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Grid Modeling of RE scenarios and recommendations on power grid

Background report to Viet Nam Energy Outlook Report 2021

2021

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Contents

1. Introduction

This project is carried out in parallel with and in support of the project "Capacity building within Balmorel and scenarios", 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).

The main purpose of this project is to contribute to the Energy Outlook Report (EOR) 2021 with a detailed analysis of the transmission grid in Vietnam under a range of scenarios and conditions of 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 with, in total, eight transmission lines interconnecting seven transmission regions (the South region divided into Southeast and Southwest region compared to EOR 2019). 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. This aims at verifying whether any assumptions for capacity between the regions should be revised in Balmorel. Also, the assumption about losses in the transmission system and the investment cost per transmission interface are reviewed.
- **Verifying the grid operation of the local transmission network within a region**. The Balmorel model does not consider the local transmission network in the simulation. In the PSS/E study, the model operators will detail assign power plants and load to nodes of the local transmission network and check the operation of local network in the aspects of:
    - 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.

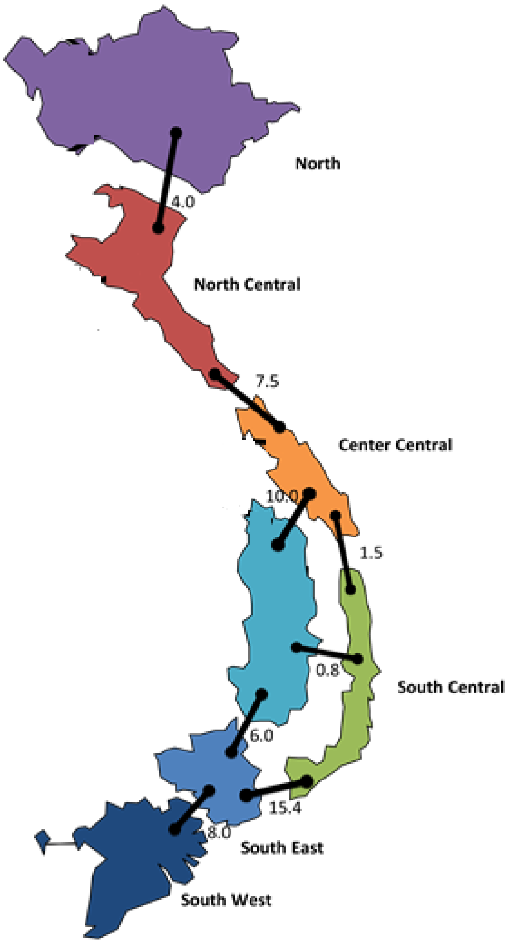


Figure 1. Transmission grid in Vietnam in the 7 regions

2. Methodology

2.1. PSS/E model

Among the power system simulation software used for power development and planning in Vietnam, Power System Simulator for Engineering (PSS/E) is the most used. PSS/E was developed by Siemens PTI, integrating many modules [1], 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 [2], [3].

The elements in the grid such as transmission lines, transformers, generators, capacitors, electric resistors, DC-AC, AC-DC converters, loads at the nodes, are modeled in the form of mathematics. PSS/E uses algebraic methods for equation solving, such as Fixed-Slope decoupled Newton-Raphson, Full Newton-Raphson, Gauss-Seiden, and 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 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 Vietnam, 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 will provide 2 important inputs to PSS/E model including:

- The installed generation capacity and installed transmission capacity between regions in each calculation years. 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 and the loading level of the transmission lines, this is called "snapshot" and transfer to PSS/E model. The most critical dispatching hours are selected to be simulated in grid operation, to check the response of the transmission system.

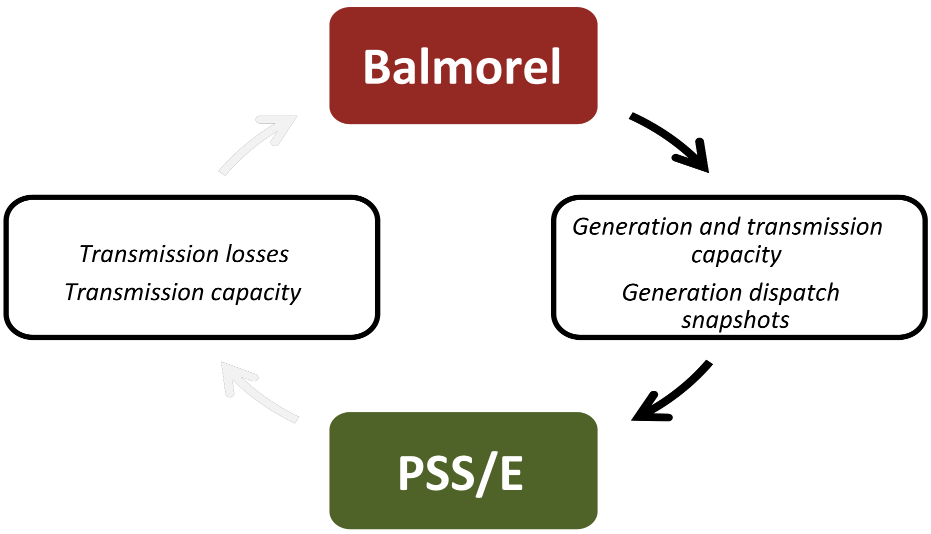


Figure 2. Methodology diagram of interaction between the Balmorel and PSS/E model. It is possible to make a full feedback loop and provide the transmission losses and transmission capacities back to Balmorel, however that was not done in this study.

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

Step 1: **Build the simulation power grid** based on the installed generation capacity of power plants and the transmission capacity between regions in each year:

+ **Power plants**: Power plants in Balmorel are shown by region, not by specific nodes, so the study needs to assign power plants and loads to the nodes of transmission system, especially the solar and wind power:
    - Build and update library linking Balmorel and PSS/E (excel file), that assign large power plants (coal, gas, large hydro) to corresponding buses in PSS/E.
    - Wind, solar, small hydro, biomass and other RE are split by provinces and assigned to suitable nodes in each province.
    - Rooftop solar is distribution generation and modeled as a negative load at the load nodes (that made the PSS/E model more convergent than small distribution plants).

- **The load**: The load is assigned to nodes in each region as in the PDP VIII. The total load of a region will be scaled up or down to matching snapshot input data.

- **The transmission system**:
    - ***The inter-regional transmission system*** will be built based on installed transmission capacity between regions from Balmorel.
    - Balmorel model does not consider the local transmission network so ***the internal power grid in each region*** will be taken from the draft PDP VIII.

Step 2: **Run load flow study** for each regime based on a snapshot of from Balmorel

- The load and power plants in each region will be dispatched according to the snapshot. This is done using an automatic tool for PSS/E written in Python language, which will create PSS/e case file for each regime.
- Run optimal power flow (OPF): The active power of power plants was set corresponding to a Balmorel snapshot, but the reactive power control of a power plant (through scheduled voltage) will be set through an OPF run that make the calculation regimes be more convergent.

- Run Power flow and add transmission lines until overload is avoided for each PSS/e case file

<u>Step 3</u>: Analysis result and write the report.

3. Building simulation transmission grid for PSS/e

Based on input data from Balmorel for the Baseline scenario, there are 241 power plants in the Vietnamese power system in 2025 and increase to 295 power plants in 2035 (some large power plants are divided into each unit and renewable energy source such as solar, wind, biomass, etc. are divided by region).

The Balmorel result of installed transmission capacity between region in the year 2020 – 2035 is as follow:

		Invested transmission capacity (MW)			Installed transmission capacity (MW)		
FromRegion	ToRegion	2020	2025	2035	2020	2025	2035
North	North_Central				2,400	4,000	4,000
	Center_Central			1,278			1,278
North_Central	North				2,400	4,000	4,000
	Center_Central			1,874	3,500	3,500	5,374
Center_Central	North			1,278			1,278
	North_Central			1,874	1,400	1,400	3,274
	Highland				2,000	6,000	6,000
	South_Central				400	400	400
Highland	Center_Central				2,000	6,000	6,000
	South_Central				800	800	800
	South_East				4,000	5,500	5,500
South_Central	Center_Central				400	400	400
	Highland				800	800	800
	South_East				8,000	10,000	10,000
South_East	Highland				4,000	5,500	5,500
	South_Central				3,500	4,500	4,500
	South_West				7,960	7,960	7,960
South_West	South_East				7,960	7,960	7,960
Yunnan_Export_N	North				700	700	700
Laos_Export_N	North					972	1,032
Laos_Export_NC	North_Central					725	1,178
Laos_Export_CC	Center_Central				250	1,110	1,770
Laos_Export_H	Highland				322	602	998

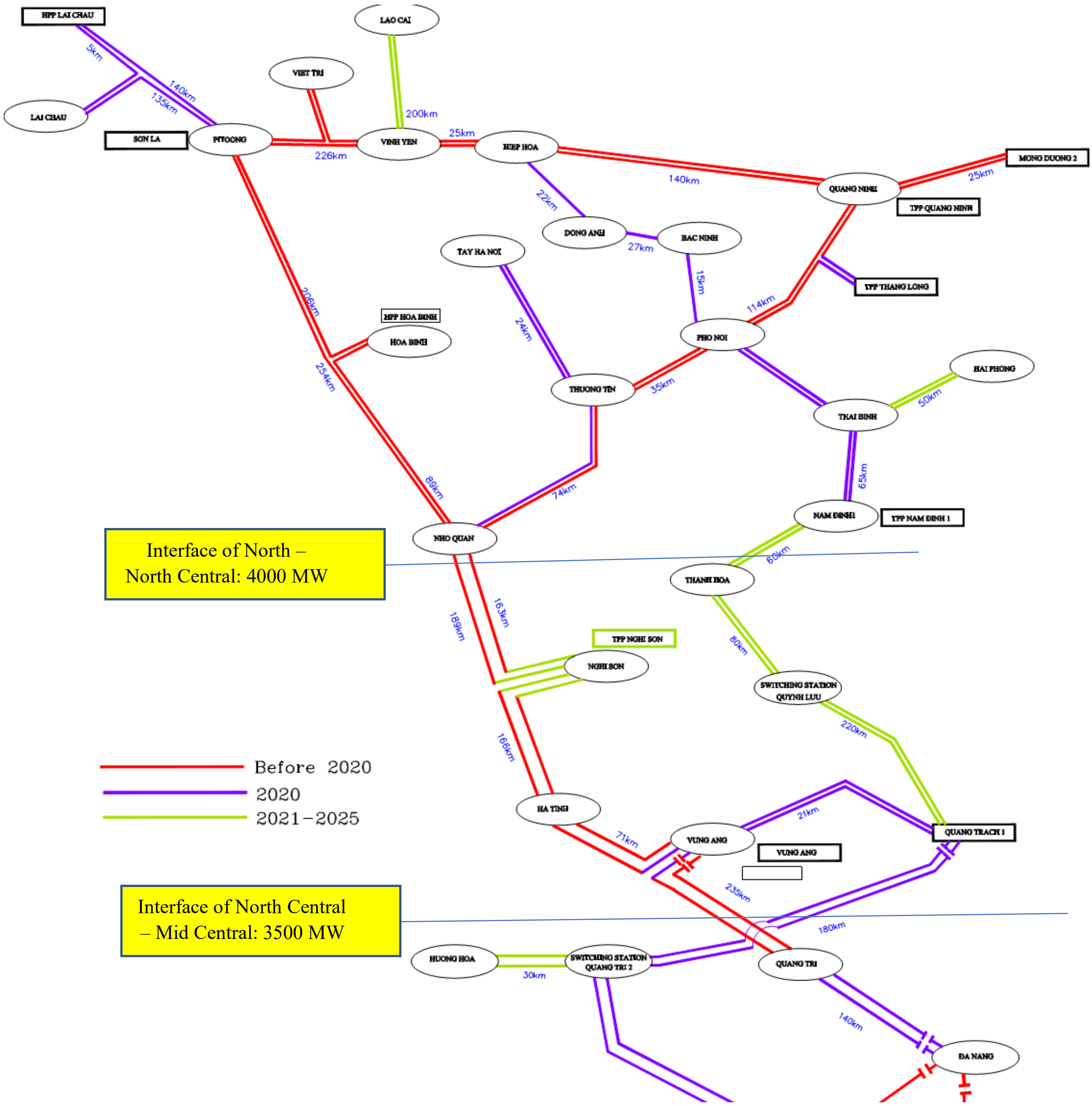
Figure 3: Installed transmission capacity between region from Balmorel in year 2020 - 2035

The years chosen to perform simulation is 2025 for the mid-term period and 2035 for the long-term period. The simulation power grid is ***500 kV and 220 kV transmission system*** of the whole country. The 110 kV and lower voltage level power grid will be represented by load in 220 kV nodes.

