A Cost-Optimal Pathway to Integrate Renewable Energy into the Future Vietnamese Power System

Dinh Thanh Viet, Vo Van Phuong, Minh Quan Duong, Ma Phuoc Khanh, Alexander Kies, and Bruno Schyska

Abstract - ***The Vietnamese power system is expected to expand considerably within the upcoming decades with a large scale penetration of renewable energy. This paper presents the techno-economic model to optimize investment and operation costs for the Vietnamese power system with the integration of wind and solar power within one decade. A simplified 46-bus Vietnamese power system has been tested to validate the model which minimizes the total annual system investment and operation costs. The cost-optimal case shows the possible location, total wind or solar capacity installed at each bus, and satisfies the power balance, transmission lines capability and system reserve. The paper results can be used for Vietnamese power system planning and grid expansion with a reasonable integration of renewable energy.***

Keywords: ***renewable energy; wind energy; solar energy; grid expansion; Vietnamese power system.***

I. INTRODUCTION

In modern society, energy plays a very important role in economic development and human needs. However, as fossil-fuel resources are gradually depleted, and with strong commitment of the countries in sustainable development strategy, renewable energy is the inevitable choice today. Among different types of renewable energy, wind and solar energy are dominant sources in practice.

In Vietnam, the Prime Minister has approved the revised National Electricity Development Plan for 2011-2020 with a vision to 2030. In this plan, the expected demand of electricity is 235-245 billion kWh in 2020, 352-379 billion kWh in 2025 and 506-559 billion kWh in 2030, based on an average annual growth rate of 8.0-8.7% per year. To meet this new demand, the system capacity is planned to increase to 60,000 MW by 2020 and 129,500 MW by 2030. The revised plan also emphasized the priority of developing renewable energy sources for power generation, increasing the proportion of electricity produced from renewable energy sources at about 7% by 2020 and more than 10% by 2030 [1], [2]. Data for wind and solar power development in Vietnam by 2030 is presented in Table 1 [1].

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According to Wilson and Biewald [3], the need for new resources must be identified by a multi-step process, including analysis of load forecast data, the existing resources as well as consideration of supply, demand, grid transmission and distribution capacity (T&D) (Fig. 1).

TABLE 1. DATA OF WIND AND SOLAR ENERGY DEVELOPMENT PLANNING IN VIETNAM

Energy source	Power (MW)			Percentage of energy production		
	2020	2025	2030	2020	2025	2030
Wind	800	2,000	6,000	0.8	1.0	2.1
Solar	850	4,000	12,000	0.5	1.6	3.3

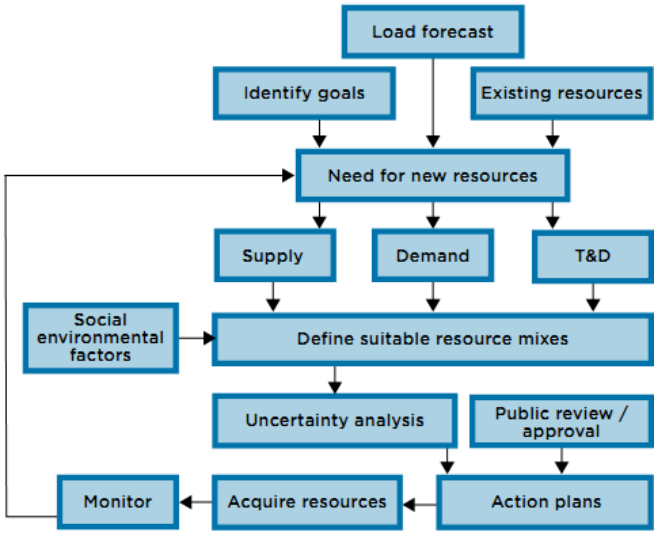


Figure 1. *Flow chart for integrated resource planning*

In the guidance of the International Renewable Energy Agency (IRENA) [4], there are four key stages in the cost-effective planning process for power sector transition as follows:

- Long-term generation expansion planning (typically spanning a period of 20-40 years),
- Geo-spatial planning for transmission (typically spanning a period of 5-20 years),
- Dispatch simulation (typically spanning a period of weeks to several years),
- Technical network studies (typically spanning up to five years).

