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Impact of large-scale renewable power plants on the tie-line loadings of a Vietnamese power network

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ABSTRACT

The rapid integration of wind power and power solar plants into the electrical power system has caused several operation issues in recent decades. To investigate the impact of large-scale renewable power plants on the tie-line loadings of a practical power grid, the 110 kV power network of Binh Dinh province, Vietnam is utilized in this paper. This power network with and without three solar power plants (including Fujiwara plant with a peak capacity of 50 MWp, Cat Hiep plant with a peak capacity of 49.5 MWp, and Dam Tra O plant with a peak capacity of 50 MWp) and three wind power plants (including Nhon Hoi plant with a capacity of 60 MW, Phuong Mai 1 plant with a capacity of 26.4 MW, and Phuong Mai 3 plant with a capacity of 20.7 MW) is modeled by using the PSS/E software to examine the tie-line loadings capacity. The simulation results showed that the tie-line loadings of the current power network increase when six renewable power plants are integrated into this network. Therefore, three different scenarios to upgrade the existing power network are proposed. The final results demonstrated the efficiency of the proposed scenarios in solving the tie-line loadings issue of the practical power network.

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1. INTRODUCTION

Since fossil fuels have several disadvantages such as rapid exhaustion, high-cost effects, and related environmental concerns, renewable energy resources have been developed worldwide. Solar power and wind power are considered green and renewable energies. In Vietnam, there are renewable resources incentive programs to increase the utilization of wind power and solar energy. Therefore, several solar power and wind power plants are continuing to be installed in the central and central highlands of Vietnam, especially in Ninh Thuan, Binh Thuan, Binh Dinh, and Dak Lak provinces. According to the report of the Ministry of Industry and Trade of Vietnam on July 21st, 2022, among the total 78121 MW of installed capacity nationwide, 16564 MW of solar power (consisting of 8904 MW of centralized solar power and 7660 MW of rooftop solar power) and 4126 MW of wind power have entered into operation and are benefiting from FIT according to Decisions of the Prime Minister [1]. Nguyen *et al.* [2] provided a review of past studies of the levelized international costs for various renewable energy resources and compares them to the costs of renewable energy resources in Vietnam. Unfortunately, the large-scale wind and solar power plants integrated into the power system can cause many difficulties and challenges for the power system operation [3], [4]. With the huge amount of transmitted power, the transmission lines in these power networks may be overloaded since the existing network infrastructure may not be upgraded concurrently.

In the literature, several studies are carried out to investigate the impacts of renewable resources on electrical power networks. Swarna *et al*. [5] analysed the power variation and voltage variation through load flow analysis in a network with solar power and wind power integration by using the PSS-SINCAL software. Subba *et al*. [6] presented the impact on the bus voltage due to the integration of renewable energy sources into the power network of Bhutan by using MATLAB/Simulink and DIgSILENT. A methodology was developed for determining appropriate locations for integration of renewable distributed generators within the radial distribution network of a particular area of Gujarat state, India with the objective of improving voltage profile and reduction in losses in [7]. Chiandone *et al*. [8] estimated power losses on an actual low voltage distribution network according to the distributed generation penetration and placement of the power units by using a Python-based software tool for power system analysis. Imen *et al*. [9] analysed the influence of wind farm integration on load flow and voltage in electrical power system. An assessment framework to address the power quality issues that have arisen after integrating large-scale wind farms into weak transmission grids, especially considering inter-farm wake effect, seasonal variations, reactive power depletion, and compensation with a variety of voltage-ampere reactive devices by using MATLAB/Simulink was presented in [10]. The impact of solar and wind farm disturbances on the stability of the distribution network was found out in [11]. The stability of electricity networks in the presence of renewable energies in interconnected power system: transmission-distribution was presented in [12]. The impact of power solar and wind systems on electrical power network stability was performed in [13]. The voltage profile and stability of the electrical transmission network with renewable energy integration by using the PSSE software were investigated in [14]. Yuan *et al*. [15] presented the impact of renewable energy integration on overcurrent protection in the distribution network by using the PSCAD/EMTDC program. El Naily *et al*. [16] investigated the impact of distributed generation on the protection setup of the existing distribution network. A brief illustration of the influence of renewable energy sources on distribution network availability was provided in [17]. Meyer *et al*. [18] presented the impact of the large share of renewable generation on investment costs in the example of the AUW distribution network. The impact of renewable energy sources curtailment on the planning of high voltage distribution networks was investigated in [19]. Other works analysed the influence of renewable resources on a specific power network. The potential of integrating wind and solar power in Europe using spatial optimization under various scenarios was presented in [20]. The impact analysis of wind farms in the Jeju island power system by using the PSCAD/EMTDC program was shown in [21]. Wattana and Aungyut [22] analysed the impacts of solar electricity generation on the Thai electricity industry. An analysis of the impact of the integration of large photovoltaics generation capacity and optimization of photovoltaics capacity in Taiwan using the PSS/E software was conducted in [23]. The stability of the Portuguese transmission network with a high share of renewable energies was examined in [24].