Building the inter-regional power transmission system in 2025: There are no new invested transmission capacity chosen by the model except for the following committed transmission lines:

1. Interface North – North Central: the transmission capacity in 2025 will be 4000 MW, this capacity is equivalent to the Total Transfer Capacity (TTC) of this interface, corresponding to 4 circuits of 500 kV transmission line (include the existing 500kV double circuit line Vung Ang – Ha Tinh – Nghi Son – Nho Quan and new built 500 kV double circuit line Quang Trach – Thanh Hoa – Nam Dinh – Pho Noi) and 3 circuits of 220 kV transmission line.
2. Interface North Central – Mid Central: the transmission capacity in 2025 will be 3500 MW, equivalent to 4 circuits of 500 kV transmission line (2 existing 500 kV double circuit lines Vung Ang – Quang Tri – Da Nang and Quang Trach – Switching station Quang Tri 2 – Doc Soi) and 2 circuits of 220 kV transmission line. Note that the length of this interface is more than 300 km so the transmission limit of this interface will be the stability limit, that's why with the same configuration of 4 circuits of 500 kV transmission line as interface North – North Central but the TTC is smaller.
3. Interface Mid Central – Highland: the transmission capacity in 2025 will be 6000 MW, equivalent to 4 circuits of 500 kV transmission line (2 single circuit lines Thanh My – Pleiku 2, Doc Soi – Pleiku and 1 double circuit line Doc Soi – Pleiku 2).
4. Interface Mid Central – South Central: the transmission capacity in 2025 will be 400 MW, equivalent to 4 circuits of 220 kV transmission line (1 double circuit line Quang Ngai – Phu My). Note that the CVX gas thermal complex is delay schedule to 2026 – 2030 so the 500 kV transmission line CCGT Dung Quat – Krong Buk also delay after 2025.
5. Interface Highland – Southeast: the transmission capacity in 2025 will be 5500 MW, equivalent to 5 circuits of 500 kV transmission line (2 double circuit lines Krong Buk – Chon Thanh and Krong Buk – Tay Ninh, 1 single circuit Dak Nong – Cau Bong) and 2 circuits of 220 kV transmission line.
6. Interface Highland – South Central: the transmission capacity in 2025 will be 800 MW, equivalent to 1 circuit of 500 kV transmission line (1 existing single circuit line Pleiku – Di Linh) and 4 circuits of 220 kV transmission line.
7. Interface South Central - Southeast: the transmission capacity in 2025 will be 10000 MW, equivalent to 7 circuits of 500 kV transmission line (3 double circuit lines Vinh Tan – Song May, Vinh Tan – Dong Nai 2, Ninh Son – Chon Thanh, 1 single circuit line Di Linh – Tan Dinh) and 6 circuits of 220 kV transmission line.
8. Interface Southeast – Southwest: the transmission capacity in 2025 will be 7960 MW, equivalent to 8 circuits of 500 kV transmission line (3 double circuit lines Duc Hoa – Phu Lam, Duc Hoa – Cau Bong, Tay Ninh/Cu Chi – My Tho, 2 single circuit lines Phu Lam – My Tho and Long An – Nha Be) and 6 circuits of 220 kV transmission line. The 2 double circuit 500 kV transmission line Duc Hoa –

Phu Lam and Duc Hoa – Cau Bong (connects transit on 2 circuits of Phu Lam – Cau Bong 500 kV) is also the link between the East and the West of Southeast, the direction of power transmission is usually opposite. Therefore, the contribution to the inter-regional interface of Southeast and Southwest is small.



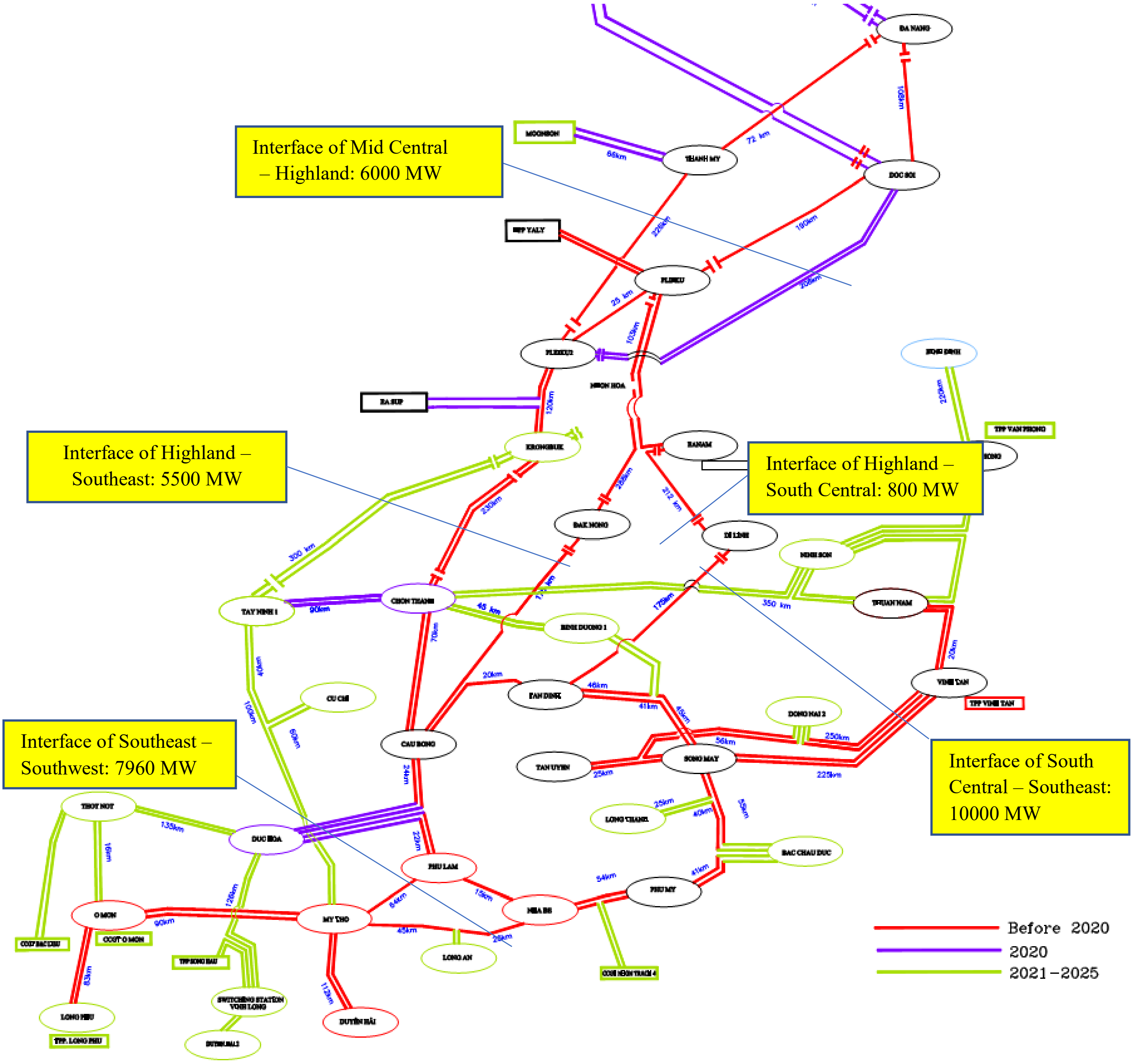


Figure 4: Transmission system of Vietnam at 500 kV voltage level in 2025

Building the inter-regional power transmission system in 2035: The result from Balmorel shows that up to 2035, the model only chooses to upgrade the interface Mid-Central to North Central with 1800 MW and interface Mid-Central to North with 1200 MW. The interface Mid-Central to North is a HVDC transmission line with the length of around 600 km, the invested capacity of 1200 MW is quite small for a HVDC system. A minimum capacity of a HVDC system is often 2000 – 2500 MW. At the capacity of smaller than 2000 MW, the HVDC system will not be able to compete with HVAC system. From that point, the study proposes to review the input data of HVDC Mid-Central – North Central in Balmorel model and this study will consider 1200 MW invested capacity from Mid-Central to North Central as HVAC system. That mean up to 2035 the interface Mid-Central to North Central will be upgrade with 3000 MW and interface North Central to North will be upgraded with 1200 MW.

1. Interface North – North Central: upgrade with 1200 MW equivalent to renovate the single circuit 500 kV transmission line Vung Ang – Ha Tinh – Nho Quan to double circuit 500 kV transmission line. Total installed transmission capacity will be 5200 MW.
2. Interface North Central – Mid-Central: upgrade with 3000 MW equivalent to build a new double circuit line Dung Quat – Hoa Lien – Quang Trach, total installed transmission capacity will be 6500 MW.
3. Other interfaces remain the same as in 2025

The local power grid in each region: The Balmorel model does not consider the local transmission network, so the local grid in each region at 500 kV and 220 kV will be taken from draft PDP VIII. The 110 kV and lower voltage level power grid will be equivalent to the 220 kV nodes.

Other assumptions:

Power factor at load nodes (Cosφ):

The voltage on the grid depends very much 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 the 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). *Limitation capacity of an interface* is taken from Total Transfer Capacity (TTC) calculation result.

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

Resistor, resistance of line and transformer parameters (R_0, X_0, B_0): typical parameters on the current transmission grid are used.

4. Scenarios in the transmission grid modeling

There are around 8760 hours of generation dispatching mix 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 respond to generation dispatching and load at the same time. However, not all 8760 grid operation modes are critical. In the grid simulation of the planning problem, it is often only some of most critical operation modes that are interesting to reduce the calculated volume. If the most critical operation modes are satisfied, the grid can respond well to the remaining operation cases.

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)

The HG snapshot usually is in the period 10:00-14:00 or 19:00-21:00 [10] and is used to check the capability of transmission lines in the heaviest load condition. 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 LRD snapshot is considered locally to check the possibility of releasing power from coal thermal plants and wind power plants, as this snapshot represents the heaviest operation condition for transmission lines.

In the period 19:00-21:00 in the evening, 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 releasing power from traditional power plants (coal-thermal, LNG, hydro power plants).

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 the lowest; supply grid for battery is in charge mode; and, the possibility of releasing power from wind and PV solar power plants when the output power of these sources is high.

The HF and LF snapshots are used to check the responsiveness of the transmission grid in two states: the highest flow and lowest flow on all interconnections. HF is usually a condition where sources in one region have high output power and transmit to other regions over a large transmission distance. 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 investment for transmission lines.