At present, the planning process of renewable energy sources in Vietnam is still implemented under the method of

bottom up, where renewable energy potential in the local provinces and cities is discovered and reported for planning. This approach faces big challenge that it does not match development of the existing configuration and capacity of the transmission lines systematically. Consequently, a system approach in power sources planning must be considered in composition with the transmission grid expansion. Besides, renewable energy planning strongly depends on the location with weather data.

In this research, the dispatch of generators is optimized using the linear optimal power flow, then a non-linear power flow is run on the resulting dispatch. The cost-minimizing integration of wind and solar pairs well with the daily variation of wind speed and solar radiation while thermal and hydropower balance the seasonal variation of demand. There are different solutions to integrate renewable energy into existing power system by optimizing the mix of generation from different renewable sources [5]-[10]. In order to integrate the power generation sources, especially renewable energy, into the Vietnamese power system in the future, optimization of the investment cost and operating system cost for dispatch and technical network studies until 2020 is a new approach for solving problem of Vietnamese power sources planning.

II. METHODOLOGY

A. Objective function

In this paper, the planning for the development of renewable energy sources into Vietnamese power system in the future is optimized. The objective function of the problem is to minimize the cost of investing and operating power plants, as shown in formula (1) [2]:

$$\min_{g,G,f,F}\left[\sum_l c_l.F_l + \sum_{n,s} c_{n,s}.G_{n,s} + \sum_{n,s,t}\left(o_{n,s}.g_{n,s,t}\right)\right] \quad (1)$$

where

- $c_{n,s}$ is the expansion cost of 1 MW for plant s at bus n,
- $G_{n,s}$ is the rated power of the plant s at bus n,
- c_l is the cost of expanding the transmission capacity of the line l by 1 MW,
- F_l is the transmission capacity of the line l,
- $o_{n,s}$ is the marginal cost for the plant at bus n,
- $g_{n,s,t}$ is the power of the plant s at bus n at time t,
- n is the bus in power system,
- s represents the type of power plant in the model.

B. Constraints in power system

In order to ensure the economic operation and stability of the whole system, the relevant constraints in the power system must be satisfied.

Constraint on power generation capacity of power plants are shown in formula (2):

$$0 \le g_{n,s,t} \le G_{n,s} \quad (2)$$

For wind and solar power plants, the output power at time t is also limited in relationship with weather conditions such as formula (3):

$$0 \le g_{n,s,t} \le \partial_{n,s,t} G_{n,s} \quad (3)$$

where $\partial_{n,s,t}$ is the maximum power generation coefficient of the plant s at time t. This coefficient is determined by the weather conditions at time t.

$$0 \le \partial_{n,s,t} \le 1 \quad (4)$$

The power balance constraint at the bus n is described in formula (5):

$$\sum_s g_{n,s,t} - d_{n,t} = \sum_l K_{n,l} f_{l,t} \ \forall n \quad (5)$$

where $d_{n,t}$ is the load at bus n at time t; K is the incident matrix of the power system and $f_{l,t}$ is the power transmitted through line l at time t.

In addition, the constraint on transmission capacity of the lines must also be complied with formula (6):

