Improving transmission network using renewable resources efficiency by integrating pumped-storage hydroelectricity

Minh Quan Duong*, Tuan Le, Anh Hao Pham, Dinh Thanh Viet, Kim Hung Le

Abstract—Due to the increasing load demand, integrating renewable energy into the power system to satisfy the electrical consumption is the trend to develop the modern power system. However, the uncertainty of renewable energy sources affects the energy transmission efficiency and the reliability of power systems. To get this under control, connecting storage systems such as pumped-storage hydroelectricity is seen to be an efficient solution. In this paper, Python language is used to describe input data and model the Vietnamese power system. The results show the feasibility of the hydro-storage model in improving the power system performance when renewable energy sources are involved.

Index Terms—Pumped-storage hydroelectricity, Power system, Storage, Renewable energy, Operation.

1. Introduction

NOWADAYS, new and modern technologies create more opportunities for countries to develop sustainable and reliable power systems. In which, the rapid development of renewable energy sources forces traditional power systems to change the old ways of operating in response to high levels of penetration of these sources. On the contrary, it also brings many challenges when power systems gradually use renewable energy sources to replace conventional source

Vietnamese power system has the high growth rate of renewable energy installation in the world, reaching 9.6% in the period 2011-2020 [1], although it decreases in 2020 because of the Covid-19 pandemic. By the end of 2020, the total installed capacity of the system will reach 69,342 MW, of which reach 16,428 MW and 538 MW of solar energy and wind energy, respectively. The explosion population has led to an increase in the electricity demand, making it more difficult for the power system to transmit and generate electricity. Besides the benefits of renewable energy, grid integration will be a big challenge for operation and safety, causing system instability with high-level penetration of this source.

Some previous studies have proposed to improve the efficiency of power system operation by methods such as planning to expand transmission lines to release the amount of power generated from renewable energy sources, increase available supported traditional power installations in the event of a sudden loss of power from these sources. However, these planning methods are not sustainable and adversely affect the environment if too many hydroelectric or thermal power generators are installed. For modern power grids with high penetration of renewable energy sources, storage solutions are proving effective in supporting the operation of renewable energy sources [2], [3]. Storage battery technologies are increasingly focused on manufacturing technology, life cycle length, but still cost a lot of investment and quickly degrade with high operating intensity and difficult to control the battery degradation cycle [4]. In order to ensure high reliability and lower cost, pumped-storage hydroelectric models are gradually receiving much attention. With the goal of improving the efficiency of power system operation, this study proposes solutions and implementation based on the model of Vietnam's power system with a high degree of penetration of renewable energy sources in the future by using pumped-storage hydroelectricity to store electricity

Through the Python language, Vietnam's electricity system is built and analyzed based on regional characteristics such as geographical potential, technology, operating costs and load demand of the regions. Specific data provided by Vietnam Electricity Corporation. The economic - technical factors will be assessed through the operation of the electricity market in a short time, taking into account the specific operating costs of the separate connection areas. Besides, the constraint conditions in the model are constantly updated due to the innovation of the system.

A previous study suggested improving efficiency by methods such as line extension, expansion of existing traditional electrical installation capacity. But the above methods face some problems in operation such as Line

Minh Quan Duong, Kim Hung Le, Dinh Thanh Viet and Hao Anh Pham are with the University of Danang - University of Science and Technology, Danang, Vietnam (E-mail: dmquan@dut.udn.vn, lekimhung@dut.udn.vn, dtviet@ac.udn.vn, anhhaobkdn18@gmail.com).

Tuan Le is with Roberval Laboratory, Compiègne University of Technology, France (E-mail: ltuanddgl@gmail.com).

