MINISTRY OF INDUSTRY AND TRADE
INSTITUTE OF ENERGY

Global Energy Alliance for People and Planet
GEAPP

ENHANCING VIETNAM'S GRID STABILITY WITH BESS

Improvement of Frequency Stability in Vietnam's Power System with High Penetration of Renewable Energy by Battery Storage

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ABBREVIATIONS

EVN	Electricity of Vietnam
HPP	Hydro Power Plant
NPT	National Power Transmission Corporation
PDP	Power Development Plan
PV	Photovoltaic
RE	Renewable Energy
RoCof	Rate of Change of Frequency
TPP	Thermal Power Plant
WPP	Wind Power Plant

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FOREWORD

By Sunita Dubey

Country Delivery Lead- Vietnam, Global Energy Alliance for People and Planet (GEAPP)

I am delighted to present this detailed study on Enhancing Vietnam's Grid Stability with BESS-Improvement of Frequency Stability in the Vietnam Power System with High Penetration of Renewable Energy by Battery Storage. Developed as a collaborative effort of Global Energy Alliance for People and Planet (GEAPP) and the Institute of Energy (IE), this study represents the significant first step towards understanding the value of BESS in Vietnam's power system. Vietnam's leadership on renewable energy in the region has been remarkable, the inclusion of BESS and ambitious RE targets in the Eight National Power Development Plan (PDP8) marks a pivotal moment in Vietnam's clean energy transition towards a resilient power system and green growth future. It not only marks the advent of BESS in the Vietnamese market but also heralds a new era of resilience and efficiency in power management.

As a pioneering endeavour in the Vietnam power market, the study addresses the pressing need for improved frequency stability and catalysing the development of the BESS market at both domestic and international scales. By aligning with Vietnam's strategic energy goals, including Vietnam's PDP8 and the Just Energy Transition Partnerships (JETP), the study underscores our commitment to advancing the nation's energy landscape in line with global sustainability targets.

With a targeted capacity of 300 MW of BESS by 2030, as outlined in PDP8, and the approval of Decision No. 1009/QĐ-TTg dated August 31st 2023 on the JETP Implementation Plan, which prioritises BESS pilot investments, this study lays the foundation for accelerated RE integration and future scale-up initiatives. Partnerships with eminent stakeholders such as the Ministry of Industry and Trade (MOIT), Electricity of Vietnam (EVN), Asian Development Bank (ADB), and Rocky Mountain Institute (RMI) have been leveraged to ensure that the research is grounded in the regional context and tailored to address the unique challenges and opportunities of the Vietnamese energy market while learning from other countries.

In addition to assessing technical solutions, the study also explores the economic and regulatory frameworks necessary to unlock the full potential of BESS deployment in Vietnam. The engagement of both the public and private sectors is being targeted to prompt investment opportunities and establish BESS as a critical enabler of RE growth, integration, and grid stability.

This study will aid in understanding the full potential of incorporating BESS into the power system. By advocating for renewable alternatives, GEAPP not only envisages a greener future but also seeks to create tangible socio-economic benefits, including the generation of green jobs and the reduction of carbon emissions.

I extend my gratitude to GEAPP, IE, and all stakeholders, from government bodies to private enterprises, researchers and experts for contributing their efforts and insights into building this incredible knowledge resource. With our collective vision and commitment, clean energy shall be made accessible to each and every individual of the emerging nations and pave the way to a more resilient and sustainable energy landscape for Vietnam.

EXECUTIVE SUMMARY

This study analyses and anticipates the challenges that may arise in frequency stability in Vietnam's power system by 2030, when the renewable energy integration is expected to increase, with the objective to gauge the scope of averting these challenges with Battery Energy Storage System (BESS).

With the growing penetration of renewables to meet Vietnam's rapidly rising electricity demand in line with the global trend of energy transitions, it is important to take into account the intermittent nature of RE affecting the power system's frequency stability.

- By 2022, Vietnam's power system had over 16 GW of solar power (including rooftop solar power) and 5 GW of wind power. Meanwhile, from 2015 onward, coal-fired power still accounts for over 30% because many plants have been put into operation during this period, such as Mong Duong 1 TPP, Vinh Tan power center, and Duyen Hai power center. With remarkable growth in recent years, the share of solar and wind power sources has increased from almost 0% in 2018 to 21% and 6% in 2022, respectively.

- This resonates with Vietnam's message at COP 26 and the Prime Minister's Decision No. 500/QD-TTg about the National Power Development Plan in the period of 2021-2030, with a vision to achieve net zero emissions by 2050 (PDP 8). In particular, it is proposed to consider measures to convert fuel for thermal power plants.

- The nominal frequency of Vietnam's power system is 50 Hz, and it is allowed to fluctuate within the range of 49.8 Hz to 50.2 Hz in normal conditions. The Rate of Change of Frequency (RoCoF) is another indicator to verify the power system frequency stability. In the power system integrating renewable energy sources, power generation and consumption in the system change constantly, affecting the frequency of the system.

- The characteristic of renewable energy power sources is variable generation capacity, depending on primary renewable energy resources, such as solar radiation and wind speed which are changed by the weather situation and natural conditions. Therefore, the output power and electricity production from renewable energy sources change unevenly over time and are difficult to predict. This characteristic causes difficulties in power system operation and planning, especially when the proportion of renewable energy sources in the power system increases.

BESS integration presents a promising case to manage frequency stability. The study attempts to delve into this by creating through dynamic simulation.

- For the purpose of this analysis, Vietnam's power transmission system (500-220kV) was simulated in peak/off-peak load conditions with the largest proportion of renewable energy sources (lowest system inertia) and the frequency response was calculated in consideration of the contingencies in the largest conventional generating unit and contingency in the largest RE power plant by using a dynamic simulator of PSS/E software with Python code. By dynamic simulation, the RoCoF and nadir of frequency in the system is estimated and compared with the values in Vietnam's technical regulations. The study records the Frequency Response without BESS and with BESS with respect to proportion of RE in the power system, and across regions.

- Without BESS, it is observed that the nadir decreases in line with the increase of proportion of RE in the power system. The frequency response will be worse in the daytime off peak load with the high proportion of RE in the system. There are no significant frequency deviations between buses at different regions.

- With BESS, it is clearly seen that with the rating of 50 MW, BESS will help to increase the frequency nadir from 48.95 Hz to 49 Hz in case of contingency in the largest conventional generating unit. It also helps to improve the frequency response in the other contingency. When the BESS rating increases, the frequency response is improved. However, the improvement is not significant.

Therefore, the study makes a compelling case that a 50MW BESS rating installed can play a significant role in managing Vietnam's power system frequency stability. It is also observed that the location of BESS does not have much effect on the frequency stability. Therefore, for the purpose of frequency stability improvement, **BESS can be installed at every bus in the power system if the land and connection plans are available.**

1. OVERVIEW OF VIETNAM'S POWER SYSTEM

1.1. Current Status of Vietnam's Power System

1.1.1. Power Consumption

Vietnam's electricity consumption in recent years has regularly grown at a high rate to meet the energy demand for socio-economic development. The growth of power consumption in Vietnam from 2011 to 2022 is summarized in Figure 1-1 and Figure 1-2. During this period, national electricity increased nearly 2.8 times from 93 billion kWh in 2011 to 242 billion kWh in 2022 with an average growth rate of about 9.2%/year.

Similar to sale electricity, the peak load (Pmax) of the power system in the period 2011 - 2022 grew rapidly with an average rate of about 9.4%/year from more than 16 GW in 2011 to over 45 GW in 2022. However, due to the impact of the Covid-19 pandemic, the peak demand in 2020 only increased by about 2.3% compared to 2019.

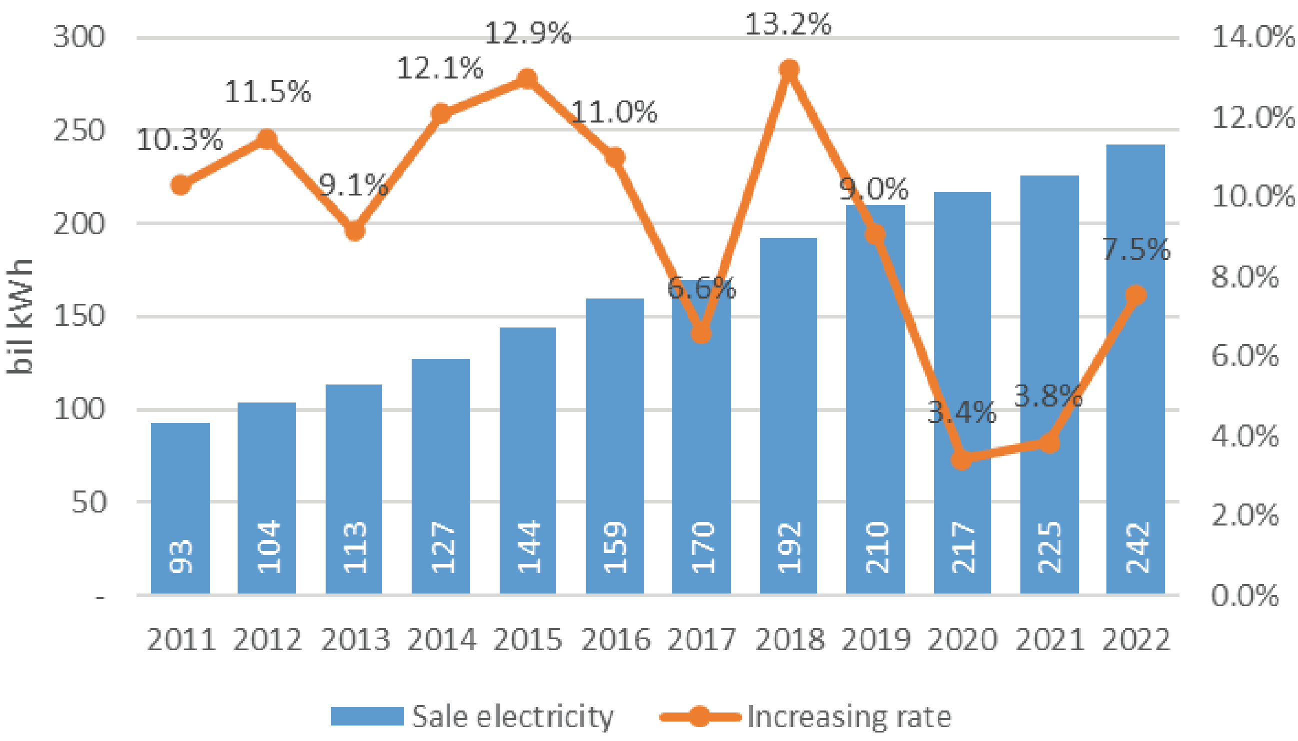


Figure 1-1. National commercial electricity and power losses in the period of 2011-2022

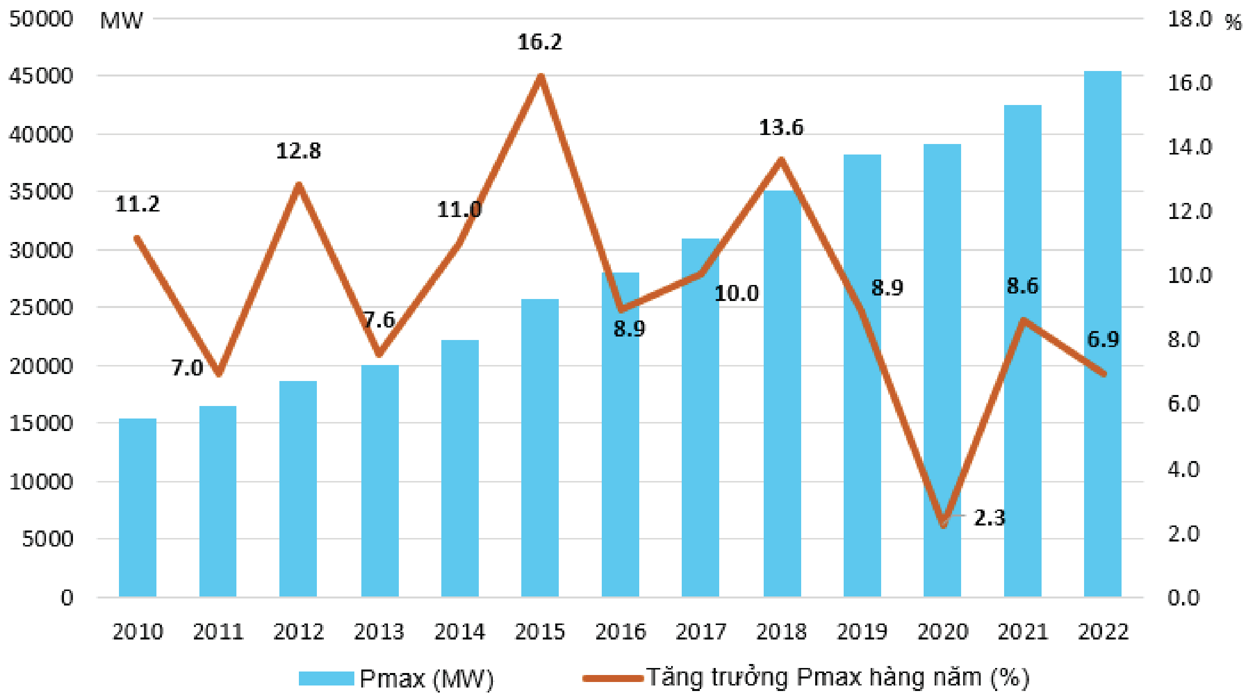


Figure 1-2. National peak load (Pmax) in the period of 2010-2022

In term of regions, during this period of 2011 - 2022, sale electricity of the North grew at an average rate of 11.5%/year from 37 billion kWh to 109 billion kWh, that of the South grew at an average rate of 8.8%/year from 48 billion kWh to 111 billion kWh, and that of the Central region grew at an average rate of 9.8%/year from 9 billion kWh to 23 billion kWh. The sale electricity growth by regions in 2011 - 2022 period is shown in Figure 1-3.