$$|f_{l,t}| \le F_l \ \forall l \quad (6)$$

III. CASE STUDY: VIETNAMESE POWER SYSTEM IN THE YEAR OF 2020

A. Simplified Vietnamese power system

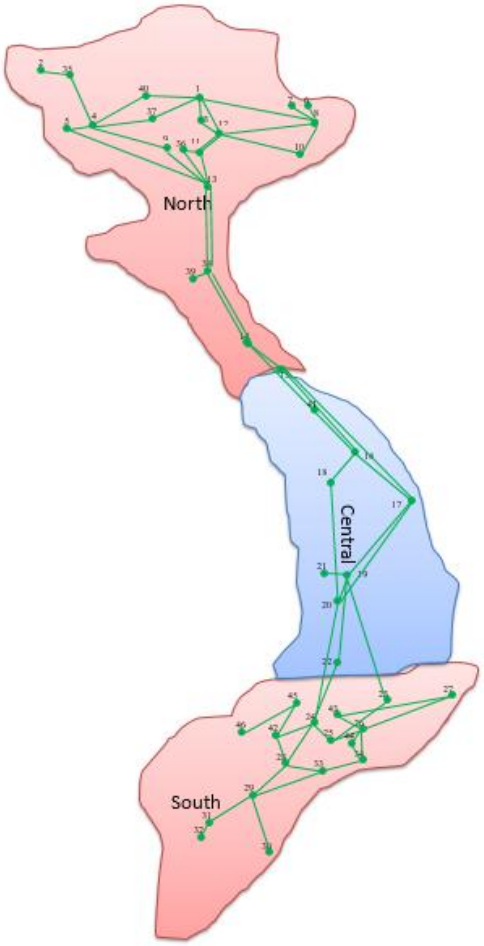


Figure 2. *Simplified 46-buses Vietnamese power system*

In order to study the planning for large system, it is necessary to eliminate small details, focusing on the important components. For a systematic planning study, we use a simplified Vietnamese power system, consisting of 46 buses with the voltage of 500kV, as shown in Figure 2.

In this section the input data for the simplified Vietnamese power system - 46 are described. Table 2 and 3 in Appendix summarizes the different investments the model can make, their costs, efficiencies, generator power, load buses and other parameters. The buses are connected together through the transmission lines.

B. System parameters

The power source and load parameters at buses as well as transmission line parameters are collected from the National Load Dispatch Centre of Vietnam according to actual operational data. These data are then combined with load forecasting information and data from the Vietnam's Renewable Energy Development Strategy to 2030 with a vision to 2050 to develop data sets in 2020 for the calculation program [11].

C. Other database

Power generation capacity of wind power plants depends on wind direction, wind speed, turbine installation height and a number of other factors. Similarly, the capacity of solar power plants depends on the intensity of the solar radiation, radiation angle and other weather factors. In order to facilitate the computation, the maximum power generation coefficient $\partial_{n,s,t}$ is collected based on global database MERRA, including parameters, which depend on the location of renewable energy sources. In this model, the hourly power generation coefficient for the wind farm is calculated using the assumption that the it uses a turbine with a height of 80m. The power output of the solar power plant at each hour of the day is calculated, assuming that the solar panels were inclined 35^0 degree from the horizontal plane and turned south.

In order to optimize the system planning, the paper uses the data collected from the reports of the Electricity of Vietnam (EVN) as shown in Table 2. This includes the investment cost per 1 MW, marginal cost, average efficiency for each type of power plant.

Investment cost to upgrade transmission capacity for the line is approximately estimated as 0.01USD/MVA.

D. Simulation and results

The optimization model (1)-(6) with the mentioned above parameters has been tested by open source code of Python language [12], [13]. According to the National Electricity Development Plan for 2011-2020 with consideration to 2030, after the simulation, load demand at 500kV stations is characterized by the size of the circle. The greater the size of the circle, the higher the load demand and vice versa (Fig. 2). In addition, the substations in neighboring areas are connected through the green transmission lines. The larger the width of the line, the greater the transmission capacity on the line.

Fig. 3 also shows the distribution of different types of existing energy sources (hydro source represented by blue, thermal - black, solar - red and wind - yellow) in the different areas, according to the planning data, referred to the buses. Obviously, wind and solar energy is concentrated mainly in the South of Vietnam, while in the North the thermal and hydro power sources are dominant. These four main types of power sources (thermal, hydro, wind, solar) will be the subjects for study in the paper.