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

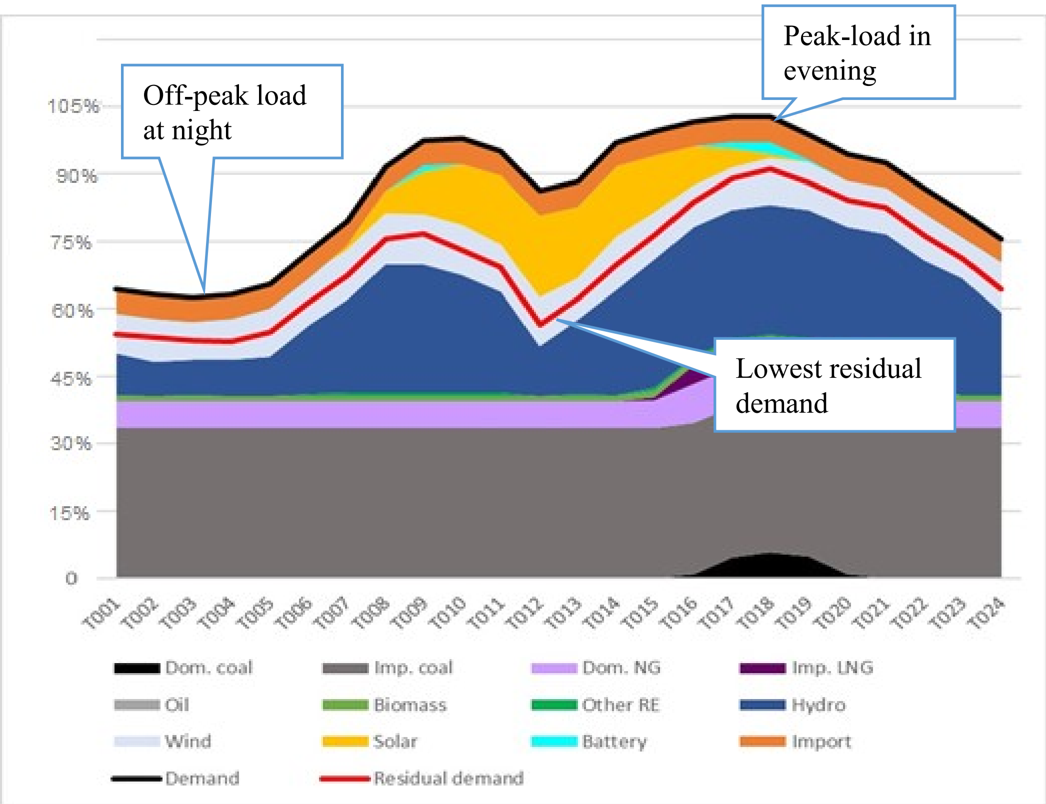


Figure 5. Power generation dispatching on a typical day of Vietnam power system

5. Results of grid simulation corresponding to power generation development scenarios

5.1. Results of grid simulation in 2025

Under normal operation conditions (N-0):

In all of 7 calculation snapshots, no elements are overloaded (carry a load more than 100%). Considering all elements with loading of more than 70%, which may cause overload in N-1 fault regimes leading to the following comments:

- LG, LF, HC, LRD modes have no element carrying a load over 70%, including elements belonging to the inter-regional transmission network and intra-regional transmission network. The modes LG - the lowest generating capacity and HC – the highest RE curtailment are all modes related to the Lunar New Year from week 4 to week 5, with the load dropping to only about 16 GW, equal to about 30% of Pmax in 2025. LRD and LF modes have a peak load of about 30 GW, equal to nearly 60% of Pmax per year.
- The remaining modes including HG, HRD, HF also have an inter-regional transmission network carrying a load of less than 70%, but some elements of the local transmission network are relatively heavy.
    - Firstly, the power transmission circuits of Hoa Binh Power Plant to Ha Noi (2 transformers Hoa Binh - Tay Ha Noi carry 75% load). This is an important electrical circuit supplying power to Ha Noi City, although it has been enhanced with 5 power transmission circuits including Hoa Binh - Tay Ha Noi, Hoa Binh - Van Dien and Hoa Binh - Ha Dong, but the load in Ha Noi load center of the North region where the demand is forecasted to increase with highest rate among 7 regions [1]. The HG and HRD modes are all at the time of July (week 32) which is the peak month of the rainy season. The hydro power plants in the Northwest region have high output generation, leading to some transmission circuits to the center of Hanoi operating quite heavily load at 72%, so it is necessary to consider strengthening the power transmission grid for these circuits.

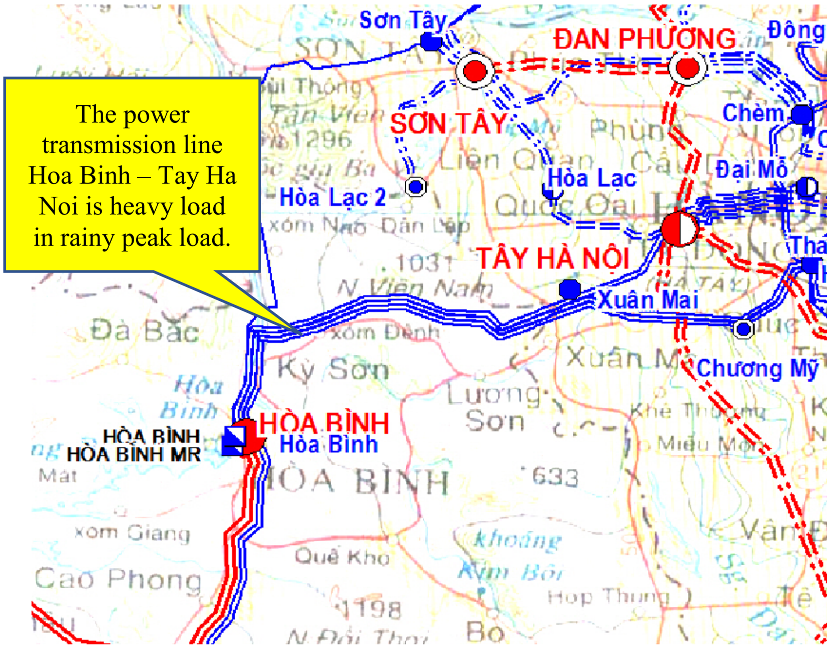


Figure 6: Power transmission system at the area of Hoa Binh – Tay Ha Noi

- Second, the power release circuits from Phu My thermal power plant include Phu My - Nam Hiep Phuoc, Phu My - Ba Ria and Phu My - My Xuan, these are important circuits supplying power to Ho Chi Minh City and the industrial area Phu My - Tan Thanh of Ba Ria Vung Tau (BRVT). These circuits have been operating synchronously with Phu My thermal power plant since the early 2000s with small cross-sections and are now fully loaded. It is recommended to increase the load capacity of these circuits to ensure safe and reliable operation.

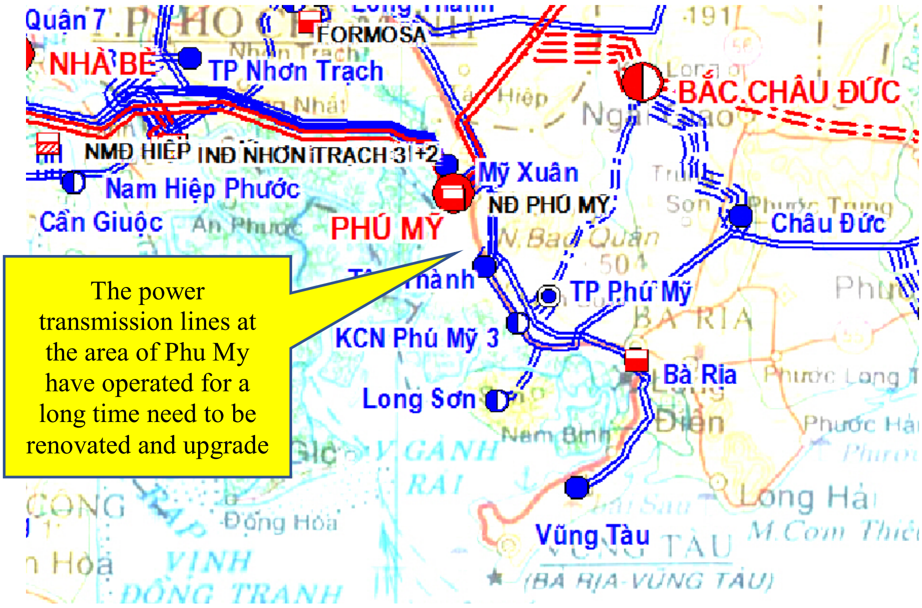


Figure 7: Power transmission system at the area of Phu My – BRVT province

The electricity grid in the South-Central region, where development of wind and solar has been rapid in recent years, has been upgraded and supplemented in a timely manner and no longer occurs with overload or heavy load with important lines coming into operation such as Thuan Nam 500 kV substation, Ninh Son 220 kV substation, Ninh Phuoc - Thuan Nam 220 kV TL, circuit 3,4 of Ninh Phuoc - Ninh Son 220 kV TL, and Thuan Nam - Chon Thanh 500kV TL. Therefore, it is necessary to take measures to ensure that these lines can be put into operation on schedule in the period up to 2025, especially with long transmission lines like Thuan Nam - Chon Thanh.

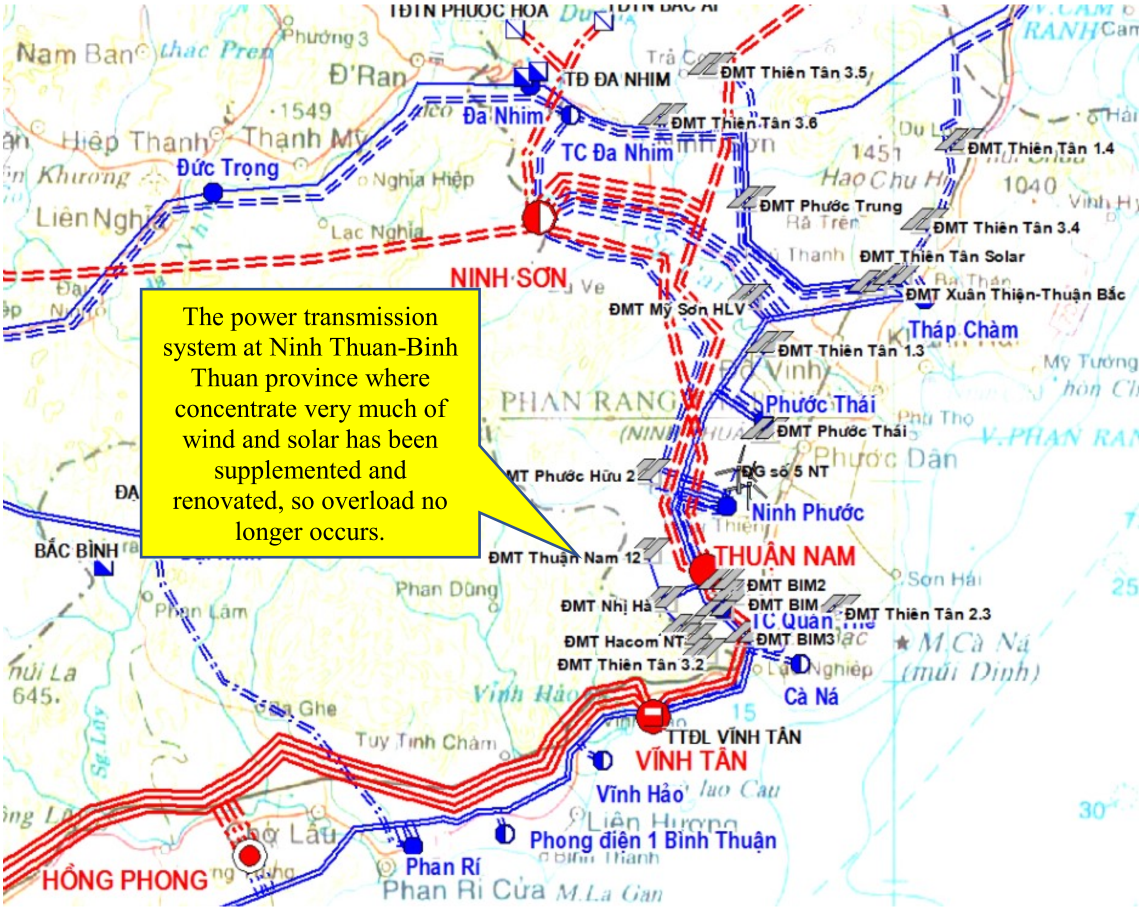


Figure 8: The power transmission system at South Central region

Regarding voltage issues, in normal operation condition in all of 7 regimes, there is no low or high voltage that exceeds the allowable range according to Grid code (0.95 pu – 1.05 pu).

In the N-1 contingency cases (N-1):

When one element in the transmission grid has contingency, other elements could operate under higher loading or overload in some cases. When N-1 contingency cases make other elements overload, the N-1 criteria are not satisfied. The effect of

contingency for all 650 grid elements of the Vietnamese power transmission system (500 kV and 220 kV) in 2025 modelled was tested one by one.
The amount of N-1 contingency cases which result in other elements overloading are summarized for the 7 Balmorel snapshot as follows:

- HG: 41/650 cases (6.3%)
- LG: 2/650 cases (0.3%)
- HRD: 8/650 cases (1.2%)
- LRD: 2/650 cases (0.3%)
- HF: 5/650 cases (0.77%)
- LF: 2/650 cases (0.3%)
- HC: 2/650 cases (0.3%)

The results show that HG is the snapshot with the highest number of N-1 criteria not met (highest violation rate) with 41 violations (6.3%). The second is HRD with 8 violations, accounting for 1.2%. In the other snapshots, the N-1 criteria violations is smaller than 1%.