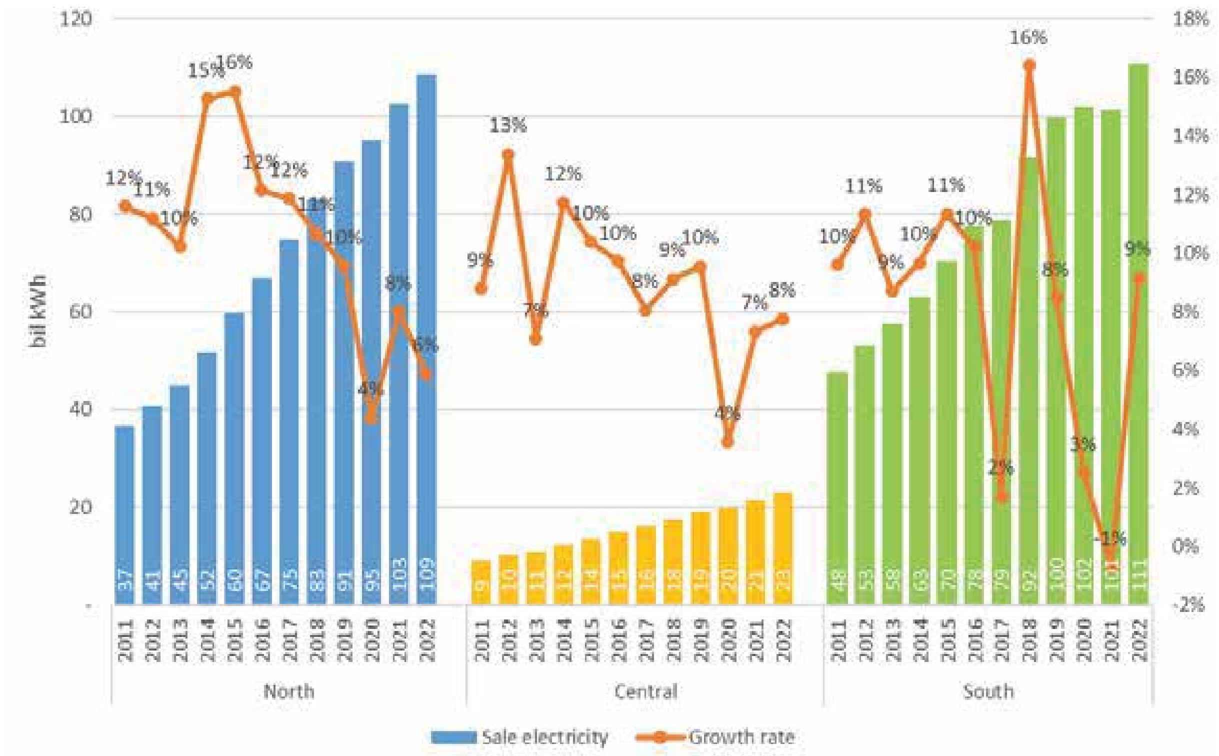
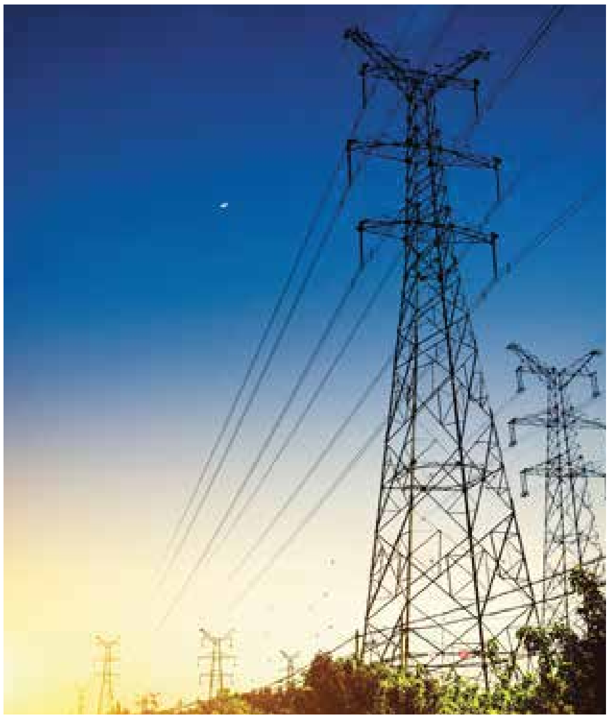


Figure 1-3. Regional sale electricity growth in the period 2011 – 2022

1.1.2. Power Generation

Vietnam's power system has been rising to the top of the ASEAN in terms of power capacity source. The growth of the installed capacity in the period of 2011 - 2022 is shown in Figure 1-4. In this period, the total installed capacity grew from 23 GW to over 80 GW with the average rate of 12% per year. Before 2019, Vietnam's power sources were mostly traditional plants, such as coal-fired, gas-fired, and hydropower plants. From 2019 onwards, the government enacted the renewable energy development mechanisms, thus, solar and wind power sources have developed significantly. By 2022, Vietnam's power system had over 16 GW of solar power (including rooftop solar power) and 5 GW of wind power. The conventional power plants had a total installed capacity of about 59 GW, including 26 GW of coal-fired thermal power, 22 GW of hydropower, and 7 GW of gas turbines.



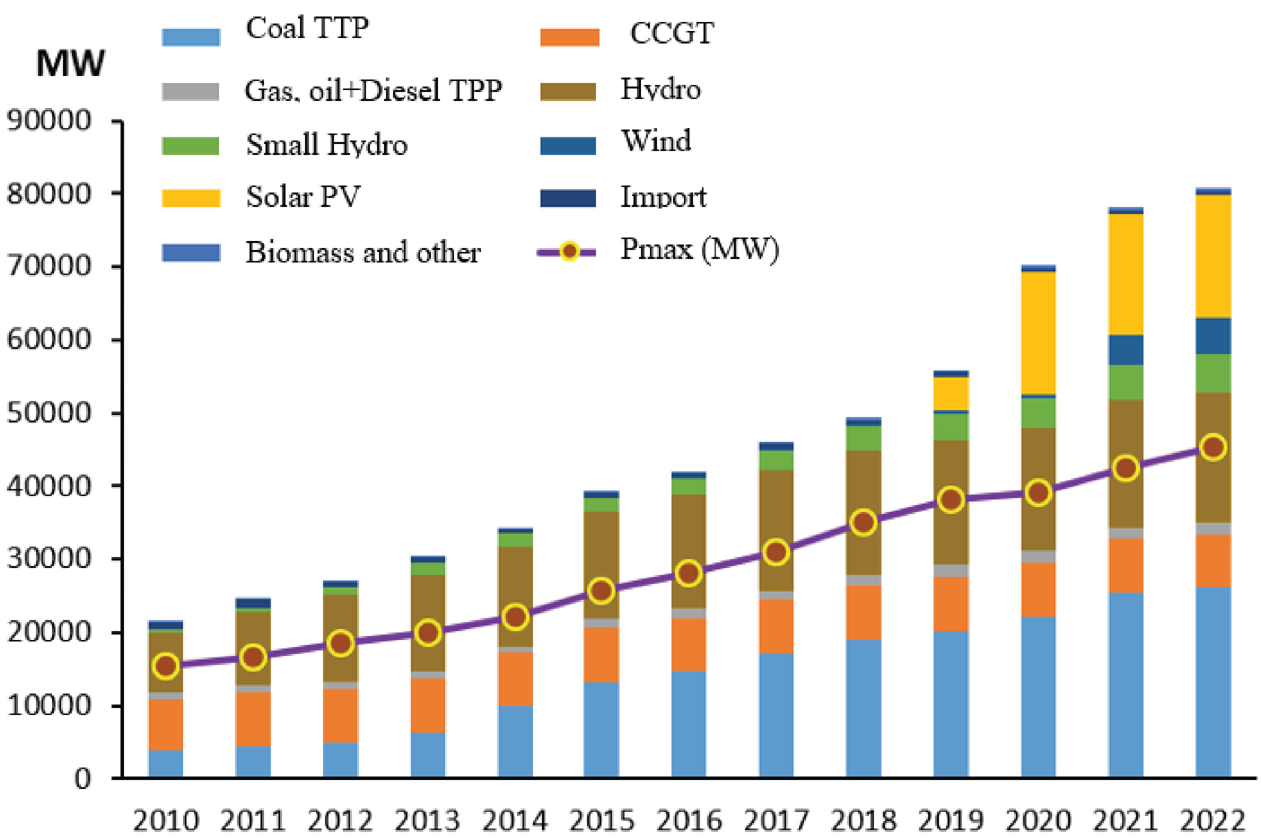


Figure 1-4. National installed capacity growth by type in the period of 2011 - 2022

The national installed capacity structure by type of sources in the period 2011 - 2022 is presented in Figure 1-5. The proportion of hydropower plants (including small hydropower) tends to decrease gradually because the potential has been fully exploited. In 2022, hydropower only accounted for about 29% of the national installed capacity. Meanwhile, from 2015 onward, coal-fired power still accounts for over 30% because many plants have been put into operation during this period, such as Mong Duong 1 TPP, Vinh Tan power center, and Duyen Hai power center. With remarkable growth in recent years, the share of solar and wind power sources has increased from almost 0% in 2018 to 21% and 6% in 2022, respectively. The gas turbine power source was not developed in the past 10 years. Therefore, the proportion of power sources decreased from 32% in 2011 to 9% in 2022. The remaining types of power sources currently account for a small proportion of the national power supply structure.

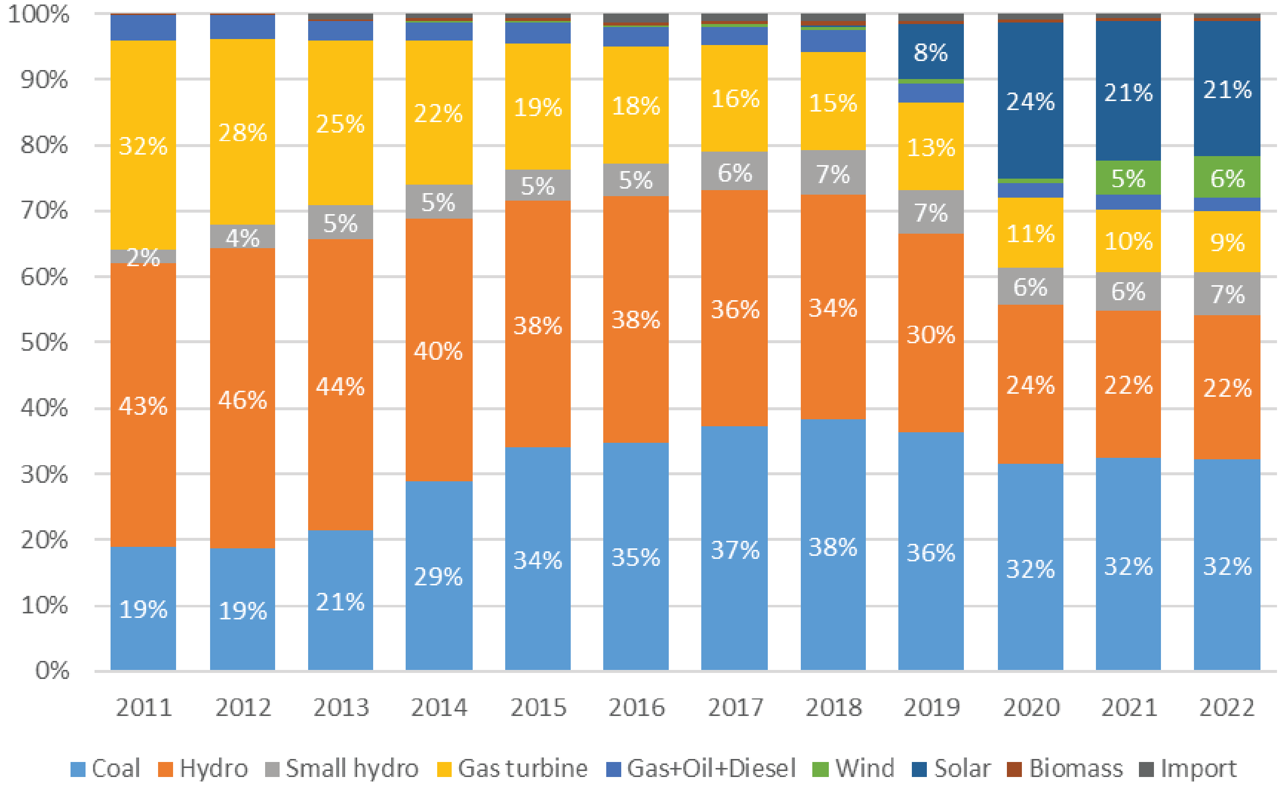


Figure 1-5. National installed capacity structure by type of sources in the period 2011 - 2022

In terms of regions, the growth of installed capacity in the period 2016 - 2022 is shown in Figure 1-5. In the North, due to many power plants being behind schedule, the installed capacity of power sources in the last recent years has grown slowly, from about 21 GW in 2016 to nearly 29 GW in 2022, the average rate is about 6 % per year. Most of the power sources in the North are coal-fired power and hydropower sources. In 2022, the North has over 15 GW of coal-fired power and 13 GW of hydropower, accounting for 53% and 44% of the region's total installed capacity, respectively.

In the Central region, the installed capacity of power sources grew by an average of 22% per year, from nearly 6 GW in 2016 to over 16 GW in 2022. Before 2019, hydropower was the main source which accounted for about 86% in the power structure of the region. From 2019 onwards, the Central region has been supplemented with a significant amount of solar and wind power sources. By 2022, the installed capacity of these two types of sources were about 5 GW and 2 GW, respectively, accounting for 32% and 16% of the region's source structure. The installed capacity of hydropower is about 7 GW, accounting for 47% of the region's total installed capacity.

In the South, the installed capacity of power sources grew by an average of 15% per year, from about 15 GW in 2016 to 35 GW in 2022. Before 2019, the Southern power sources were mainly gas turbines and coal-fired thermal power. From 2019 onwards, the South has been supplemented with a significant amount of solar and wind power sources. By 2022, the installed capacity of these two types of sources were about 11 GW and 2 GW, respectively, accounting for 31% and 7% of the region's source structure. The installed capacity of coal-fired and gas turbine power sources is about 10 GW and 7 GW respectively, accounting for 30% and 21% of the region's total installed capacity.

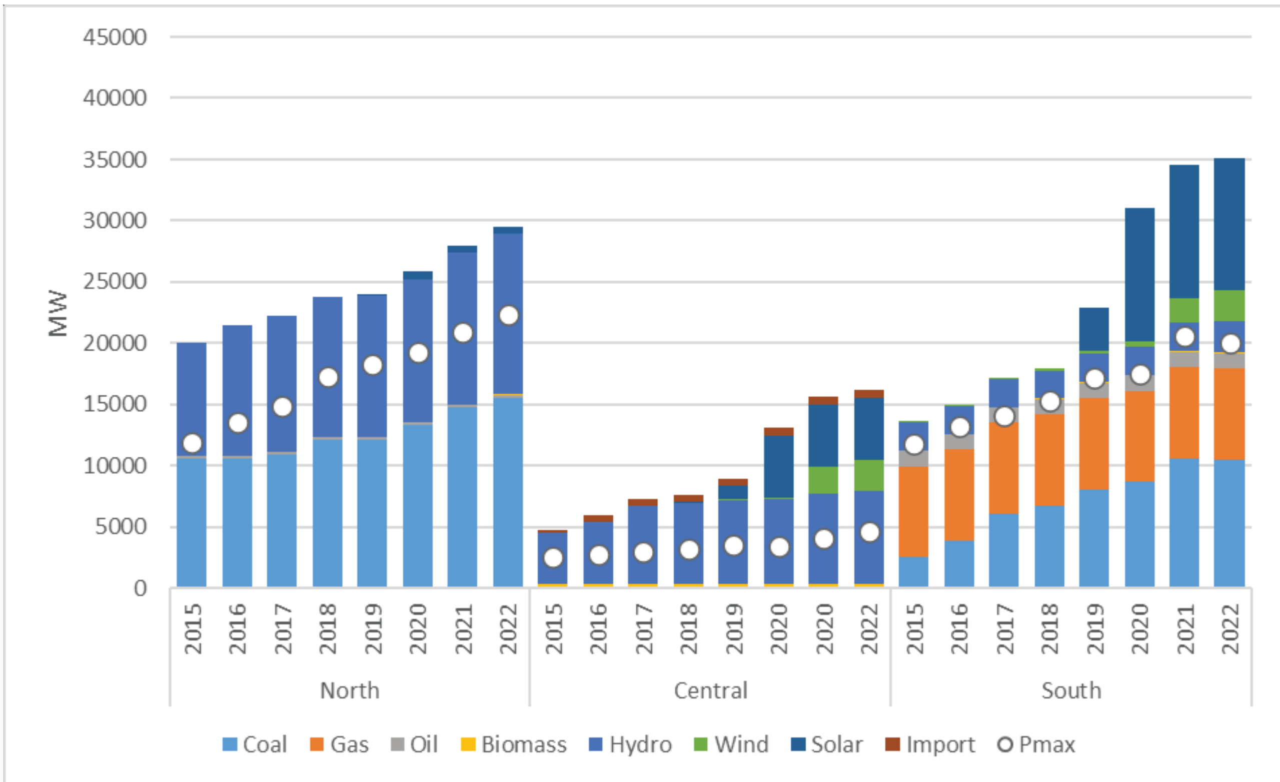


Figure 1-6. Regional installed capacity in the period 2016 - 2022

1.1.3. Power Transmission Grid

Vietnam's power system is currently operating with an ultra-high voltage level of 500 kV, high voltage of 220 kV - 110 kV, medium voltage levels from 35 kV to 6 kV, and low voltage levels. The 500 - 220kV transmission grid is mainly managed by the National Power Transmission Corporation (EVNNPT) while the distribution grid at 110 kV voltage level and medium voltage grid at voltage levels from 6 kV to 35 kV are managed by regional Power Corporation (PC).