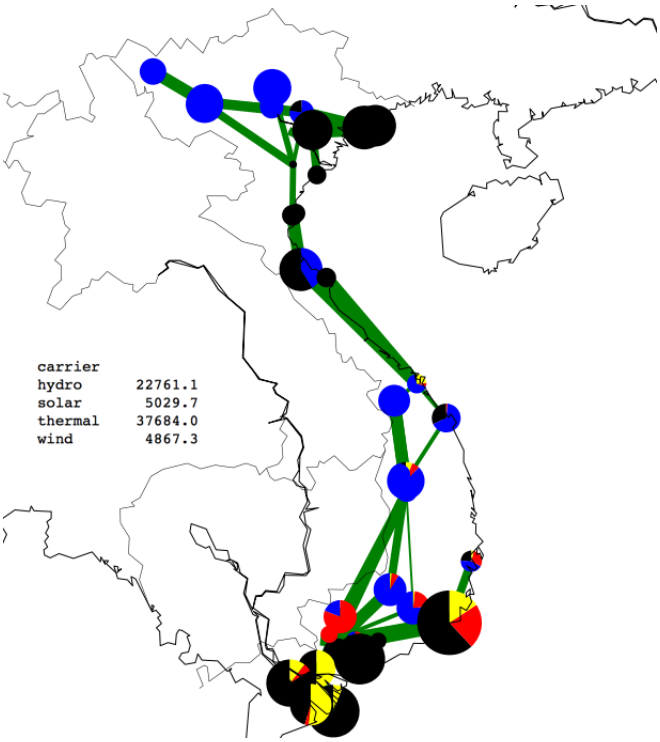


Figure 3. *The distribution of the load and of generating technology*

We consider two case studies of simulation for a typical day as follows:

- Case study 1: Optimal distribution of power sources in the context that existing lines capacity is not expanded.
- Case study 2: Optimal distribution of power sources in the context that existing line capacity is expanded.

Fig. 4 shows the results after solving optimization problem with the objective function (1) and constraints (2) - (6). It is clear from Fig.4a that thermal and hydro power sources take a larger proportion related to lower investment cost and electricity price in comparison with solar and wind power. In addition, Figure 4a also shows the optimal power output of each type of power plants over a 24-hour period. Meanwhile, Fig. 4b shows that the wind and solar power generation tends to be higher in case study 2. It can be explained that if the capacity from transmission line would be expanded, the participation of wind power and solar power in a daily load curve would be higher.