In Binh Dinh province, Vietnam, several large-scale solar power and wind power plants have been integrated into the existing electrical power network in recent times. Consequently, the investigation of these renewable plants on the current electrical network may receive considerable attention from several researchers. Therefore, the primary purpose of this paper is to investigate the tie-line loadings of the 110 kV power network of Binh Dinh province in Vietnam with and without the integration of three large-scale solar power plants and three large-scale wind power plants. The PSS/E software is used to model and simulate the two different cases of the power network. Based on the load flow results, the tie-line loadings in this power network are examined. The tie-line loadings of the power network with the integration of the large-scale renewable power plants are higher than the network without the integration of these power plants. To solve this issue, several scenarios are proposed to upgrade the existing electrical power network. The tie-line loadings of the upgraded power network with the integration of the large-scale renewable power plants are compared with the existing power network.

2. NETWORK MODELING

2.1. Before integrating the renewable energy plants

In May 2019, the renewable energy plants were not integrated into the investigated power network. The 110 kV power network of Binh Dinh province in this period consists of 12 substations and 433.266 kilometers of transmission line. Two main supplies for this 110 kV network are the 220 kV substations (220 kV Phu My and 220 kV Quy Nhon) and 4 small and medium hydropower plants (Dinh Binh 3*3.3 MW, Tien Thuan 9.5 MW, Van Phong 6 MW, and Nuoc Xang 12.5 MW). The parameters of the substations and lines of the 110 kV power network of Binh Dinh province in May 2019 are shown in Tables 1 and 2, respectively. In addition, some small-scale hydropower plants are connected to 22 kV buses. These hydropower plants are not considered in this power network. Therefore, the overall diagram of the 110 kV power network of Binh Dinh province in May 2019 by using PSS/E is shown in Figure 1.