The total volume of transmission lines and substations in the period of 2017 - 2022 is listed in the table below.

Table 1-1. Volume of transmission lines and substations in the period of 2017-2022

Year	2017		2018		2019		2020		2021		2022	
Volume	km	MVA	km	MVA	km	MVA	km	MVA	km	MVA	km	MVA
500kV	7414	29400	7799	33300	8496	47100	8510	4290	9008	47100	10152	49500
220kV	17126	48553	17861	57441	18391	70464	18477	67824	19145	70464	19567	72848
Total	24540	77953	25660	90741	26887	117564	27615	110724	28153	117564	29719	122348
Growth rate (%)												
500kV	0.9%	12.6%	5.2%	13.3%	8.9%	9.8%	7.6%	26.0%	5.9%	9.8	13%	5%
220kV	3.2%	7.8%	4.3%	18.3%	3.0%	3.9%	0.5%	9.0%	3.6%	3.9%	2%	3%

In the period of 2017-2022, the growth rate of volume of 500kV transmission lines and substation capacity is about 6.9%/ year and 12.8%/year, respectively. The growth rate of volume of 220kV transmission lines and substation capacity is about 2.8%/year and 7.7% /year, respectively in the same period.

1.2. Vietnam’s Power System Development Plan

On May 15, 2023, the Prime Minister approved Decision No. 500/QD-TTg about the National Power Development Plan in the period of 2021-2030, with a vision to 2050 (PDP 8). It clearly states the national power development orientation:

- Synchronously develop and diversify types of power sources with a reasonable structure to ensure energy security, improve the autonomy of the electricity industry, and reduce dependence on imported fuels.
- Continue to promote the development of renewable energy sources (hydroelectricity, onshore and offshore wind power, solar, biomass...), new energy, and clean energy (hydrogen, green ammonia...) suitable with the ability to ensure system safety with reasonable electricity prices, especially self-generated, self-dissipating, and rooftop solar power sources.
- Efficiently exploiting and using domestic fossil energy sources in combination with imports: Gradually reducing the proportion of coal-fired thermal power, prioritizing the development of domestic gas power, and developing imported LNG gas power sources with suitable tissue. Implement energy transition in line with the trend of technology development and cost in the world.
- Develop a balanced power source by region, aiming to balance supply and demand in the region. Reasonable arrangement of power sources in localities in the region in order to efficiently exploit power sources, ensure reliable power supply on the spot, reduce technical losses, and power transmission over long distances.
- Developing new power sources with modern technology coupled with technological innovation of operating plants towards decommissioning of factories that do not meet environmental standards.
- Diversify forms of investment and development of power sources in order to enhance competition and improve economic efficiency.

The main contents of PDP 8 are summarized as below:

1.2.1. National Power Demand Forecast

The load forecast results in PDP 8 are summarized as follows:

Table 1-2. National electricity demand forecast according to scenarios until 2030

Year	2025	2030
Sale electricity (bil.kWh)	335	505
Peak load (GW)	59	91

The main results are as follows:

- Commercial electricity in 2030 reach about 505 billion kWh, the average growth in the period of 2021-2030 is: 8.8%/year;
- Electricity production in 2030 reach about 567 billion kWh, the average growth in the period of 2021-2030 is: 8.7%/year;
- The maximum power load (Pmax) in 2030 is about 90,500 MW, the average growth in the period of 2021-2030 is: 8.9%/year;

The electricity demand forecast results of the load forecast scenarios reflect the socio-economic development orientation set out in Resolution 81, especially the targets on GDP growth and national GDP restructuring. They are consistent with Vietnam's orientation and requirements to improve power efficiency in the future.

1.2.2. National Power Generation Development Plan

The first period of 2022 has taken place in the context of geopolitical and geo-economic fluctuations in the world, the trend of shifting to green and clean energy sources after COP26, and the rapid development of science and technology. In line with Vietnam's message at COP 26 (achieve net zero emissions by 2050), the PDP8 has launched scenarios to meet this Net Zero commitment in 2050. In particular, it is proposed to consider measures to convert fuel for thermal power plants (gradually switching to green, clean fuel sources with no CO2 emissions).

Details:

- Coal-fired power sources will be decommissioned after 40 years of life. Coal-fired power plants that are decommissioned before 2050 will not have to convert fuel. The remaining coal power plants will have to start burning with biomass or ammonia (from 20%) after 20 years of operation, gradually increase the proportion of biomass or ammonia and switch to complete burning of biomass or ammonia in the next 10 years. By 2050, coal-fired power plants must switch to biomass or ammonia completely.

- LNG thermal power sources will have to start burning with hydrogen (from 20%) after 10 years of operation, gradually increasing the proportion of hydrogen and switching to hydrogen completely in the next 10 years.

- Due to the gas decline in the Southeast and Southwest, domestic gas-fired thermal power sources (except Block B and Blue Whale) will switch to LNG and start burning with hydrogen from 2031 - 2035 (20%), gradually increasing the proportion of hydrogen and switching to hydrogen completely in the period of 2041 - 2045.

- Domestic gas-fired power plants with a capacity of 7.8 GW (receive gas from Block B and Blue Whale) are given priority to use domestic gas for electricity production to ensure autonomy in electricity production and energy security. In case domestic gas is not enough, import LNG will be considered.

- No new coal-fired thermal power sources will be developed after 2030. As for LNG power, no new LNG power sources will be developed after 2035.

- No commitment of capacity factor for thermal power plants after fuel conversion.

Specifically, by 2030 the total capacity source will be 150489 MW (excluding exports, existing rooftop solar, and renewable energy to produce new energy), of which:

- Onshore wind power: 21,880 MW (14.5% of total capacity of power plants);
- Offshore wind power of 6,000 MW (4.0%). In case the technology develops quickly and the electricity prices and transmission costs are reasonable, the scale will be higher;
- Solar power: 12,836 MW (8.5%, excluding existing rooftop solar power), including 10,236 MW of concentrated solar power sources, and 2,600 MW of self-produced and self-consumption solar power. Self-produced and self-dissipating solar power sources are prioritized for unlimited capacity development;
- Biomass electricity and electricity produced from waste: 2,270 MW (1.5%). In case of sufficient raw materials, high land use efficiency, environmental treatment requirements, allowable grid infrastructure, electricity price, and reasonable transmission costs, the larger scale development;
- Hydropower: 29,346 MW (19.5%), which can be further developed if economic - technical conditions allow;
- Hydroelectricity: 2,400 MW (1.6%);
- 300 MW (0.2%) storage battery;
- Cogeneration of electricity, using residual heat, blast furnace gas, byproducts of the technological chain in industrial facilities: 2,700 MW (1.8%), the scale can be increased in accordance with the capacity of the company. Industrial facilities;
- Coal thermal power: 30,127 MW (20.0%),
- Domestic gas thermal power plant: 14,930 MW (9.9%);
- 22,400 MW LNG thermal power (14.9%);
- Flexible power source: 300 MW (0.2%);
- Import of electricity: 5,000 MW (3.3%), can be up to 8,000 MW

The details of Vietnam's power development scenario to 2030 are presented in the following table:

Table 1-3. Vietnam power source development plan until 2030 – Unit: MW

Item/Year	2030
Onshore & nearshore wind	21880
Offshore wind	6000
Solar power (*)	12836
Biomass, waste to power & other RE	2270
Hydro power	29346
Pumped hydro, battery storage & other storage	2700
Co-generation	2700
Coal thermal power	30127
Biomass/ammonia thermal power	-
Domestic gas turbine change to LNG	14930
Domestic gas turbine totally change to hydrogen	-
New LNG thermal power	22400
LNG and hydrogen co-firing	-
LNG thermal power totally change to hydrogen	-
Flexible power source	300
Import	5000
Total installed capacity	150489

1.2.3. National Power Transmission Grid Development Plan

By 2025

In the period up to 2025, it is necessary to continue developing inter-regional 500 kV transmission lines to increase the efficiency of power system operation. This will help evacuate the electricity from renewable energy sources and increase the transmission capacity, ensuring electricity supply for the socio-economic development of northern and southern load centers.

On the Central - North Central - Northern Vietnam section, it is necessary to ensure the progress of the 500 kV Quang Trach – Quynh Luu – Thanh Hoa – Nam Dinh – Pho Noi transmission line. This project is being implemented, playing an important role in ensuring Northern power supply and limiting congestion on the North Central - Northern transmission grid. After the above-mentioned lines are put into operation, there will be 04 circuits of 500 kV transmission line between the Central Central - North Central - North Central - Northern regions.

On the Central Highlands - Southern and South Central – Southern sections, it is necessary to implement 500 kV transmission lines such as the 500 kV Krong Buk - Tay Ninh 1 (Central Highlands - Southern) and Ninh Son - Chon Thanh (South Central - Southern), bringing the total number of 500 kV transmission lines linking from the Central Highlands and South Central to the Southern to 12 circuits. These lines will support the evacuating of regional renewable energy capacity, while contributing to ensuring power supply for the Southern load center.

On the Southwest - Southeast interface, in the period to 2025, it is necessary to pay attention to the 500 kV Song Hau - Duc Hoa transmission line. This is a line connecting Song Hau CFPP, which is under construction.

In addition to the 500kV inter-regional transmission lines, transmission grid projects connecting power sources, releasing hydropower capacity, and importing electricity also play an important role, especially in the situation of slow deployment of many thermal power sources and the risk of shortage of power supply capacity for the North. Specifically, some notable projects such as: 500 kV Van Phong – Vinh Tan transmission line connecting Van Phong plant; 500 kV and 220 kV lines connecting Nhon Trach 3,4 CCGT; 500 kV Lao Cai substation and 500 kV Lao Cai – Vinh Yen transmission line, 220 kV TL and substation projects in the Northwest region to evacuating hydropower; Lao Bao 500 kV substation and connection lines to evacuating renewable energy, 500-220 kV lines importing electricity from Laos such as 500 kV Monsoon - Thanh My TL, 220 kV Nam Mo – Tuong Duong, Nam Sum - Nong Cong, Nam E-Moun - Dak Ooc switching station, Nam Kong 3 – Bo Y switching station.

Finally, it is not least important for substation and transmission line projects to load power supply, especially load center areas, with fast growth of economic and electricity demand. Some notable projects are the 500 kV substation Vinh Yen, Thai Nguyen, Bac Ninh, Hai Phong, Thai Binh, Nam Dinh, Thanh Hoa, Long Thanh, Cu Chi, Binh Duong 1, Bac Chau Duc, Dong Nai 2.

In the period of 2026-2030

In this period, inter-regional transmission capacity will be strengthened, especially the North Central – Northern and South Central - Southern interfaces. The inter-regional links to 2030 are expected as follows:

- North Central – Northern: Including 05 circuits of 500 kV transmission line, specifically: 01 existing Vung Ang – Nho Quan circuit, building 01 new double-circuit transmission line Quang Trach – Quynh Luu – Thanh Hoa – Nam Dinh (2021 - 2025), upgrading Vung Ang – Nghi Son – Nho Quan circuit into a double circuit transmission line (2026 - 2030). In case of high development of LNG power sources in the North Central region, consider building a new 500 kV double-circuit transmission line to transmit LNG power capacity from North Central to the North.

- Central Central – North Central: Including 04 circuits of 500 kV transmission lines, specifically: 2 single circuits Da Nang – Vung Ang, 1 double circuit Doc Soi – Quang Tri – Quang Trach (2022).

- Central Highlands – Central Central Vietnam: Including 5 circuits of 500 kV transmission lines, including existing single-circuit Pleiku – Doc Soi and Pleiku 2 – Doc Soi, upgrading the Pleiku – Thanh My single-circuit 500 kV line into double circuit (2026-2030).

- South Central – Central Central Link: Including 2 circuits of 500 kV transmission lines: Thuan Nam – Van Phong – Binh Dinh – Dung Quat double-circuit, completing the whole route in the period of 2026-2030.
  South Central – Central Highlands link: Includes 3 circuits 500 kV transmission lines: existing single circuit Pleiku – Di Linh and double-circuit Krong Buk – Binh Dinh.

- South Central – Southern Link: Including 7 circuits of 500 kV transmission lines. Specifically: the existing single circuit Di Linh – Tan Dinh TL, 2 double-circuit of the existing 500 kV Vinh Tan – Dong Nai – Song May TL, new double-circuit 500 kV Ninh Son – Chon Thanh TL. In case of LNG Ca Na development, build a new double-circuit 500 kV line from South Central to Southern Vietnam.

- Central Highlands – Southern Vietnam linkage: Including 500 kV transmission lines: the existing double-circuit Pleiku – Chon Thanh TL, the existing single circuit Dak Nong – Tan Dinh TL and the double-circuit Krong Buk – Tay Ninh 1.

1.3 Frequency Regulations in Vietnam's Power System

Frequency regulations in Vietnam's power system are stated in the following legal bases:

- Circular 25/2016/TT-BCT dated 30/11/2016 of the Ministry of Industry and Trade on the regulation of power transmission systems.
- Circular 30/2019/TT-BCT dated 18/11/2019 of the Ministry of Industry and Trade on amending and supplementing a number of articles of Circulars No. 25/2016/TT-BCT and No. 39/2015/TT-BCT of the Minister of Industry and Trade.
- Circular 39/2022/TT-BCT dated 30/12/2022 of the Ministry of Industry and Trade on amending and supplementing a number of articles of Circulars No. 25/2016/TT-BCT, No. 39/2015/TT-BCT and No. 30/2019/TT-BCT of the Minister of Industry and Trade.
- Decision No. 106/QD-DTDL dated 14/12/2018 of the Electricity Regulatory Authority - Ministry of Industry and Trade on Promulgating the process of identifying and operating ancillary services.

The nominal frequency of Vietnam's power system is 50 Hz, and it is allowed to fluctuate within the range of 49.8 Hz to 50.2 Hz in normal conditions. In the other conditions, the allowable frequency range and the duration to restore the power system to the normal state are summarized in the following table.

