	x	900	New build
3	Wind Highlands 2	-			2	x	900	New build
4	Wind Highlands 3	-			2	x	900	New build
	South East							
	South West							
1	Bac Lieu	2	x	900	3	x	900	Upgrade
2	Wind South West 1	-			2	x	900	New build
3	Wind South West 2	-			2	x	900	New build

Appendix 3. Estimated list of additional 500 kV lines for the NZ scenario compared to PDP VIII

No	Project	Scale according to PDP VIII (no. of circuit x km)	Scale according to NZ scenario (no. of circuit x km)			Note
	North					
1	Lai Chau - Dien Bien	-	2	x	52	New build
2	Dien Bien - Son La	-	2	x	210	New build
3	Son La - Son Tay	-	2	x	120	New build
4	Yen Bai transit on Lao Cai - Vinh Yen	-	4	x	20	New build
5	Than Uyen - Lai Chau	-	2	x	139	New build
6	Than Uyen - Lao Cai	-	2	x	38	New build
	North Central					
1	RE Thanh Hoa transit on Thanh Hoa - Quynh Luu	-	4	x	10	New build
	Center Central					
1	Upgrade Da Nang - Quang Tri	-	2	x	140	Upgrade
2	Upgrade Quang Binh - Quang Tri	-	2	x	150	Upgrade
	South Central					
1	Connecting Solar South Central 1	-	2	x	20	New build
2	Connecting Solar South Central 2	-	2	x	20	New build
	Highlands					
1	Connecting Wind Highlands 1	-	2	x	20	New build
2	Connecting Wind Highlands 2	-	2	x	20	New build
3	Connecting Wind Highlands 3	-	2	x	20	New build
	South East					
	South West					
1	Connecting Wind South West 1	-	2	x	20	New build
2	Connecting Wind South West 2	-	2	x	20	New build

Appendix 4. Estimated list of additional 220 kV substations for the NZ scenario compared to PDP VIII

No	Project	Capacity according to PDP VIII (MVA)	Capacity according to NZ scenario (MVA)			Note
	North					
1	Solar North 1	-	3	x	250	New build
2	Solar North 2	-	3	x	250	New build
3	Solar North 3	-	3	x	250	New build
4	Solar North 4	-	3	x	250	New build

No	Project	Capacity according to PDP VIII (MVA)	Capacity according to NZ scenario (MVA)			Note
5	Solar North 5	-	3	x	250	New build
6	Solar North 6	-	3	x	250	New build
7	Solar North 7	-	3	x	250	New build
8	Solar North 8	-	3	x	250	New build
9	Solar North 9	-	3	x	250	New build
10	Solar North 10	-	3	x	250	New build
11	Solar North 11	-	3	x	250	New build
12	Solar North 12	-	3	x	250	New build
13	Solar North 13	-	3	x	250	New build
14	Solar North 14	-	3	x	250	New build
15	Solar North 15	-	3	x	250	New build
	North Central					
1	Solar North Central 1	-	3	x	250	New build
2	Solar North Central 2	-	3	x	250	New build
3	Solar North Central 3	-	3	x	250	New build
4	Solar North Central 4	-	3	x	250	New build
5	Solar North Central 5	-	3	x	250	New build
6	Solar North Central 6	-	3	x	250	New build
7	Solar North Central 7	-	3	x	250	New build
8	Solar North Central 8	-	3	x	250	New build
9	Solar North Central 9	-	3	x	250	New build
10	Solar North Central 10	-	3	x	250	New build
11	Solar North Central 11	-	3	x	250	New build
12	Solar North Central 12	-	3	x	250	New build
13	Solar North Central 13	-	3	x	250	New build
14	Solar North Central 14	-	3	x	250	New build
	Center Central					
	South Central					
1	Solar South Central 1	-	3	x	250	New build
2	Solar South Central 2	-	3	x	250	New build
3	Solar South Central 3	-	3	x	250	New build
4	Solar South Central 4	-	3	x	250	New build
5	Solar South Central 5	-	3	x	250	New build
6	Solar South Central 6	-	3	x	250	New build
7	Solar South Central 7	-	3	x	250	New build
8	Solar South Central 8	-	3	x	250	New build
9	Solar South Central 9	-	3	x	250	New build
10	Solar South Central 10	-	3	x	250	New build
	Highlands					
1	Solar Highlands 1	-	3	x	250	New build
2	Solar Highlands 2	-	3	x	250	New build

No	Project	Capacity according to PDP VIII (MVA)	Capacity according to NZ scenario (MVA)			Note
3	Solar Highlands 3	-	3	x	250	New build
4	Solar Highlands 4	-	3	x	250	New build
5	Solar Highlands 5	-	3	x	250	New build
6	Solar Highlands 6	-	3	x	250	New build
7	Solar Highlands 7	-	3	x	250	New build
8	Solar Highlands 8	-	3	x	250	New build
9	Solar Highlands 9	-	3	x	250	New build
10	Solar Highlands 10	-	3	x	250	New build
	South East					
1	Solar South East 1	-	3	x	250	New build
2	Solar South East 2	-	3	x	250	New build
3	Solar South East 3	-	3	x	250	New build
4	Solar South East 4	-	3	x	250	New build
5	Solar South East 5	-	3	x	250	New build
	South West					
1	Solar South West 1	-	3	x	250	New build
2	Solar South West 2	-	3	x	250	New build
3	Solar South West 3	-	3	x	250	New build

Appendix 5. Estimated list of additional 220 kV lines for the NZ scenario compared to PDP VIII