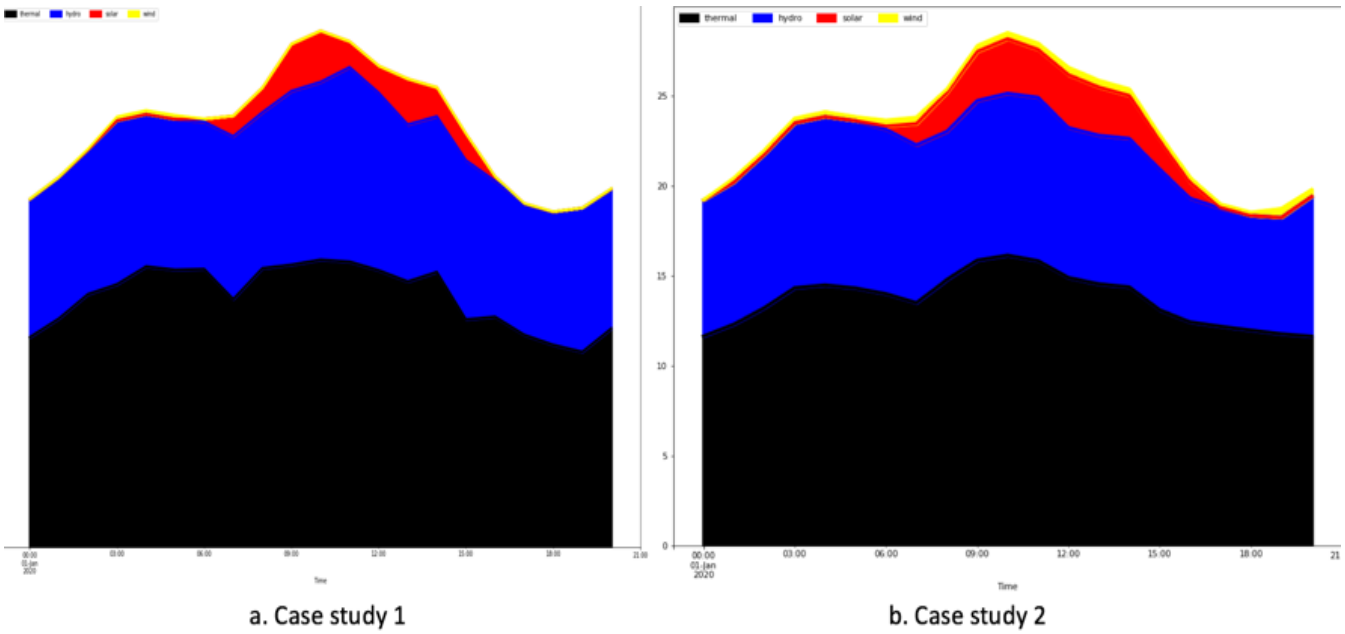


Figure 4. *Optimal distribution of power sources in a typical day*

Fig. 5 shows the contribution of various types of power sources at each bus after optimization. The circle size and line width show the distribution of the source power at each node and the load power flow of the line. In case 1 (Fig.5a), it is visible that there are some buses without participation of the power sources. Meanwhile, in case 2 (Fig.5b), with the increasing in the capacity of transmission line, solar and wind power have higher penetration rates than in case 1 without expansion of the lines. In both cases, most of renewable energy sources are located in the South of Vietnam.