Corresponding author: Minh Quan Duong (e-mail: dmquan@dut.udn.vn)
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overload, which cannot use too many renewable energy sources. However, to ensure stable operation and improve the reliability of the network, the methods of improving the transmission performance of the network should pay attention to the storage method. With the simulation program built on Python programming language [5], detailed analysis functions can be performed on PyPSA:

- Static power distribution;
- Economics - linear optimal power distribution technique;
- Optimization of power distribution with system security constraints;
- Optimizing the minimum total cost for the electrical/energy system based on the current law;

Therefore, this study will propose and propose solutions to improve transmission efficiency on the Vietnamese power grid, based on the Vietnamese power system with a large penetration of energy sources. Future renewable energy uses hydroelectricity to store electricity. Vietnam's power system is modelled in Python language for synthesis and analysis with specific application elements in Vietnam, applied research elements based on regional characteristics such as local management, technology, operating costs and load demand in the regions. Using data provided by Vietnam Electricity Corporation. Short-term performance in the electricity market with prices at each bus bar is also analyzed. Besides, the continuous innovation of system operation is ensured by constraints in the model.

2. Modeling Vietnam's power system

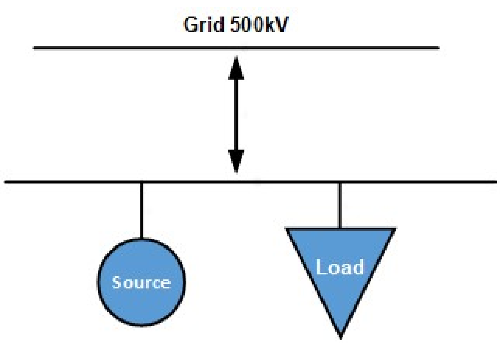

Fig. 1: Elements at a node in Vietnam. One node represents a 500kV substation

The calculation equations of the actual power system model are specifically calculated in the PyPSA framework, using linear optimization to minimize the annual investment and operating costs under technical and physical constraints. The nodes in Vietnam except the BacAi node in the model are connected to each other by a high-voltage transmission line combined with source, and load Fig. 1 The generator installed capacity, storage capacity and transmission capacity must all operate under the constraints of the optimization process and be ready for the capacity manoeuvring of each generating set in every hour. Hourly updated weather data and load graphs along with the assumption of absolute accuracy in future forecasting are considered to establish the most optimal calculation process.

2.1. Objective function

The topic focuses on model Vietnam's electricity system in the future, when renewable energy is expected to penetrate strongly into the traditional power grid, requiring the old power system to be upgraded and opened. wide. The linear optimization method of the total annual cost expressed by equation (1) [6] is based on the planned expansion of the transmission system and the penetration of renewable energy sources in the future:

$$\min_{G_{n,s},E_{n,s},F_l,g_{n,s,t},f_{l,t}} \left(\sum_{n,s} c_{n,s} G_{n,s} + \sum_l c_l F_l + \sum_{n,s,t} o_{n,s,t} g_{n,s,t} + \sum_{l,t} o_{l,t} f_{l,t} \right) \quad (1)$$

In which nodes are denoted by n, source technology is s, time of year is t, transmission line connecting between nodes is l. Then the total annual operating cost includes: Annual fixed cost $c_{n,s}$ correspond to the installed capacity $G_{n,s}$; Annual fixed cost c_l correspond to transmission limit F_l of the line; Cost $o_{n,s,t}$ depends on the ability to dispatched $g_{n,s,t}$ and cost $o_{l,t}$ depends on the power to be distributed $f_{l,t}$ on the line l.

2.2. Generator constraints

Energy demand $d_{n,t}$ at each node n must be response at each time t by transmitter and local storage $f_{l,t}$ coming from the branches l connected.

$$\sum_s g_{n,s,t} + \sum_l \alpha_{l,n,t} f_{l,t} = d_{n,t} \quad (2)$$

with $\alpha_{l,n,t} = -1$ if branch l start at node n and $\alpha_{l,n,t} = \eta_{l,t}$ if branch l ends at node n; with $\eta_{l,t}$ is the branch power transmission efficiency factor l.

Mobilization capacity $g_{n,s,t}$ of transmitter or storage is limited by the installed capacity $G_{n,s}$ and availability depends on time $\overline{g}_{n,s,t}$ and $\underline{g}_{n,s,t}$ with relative units according to installed capacity $G_{n,s}$

$$\underline{g}_{n,s,t} G_{n,s} \le g_{n,s,t} \le \overline{g}_{n,s,t} G_{n,s} \quad \forall n,s,t \quad (3)$$

with the traditional power supply type, the power source is available flexibly fixed at $\underline{g}_{n,s,t} = 0$ and $\overline{g}_{n,s,t} = 1$. With a variable type of renewable energy source such as wind or solar, time changes $\overline{g}_{n,s,t}$ reflects the available power depending on time. With storage system $\underline{g}_{n,s,t} = -1$ and $\overline{g}_{n,s,t} = 1$.