Table 1-4. Permissible frequency range and duration to restore the power system to normal state

Condition	Permissible frequency oscillations	Recovery time, from the moment of contingency	
		Unstable state (post-fault recovery mode)	**Restore to normal state**
Single fault contingency	49 Hz ÷ 51 Hz	Restore the frequency to the range of 49.5 Hz ÷ 50.5 Hz within 02 minutes	Restore the frequency to the range of 49.8 Hz ÷ 50.2 Hz within 05 minutes
Multiple fault contingency, serious contingency, or Extreme emergency mode	47.5 Hz ÷ 52 Hz	Restore the frequency to the range of 49 Hz ÷ 51 Hz within 10 seconds Restore the frequency to the range of 49.5 Hz ÷ 50.5 Hz within 05 minutes	Restore the frequency to the range of 49.8 Hz ÷ 50.2 Hz within 10 minutes

Source: Circular 25/2016/TT-BCT [1]

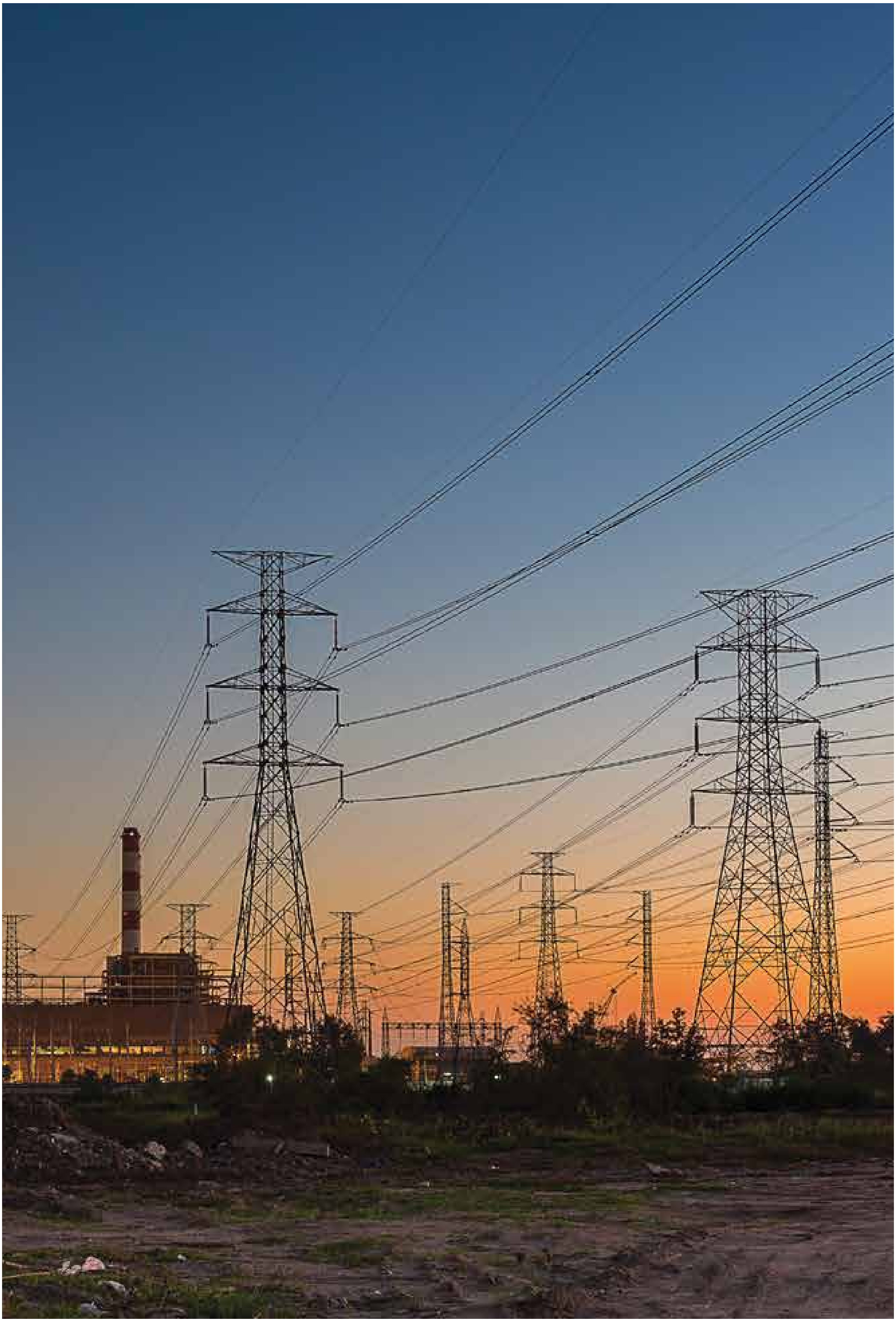
In addition, the Rate of Change of Frequency (RoCoF) is another indicator to verify the power system frequency stability, especially in the system with high penetration of renewable power plants. Wind and power plants connected to the grid must maintain operation when the RoCoF of the system is in the range from 0 Hz/s to 01 Hz/s measured in a time frame of 500 milliseconds.

Frequency control in the power system is the control process to maintain the stable operation of the power system including 3 levels: primary frequency control, secondary frequency control, and tertiary frequency control.

- Primary frequency control is the process of instantaneous control of the frequency of the electrical system performed automatically by a large number of generator sets equipped with a governor;
- Secondary frequency control is the subsequent control process of primary frequency control realized through the action of the AGC system to bring the frequency to the permissible long-term operation range;
- Tertiary frequency control is the subsequent control process of secondary frequency control carried out by the dispatch command to bring the frequency to operate stably according to regulations and ensure the economic distribution of generators

The primary frequency control will have an instantaneous impact, capable of maintaining a minimum variable capacity for 30 seconds before returning to the original output power value. The secondary frequency control will act to control the frequency before the 30th second from the time of receiving the dispatch command. The tertiary frequency control will act to control the frequency after a maximum period of 10 minutes from the time of receiving the order from the dispatcher.

Operators of power system and power market will be responsible for calculating and determining reserve capacity needs and power plants, generators provided for frequency dispatch services, and announcing them in accordance with the regulations on operation of competitive wholesale electricity market promulgated by the Ministry of Industry and Trade.



2. THEORETICAL BACKGROUND

In conventional power systems, the kinetic energy held in the rotating components of synchronous generators is an essential characteristic, with inertia playing a crucial and inherent role [2]. The inertia of the system is a key parameter for the synchronized operation of power systems [3]. The spinning mass of a synchronous generator either injects or absorbs kinetic energy into or from the grid, depending on system frequency changes, thereby slowing down system dynamics and ensuring frequency stability [3]. This implies that in the event of any power imbalance in the system, synchronous generators adjust their rotational speed based on rotor inertia and controller actions, aiding in maintaining system balance. However, the growing prevalence of inverter-based power sources like wind turbines and solar photovoltaic systems has resulted in a decrease in system inertia. These sources are not electromechanically connected to the utility grid and hence do not contribute to system inertia. The decrease in system inertia heightens the likelihood of a larger Rate of Change of Frequency (RoCoF) and frequency deviation. System operators highly prefer to keep RoCoF and frequency deviation as minimal as possible.

2.1. Inertia of a Single Machine

Synchronous power plants store energy in the form of kinetic energy of rotors and turbines. This amount of kinetic energy is expressed through the inertia constant of each unit. The inertia constant of a unit depends on the moment of inertia of a generator and turbine, rated mechanical angular velocity of the rotor and rated apparent power of the generator.

$$H = \frac{1}{2}\frac{J\omega_n^2}{S_n}, \quad (1)$$

where H is the inertia constant (s), J is the moment of inertia of a generator and turbine (kg.m2), ω_n is the rated mechanical angular velocity of the rotor (rad/s), and S_n is the rated apparent power of the generator (VA).

The inertia constant is given in seconds, and it can be interpreted as the time that energy stored in rotating parts of a turbine-generator is able to supply a load equal to the rated apparent power of the turbine-generator.

2.2. Inertia of a Power System

The inertia constants and rated apparent powers of individual turbine-generators can be used to calculate inertia of a power system.

$$H_{sys} = \frac{\sum_{i=1}^{N} S_{ni} H_i}{S_{n,sys}}, \quad (2)$$

where $S_{n,sys} = \sum_{i=1}^{N} S_{ni}$, S_{ni} is the rated apparent power of generator i (VA) và H_i is the inertia constant of turbine-generator i (s).

Motors connected synchronously to power systems also contribute to system inertia and can be taken into account in a similar way as generators.

2.3. The Impact of Renewable Energy Sources on Power System Operation

The characteristic of renewable energy power sources is variable generation capacity, depending on primary renewable energy resources, such as solar radiation and wind speed which are changed by the weather situation and natural conditions. Therefore, the output power and electricity production from renewable energy sources change unevenly over time and are difficult to predict. In fact, with a single renewable energy power plant, the output power can change by 50-60% within 1 minute or up to 90% in about 4-5 minutes. Figure 2-1 illustrates the variable characteristics of several wind and solar power plants in Vietnam. This characteristic causes difficulties in power system operation and planning, especially when the proportion of renewable energy sources in the power system increases.

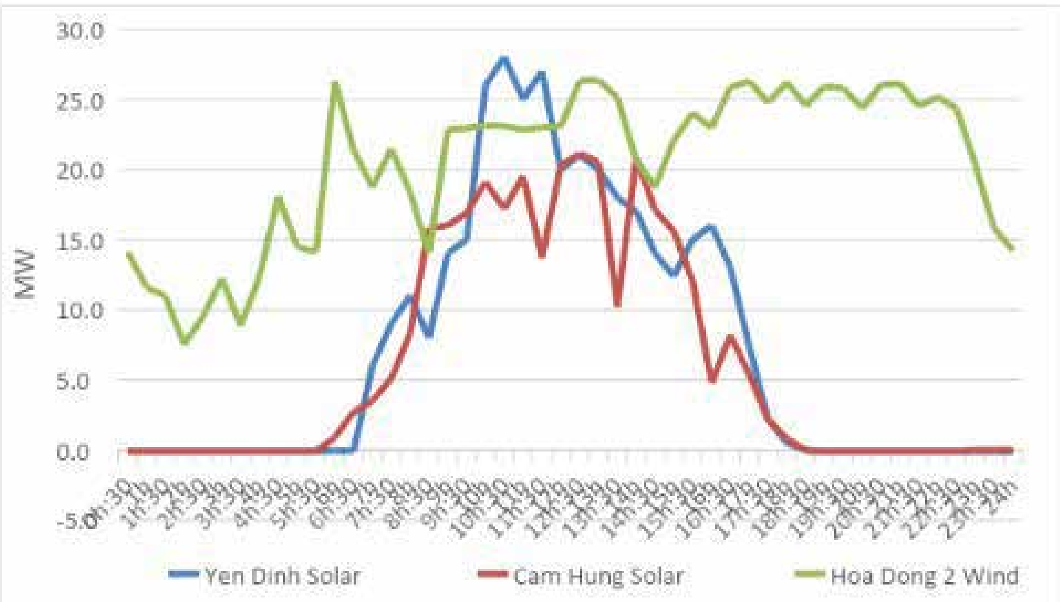


Figure 2-1. Illustration of renewable energy variability in Vietnam

In addition, the fact that the power system integrates renewable energy sources at a high proportion also leads to a decrease in the inertia of the power system. The inertia of the power system is largely contributed by the inertia from the kinetic energy of the turbines from the system power units. In the power system integrating renewable energy sources, the power generation and consumption in the system change constantly, affecting the frequency of the system. With small changes in the system, the frequency response is only expressed in the forms of a noise or small oscillation. However, when there is a contingency in the power system that causes a large power imbalance, the frequency can vary greatly from the rated frequency. For example, when there is a contingency on a large capacity unit, the power system will have a power imbalance. The amount of kinetic energy of the whole system decreases. The rotation speed of the rotors gradually decreases and leads to a decrease in the frequency. The speed and amplitude of frequency change in the power system depend on the amount of power changed and the inertia of the power system. Which is shown in the equation (3) and illustrated in Figure 2-2.

$$H_i \frac{df_i}{dt} = \frac{f_n^2}{2S_{ni} f_i}\left(P_{mi} - P_{ei}\right),$$

where fi is the frequency of the i-th generator, fn is the nominal frequency, Pmi is the mechanical power of turbine-generator, and Pei is the electrical power of the i-th generator.

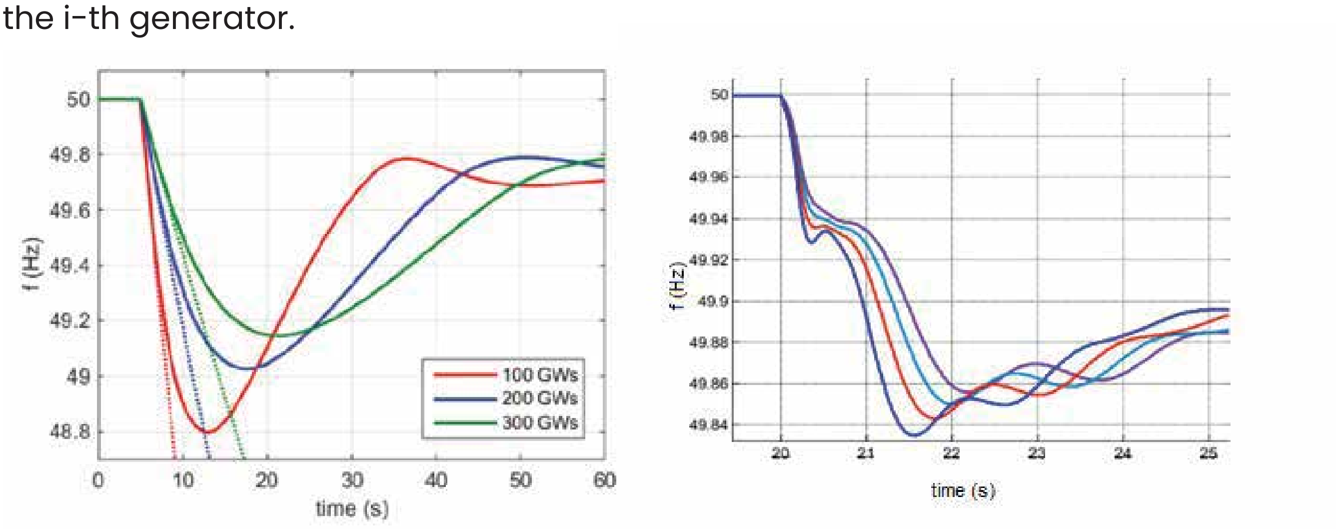


Figure 2-2. Illustration of frequency response with variable amounts of kinetic energy in power system [4]

When the power system has an imbalance, the system frequency will change, large inertia will help the system resist major changes, contributing to enhancing the stability of the power system. Renewable energy sources such as modern wind turbines and solar power plants are connected to the power system through converters and power electronic controls so the rotation speed of the turbine (if any) is isolated from the frequency of the system. Therefore, renewable energy power sources do not have the same natural inertial response as traditional power plants and they do not contribute to the inertia of the power system. Thus, with the same size of total power installed capacity, the integration of renewable energy sources with a larger proportion will reduce the inertia of the power system.