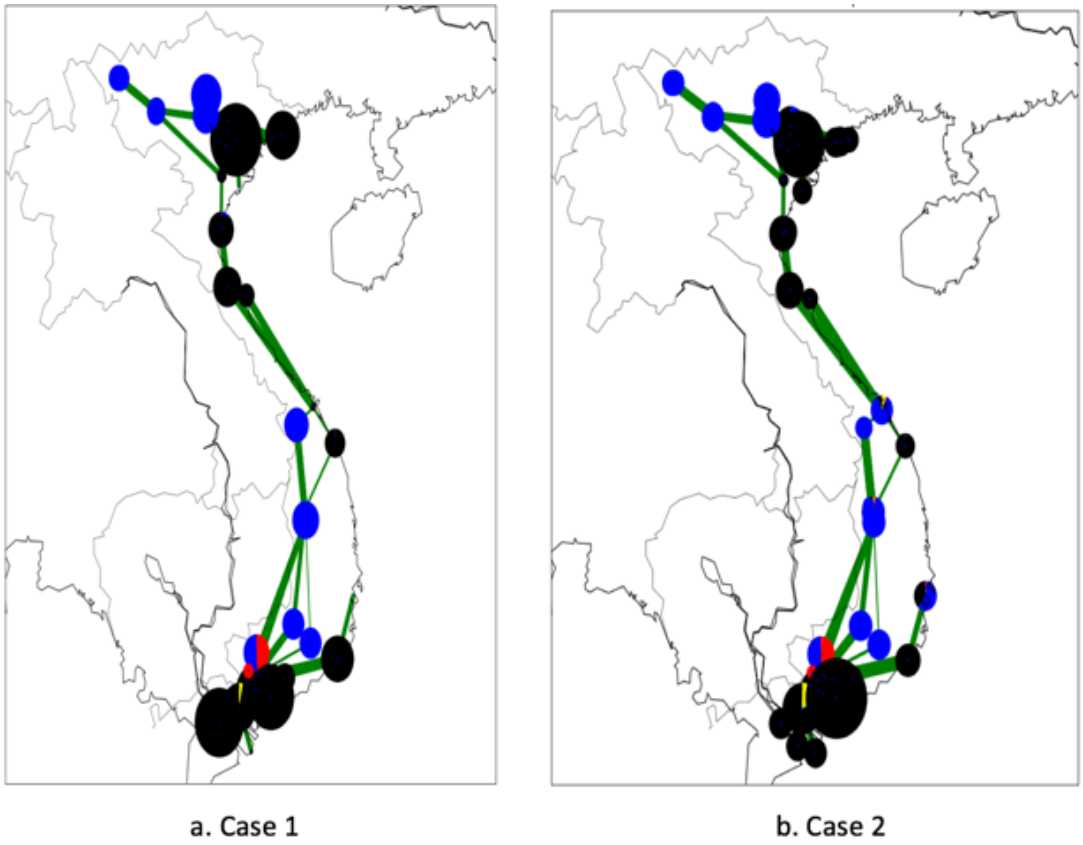
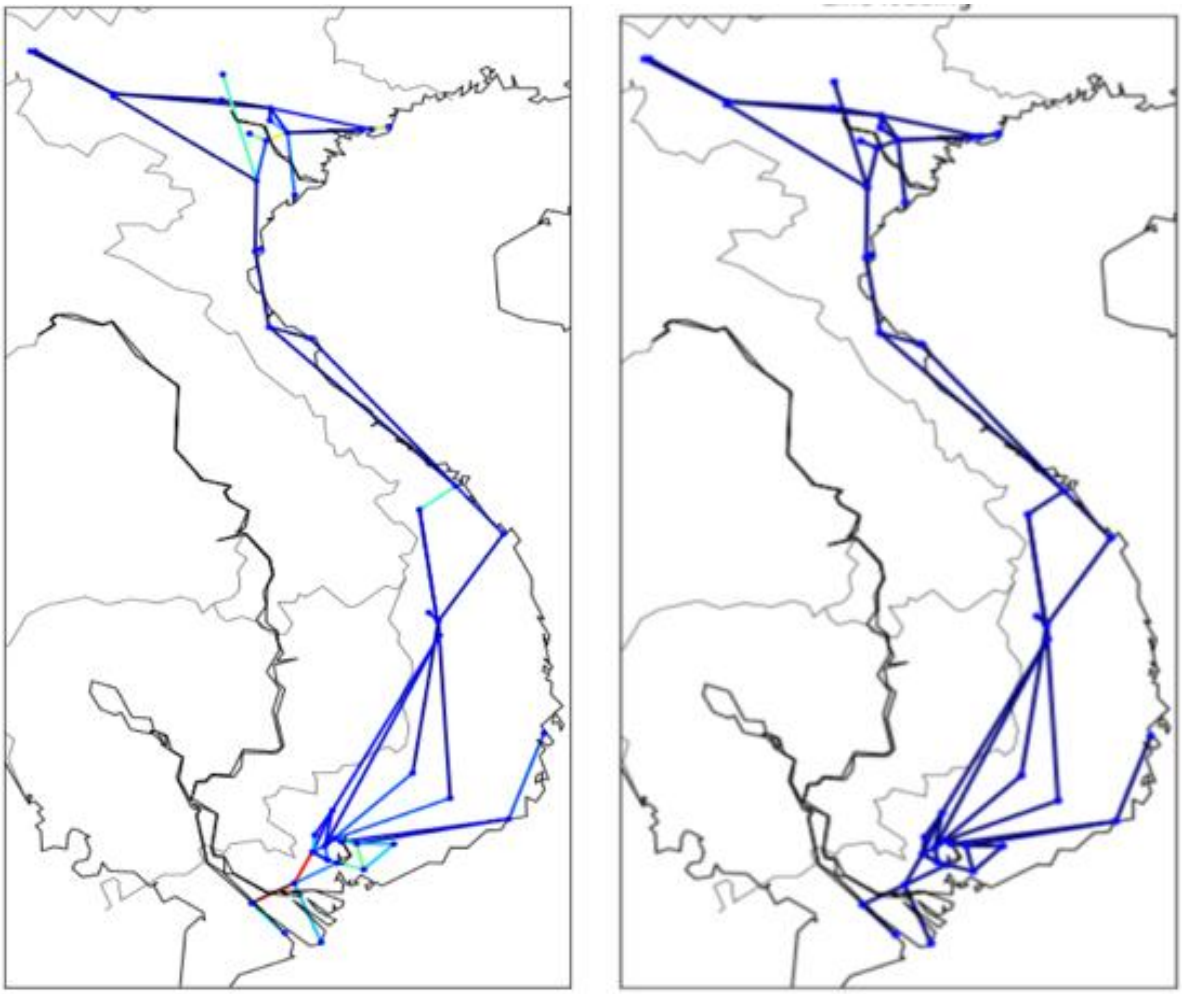


Figure 5. *Optimal distribution of power sources output at the buses in a typical day.*

Fig. 6a shows the power flow of the line after optimization in the case study 1. The blue color indicates that power in the transmission line less than 90% of the maximum capacity, ensuring transmission limit issue. Meanwhile, there

are few red lines (90% or more of loading), representing overload possibility in the future. In opposite, result of case study 2 (Fig. 6b) shows normal status of transmission lines regarding transmission limit.