The transmission system can be divided into 3 parts: the grid of power source releasing, the inter-regional grid, and the demand supply grid. The results show that N-1 criteria violation happen mostly in the grid for demand supply. There are only a few violations in grid for power source releasing and ***no violation in inter-region transmission system in 2025***.

The CCGT Nhon Trach – Nha Be 220 kV transmission line is the most frequent violation, it happens in all of 7 calculation regimes. When there is a fault in a circuit of CCGT Nhon Trach – Nha Be, the remaining circuit will be overload nearly 30%. The existing CCGT Nhon Trach with capacity of 750 MW is connect at 220 kV voltage and supply directly to Ho Chi Minh city demand. There are 6 circuits releasing power of CCGT Nhon Trach including Nhon Trach – Nha Be, Nhon Trach – Cat Lai, Nhon Trach – TP Nhon Trach but are separating busbar to reduce the short circuit current causing overload in N-1. Therefore, this study proposes to separate busbar more suitably to avoid this happen.

HG snapshot:

The HG snapshot has peak load of 51.2 GW, is the highest among 7 calculation regimes, so the demand supply grid is under heavy load. The grid simulation result show that there are 41 violation cases of N-1 criteria in which three fourths (more than 30 cases) relate to CCGT Phu My – My Xuan 220 kV transmission line so this is the most critical element of Southern power grid. The busbar of CCGT Phu My is also separated to reduce the short circuit current the same as CCGT Nhon Trach. Although this transmission line uses a thermal resistant conductor with a capacity limit increase to nearly 800 MVA/circuit, the load distribution between the two circuits is uneven because of an overload in the N-1 fault regime. So it is necessary to separate busbar more suitably to avoid N-1 overload.

The 220 kV transmission line Nam Hiep Phuoc – CCGT Hiep Phuoc, Nam Hiep Phuoc – Phu My which carry heavy load in normal operation condition will be overload up to 20% in N-1 fault regime.

In the Highland region, the 220 kV transmission line from 220 kV busbar of Krong Buk 500 kV substation to Krong Buk 220 kV substation is also overloaded quite heavily of 15% when fault occur in 1 circuit.

Northern transmission system is quite good and there is no overload in N-1 fault condition. The 220 kV transmission line Hoa Binh – Tay Ha Noi is under quite heavy load in normal operational condition, but it has a strong connection with 5 circuit so other circuits could bear the load without being overloaded when fault occur at a circuit.

HRD regime

In HRD snapshot, in addition to Southern elements violate N-1 criteria (Nha Be – Nhon Trach 220 kV TL, Nam Hiep Phuoc – Phu My 220 kV TL, Phu My – My Xuan 220 kV TL), there is also violations in North Central (Vung Ang TPP – Vung Ang TL overload 7% when there is fault in one circuit) and in North (Thai Binh TPP – Thai Thuy 220 kV TL overload 10% in N-1 fault regime).

HF regime

This is the highest load on inter-regional transmission system, but the simulation shows that the overload does not occur in N-1 fault regime on inter-regional power grid. In the internal there are three critical elements that will be overloaded in N-1 fault regimes. They include Nha Be – Nhon Trach 220 kV TL in Southeast, WPP Phu My – Phu My 220 kV TL in South Central, Bac Lieu – Soc Trang 220 kV TL in Southwest

4 remaining snapshots: LG, LRD, LF, HC

These are 4 quite light load regimes in normal operational condition. In N-1 fault regimes the only critical element is Nhon Trach – Nha Be 220 kV TL in the Southeast.

The voltage issues:

In recent years, the most voltage issue of the Vietnamese power system is high voltage in light load regimes such as Pmin. The simulation result shows that in 2025, the power system can maintain voltage quite good in allowance range, even in some very light load such as LG, LRD or HC, except for only Takeo busbar in inter-connection with Cambodia where a high voltage of more than 1.1 pu still occurs. Thus, this study proposes to install compensation resistance/FACTS devices at this node to keep voltage within the allowance range.

Conclusion in 2025:

The grid simulation shows that the inter-regional transmission system corresponding to the output of Balmorel in 2025 met N-1 criteria, there is no overload or high/low voltage occurrences in 7 simulation regimes. This means that the transmission capacity in Balmorel model in 2025 is suitable.

The simulation result shows that in 2025 the power system can maintain voltage quite well within the allowance range, even in some very light load such as LG, LRD or HC.

However, the internal transmission regimes in general are not met the N-1 criteria, especially in the demand supply grid. Some critical elements are as follow:

- North: Thai Binh TPP – Thai Thuy 220 kV TL
- North Central: Vung Ang TPP – Vung Ang 220 kV TL
- Highland: Krong Buk 500 kV substation to Krong Buk 220 kV
- South Central: WPP Phu My – Phu My 220 kV TL
- Southeast: Nhon Trach – Nha Be, Nam Hiep Phuoc – CCGT Hiep Phuoc, Nam Hiep Phuoc – Phu My, Phu My – My Xuan 220 kV TL
- Southwest: Bac Lieu – Soc Trang 220 kV TL

This is consistent with the result of the Investment plan of power transmission system in 2021 with a vision to 2025 of National Power Transmission Corporation (NPT) prepared by Institute of Energy. In general, the Vietnamese power transmission system does not completely meet N-1 criteria due to the difficulties in mobilizing investment capital.

Since the simulation shows that there is no overload in the highest curtailment snapshot – the HC snapshot, the reason for curtailing renewable energy in this regime is system-wide excess power. This regime is during the Tet holiday in Vietnam when the peak load reduce substantially to only 16 GW and account for 30% of Pmax year, so the model chooses to curtail renewable energy such as wind, solar and hydro to balance the power demand and source.

5.2. Results of the grid simulation in 2035

The Pmax in 2035 is more than 100 GW, nearly double compared to 2025, so the power transmission system is strongly developed from 650 elements in 2025 to 921 elements (at 500 kV and 220 kV). The output from Balmorel shows that the model chooses only to strengthen the interface from North – North Central and North Central to Mid-Central. The PSS/E grid modelling will check whether such an inter-regional transmission system can operate safely and reliably through simulating 7 critical operation conditions. In addition, this study will check the internal transmission grid from draft PDP VIII to show which element need to be renovated to meet operation requirement of power development program in the EOR 2021.

5.2.1. The inter-regional transmission system in 2035

The transmission flow on the inter-regional grid in each regime is consistent with Balmorel output. The simulation result show that in 2035, the inter-regional transmission system operates safely and reliably, there is no overloading, and the voltage is maintained in allowed range in both normal operation and in N-1 fault regimes. The following analysis will dive deeply into the highest transmission flow snapshot HF:

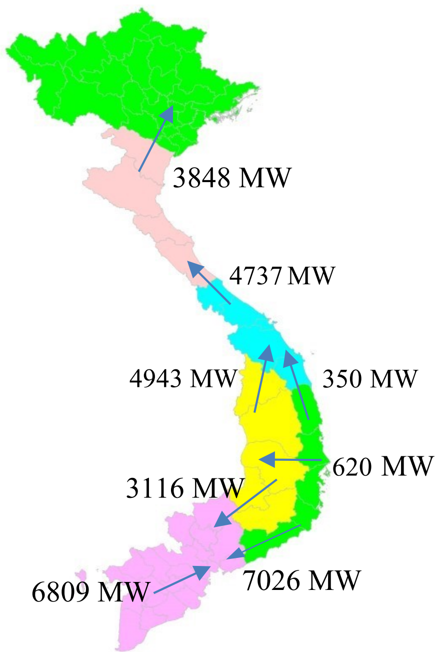
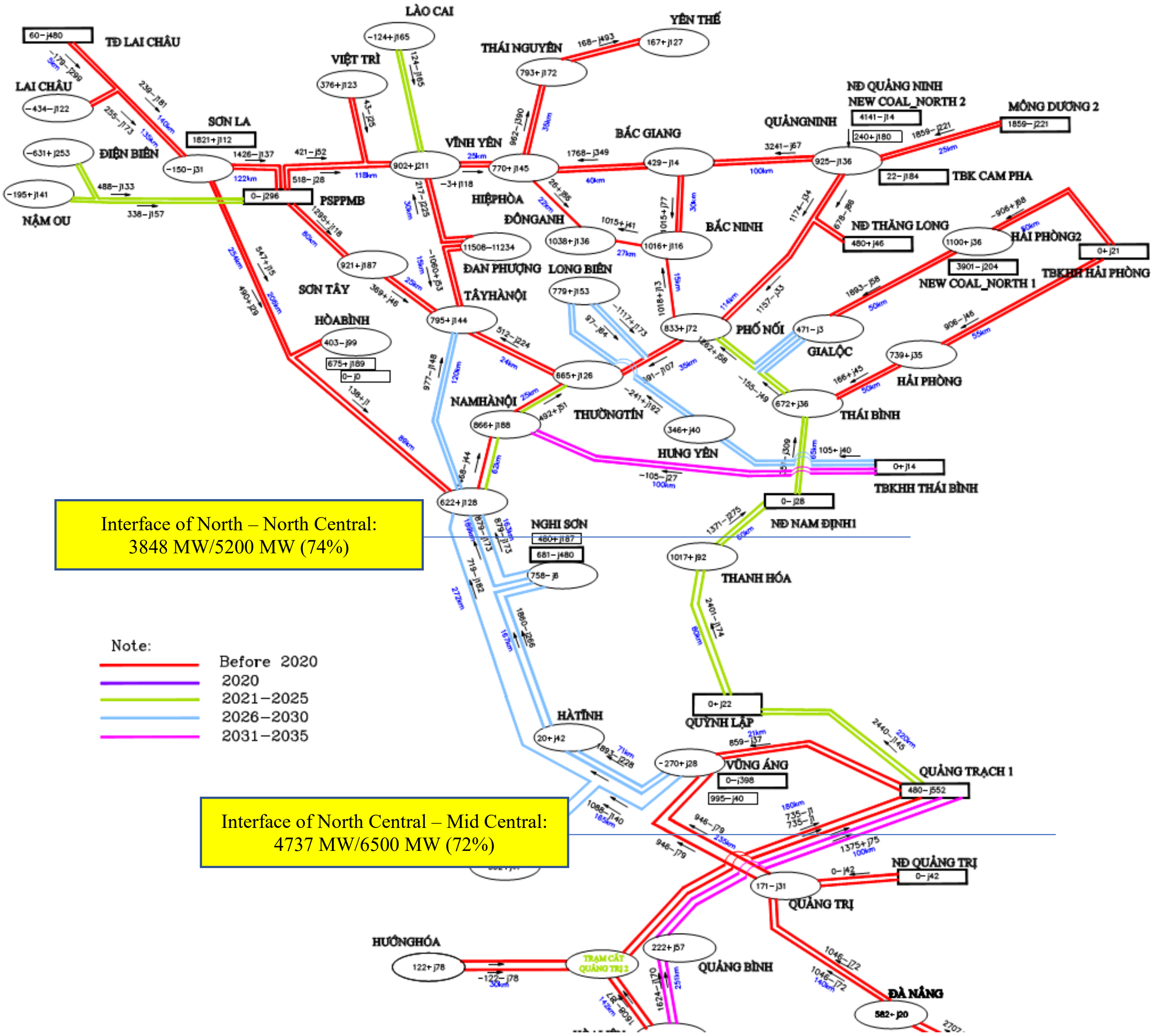


Figure 9: Transmission flow on the inter-regional grid in 2035 in HF snapshot

The load flow diagram in the HF snapshot in 2035 is shown below:


LÀO CAI
YÊN THẾ
TĐ LAI CHÂU
VIỆT TRÌ
THÁI NGUYÊN
LAI CHÂU
SƠN LA
VĨNH YÊN
BẮC GIANG
QUẢNGNINH
NĐ QUẢNG NINH
NEW COAL_NORTH 2
MÔNG DƯƠNG 2
ĐIỆN BIÊN
TBK CAM PHA
NẬM OU
PSPPMB
HIỆPHÒA
ĐÔNGANH
BẮC NINH
NĐ THĂNG LONG
HẢI PHÒNG2
SƠN TÂY
ĐAN PHƯỢNG
LONG BIÊN
NEW COAL_NORTH 1
TBKHH HẢI PHÒNG
TÂYHÀNỘI
HÒABÌNH
PHỐ NỐI
GIALỘC
HẢI PHÒNG
NAMHÀNỘI
THƯỜNGTÍN
THÁI BÌNH
HƯNG YÊN
TBKHH THÁI BÌNH
Interface of North – North Central:
3848 MW/5200 MW (74%)
NGHI SƠN
NĐ NAM ĐỊNH1
THANH HÓA
Note:
Before 2020
2020
2021–2025
2026–2030
2031–2035
HÀTĨNH
QUỲNH LẬP
VŨNG ÁNG
QUẢNG TRẠCH 1
Interface of North Central – Mid Central:
4737 MW/6500 MW (72%)
NĐ QUẢNG TRỊ
QUẢNG TRỊ
HƯỚNGHÓA
QUẢNG BÌNH
ĐÀ NẴNG