3. FREQUENCY STABILITY PROBLEM DETERMINATION IN VIETNAM'S POWER SYSTEM

3.1. Methodology

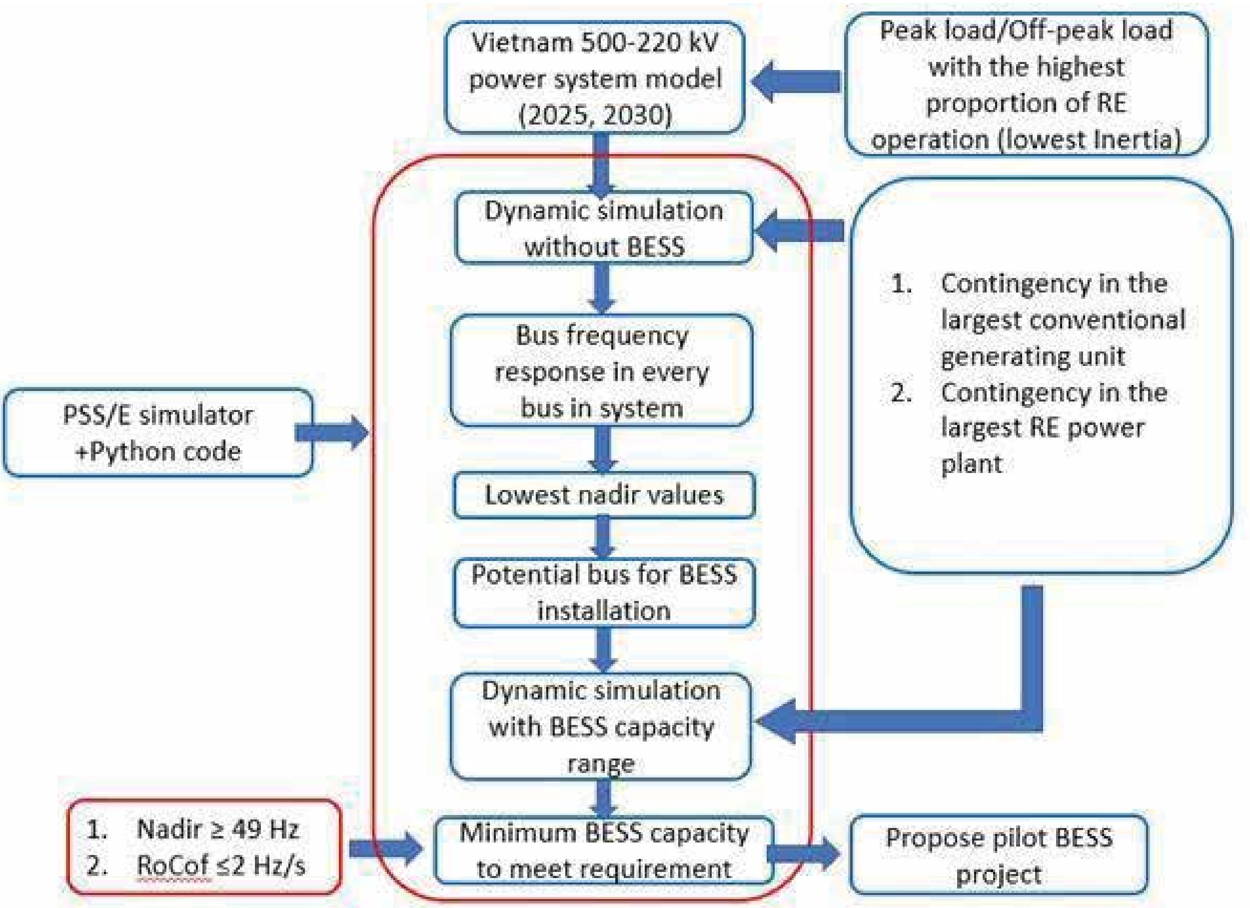


Figure 3-1. Methodology for the study on the Improvement of Frequency Stability Vietnam's Power System with High Penetration of RE by BESS

The methodology for the study is briefly shown in Figure 3-1. In this study, Vietnam's power transmission system (500-220kV) will be simulated in peak/off-peak load conditions with the largest proportion of renewable energy sources (lowest system inertia). The frequency response is calculated in consideration of the contingencies in the largest conventional generating unit and contingency in the largest RE power plant by using a dynamic simulator of PSS/E software with Python code.

The frequency response will be compared with the frequency regulations in Vietnam's power system as shown in section 1.3. In case the frequency standards are not met, an appropriate amount of capacity and position of BESS to support the frequency response will be suggested.

3.2. Simulation of the Frequency Response of Vietnam's Power System

As presented in Section 1.1.2, by the end of 2022, the total installed capacity in Vietnam reached 80.7 GW. In which, renewable energy sources reached nearly 14 GW (about 27%). If all generating units in the system are considered, the total inertia of Vietnam's power system in 2022 is about 1.785s. By 2030, the proportion of renewable energy in Vietnam's power system is expected to increase to about 30%, the total inertia of the system will be reduced to 1.777s.

The simulation is performed by using data from Vietnam's power transmission system (500 – 220 kV) in 2030 according to the PDP 8. The following operation modes are considered in the simulation:

- Day time peak load- The proportion of renewable energy proportion is about 21.4%.
- Night time off-peak load- The proportion of renewable energy rate is about 18.9%.
- Day time off-peak load- The proportion of renewable energy rate is about 30.7%.

In order to evaluate the effectiveness of the BESS in frequency response, dynamic simulations are conducted in cases of without BESS and with BESS in Vietnam's power system. The frequency response is calculated in consideration of the contingencies in the largest conventional generating unit and contingency in the largest RE power plant.

3.2.1. Frequency Response without BESS

3.2.1.1. Contingency in the Largest Conventional Generating Unit

According to PDP 8, by 2030, a generating unit of O Mon thermal power plant will be the largest conventional generating unit in Vietnam's power system with the capacity of 1050 MW. The contingency in that unit is simulated at 5 s after the normal steady state operation. The ROCOF and bus frequencies in the whole system in the considered operation modes are collected and summarized in the following figures.

Day time Peak load mode

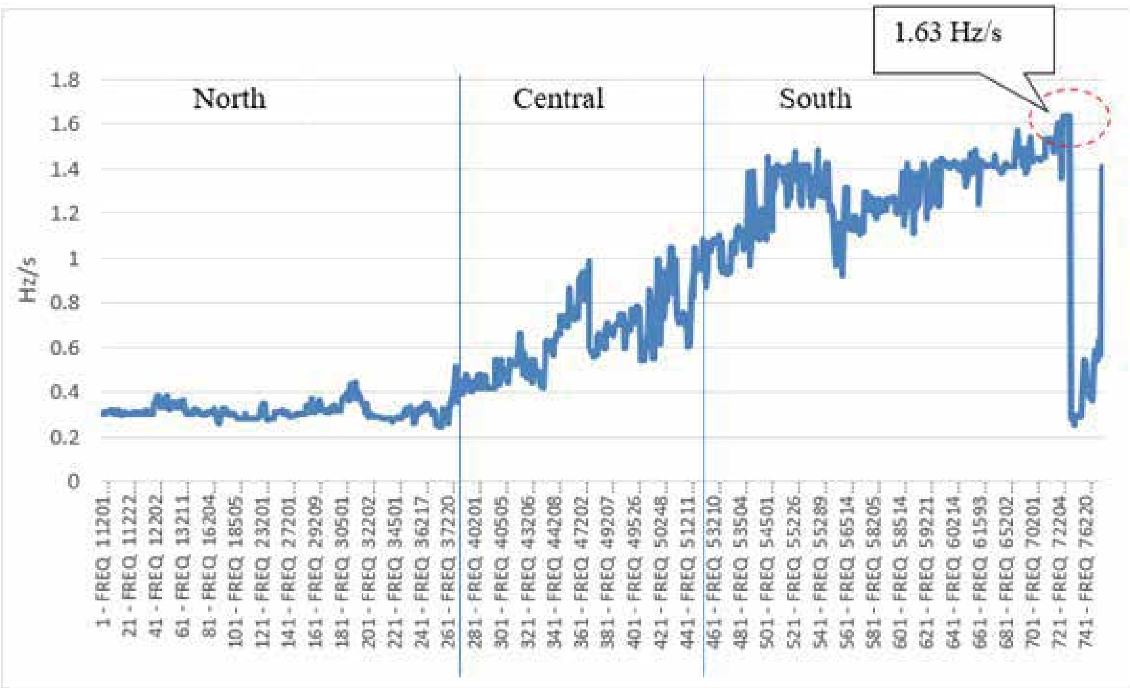


Figure 3-2. RoCof of every bus in the power system in 2030 – Peak load mode - Contingency in the largest conventional generating unit

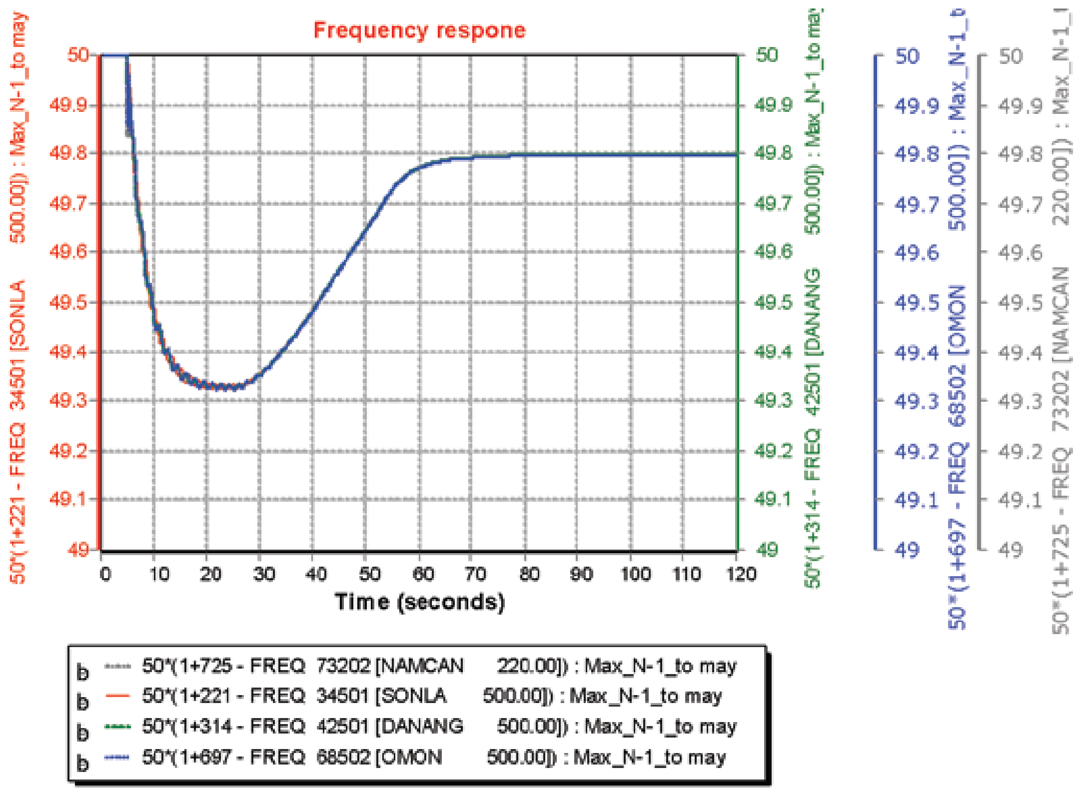


Figure 3-3. Frequency response at some bus of each area – Peak load mode - Contingency in the largest conventional generating unit

Night time off-peak load

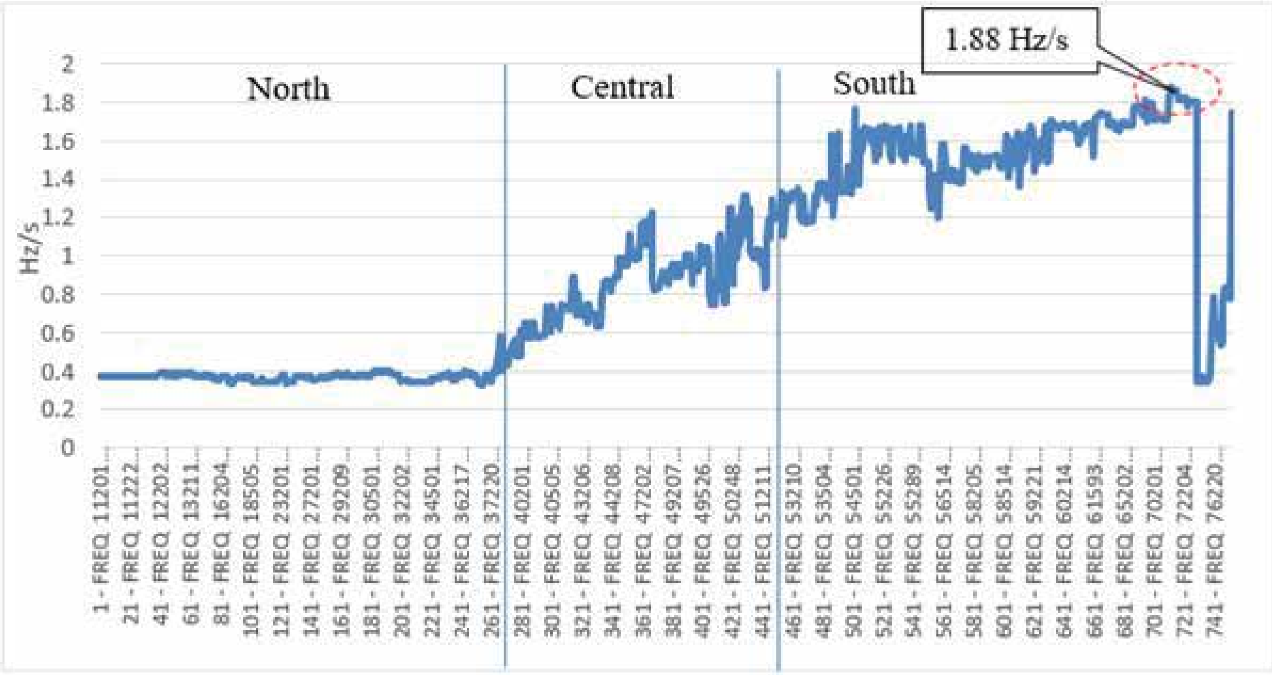


Figure 3-4. RoCoF of every bus in the power system in 2030 – Off-Peak load mode at the night - Contingency in the largest conventional generating unit

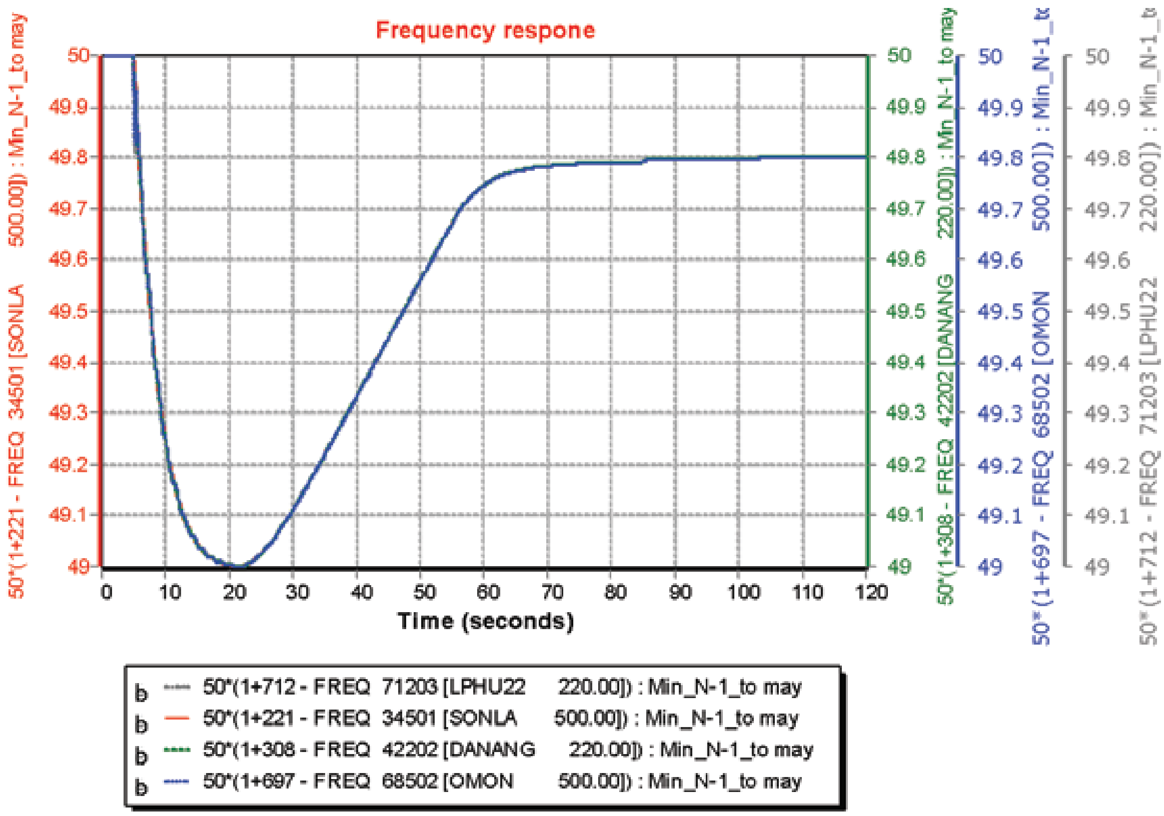


Figure 3-5. Frequency response at some bus of each area – Off Peak load mode at the night - Contingency in the largest conventional generating unit