Installed capacity $G_{n,s}$ optimized with the limit of minimal geographic potential $\underline{G}_{n,s}$ = and maximum $\overline{G}_{n,s}$.

$$\underline{G}_{n,s} \le G_{n,s} \le \overline{G}_{n,s} \quad \forall n,s \quad (4)$$

Storage power $e_{n,s,t}$ of storage units must match mobilization per hour of operation and be limited by storage capacity $E_{n,s}$

$$e_{n,s,t} = \eta_0 e_{n,s,t-1} - \eta_1 [g_{n,s,t}]^- - \eta_1^{-1} [g_{n,s,t}]^+ \quad (5)$$

with $e_{n,s,t-1} \leq E_{n,s}$. Beside, the transmission current on the line must also comply with the condition

$$|f_{l,t}| \leq F_l \quad \forall l \tag{6}$$

Line upgrade limits for specific conditions:

$$F_{l,opt} \leq F_{l,max} \quad \forall l \tag{7}$$

With the characteristics of Vietnam 500kV power grid when upgrading a line circuit, the Vietnam Electricity Corporation propose a method of parallel upgrading the same pylon to create a uniform line circuit and double the transmission capacity, therefore:

$$F_{l,max} = 2F_l \quad \forall l \tag{8}$$

3. Data

3.1. Network structure

The electrical power transmission system of Vietnam includes voltage levels of 500 kV, 220 kV and 110 kV. To simplify the calculation scenario, this study focuses on the 500Kv grid after converting the voltage levels to the same unit. Featuring a 500 kV power transmission system with a total length of 4670 km from North to South, creating favorable conditions for the transmission and exchange of electricity between the North, Central and South regions. The extended scope in this study covers the period up to 2025. In order to have an overall picture of the power system operation, the transmission grid needs to be simulated up to 2025. However, the current grid database is still quite limited. Line and substation projects are approved in the Power Master Plan 8 [7].

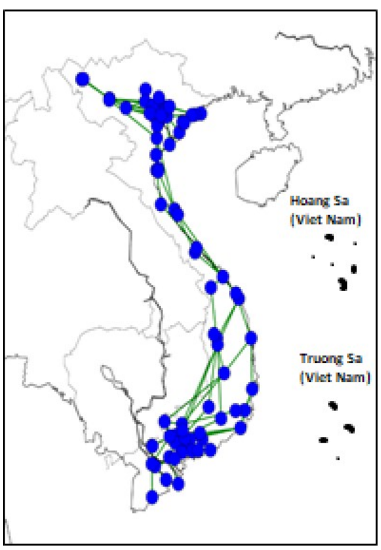

Fig. 2: Elements at the node in Vietnam

In this study, the 500 kV distribution grid will be modeled. The generating units and the demand for connection to the distribution grid will be equivalent to 500 kV busbars in the transmission grid. We simulate a 500 kV grid using power flow through 500 kV transformers in Fig. 2.

Demand nodes in the power system are identified against the modified PDP8 database [7]. Load updates against PyPSA model, to provide a snapshot of grid activity, most similar to PyPSA model results.