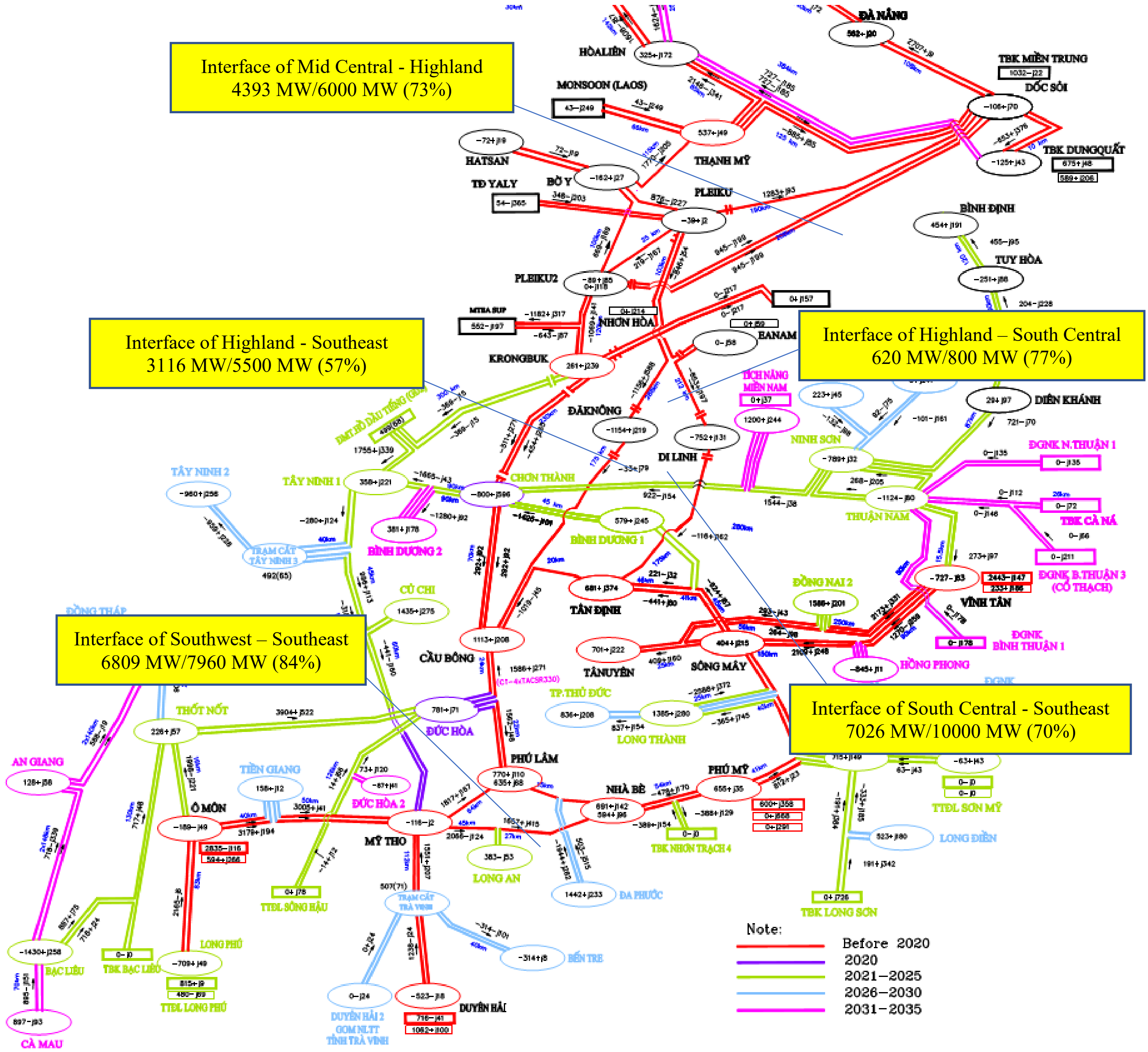


Figure 10: Load flow diagram in the HF snapshot in 2035

In the highest transmission flow regime, the interfaces carry quite a high load: 60 – 80%. The interface with the highest inter-regional flow is South Central – Southeast with more than 7000 MW (loading 70%). The most critical element of this interface in the N-1 fault regime is Vinh Tan – Dong Nai 2 500kV TL and Hong Phong - Song May 500 kV TL with highest loading of 80%.

The interface of Southwest to Southeast has the highest loading with 84%, mostly transmit capacity of the O Mon gas power complex and the Long Phu coal thermal power complex. Like the interface of South Central – Southeast, this interface has strong connection with 8 circuits of 500 kV TL, so the effect of N-1 fault is reduced with the most critical elements in My Tho – Phu Lam and Long An – Nha Be with highest loading of nearly 90% in the fault of each circuit.

Other interfaces have smaller loading in normal operation condition and there is no overload in N-1 fault regimes. The node that has the lowest voltage of inter-regional transmission systems is the Quang Trach and Vung Ang of interface Mid-Central – North Central with 497 kV (0.994 pu). This interface has the highest transmission distance of more than 300 km, so the voltage loss is also the highest. However, at the end point of Quang Trach and Vung Ang, there is Quang Trang TPP and Vung Ang TPP, which can supply reactive power to maintain voltage in the allowed range.

5.2.2. Internal transmission system in 2035

Under normal operation conditions (N-0):

The internal transmission system in 2035 is analysed according to draft PDP VIII since Balmorel model does not consider this. The difference in power source development program between the EOR 21 and PDP VIII (draft) can cause some elements to overload or low/high voltage in the internal transmission system.

The capacity of wind and solar power from Balmorel model is shown below:

Table 1: Solar and wind capacity in simulation snapshot in 2035 from Balmorel

Regions/Regimes	HG	LG	HF	LF	HRD	LRD	HC
Hours	S32-T086	S05-T002	S09-T083	S04-T064	S32-T069	S04-T084	S04-T132
Total wind	**6268**	**13296**	**11941**	**9599**	**512**	**1192**	**6268**
Wind N	467.7	28.7	259.2	398.7	172.3	201.4	0
Wind NC	11.0	303.3	2.0	363.5	0.8	372.9	315.3
Wind CC	364.0	118.0	105.0	24.0	10.0	537.2	245.8
Wind HL	128.1	4309.5	59.2	4309.5	17.7	0.0	0.0
Wind SC	4376.6	1229.1	3670.2	1726.0	78.0	27.5	22.8
Wind SE	19.1	7.2	35.7	9.1	2.8	0.0	0.0
Wind SW	901.2	7299.9	7810.1	2768.5	230.1	53.4	69.8
Total solar	**26730.8**	**0.0**	**31426.4**	**14097.6**	**3.9**	**31581.3**	**26730.8**
Solar N	7859.6	0.0	4114.0	2669.3	0.0	4241.6	282.4
Solar NC	184.7	0.0	152.0	65.9	0.0	133.2	46.6
Solar CC	169.5	0.0	286.1	68.7	0.0	211.1	148.9
Solar HL	2486.2	0.0	2799.4	1376.8	3.6	3067.7	2938.4
Solar SC	3169.1	0.0	4836.0	1742.6	0.2	4873.8	3507.3
Solar SE	11649.4	0.0	17422.5	7403.1	0.1	17384.0	15048.6
Solar SW	1212.3	0.0	1816.4	771.1	0.0	1669.9	1049.5

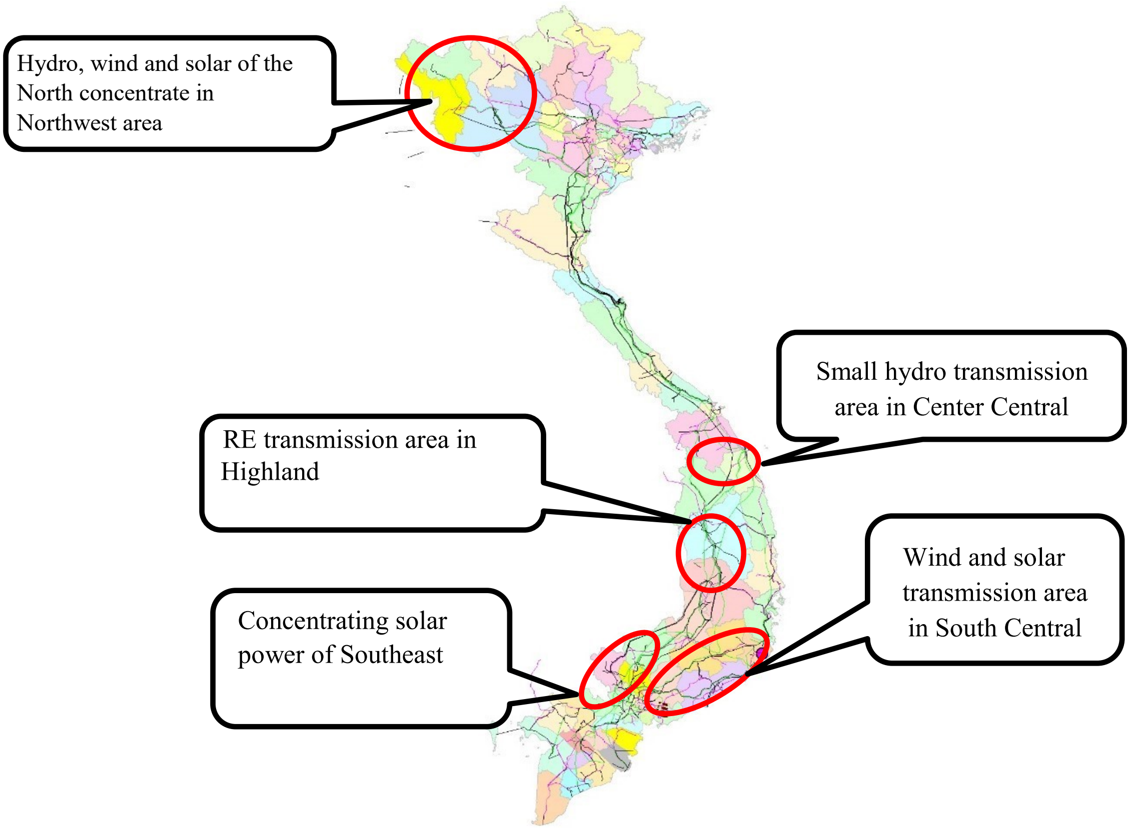


Figure 13. Some congestion areas in internal transmission grid.

Southeast region: Since there is up to 17 GW of solar power generation in the Southeast region in 2035 (17 GW in HF, LRD, 15 GW in HC and 11 GW in HG), it is one and a half-time higher than draft PDP VIII. The solar power is concentrated in the west part of Southeast (Tay Ninh and Binh Phuoc province) causes overload in some elements of the Southeast transmission system even in normal operation conditions such as Binh Long – Hon Quan – Chon Thanh 220 kV transmission line (this is the backbone of power transmit from Binh Phuoc to Ho Chi Minh city). The 220 kV transmission line Luyen Nhom – Phuoc Long – Binh Long and Tay Ninh – Tay Ninh 2 is under heavy load more than 90%. So, this study proposes:

+ Build new Binh Long 500 kV substation (3x900 MVA) and 500 kV TL Binh Long – Chon Thanh to collect and transmit to load central solar and wind capacity of Binh Phuoc and Dak Nong provinces.
+ Renovate the 220 kV backbone TL Luyen Nhom – Phuoc Long – Binh Long Tay Ninh – Tay Ninh 2 up to 3-circuit transmission line to ensure transmitting renewable power at 220 kV.