Day time off-peak load

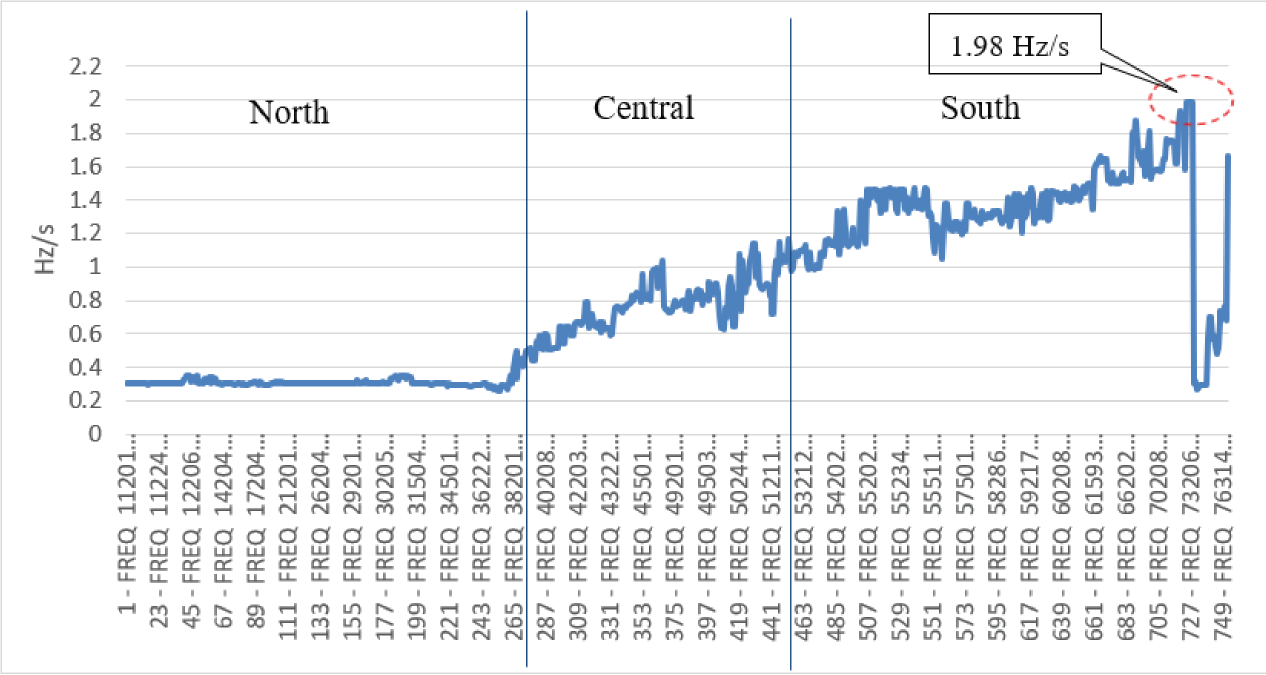


Figure 3-6. RoCoF of every bus in the power system in 2030 – Off-Peak load mode at the day - Contingency in the largest conventional generating unit

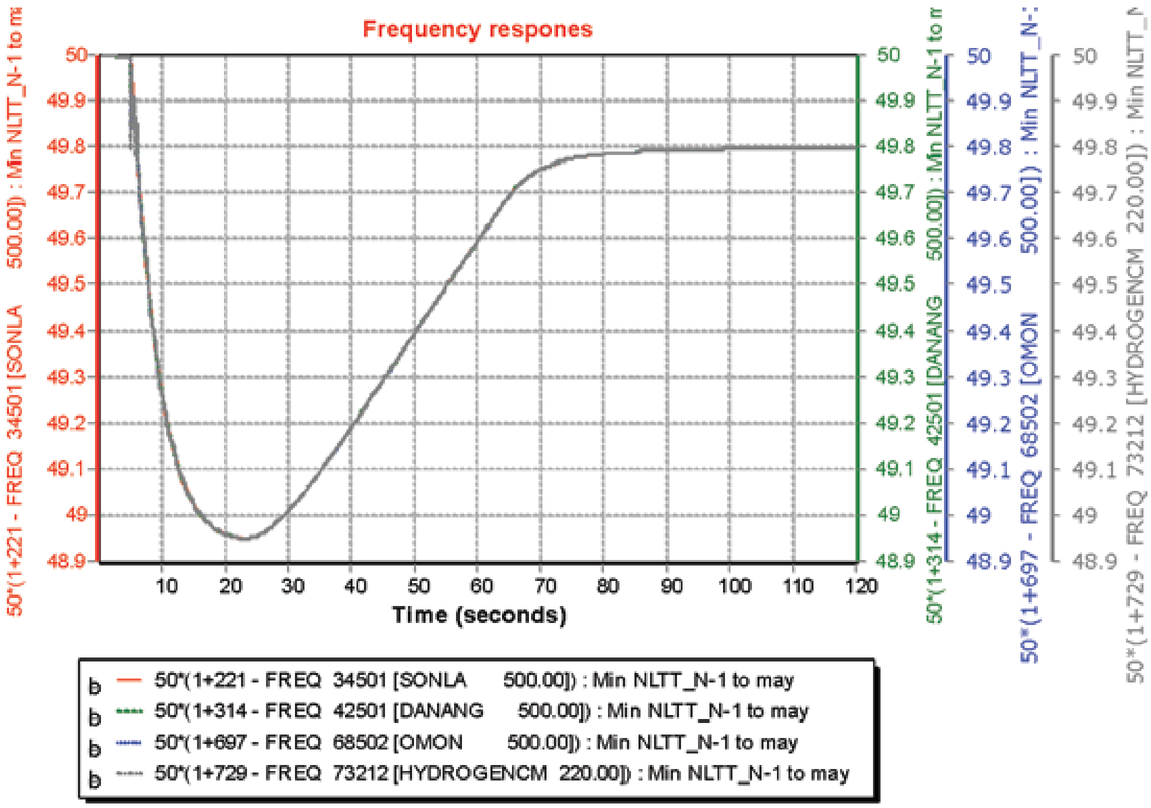


Figure 3-7. Frequency response at some bus of each area – Off-Peak load mode at the day - Contingency in the largest conventional generating unit

According to PDP 8, it is planned to develop about 2500 MW of offshore wind power in the North, and the largest offshore wind farm is about 1000 MW. In this part, the contingency in the largest offshore wind farm in the North is simulated at 5s. The RoCoF and bus frequencies in the whole system in the considered operation modes are collected and summarized in the following figures.

Day time peak load mode

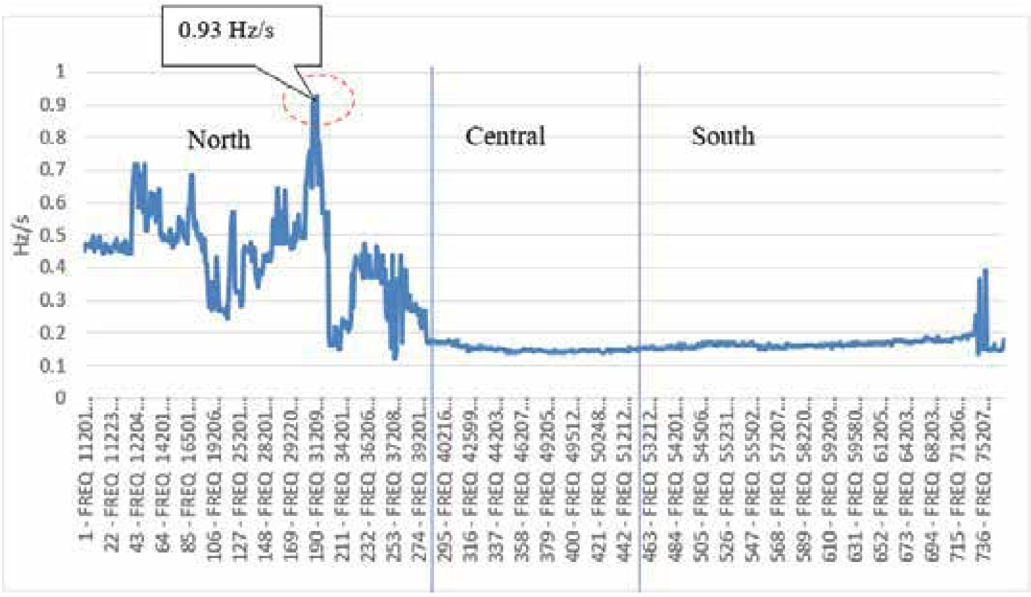


Figure 3-8. RoCoF of every bus in the power system in 2030 – Peak load mode - Contingency in the largest RE PP

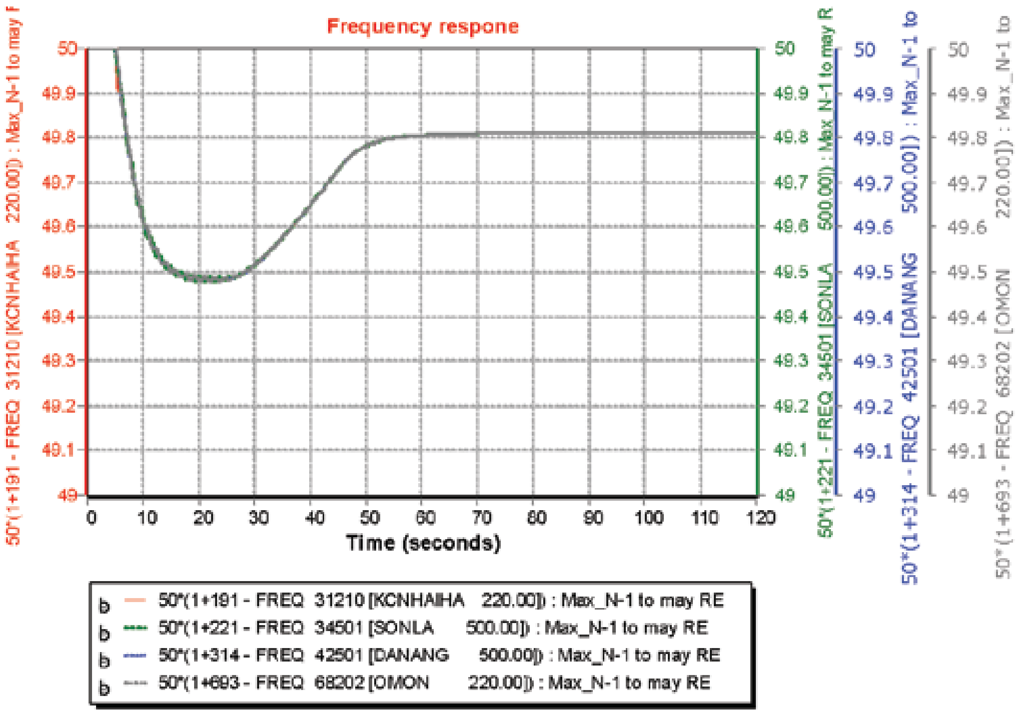


Figure 3-9. Frequency response at some bus of each area – Peak load mode - Contingency in the largest RE PP

Night time off-peak load

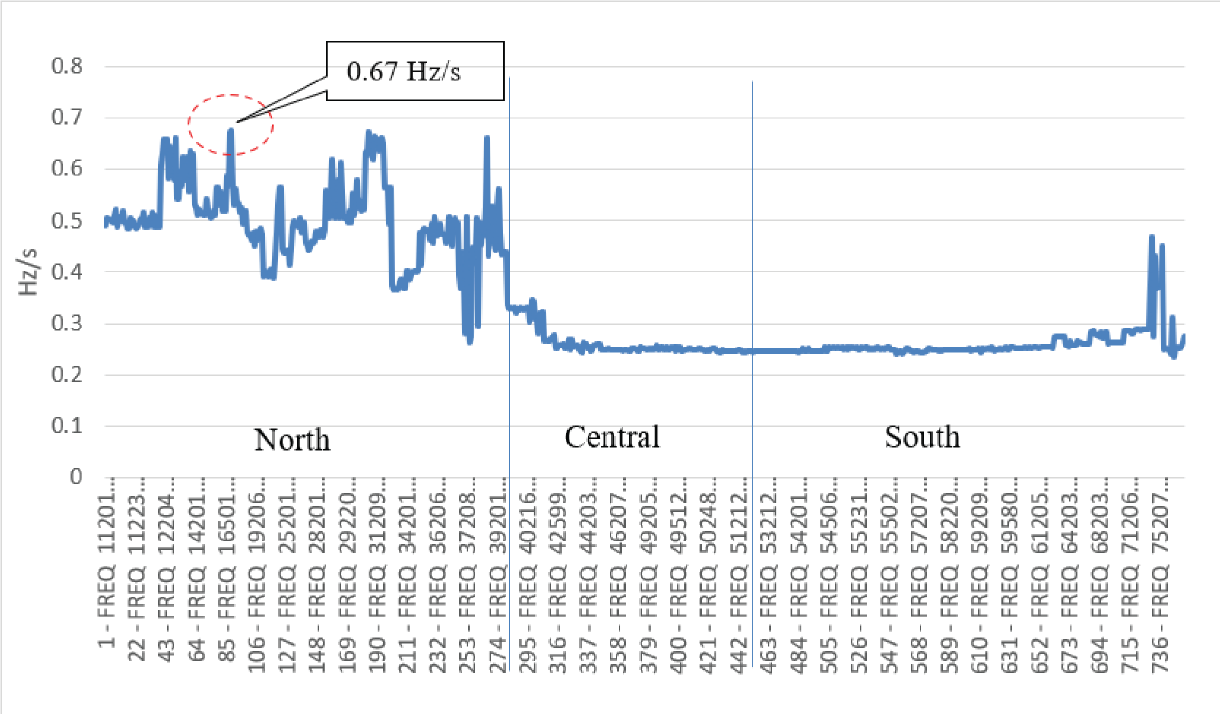


Figure 3-10. RoCoF of every bus in the power system in 2030 – Off-Peak load mode at the night - Contingency in the largest RE PP