No	Project	Scale according to PDP VIII (no. of circuit x km)	Scale according to NZ scenario (no. of circuit x km)			Note
	North					
1	Upgrade Vat Cach - Trang Bach	-	2	x	20	Upgrade
2	Upgrade Hoanh Bo - Trang Bach	-	2	x	45	Upgrade
3	Thai Thuy - TPP Thai Binh	-	1	x	1	New build
4	Truc Ninh - Hai Hau	-	2	x	18	Upgrade
5	Hai Hau - Nam Dinh	-	2	x	7	Upgrade
6	Connecting Solar North 1	-	2	x	20	New build
7	Connecting Solar North 2	-	2	x	20	New build
8	Connecting Solar North 3	-	2	x	20	New build
9	Connecting Solar North 4	-	2	x	20	New build
10	Connecting Solar North 5	-	2	x	20	New build
11	Connecting Solar North 6	-	2	x	20	New build
12	Connecting Solar North 7	-	2	x	20	New build
13	Connecting Solar North 8	-	2	x	20	New build
14	Connecting Solar North 9	-	2	x	20	New build

No	Project	Scale according to PDP VIII (no. of circuit x km)	Scale according to NZ scenario (no. of circuit x km)			Note
15	Connecting Solar North 10	-	2	x	20	New build
16	Connecting Solar North 11	-	2	x	20	New build
17	Connecting Solar North 12	-	2	x	20	New build
18	Connecting Solar North 13	-	2	x	20	New build
19	Connecting Solar North 14	-	2	x	20	New build
20	Connecting Solar North 15	-	2	x	20	New build
	North Central					
1	Connecting Solar North Central 1	-	2	x	20	New build
2	Connecting Solar North Central 2	-	2	x	20	New build
3	Connecting Solar North Central 3	-	2	x	20	New build
4	Connecting Solar North Central 4	-	2	x	20	New build
5	Connecting Solar North Central 5	-	2	x	20	New build
6	Connecting Solar North Central 6	-	2	x	20	New build
7	Connecting Solar North Central 7	-	2	x	20	New build
8	Connecting Solar North Central 8	-	2	x	20	New build
9	Connecting Solar North Central 9	-	2	x	20	New build
10	Connecting Solar North Central 10	-	2	x	20	New build
11	Connecting Solar North Central 11	-	2	x	20	New build
12	Connecting Solar North Central 12	-	2	x	20	New build
13	Connecting Solar North Central 13	-	2	x	20	New build
14	Connecting Solar North Central 14	-	2	x	20	New build
	Center Central					
1	Dak Mi 4A - Thanh My	-	1	x	44	New build
2	Upgrade Doc Soi - Quang Ngai 2 - Quang Ngai	-	2	x	57	Upgrade
	South Central					
1	Connecting Solar South Central 1	-	2	x	20	New build
2	Connecting Solar South Central 2	-	2	x	20	New build
3	Connecting Solar South Central 3	-	2	x	20	New build
4	Connecting Solar South Central 4	-	2	x	20	New build
5	Connecting Solar South Central 5	-	2	x	20	New build
6	Connecting Solar South Central 6	-	2	x	20	New build
7	Connecting Solar South Central 7	-	2	x	20	New build
8	Connecting Solar South Central 8	-	2	x	20	New build
9	Connecting Solar South Central 9	-	2	x	20	New build
10	Connecting Solar South Central 10	-	2	x	20	New build
	Highlands					
1	Upgrade Krongbuk - Krong Ana	-	1	x	73	Upgrade
2	Upgrade Krongbuk - Serepok 4	-	1	x	77	Upgrade
3	500kV Krongbuk - Krongbuk	-	2	x	27	New build
4	Upgrade Pleiku- Sesan 3 - Sesan 3A	-	2	x	40	Upgrade
5	Upgrade Chu Se - Pleiku 2	-	2	x	41	Upgrade

No	Project	Scale according to PDP VIII (no. of circuit x km)	Scale according to NZ scenario (no. of circuit x km)			Note
6	Connecting Solar Highlands 1	-	2	x	20	New build
7	Connecting Solar Highlands 2	-	2	x	20	New build
8	Connecting Solar Highlands 3	-	2	x	20	New build
9	Connecting Solar Highlands 4	-	2	x	20	New build
10	Connecting Solar Highlands 5	-	2	x	20	New build
11	Connecting Solar Highlands 6	-	2	x	20	New build
12	Connecting Solar Highlands 7	-	2	x	20	New build
13	Connecting Solar Highlands 8	-	2	x	20	New build
14	Connecting Solar Highlands 9	-	2	x	20	New build
15	Connecting Solar Highlands 10	-	2	x	20	New build
	South East					
1	Cu Chi - 500 kV Cu Chi	-	1	x	0,5	New build
2	Connecting Solar South East 1	-	2	x	20	New build
3	Connecting Solar South East 2	-	2	x	20	New build
4	Connecting Solar South East 3	-	2	x	20	New build
5	Connecting Solar South East 4	-	2	x	20	New build
6	Connecting Solar South East 5	-	2	x	20	New build
	South West					
1	Ca Mau - TPP Ca Mau	-	2	x	6	New build
2	Upgrade O Mon - Rach Gia	-	1	x	54	Upgrade
3	Upgrade Soc Trang - Chau Thanh	-	2	x	42	Upgrade
4	Connecting Solar South West 1	-	2	x	20	New build
5	Connecting Solar South West 2	-	2	x	20	New build
6	Connecting Solar South West 3	-	2	x	20	New build

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