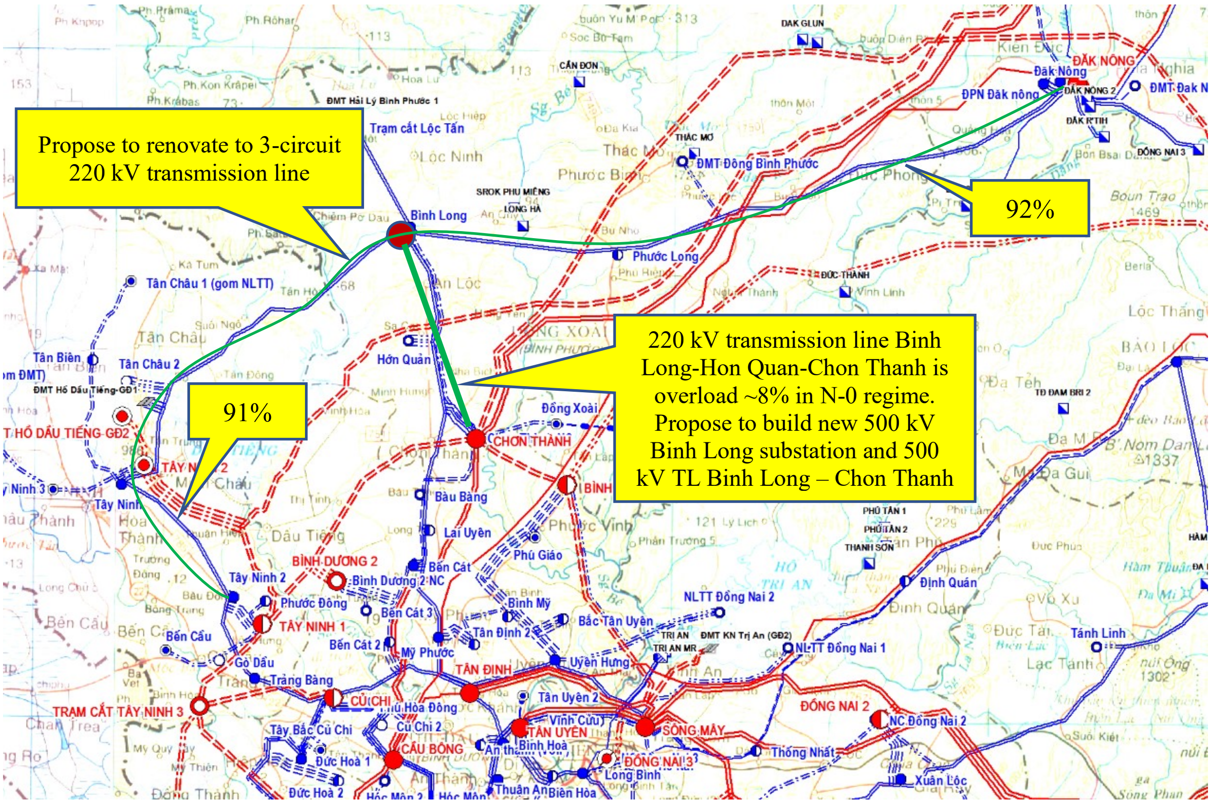


Figure 11: Power transmission system in region of Tay Ninh – Binh Phuoc province in 2035

In the Highland region, wind power capacity in HG reach 4400 MW while draft PDP VIII considers only 3000 MW (80% install capacity). This caused heavy load of more than 90% for some 220-transmission line include Krong Buk 500 kV – Krong Buk, Bo Y – Kon Tum – Pleiku. This study proposes:

+ Renovate to cross section of 3xACSR400 (rated capacity of about 800 MVA/circuit) for 220 kV backbone Bo Y – Kon Tum – Pleiku
+ Renovate the Krong Buk 500 kV – Krong Buk to 4-circuit 220 kV transmission line.

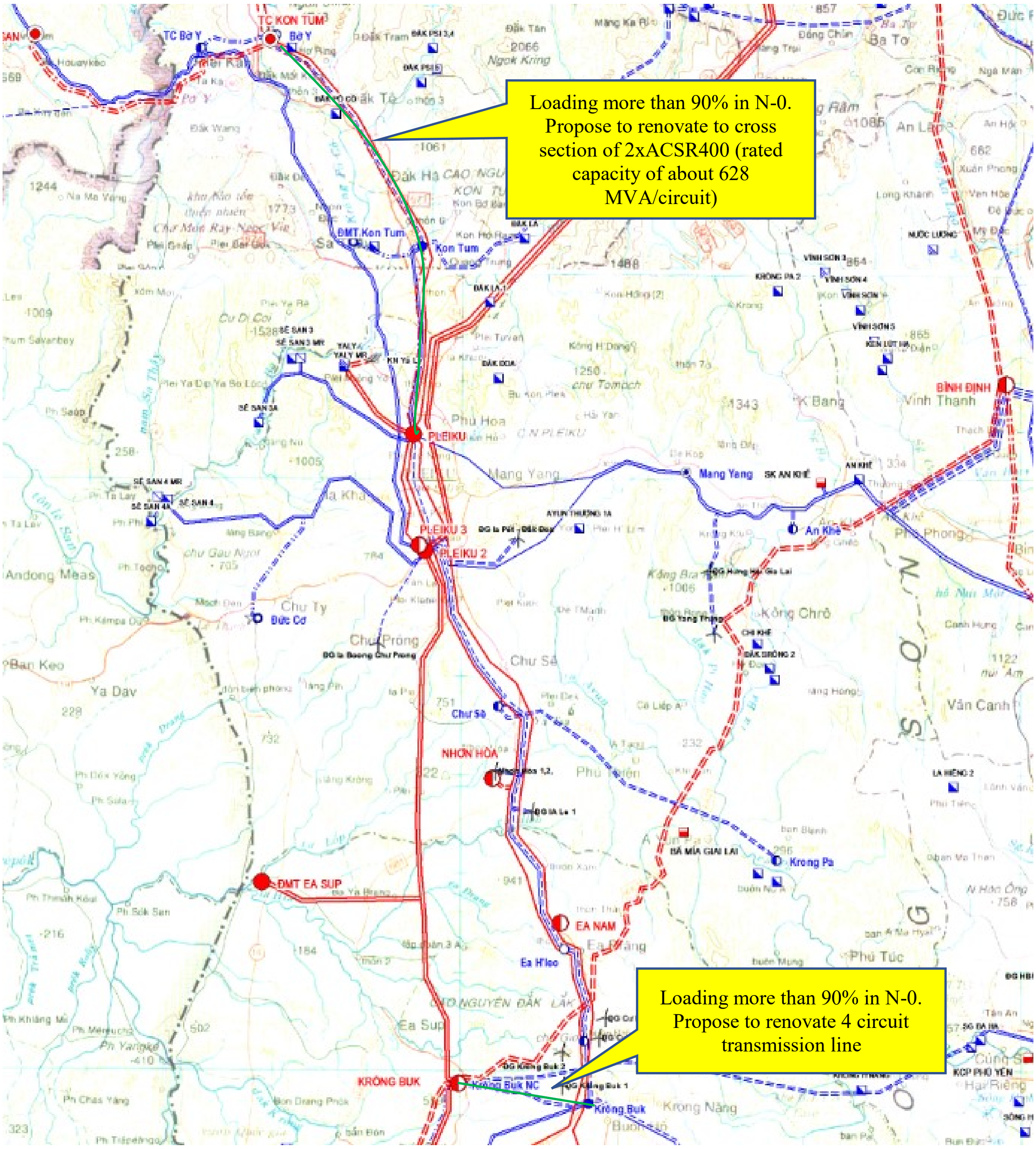


Figure 12: Power transmission system in region of Highland region in 2035

In the North, solar capacity will reach 8000 MW in 2035 in the HG snapshot, this number is 4 times higher than draft PDP VIII (2100 MW up to 2035). This solar capacity is concentrated in the Northwest (Son La, Dien Bien, Lai Chau, Lao Cai) where there is also a large capacity of hydro with a sparse power grid with very long transmission distance. In normal operational condition, the 220 kV backbone Lao Cai – Than Uyen – Son La – Muong La – Phu Tho carry a high load of nearly 90%. This 220 kV backbone is very long with a total distance of more than 300 km. Therefore, this study does not propose to renovate this backbone, but build new a

Son La 2 500 kV substation and Son La 2 – Viet Tri 500 kV TL to collect the capacity of renewable energy and reduce the load for the 220 kV transmission system.

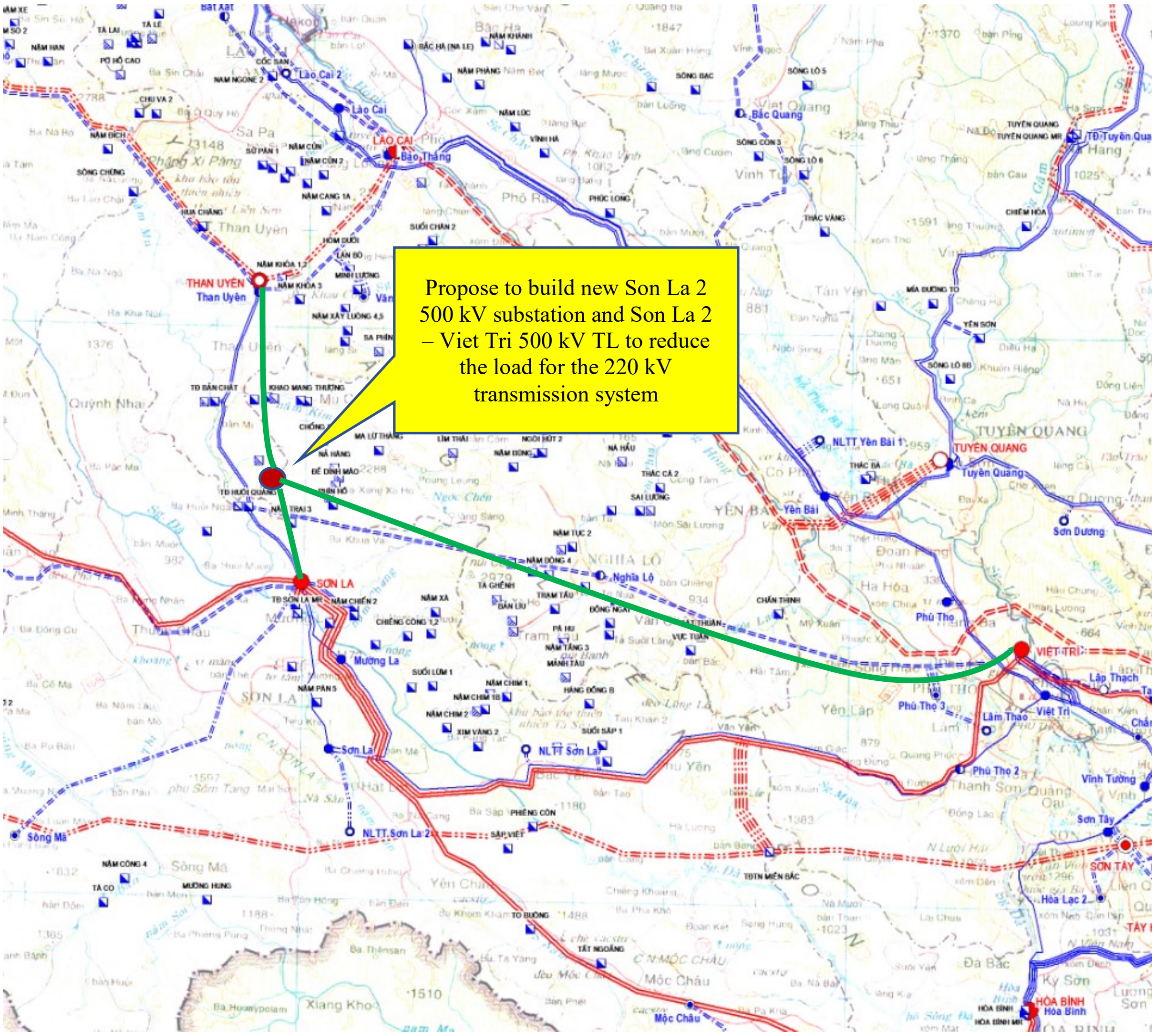


Figure 13: Power transmission system in region of Northwest region in 2035

Some other elements that carry high load more than 70% in the N-0 regime is as follow:

+ In the North: Nho Quan – Ninh Binh, Nho Quan – Yen Thuy, Son Dong – TPP Son Dong, Hoanh Bo – Trang Bach, Hoa Binh - Tay Ha Noi,
+ In the Mid-Central: Quang Ngai – Quang Ngai 2
+ In the Highland: Krong Buk – Krong Ana, Dak Nong – Luyen Nhom
+ In the South Central: Thap Cham – Thuan Bac, Ham Thuan – Phan Thiet
+ In the Southeast: Cu Chi 500 kV substation, CCGT Hiep Phuoc – Can Giuoc, Dau Tieng – Tay Ninh
+ In the Southwest: My Tho – Long An 500 kV TL, Bac Lieu 500 kV substation

Regarding voltage issues, in some high load regimes such as HG, HRD, HF some nodes are low voltage, especially at Southeast load central:

+ North: Phu Tho 2
+ Southeast: Dong Xoai, My Phuoc, Tan Dinh 2, Lai Uyen, Chon Thanh, Hon Quan, Ben Cat, Binh My, Binh Duong, Bau Bang.