3.2. Loads and Generators

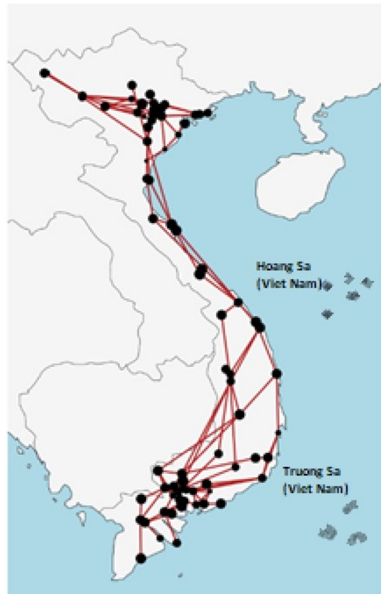

Fig. 3: Load distribution at each node and line

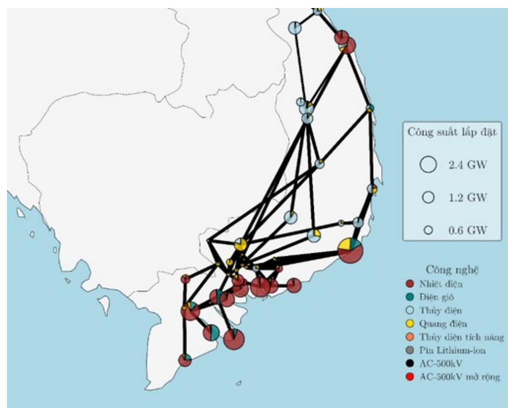

Fig. 4: Distribution of installed capacity of generators in the South of Vietnam by 2025

In the scope of the study, the power system model that is put to the test is the 500 kV power transmission system of Vietnam. Model taking parameters and data from 500kV voltage level is optimized according to formula (1) - (7) tested and simulated on PyPSAframework. According to the national electricity development plan for the period 2011-2025, after simulation, the power demand is proportional to the magnitude at each bus, the transmission capacity of each bus to each other are shown in color of the lines in Fig. 3.

Distribution of 500 kV substation-mounted renewable energy plants in their supply areas with installed capacity, capital and marginal costs derived from variable operating and maintenance costs plus operating costs and fuel cost in the future are shown in Fig. 4.

According to the forecast of the Electricity of Vietnam, by 2020 and 2025, the total capacity of generating sources can be developed, which is clearly presented in Table 1.

TABLE 1: Model inputs based on future projections

Type of power	Capacity in 2020 (GW)	Capacity in 2025 (GW)
Thermal	38	66
Hydro	22	29
Wind	5	12
Solar	5	6

3.3. Pumped-storage hydroelectricity

Electrical energy can be stored through pumped storage hydroelectricity, in which large quantities of water are pumped to higher floors, to be converted back into electrical energy using generators and turbines when the electrical energy is in short supply Fig. 5. The Advantages and disadvantages are mentioned below [8].

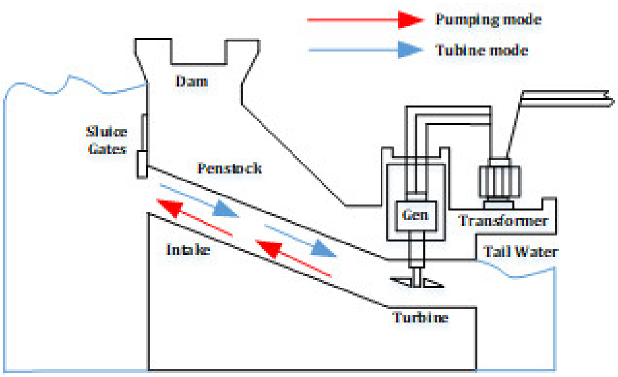

Fig. 5: Working principle of Pumped-storage hydroelectricity

Advantages:

- Increasing the efficiency of the system, when taking advantage of the excess power of thermal power plants during off-peak hours, helps to increase operational efficiency and stabilize the operation of these plants.
- Quick response when load demand increases.
- Flexibility in adjusting operating capacity according to load demand.

Disadvantages:

- Operation efficiency is not high (about 70-80%).
- Hard to find a construction and installation site.

Pump storage projects around the world are contributing significantly to the balance of large increases in volatile renewable energy production in the future (wind and solar). This technology has been established and commercialized on a large scale (up to 4000 MW), and the storage efficiency is usually around 70-85%. Therefore, the energy stored by this technique can be calculated via equation (9); The general equation for the output power P is shown in the equation (10). The BacAi node in the model is connected by a high-voltage line associated with source, pumped-storage hydroelectricity and load Fig. 6.