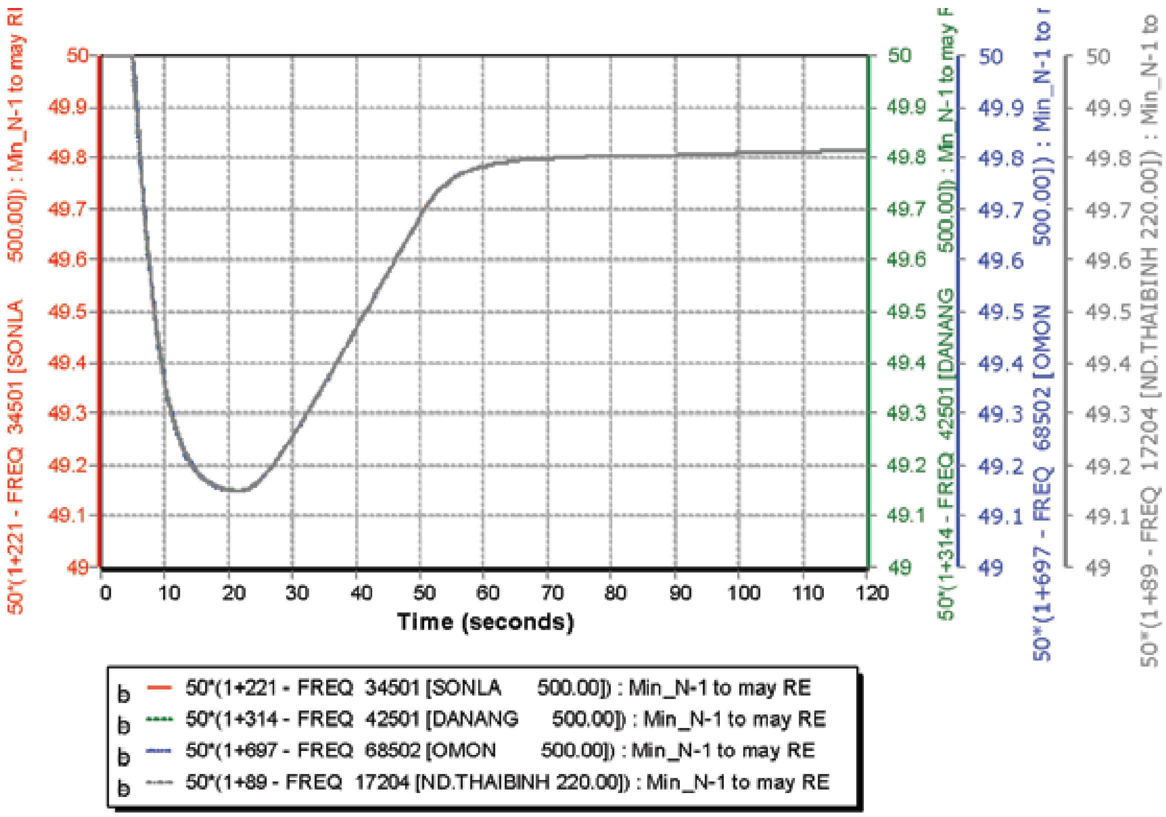


Figure 3-11. Frequency response at some bus of each area – Off-Peak load mode at the night - Contingency in the largest RE PP

Day time off-peak load

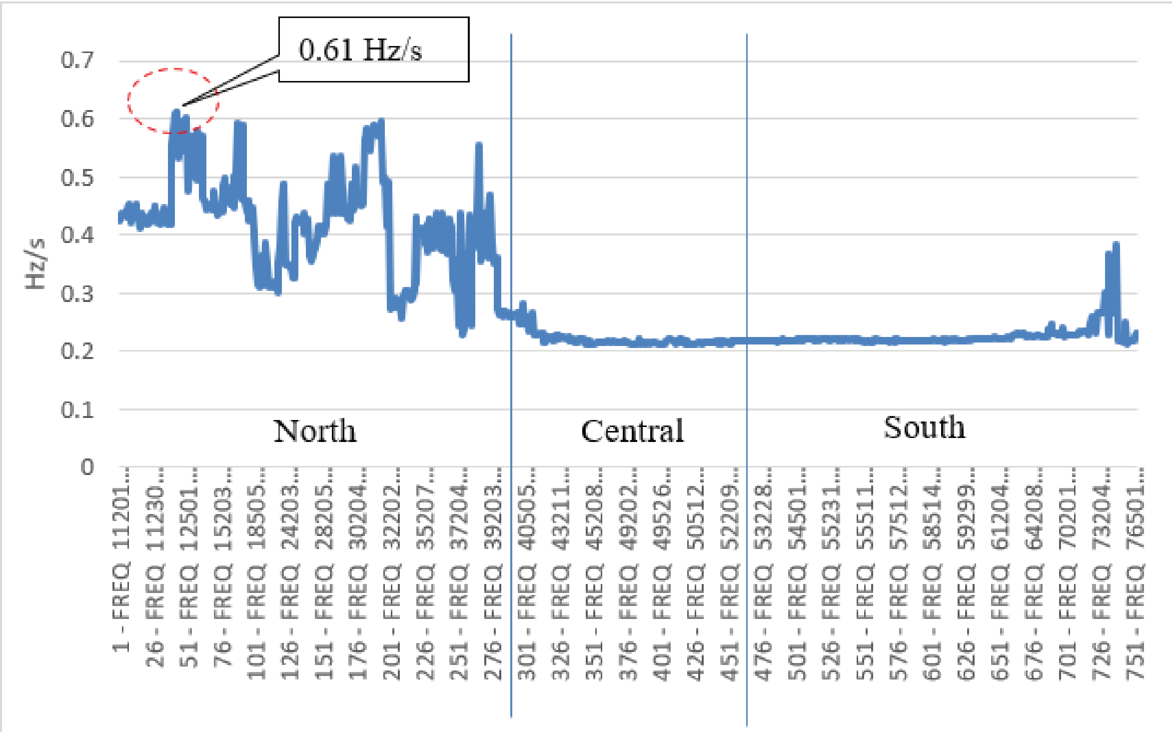


Figure 3-12. RoCoF of every bus in the power system in 2030 – Off-Peak load mode at the day - Contingency in the largest RE PP

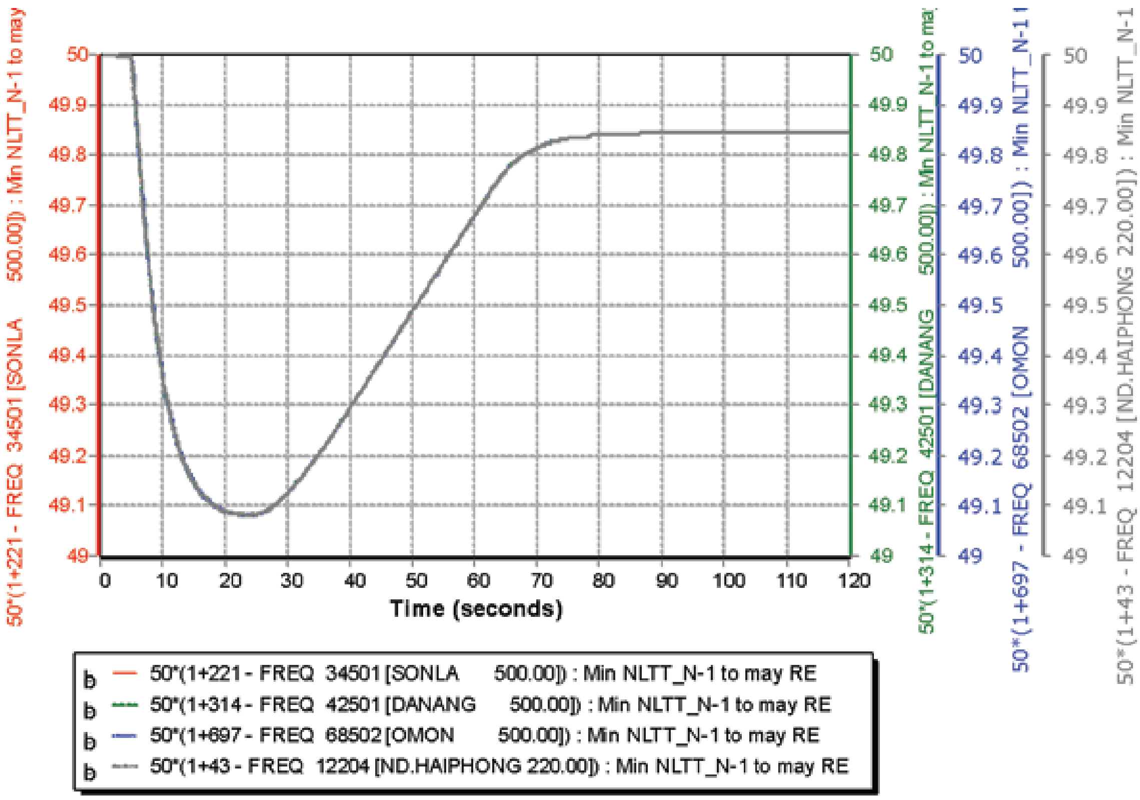


Figure 3-13. Frequency response at some bus of each area – Off-Peak load mode at the day - Contingency in the largest RE PP

3.2.1.1. Comment

From the simulation results, the following comments can be stated:

- The nadir decreases in line with the increase of proportion of RE in the power system.
- The frequency response will be worse in the daytime off peak load with the high proportion of RE in the system.
- There are no significant frequency deviations between buses at different regions.
- The contingency in the largest conventional generating unit – O Mon (1050 MW) is the heaviest contingency due to loss of large inertia. In this contingency, the nadir is about 48.95 Hz (lower than the prescribed nadir of 49Hz), the maximum RoCoF is 1.98 Hz/s in the day time off peak load condition.
- In the largest RE power plant contingency (1000 MW), the nadir drops much lower than with a loss of a conventional unit, because the RE source has a small inertia.
- The conventional power unit with the largest capacity is the O Mon (1050 MW) in the South, so when the contingency in the unit occurs, the RoCoF value will gradually increase from the North to the South. On the contrary, when the incident causes the loss of about 1,000 MW of RE sources in the North, the RoCoF value will gradually increase from the South to the North.

3.2.2. Frequency Response with BESS

In order to find the suitable BESS power rating and placement in Vietnam's power system for frequency stability improvement, the frequency response is firstly simulated under various values of BESS power ratings. After that, the simulation for the selected BESS' rating with various placements is conducted.

3.2.2.1. Frequency Response with Different BESS Ratings

As presented in 3.2.1, the contingency in the largest conventional generating unit (1050 MW) in O Mon power plant in the day time off-peak load condition is the worst contingency, the nadir is under 49 Hz, and RoCoF values at buses in the Southern region are highest. Therefore, in order to find the suitable rating, a BESS is considered to be installed in a 220 kV bus in the Southern power system. The frequency responses with different BESS ratings in the contingencies of largest conventional generating unit and largest RE power plant in the day time off-peak load condition are simulated and shown in the following figures.

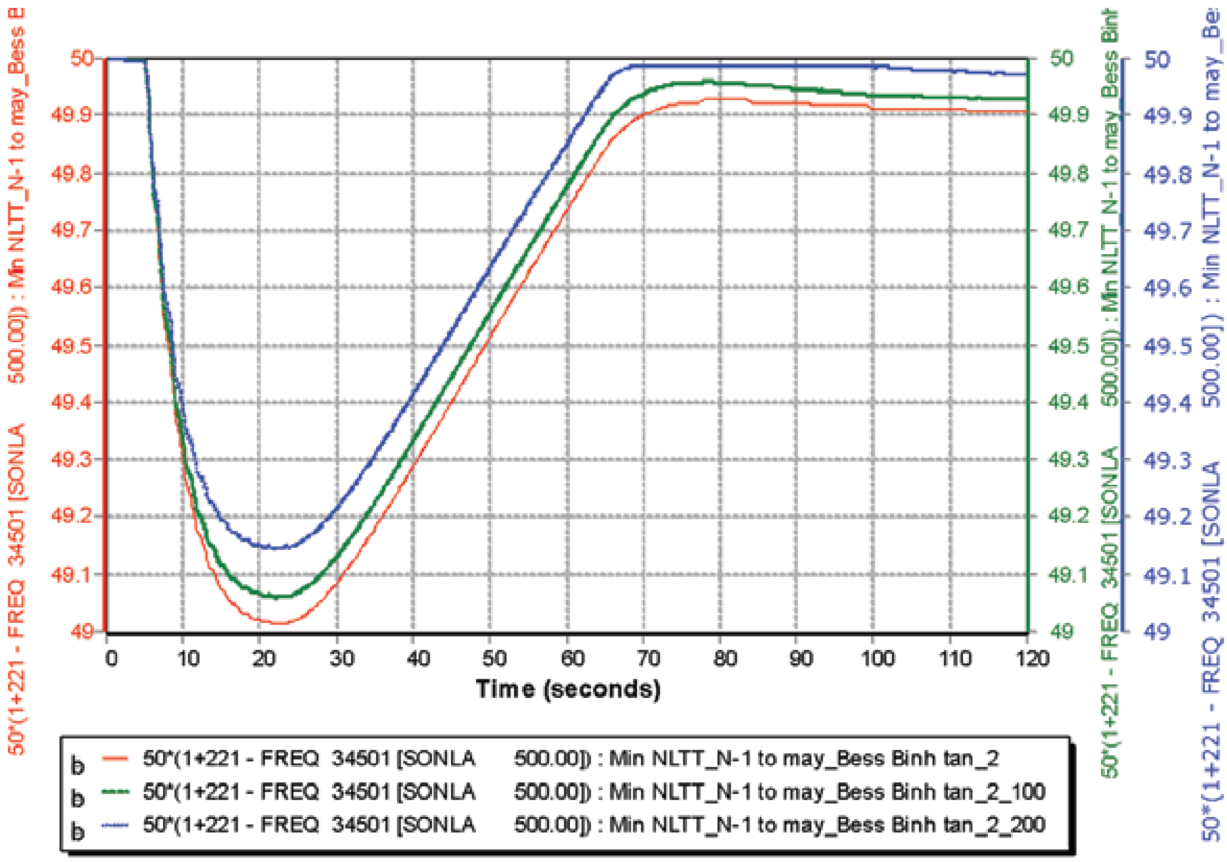


Figure 3-14. Frequency response– Off-Peak load mode at the day - Contingency in the largest conventional generating unit with different BESS capacity

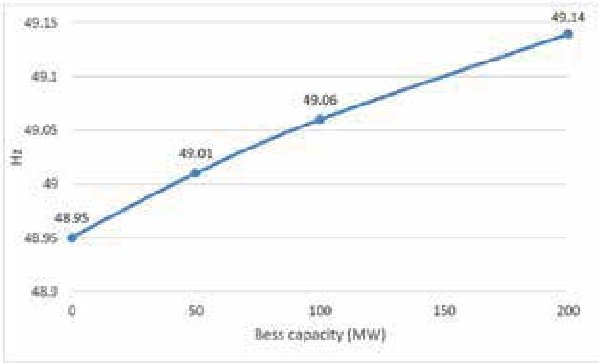


Figure 3-15. Minimum Freq – Off-Peak load mode at the day - Contingency in the largest conventional generating unit with different BESS capacity