In the N-1 contingency cases (2035):

When one element in the transmission grid has contingency, other elements could operate under higher loading, or overload in some cases. When N-1 contingency cases make other elements overload, the N-1 criteria are not satisfied. The effect of contingency for all 921 grid elements of the Vietnamese power transmission system (500 kV and 220 kV) in 2035 modelled was tested one by one.

The amount of N-1 contingency cases which result in other elements overloading are summarized for the 7 Balmorel snapshot as follows:

- HG: 43/921 cases (4.7%)
- LG: 7/921 cases (0.8%)
- HRD: 11/921 cases (1.2%)
- LRD: 29/921 cases (3.1%)
- HF: 36/921 cases (3.9%)
- LF: 9/921 cases (1%)
- HC: 22/921 cases (2.4%)

The results show that in 2035 HG is still the snapshot with the highest violation rate with 43 violations (4.7%). The second is HF with 36 violated cases and LRD with 29 cases, accounting for 3.9% and 3.1% respectively. In other snapshots, the N-1 criteria violations is 1-2%.

HG snapshot:

Some branches or transformers of the transmission system which are overloaded in N-1 fault regimes:

- North: Thai Thuy – TPP Thai Binh 220 kV TL, Nho Quan – Yen Thuy 220 kV TL, Lao Cai – Than Uyen 220 kV TL, Hai Phong – Nam Hoa 220 kV TL, Nho Quan – Ninh Binh 220 kV TL, Bac Me – Ha Giang 220 kV TL.
- Highland: KNSrepok3 – KNSrepok 220 kV TL, Krong Buk – Eakar 220 kV TL, Krong Buk 500 kV substation.
- Southeast: Cu Chi 500 kV substation, WPP Loc Ninh – Binh Long 220 kV TL, Tan Uyen – WPP 220 kV TL, Dong Nai - Song May 220 kV TL.

The result of branch and voltage checking in HG snapshot in N-1 fault is as follow:

BRANCH CHECKING

Event 1	N-1 contingency TL NINHBINH 220 ==> NHOQUAN 220 circuit 1 :
	- TL NHOQUAN 220--> NINHBINH 220 circuit 2 : 687+j(-29); overload: 9.6 %
Event 2	N-1 contingency TL HAGIANG 220 ==> HAGIANG-BUS2 220 circuit 1 :
	- TL BACME 220--> THAINGUYEN 220 circuit 1 : 563+j(188); overload: 12.8%
	- TL HAGIANG 220--> BACME 220 circuit 1 : 584+j(250); overload: 20.7%
Event 3	N-1 contingency TL LAOCAI 220 ==> VANBAN 220 circuit 1 :
	- TL THANUYEN 220--> LAOCAI 220 circuit 1 : 667+j(-3); overload: 6.1 %
	- TL THANUYEN 220--> LAOCAI 220 circuit 2 : 667+j(-3); overload: 6.1 %
Event 4	N-1 contingency TL LAOCAI 220 ==> THANUYEN 220 circuit 1 :
	- TL THANUYEN 220--> LAOCAI 220 circuit 2 : 776+j(3); overload: 23.4%
Event 5	N-1 contingency TL LAOCAI 220 ==> THANUYEN 220 circuit 2 :
	- TL THANUYEN 220--> LAOCAI 220 circuit 1 : 776+j(3); overload: 23.4%
Event 6	N-1 contingency TL VANBAN 220 ==> THANUYEN 220 circuit 1 :
	- TL THANUYEN 220--> LAOCAI 220 circuit 1 : 667+j(-11); overload: 6.1 %
	- TL THANUYEN 220--> LAOCAI 220 circuit 2 : 667+j(-11); overload: 6.1 %
Event 7	N-1 contingency TL TUYENQUANG 220 ==> YENBAI-BUS2 220 circuit 1 :
	- TL YENBAI-BUS2 220--> TUYENQUANG 220 circuit 2 : 710+j(22); overload: 16.1%
Event 8	N-1 contingency TL TUYENQUANG 220 ==> YENBAI-BUS2 220 circuit 2 :
	- TL YENBAI-BUS2 220--> TUYENQUANG 220 circuit 1 : 710+j(22); overload: 16.1%
Event 9	N-1 contingency TL DMTYENBAI 220 ==> YENBAI-BUS2 220 circuit 1 :
	- TL DMTYENBAI 220--> YENBAI-BUS2 220 circuit 2 : 784+j(-7); overload: 28.0%
Event 10	N-1 contingency TL DMTYENBAI 220 ==> YENBAI-BUS2 220 circuit 2 :
	- TL DMTYENBAI 220--> YENBAI-BUS2 220 circuit 1 : 784+j(-7); overload: 28.0%
Event 11	N-1 contingency TL VIETTRI 220 ==> VIETTRI-BUS2 220 circuit 1 :
	- TL VIETTRI-BUS2 220--> VIETTRI 220 circuit 1 : 697+j(-139); overload: 16.1%
Event 12	N-1 contingency TL PHUTHO2 220 ==> VIETTRI-BUS2 220 circuit 1 :
	- TL TX.SONLA 220--> TD.SONLA 220 circuit 1 : 358+j(-73); overload: 16.4%
Event 13	N-1 contingency TL PHUTHO2 220 ==> TX.SONLA 220 circuit 1 :
	- TL TX.SONLA 220--> TD.SONLA 220 circuit 1 : 322+j(-71); overload: 4.8 %
Event 14	N-1 contingency TL PHUTHO2 220 ==> DGSONLA 220 circuit 1 :
	- TL TX.SONLA 220--> PHUTHO2 220 circuit 1 : 327+j(63); overload: 5.9 %
	- TL TX.SONLA 220--> TD.SONLA 220 circuit 1 : 351+j(-73); overload: 14.0%
Event 15	N-1 contingency TL VIETTRI 220 ==> VIETTRI-BUS2 220 circuit 1 :
	- TL VIETTRI 220--> VIETTRI 220 circuit 1 : 603+j(-216); overload: 4.6 %
Event 16	N-1 contingency TL NDSONDONG 220 ==> SONDONG 220 circuit 1 :
	- TL HOANHBO 220--> TRANGBACH 220 circuit 1 : 574+j(-81); overload: 10.3%
Event 17	N-1 contingency TL NDSONDONG 220 ==> HOANHBO 220 circuit 1 :
	- TL HOANHBO 220--> TRANGBACH 220 circuit 1 : 568+j(-93); overload: 9.5 %
Event 18	N-1 contingency TL TRANGBACH 220 ==> HOANHBO 220 circuit 1 :
	- TL NDSONDONG 220--> SONDONG 220 circuit 1 : 546+j(-45); overload: 4.1 %
	- TL HOANHBO 220--> NDSONDONG 220 circuit 1 : 543+j(-82); overload: 4.4 %
Event 19	N-1 contingency TL DMTLAICHAU 220 ==> THANUYEN 220 circuit 1 :
	- TL DMTLAICHAU 220--> THANUYEN 220 circuit 2 : 1018+j(38); overload: 13.2%
Event 20	N-1 contingency TL DMTLAICHAU 220 ==> THANUYEN 220 circuit 2 :
	- TL DMTLAICHAU 220--> THANUYEN 220 circuit 1 : 1018+j(38); overload: 13.2%
Event 21	N-1 contingency TL TX.SONLA 220 ==> DGSONLA 220 circuit 1 :
	- TL TX.SONLA 220--> PHUTHO2 220 circuit 1 : 322+j(54); overload: 3.8 %
	- TL TX.SONLA 220--> TD.SONLA 220 circuit 1 : 339+j(-72); overload: 10.4%
Event 22	N-1 contingency TL TX.SONLA 220 ==> DMTSONLA 220 circuit 2 :
	- TL DMTSONLA 220--> MUONGLATC 220 circuit 1 : 803+j(31); overload: 27.8%
Event 23	N-1 contingency TL TCDAKOOC 220 ==> XEKAMAN3 220 circuit 1 :
	- TL XEKAMAN3 220--> TCDAKOOC 220 circuit 2 : 410+j(-51); overload: 31.5%
Event 24	N-1 contingency TL TCDAKOOC 220 ==> XEKAMAN3 220 circuit 2 :
	- TL XEKAMAN3 220--> TCDAKOOC 220 circuit 1 : 410+j(-51); overload: 31.5%
Event 25	N-1 contingency TL KRONGBUK 220 ==> KRBUK220 220 circuit 1 :
	- TL KRONGBUK 220--> KRBUK220 220 circuit 2 : 1234+j(-60); overload: 37.3%
Event 26	N-1 contingency TL KRONGBUK 220 ==> KRBUK220 220 circuit 2 :
	- TL KRONGBUK 220--> KRBUK220 220 circuit 1 : 1234+j(-60); overload: 37.3%
Event 27	N-1 contingency Transformer KRBUK220 220 ==> KRBUK500 500 transformer 1 :
	- Transformer KRBUK220 220--> KRBUK500 500 transformer 2 : 944+j(-240); overload: 8.2 %
Event 28	N-1 contingency Transformer KRBUK220 220 ==> KRBUK500 500 transformer 2 :

	- Transformer KRBUK220 220--> KRBUK500 500 transformer 1 : 944+j(-240); overload: 8.2 %
Event 29	N-1 contingency SC KRBUK500 500 ==> TUKR-TN1 500 circuit 1 :
	- TL KNSREPOK3_2 220--> KNSREPOK 220 circuit 1 : 0+j(11); overload: 6.4 %
Event 30	N-1 contingency SC KRBUK500 500 ==> TUKR-TN2 500 circuit 1 :
	- TL KNSREPOK3_2 220--> KNSREPOK 220 circuit 1 : 0+j(11); overload: 6.4 %
Event 31	N-1 contingency TL TUKR-TN1 500 ==> TUTN-KR1 500 circuit 1 :
	- TL KNSREPOK 220--> KNSREPOK3_2 220 circuit 1 : 0+j(-12); overload: 23.1%
Event 32	N-1 contingency TL TUKR-TN2 500 ==> TUTN-KR2 500 circuit 1 :
	- TL KNSREPOK3_2 220--> KNSREPOK 220 circuit 1 : 0+j(12); overload: 23.1%
Event 33	N-1 contingency TL TUKR-CT2 500 ==> KNSREPOK 500 circuit 1 :
	- TL KNSREPOK3_2 220--> KNSREPOK 220 circuit 1 : 0+j(-13); overload: 30.3%
Event 34	N-1 contingency TL TUKR-CT2 500 ==> TUCT-KR2 500 circuit 1 :
	- TL KNSREPOK3_2 220--> KNSREPOK 220 circuit 1 : 0+j(-13); overload: 28.2%
Event 35	N-1 contingency TL NHPHUOC 220 ==> TBKHPHUOC1.2 220 circuit 1 :
	- TL TBKHPHUOC1.2 220--> NHPHUOC 220 circuit 2 : 667+j(-3); overload: 6.1 %
Event 36	N-1 contingency TL NHPHUOC 220 ==> TBKHPHUOC1.2 220 circuit 2 :
	- TL TBKHPHUOC1.2 220--> NHPHUOC 220 circuit 1 : 667+j(-3); overload: 6.1 %
Event 37	N-1 contingency TL TBKHPHUOC1.2 220 ==> CANGIUOC 220 circuit 1 :
	- TL TBKHPHUOC1.2 220--> CANGIUOC 220 circuit 2 : 347+j(23); overload: 10.7%
Event 38	N-1 contingency TL TBKHPHUOC1.2 220 ==> CANGIUOC 220 circuit 2 :
	- TL TBKHPHUOC1.2 220--> CANGIUOC 220 circuit 1 : 347+j(23); overload: 10.7%
Event 39	N-1 contingency TL BINHLONG 220 ==> PH.LONG 220 circuit 1 :
	- TL BINHLONG 220--> HONQUAN 220 circuit 1 : 933+j(121); overload: 4.5 %
	- TL BINHLONG 220--> HONQUAN 220 circuit 2 : 933+j(121); overload: 4.5 %