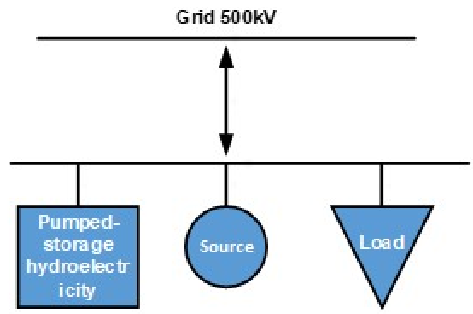

Fig. 6: Components at node BacAi

In these equations, Q is the volume flow through the turbine m^3/S, ρ is the density of water $[kg/m^3]$, and η is the hydraulic efficiency of the turbin $[\%]$. The acceleration due to gravity and the height are expressed as respectively $g[m/s^3]$ and $h[m]$

$$W = mgh \tag{9}$$

$$P = Qh\rho g\eta \tag{10}$$

4. Calculation result to improve transmission network performance in Vietnam

In order to be able to analyze and evaluate the transmission capacity on the line, the author proposes the scenario of creating the maximum overload current by letting the transmission system operate at a specific peak hour frame of the day, according to data provided at 11 a.m. on January 2, 2025 [9], [10]. After the simulation, the load demand is proportional to the strength per busbar and the carrying capacity of each busbar is shown by the corresponding colour.

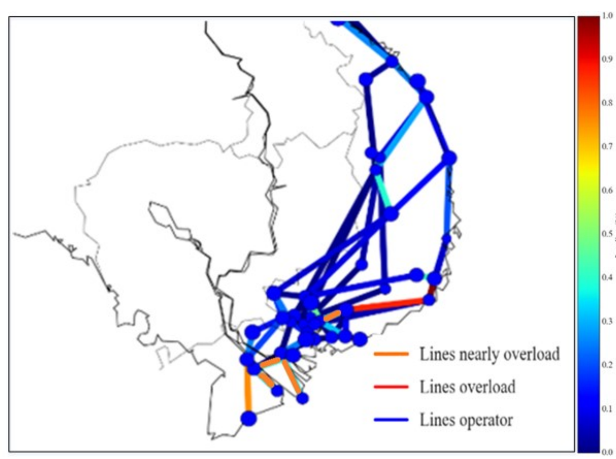

Fig. 7: Distributed load and future transmission status

It can be seen that in the south, the lines are carrying a large amount of electricity, of which the blue line is the normal operating line, the red line carries over 90% of the capacity and the orange line is from 80%. Up to 90% of rated power Fig. 7. Details of feeders that are overloaded when load consumption is high during peak hours are shown in Table 2

TABLE 2: The capacity of the overload lines at time t

Bus 0	Bus 1	Power nominal (MVA)	Actual results (MW)	Ratio (%)
VinhTan	BacAiPSH	1732	1599.25	92%
VinhTan	NhaTrang	1732	1732.25	100%
NhaTrang	NinhHoa	1732	1732.00	100%
CaMau	RachGia	1732	1512.68	87%
RachGia	BacLieu	1732	1393.68	80%
VinhLong	TraVinh	1732	1401.48	81%

It can be seen that the southern transmission lines have overloaded phenomena. The main reason is that this is a key economic region, where a large number of large industrial parks are concentrated, so the demand for electricity is extremely large, leading to overload of transmission lines. For that reason, this study focuses on solving the problem of optimizing the working efficiency of the Vietnam grid by integrating pumped-storage hydroelectricity into the grid.

5. Pumped-storage hydroelectricity in BacAi area.

BacAi belongs to the list of power source projects approved and adjusted by the Prime Minister in the National Power Development Master pumped-storage hydroelectricity project Plan for the period 2011 - 2020 with a vision to 2030.

- Construction site: BacAi district, Ninh Thuan province, 65km from Phan Rang - Thap Cham city to the west-northwest;
- Scale: Capacity 1,200MW (300MW x 4 units);
- Total investment: More than 21 trillion VND;

When using the method of integrating pumped-storage hydroelectricity into BacAi area, it will overcome overloaded and "coming soon" overloaded lines in the South and in addition, it will also help store excess renewable energy generated out. Enhance the ability to meet high load demand and the rapid development of renewable resources in the future.