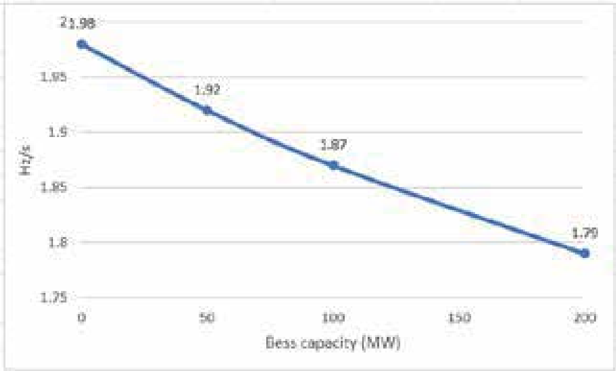


Figure 3-16. Maximum RoCoF – Off-Peak load mode at the day - Contingency in the largest conventional generating unit with different BESS capacity

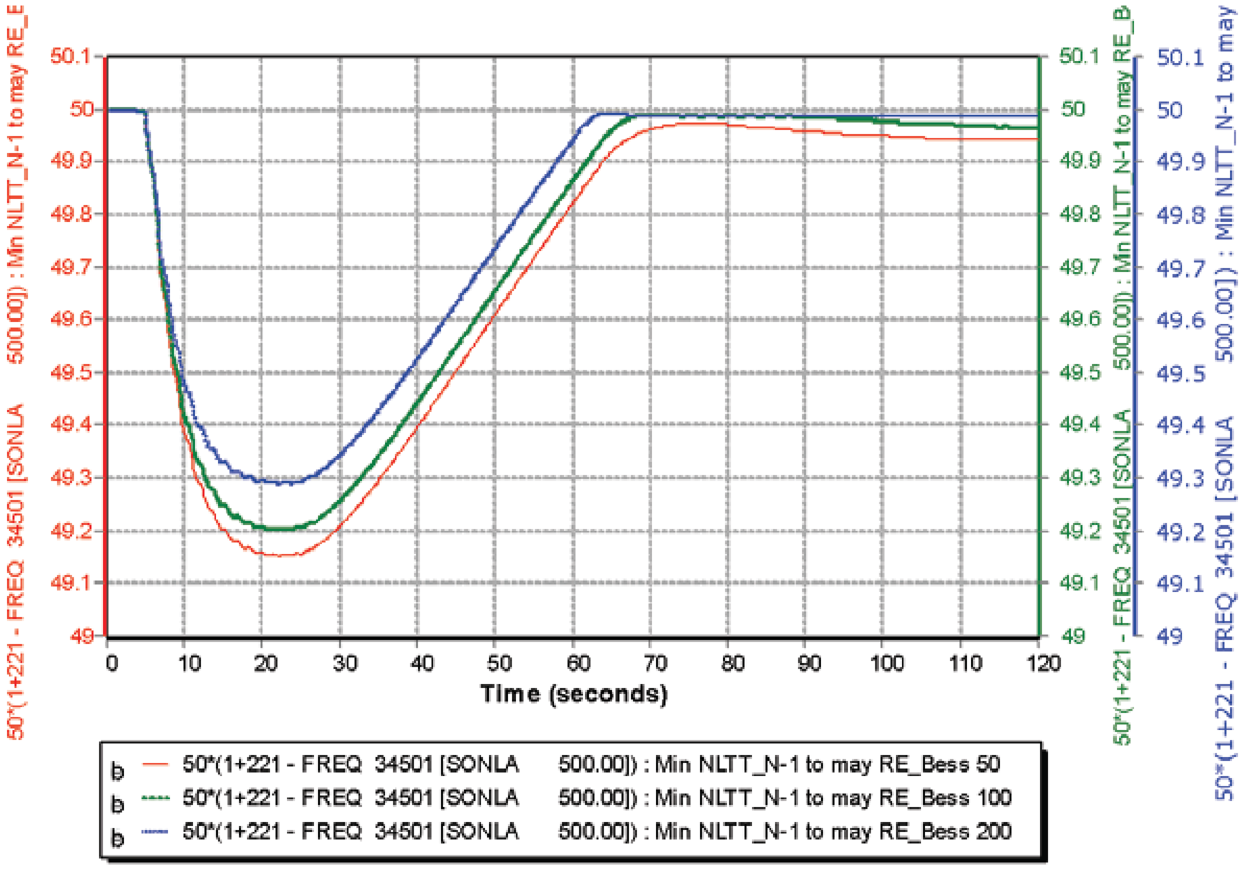


Figure 3-17. Frequency response– Off-Peak load mode at the day - Contingency in the largest RE power plant with different BESS capacity

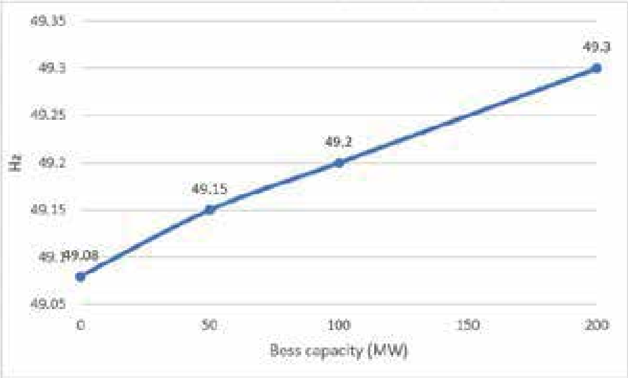


Figure 3-18. Minimum Freq – Off-Peak load mode at the day - Contingency in the largest RE power plant with different BESS capacity

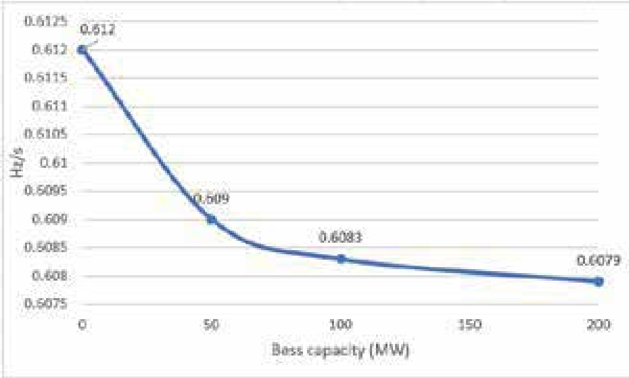


Figure 3-19. Maximum RoCoF – Off-Peak load mode at the day - Contingency in the largest RE power plant with different BESS capacity

Comment

From the above simulation results, it is clearly seen that with the rating of 50 MW, BESS will help to increase the frequency nadir from 48.95 Hz to 49 Hz in case of contingency in the largest conventional generating unit. It also helps to improve the frequency response in the other contingency. When the BESS rating increases, the frequency response is improved. However, the improvement is not significant. Therefore, the suitable BESS rating is selected as 50 MW.

3.2.2.2. Frequency Response with Different Location of BESS

With the rating of 50 MW, BESS is assumed to be installed in the Northern and the Southern power system at Tay Hanoi and Binh Tan 220 kV substation to investigate the impact of the placement on the frequency response. The dynamic simulations are conducted the contingencies of largest conventional generating unit and largest RE power plant in the day time off-peak load condition are simulated and shown in the following figures.

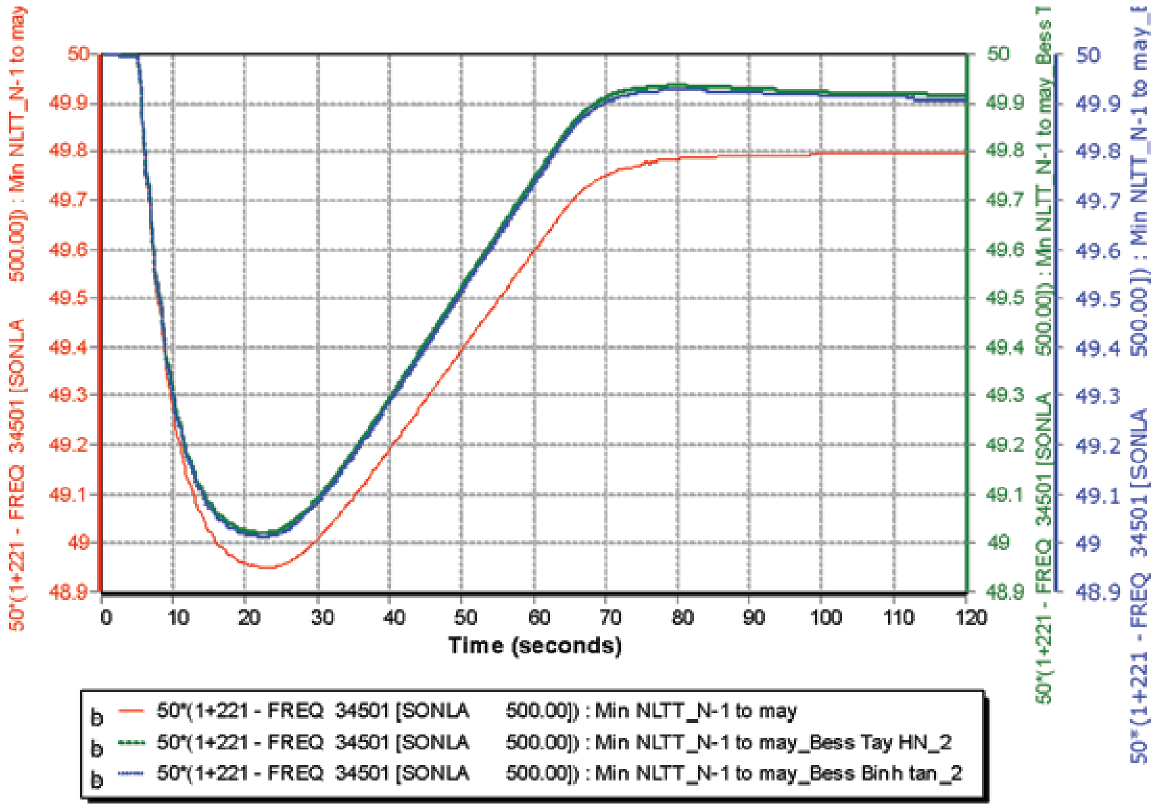


Figure 3-20. Frequency response– Off-Peak load mode at the day - Contingency in the largest conventional generating unit with different BESS location

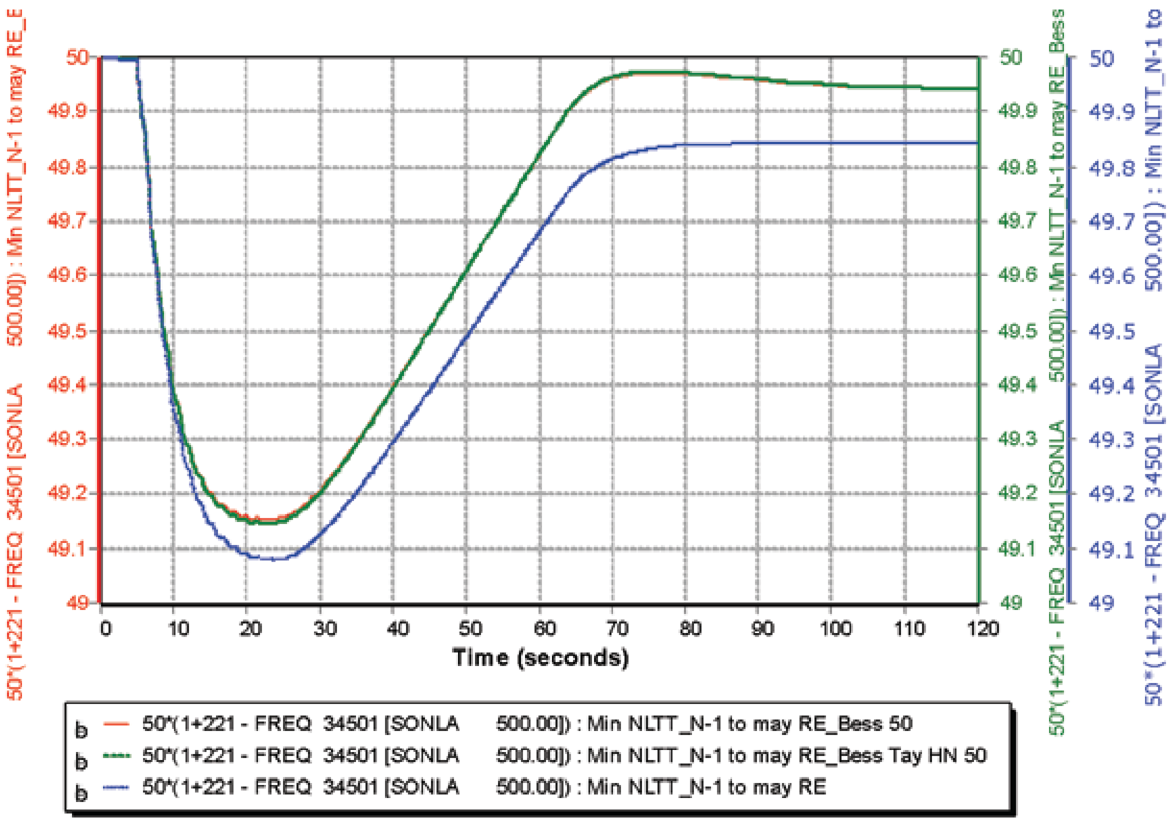


Figure 3-21. Frequency response– Off-Peak load mode at the day - Contingency in the largest RE power plant with different BESS location

Summary of RoCoF values in the calculation cases is as follows:

Table 3-1. RoCoF values in the calculation cases

	Contingency 1050 MW conventional unit in the South	Contingency 1000 MW RE PP in the North
BESS in the North	1.97	0.597
BESS in the South	1.93	0.61

Comment

From the above simulation results, it is clearly seen that the location of BESS does not have much effect on the frequency stability. Therefore, for the frequency stability improvement purpose, **BESS can be installed at every bus in the power system if the land and connection plans are available.**

4. Conclusions and future work

4.1. Conclusions

This report presents the efforts made to firstly analyze the frequency stability problem in Vietnam's power system by 2030 when the renewable energy integration is expected to increase. By dynamic simulation, the RoCoF and nadir of frequency in the system is estimated and compared with the values in Vietnam's technical regulations. After that, the suitable rating and location of BESS are proposed to solve the frequency stability problem in Vietnam's power system.

The simulation results have shown that the suitable rating of BESS is about 50 MW which can help to increase the nadir in the worst contingency of the largest conventional generating unit placed in the Southern system. In terms of the location, BESS can be placed everywhere in the power system to perform the frequency support as long as land and connection plans are available.

4.2. Future Work

BESS is the novel unit in Vietnam's power system which has been just proposed in PDP 8. Therefore, the following studies can be conducted for BESS in Vietnam:

- Pilot BESS project: Study on-land use and the financial mechanism for BESS operation in Vietnam's power system.
- Technical Requirements for BESS in Vietnam: Safety requirements, fire protection requirements, environmental requirements, grid code for BESS.
- Optimal BESS location and capacity based on optimization method (heuristic optimization – for academic study).

5. REFERENCES

- Bộ Công thương, "Thông tư số 25/2016/TT-BCT quy định hệ thống điện truyền tải." Bộ Công thương, 2016.

- K. S. Ratnam, K. Palanisamy, and G. Yang, "Future low-inertia power systems: Requirements, issues, and solutions - A review," Renew. Sustain. Energy Rev., vol. 124, p. 109773, 2020, doi: https://doi.org/10.1016/j.rser.2020.109773.

- D. Fernández-Muñoz, J. I. Pérez-Díaz, I. Guisández, M. Chazarra, and Á. Fernández-Espina, "Fast frequency control ancillary services: An international review," Renew. Sustain. Energy Rev., vol. 120, p. 109662, 2020, doi: https://doi.org/10.1016/j.rser.2019.109662.

- ENTSO-E, "Future system inertia," 2018.