VOLTAGE CHECKING

Event 1	N-1 contingency TL HAGIANG 220 ==> HAGIANG-BUS2 220 circuit 1
	- Bus BACME 220: 0.90 pu; 197.6 kV
Event 2	N-1 contingency TL YENBAI 220 ==> YENBAI-BUS2 220 circuit 1
	- Bus YENBAI 220: 0.88 pu; 194.7 kV
Event 3	N-1 contingency SC KRBUK500 500 ==> TUKR-TN1 500 circuit 1
	- Bus TUKR-TN1 500: 1.18 pu; 587.6 kV
	- Bus TUTN-KR1 500: 1.14 pu; 568.9 kV
Event 4	N-1 contingency SC KRBUK500 500 ==> TUKR-TN2 500 circuit 1
	- Bus TUKR-TN2 500: 1.18 pu; 587.6 kV
	- Bus TUTN-KR2 500: 1.14 pu; 568.9 kV

Other snapshots:

Some branches or transformers of the transmission system which are overloaded in N-1 fault regimes:

- North: Thai Binh TPP – Thai Thuy 220 kV TL, Cam Pha – Cong Hoa 220 kV TL,
- North Central: Do Luong – Khe Bo 220 kV TL, Ban Ve – Tuong Duong 220 kV TL,
- Mid Central: Thanh My – Dak Ooc 220 kV TL, Dak Ooc – Xekaman 3 220 kV TL, Quang Ngai 2 – Quang Ngai 220 kV TL,
- Highland: Pleiku – Sesan 3, Srepok 2 – Krong Ana 220 kV TL, Buon Kuop – Krong Ana
- Southeast: Sa Dec – O Mon 220 TL, CCGT Hiep Phuoc – Can Giuoc 220 kV TL, Luyen Nhom – Dak Nong, Thuan An – Tan Son Nhat, WPP Tri An – Uyen Hung

- Southwest: Bac Lieu 500 kV substation, O Mon – Tien Giang 500 kV TL.

Some nodes with high and low voltage:

High voltage: Phu Quoc 220 kV (SW), WPP Xuyen Ha 220 kV (HL), Phu Tho 2 220 kV (N), Tay Ninh 2 500 kV (SE),

Low voltage: Binh Long 220 kV, Phuoc Long 220 kV, Tay Ninh 220 kV, Tan Bien 220 kV, My Phuoc 220 kV, Ben Cat 220 kV, Lai Uyen 220 kV, Bau Bang 220 kV (all is in Southeast).

Based on calculation results of PSS/E of the element that is overloaded or experiencing voltage violation in normal operation and N-1 fault regimes, the study will propose the volume of transmission grid need to be built new/renovated to meet the operation requirement of the Grid code. Then we will estimate the volume and cost for the transmission system including internal grid for the baseline scenario in the years 2025, 2035.

5.3. Transmission loss

Transmission loss between regions is an input to the Balmorel model to clarify simulations of inter-region transmission in 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:

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

Since the result from the PSS/E model shows only power losses in the inter-regional transmission system, energy transmission loss in interface k in year i is calculated approximately by power loss in the Highest generation snapshot 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)2x8760)).

Based on the calculation years selected in the load flow calculation, the report will use simulated grid data in 2025 and 2035 to calculate the transmission loss by PSS/E software. The transmission loss is fed back into the Balmorel model in loop is taken as the average of the calculated transmission loss over the two years above.

On each interface, it is assumed that the number of line circuits and conductor size are identical with the 500 kV lines designed from the input of the resulting power source development. The transmission distance between the two regions is approximated by the typical distance from the center of the power source in one region to the center of the load in the other. 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.

A Summary of transmission distances and number of line circuits on interfaces in 2025 and 2035 can be found in the following table:

The results of the transmission loss are as follows:

Table 2: The results of the transmission loss in inter-regional grid

Interface		2025	2035	Average power loss (%) (1)	Current power loss in Balmorel (2)	Difference (1) - (2)
		Power loss (%)	Power loss (%)			
North	North Central	1.74%	1.81%	1.77%	3.2%	-1.43%
North Central	Center Central	2.67%	3.45%	3.06%	3.6%	-0.55%
Center Central	Highland	1.36%	1.36%	1.36%	2.5%	-1.13%
Center Central	South Central	2.47%	2.47%	2.47%	3.8%	-1.30%
Highland	Southeast	2.36%	2.36%	2.36%	3.5%	-1.14%
South Central	Southeast	2.35%	2.35%	2.35%	3.0%	-0.65%
Highland	South Central	1.05%	1.05%	1.05%	2.4%	-1.33%
Southeast	Southwest	2.06%	2.06%	2.06%	3.2%	-1.14%

Using the loop between the two models, Balmorel and PSS/E, to determine transmission loss will help 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 the PSS/E software differs from transmission loss value put into Balmorel model by about 0.6%-1.4% depending on the interface.

5.4. Estimated total volume and cost of power transmission system for the Baseline scenario in EOR2021

The estimated volume of additional substation and transmission line supplement to simulation grid in 2025 and 2035 to meet the requirement of Grid code (in both inter-regional and internal grid) is shown below:

Table 3: Estimated volume of additional substation and transmission line supplement to simulation grid in 2025 and 2035

Region	500kV transformer (MVA)	500kV line (km)	220kV transformer (MVA)	220kV line (km)
2025				
North	1800	120	750	110
North Central			500	105
Center Central			250	40
Highland			250	90
South Central			500	130
Southeast		50	750	150
Southwest			250	85
Total 2025	**1800**	**170**	**3250**	**710**
2035				
North	2700	240	1300	520
North Central			425	170
Center Central			525	210
Highland	1800	250	1050	420
South Central			725	290
Southeast	1800	90	1075	430
Southwest	1800	135	425	170
Total 2035	**8100**	**715**	**5525**	**2210**

The estimated total volume and cost of substation and transmission line of simulation transmission system (at 500 kV and 220 kV) for the Baseline scenario in EOR2021 in 2025 and 2035 is shown in Table 4 and Table 5. For estimating the investment cost, the unit price of lines and substations according to draft PDP VIII [1] are used. In particular:

+ Cost for 500 kV line amounts to 0.9 million USD/km with capacity of about 2000MW.
+ Cost for 220 kV line amounts to 0.3 million USD/km with capacity of about 600MW.
+ Cost for 500 kV and 220 kV substation amounts to about 0.03 million USD/MVA and 0.02 million USD/MVA respectively.

Table 4: Estimated total volume of substation and transmission line of simulation transmission system for the Baseline scenario in EOR2021 in 2025 and 2035

Region	500kV transformer (MVA)	500kV line (km)	220kV transformer (MVA)	220kV line (km)
2025				
North	25,900	3,477	42,971	9,723
North Central	12,950	1,739	20,441	4,882
Center Central	5,860	2,169	5,848	3,215
Highland	5,441	2,423	5,430	2,872
South Central	6,056	1,988	5,625	3,101
Southeast	26,800	3,047	40,470	8,378
Southwest	12,400	1,897	18,395	5,009
Total 2025	**95,406**	**16,740**	**139,180**	**37,180**
2035				
North	50,365	7,443	75,521	12,359
North Central	24,600	3,438	37,491	6,012
Center Central	16,443	2,708	11,473	3,805
Highland	14,100	3,039	10,352	3,388
South Central	16,082	2,563	11,056	3,651
Southeast	53,785	5,561	66,938	11,434
Southwest	25,250	3,573	29,739	6,755
Total 2035	**200,625**	**28,325**	**242,570**	**47,403**

Table 5: Estimated total cost of substation and transmission line of simulation transmission system for the Baseline scenario in EOR2021 in 2025 and 2035

Region	500kV transformer (mil. USD)	500kV line (mil. USD)	220kV transformer (mil. USD)	220kV line (mil. USD)
2025				
North	777	3,130	859	2,917
North Central	389	1,565	409	1,465
Center Central	176	1,952	117	965
Highland	163	2,181	109	862
South Central	182	1,789	113	930
Southeast	804	2,742	809	2,513
Southwest	372	1,707	368	1,503
Total	2,862	15,066	2,784	11,154
Total 2025 (mil. USD)	**31866**			
2035				
North	1,511	6,699	1,510	3,708
North Central	738	3,094	750	1,804
Center Central	493	2,438	229	1,141

Region	500kV transformer (mil. USD)	500kV line (mil. USD)	220kV transformer (mil. USD)	220kV line (mil. USD)
Highland	423	2,735	207	1,016
South Central	482	2,307	221	1,095
Southeast	1,614	5,005	1,339	3,430
Southwest	758	3,216	595	2,026
Total	6,019	25,493	4,851	14,221
Total 2035 (mil. USD)	**50,584**			

From the results of the grid analysis, the estimated total investment cost for the transmission grid in the Baseline scenario in 2025 is about 31.8 billion USD and in 2035, it is about 50.5 billion USD. These costs include the cost for both the inter-regional grid between regions and internal grid.

Considering separately the inter-regional transmission system, the investment cost for the inter-regional transmission grid accounts for about 6-8% of the total investment cost. Detailed grid modelling in PSS/E shows that the investment cost for inter-regional grid is quite consistent with Balmorel but is a little higher. The detailed investment cost for each interface is shown below:

Table 6. Investment cost for interregional transmission lines in the Baseline scenario in the period 2020-2030.

Interfaces		Estimated cost for inter-regional power grid in 2025 from PSS/E (mil.USD)	Balmorel cost of inter-regional power grid in 2025 for the Baseline scenario (mil.USD)	Estimated cost for inter-regional power grid in 2035 from PSS/E (mil.USD)	Balmorel cost of inter-regional power grid in 2035 for the Baseline scenario (mil.USD)
North	North Central	348	277	447	360
North Central	Mid Central	502	451	887	837
Mid Central	Highland	192	153	192	153
Mid Central	South Central	69	45	69	45
Highland	South Central	48	31	48	31
Highland	Southeast	414	399	414	399
South Central	Southeast	450	397	450	397
Southwest	Southeast	504	410	504	410
Total		**2,527**	**2,161**	**3,011**	**2,630**

6. Conclusions

In this study, the detail grid of Vietnam power system for Baseline scenario in EOR 2021 has been built and checked the operation in the typical regimes. The inter-regional transmission system is built based on the transmission capacity from the Balmorel model and the internal transmission grid is from draft PDP VIII. The detail grid after being built will be based on calculation and check by PSS/E software in 7 typical operation snapshots include highest generation (HG), lowest generation (LG), Highest transmission flow (HF), Lowest transmission flow (LF), Highest residual demand (HRD), Lowest residual demand (LRD), Highest curtailment (HC).

The grid simulation result shows that in both 2025 and 2035 the inter-regional transmission system according to Balmorel will operate safe and reliably, there is no element with overload or high/low voltage, and it will meet the requirement of grid code in normal operation condition as well as N-1 contingency condition. Therefore, the transmission capacity in Balmorel model in 2025 and 2035 has been reviewed and confirmed.

Regarding the internal transmission grid inside each region, the study show that all 7 regions will occur overload and high/low voltage and the highest case of violation is in North (in Northwest where concentrate hydro power, wind and solar with long distance of transmission), Highland (strong development of wind and solar powers) and Southeast (load center, also strong develop of solar). Then the study has proposed the transmission line or substation need to be built new or renovated to meet the requirement of Grid code.

Since the transmission loss depend on grid configuration and the transmission flow in each year, the study has calculated the energy loss in 2025 and 2035 on inter-regional grid between regions based on the simulation grid had been built for Baseline scenario of EOR 2021. The results show that the calculated transmission loss value in PSS/E software differs from transmission loss value put initial into Balmorel model by about 0.6%-1.4% depending on the interface.

Finally, the study estimated total volume and cost of substation and transmission line of simulation transmission system (at 500 kV and 220 kV) for Baseline scenario in EOR2021 in 2025 and 2035. The estimated total investment cost for the transmission grid in 2025 is about 31.8 billion USD and in 2035 is about 50.5 billion USD. Considering separately the inter-regional transmission system, detailed grid modelling in PSS/E show that the investment cost for inter-regional grid is quite consistent with Balmorel but is a little higher.

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