After integrating, Fig. 8 shows that the transmission lines have been improved in terms of maximum transmission capacity and ensure the target functions as shown above. The specific capacity of these lines is shown in Table 3.

TABLE 3: The capacity of the overload lines at time t

Bus 0	Bus 1	Power nominal (MVA)	Power optimal (MW)
VinhTan	BacAiPSH	1732	2247.77
VinhTan	NhaTrang	1732	2014.18
NhaTrang	NinhHoa	1732	1832.60
CaMau	RachGia	1732	1812.68
RachGia	BacLieu	1732	1993.68
VinhLong	TraVinh	1732	1801.48

The data in Table 3 show that the results obtained from overloaded and "nearly" overloaded lines on the southern in Table 2 are fully offset. At this point, the low-load lines are already safe or high to compensate for the overloaded lines.

The line capacity expansion in the system has changed the current. This allows power transmission on overloaded and "nearly"-overload lines in case of current optimization with the old transmission system share adjacent lines. Therefore, operating safety will be improved and respond to the development of power and load.

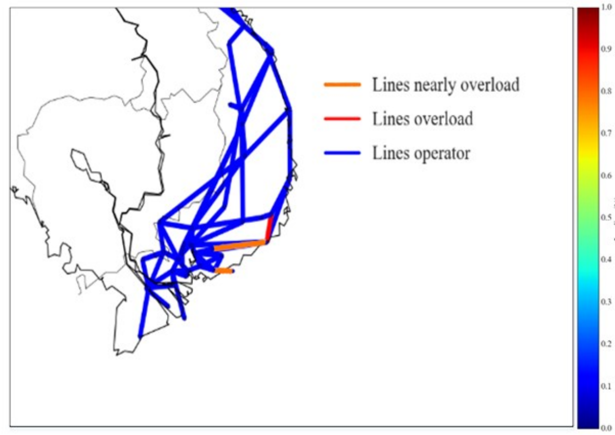

Fig. 8: Line after integrating pumped-stored hydroelectricity

6. Conclusions

This paper studies and proposes a method of using stored hydroelectricity to connect to Vietnam's electricity grid in the future, meeting the large penetration from renewable energy sources. The proposed method has overcome problems such as line overload, not using many renewable energy sources. Besides, improving stability during operation, improving operational safety and meeting the development of capacity and load in the future, improving transmission efficiency.

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Minh Quan Duong received his B.E. (2008) in Electrical Engineering Department at the University of Danang, University of Science and Technology, Vietnam, and M.S. (2012) degrees in Electrical Engineering at Dongguk University, Seoul, South Korea; and Ph.D. degree (2016) in Electrical Engineering at Politecnico di Milano, Milan, Italy. His research interests include Renewable Energy in Power system, Planning and Smart Grid.

Tuan Le received his B.E. (2020) at the University of Danang - University of Science and Technology (DUT), Vietnam. He is working toward the Ph.D. degree at Roberval Laboratory, Compiègne University of Technology, France. His research interests include Power system optimization and Machine learning.

Hao Anh Pham is working toward the B.E. degree at the University of Danang - University of Science and Technology (DUT), Vietnam. His research interests include Renewable Energy in Power system and Microgrid.

Dinh Thanh Viet received his B.E. in Vinnytsia Polytechnic University, Ukraine; and Ph.D. degree (1997) in Vinnitsa National Technical University – Ukraine. Now, he is Associate Professor, and is active in teaching at the University of Danang. His research interests include Renewable Energy in Power system, Power quality, Storage and Smart grid.

Kim Hung Le received his B.E. (1980 at the University of Danang - University of Science and Technology (DUT), Vietnam, M.S. (1992) and Ph.D. (1995) degrees at Grenoble National Institute of Polytechnic (France), respectively, all in electrical engineering. In 2014, he got the title of Professor, the highest title of academic system in Vietnam. Now, he is lecturer of Faculty of Electrical Engineering. His current research interest lies in the area of electrical engineering with special emphasis on power system transmission protection and control, and power system analysis, and power system operation with distributed generators. Prof. Kim Hung Le is an author/co-author of five textbooks, eight research projects, and over 90 journal and conference papers.