a. Case study 1 b. Case study 2

Figure 6. *Transmission lines power flow in planning simulation*

IV. CONCLUSION

The paper develops an optimization model for planning the integration of renewable energy sources into Vietnamese power system in the future, where the objective function is minimum of investment and operation costs. The proposed optimal power sources planning solution has been tested with a Vietnamese 46-bus power grid. The data for simulation included not only power system parameters but also global database MERRA. This suggested methodology overcomes the disadvantage in planning and development of renewable energy sources in the provinces and cities.

The simulation results show that the issue of transmission grid expansion must be considered at the same time with the planning of energy sources, especially renewable energy. The expansion of transmission grid will enhance high penetration of wind and solar energy into the existing Vietnamese power system.

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APPENDIX

TABLE 2. PARAMETERS USED IN OPTIMIZATION PROCESS

Type of power plant	Investment cost (USD/MW)	Marginal cost (USD/MWh)	Average efficiency
Thermal	1,155,000	0.629	0.39
Solar	1,235,000	0.6	0.19
Wind	1,935,000	0.6	0.5
Hydro	1,100,000	0.5	0.95

TABLE 3. DATA FOR THE 46-BUS TEST SYSTEM

Bus number	Bus name	Wind Generator (p.u)	Solar Generator (p.u)	Load (MVA)
1	Hiệp Hòa	0.001	0.423	570.8687
2	NMTĐ Lai Châu	0.002	0.37	428.1515
3	Đông Anh	0.001	0.446	842.0000
4	Sơn La	0.003	0.296	428.1515
5	NMTĐ Sơn La	0.004	0.298	285.4343
6	Mông Dương 1	0.078	0.417	428.1515
7	Mông Dương 2	0.079	0.417	285.4343
8	Quảng Ninh	0.041	0.439	570.8687
9	Nghi Sơn	0.208	0.419	856.3030
10	Hòa Bình	0.002	0.496	713.5858
11	Thăng Long	0.031	0.439	570.8687
12	Thường Tín	0.003	0.464	713.5858
13	Phố Nối	0.001	0.465	856.3030
14	Nho Quan	0.023	0.451	570.8687
15	Hà Tĩnh	0.286	0.33	856.3030
16	Vũng Áng	0.217	0.719	285.4343
17	Đà Nẵng	0.459	0.568	856.3030
18	Dốc Sỏi	0.491	0.631	285.4343
19	Thạnh Mỹ	0.605	0.558	142.7172
20	Pleiku	0.618	0.708	570.8687
21	Pleiku 2	0.641	0.708	285.4343
22	Yali	0.618	0.708	142.7172
23	Đăk Nông	0.466	0.737	285.4343
24	Di Linh	0.472	0.75	285.4343
25	Cầu Bông	0.117	0.707	1141.7373
26	Tân Định	0.107	0.709	856.3030
27	Sông Mây	0.114	0.713	856.3030
28	Vĩnh Tân	0.851	0.723	570.8687
29	Phú Lâm	0.142	0.711	1141.7373
30	Mỹ Tho	0.21	0.713	570.8687
31	Duyên Hải	0.551	0.718	570.8687
32	Chơn Thành	0.081	0.708	856.3030
33	Ô Môn	0.242	0.707	570.8687
34	Củ Chi	0.117	0.707	856.3030
35	Nhà Bè	0.159	0.714	1141.7373
36	Phú Mỹ	0.249	0.718	856.3030
37	Lai Châu	0.001	0.397	428.1515
38	Tây Hà Nội	0	0.445	856.3030
39	Việt Trì	0	0.418	856.3030
40	Văn Phong	0.819	0.693	570.8687
41	NĐ Công Thanh	0.21	0.411	428.1515
42	Nam Định1	0.085	0.375	428.1515
43	Long Phú	0.447	0.717	570.8687
44	Đức Hòa	0.13	0.707	856.3030
45	Tân Uyên	0.095	0.71	856.3030
46	Long Thành	0.217	0.719	570.8687