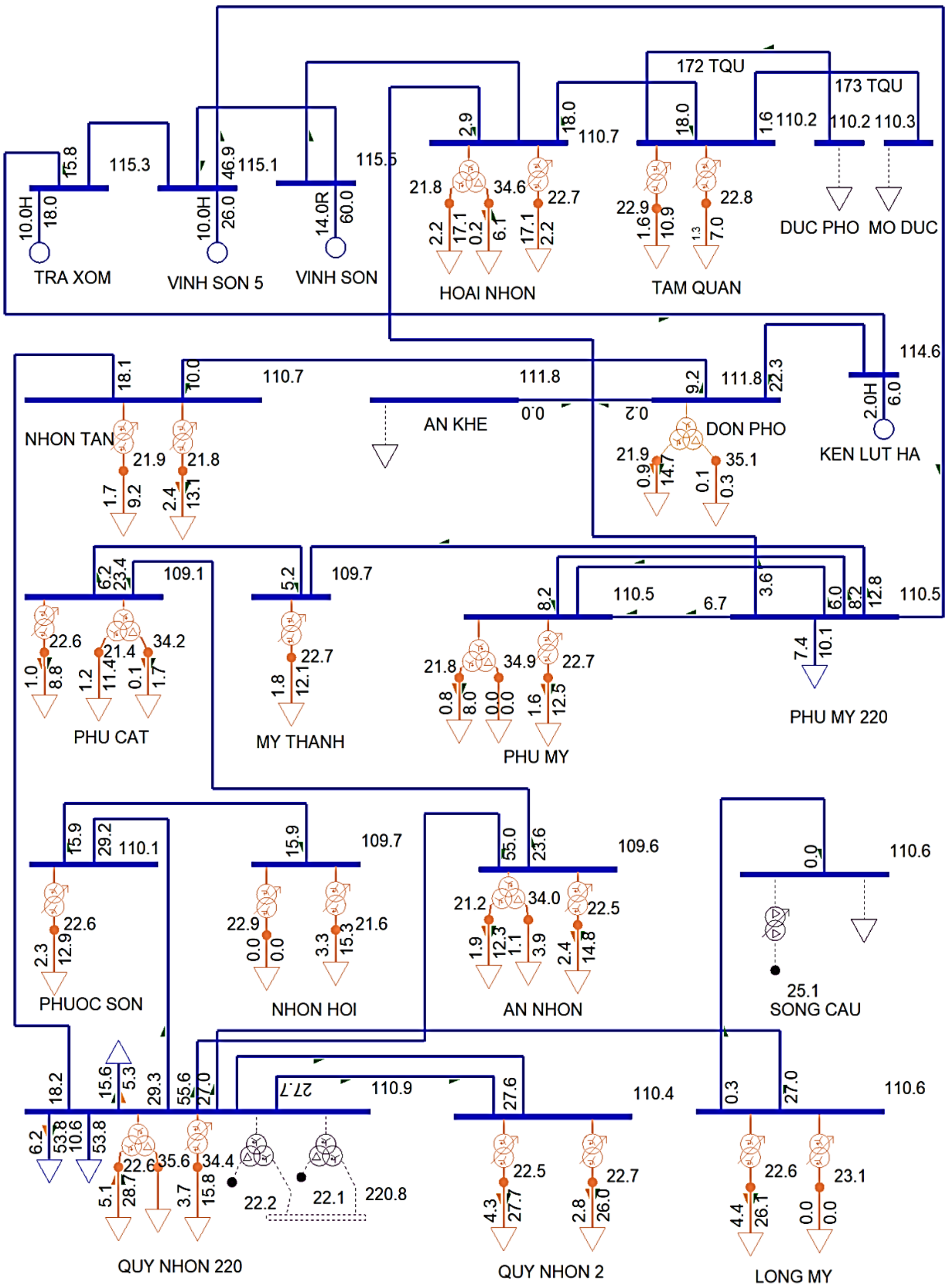

Figure 1. The 110 kV power network of Binh Dinh province in May 2019

Table 1. Parameters of the substations of the 110 kV power network of Binh Dinh province in May 2019

Name	No.	Nominal capacity (MVA)
Quy Nhon 2	2	2*40
Nhon Hoi	2	40 + 63
Quy Nhon	2	35 + 40
Long My	1	40
Phuoc Son	1	25
An Nhon	2	25 + 63
Phu Cat	2	2*25
Phu My	2	25 + 40
My Thanh	1	40
Hoai Nhon	2	2*25
Tam Quan	2	25 + 40
Nhon Tan	2	2*25
Don Pho	1	25

Table 2. Parameters of the 110 kV lines of the 110 kV power network of Binh Dinh province in May 2019

No.	From bus	To bus	Type	L (km)	No.	From bus	To bus	Type	L (km)
1	SONGCAU	LONG_MY	AC-185	7.73	14	DON_PHO	NHON_TAN	AC-185	29.51
2	KENLUTHA	DON_PHO	AC-185	43.90	15	DON_PHO	AN_KHE	AC-185	6.84
3	KENLUTHA	TRA_XOM	AC-185	13.40	16	PHU_CAT	AN_NHON	AC-185	16.60
4	MO_DUC	TAM_QUAN	AC-185	48.70	17	QUY_NHON2	QUY_NHON220	AC-240	9.95
5	DUC_PHO	TAM_QUAN	AC-185	23.30	18	QUY_NHON2	QUY_NHON220	AC-240	9.95
6	TAM_QUAN	HOAI_NHON	AC-185	17.70	19	QUY_NHON220	AN_NHON	AC-185	12.67
7	PHU_MY	PHUMY220	AC-185	4.89	20	QUY_NHON220	PHUOC_SON	AC-240	13.24
8	PHU_MY	PHUMY220	AC-185	6.73	21	QUY_NHON220	LONG_MY	AC-185	5.67
9	PHU_MY	PHUMY220	AC-185	6.00	22	QUY_NHON220	NHON_TAN	AC-185	14.86
10	MY_THANH	PHU_CAT	AC-185	32.42	23	PHUMY220	TD VSON 5	AC-240	43.61
11	MY_THANH	PHUMY220	AC-185	19.50	24	VINH_SON	TD VSON 5	AC-185	11.89
12	HOAI_NHON	PHUMY220	AC-185	23.90	25	TD VSON 5	TRA_XOM	AC-185	7.17
13	HOAI_NHON	VINH_SON	AC-185	45.92	26	NHON_HOI	PHUOC_SON	AC-240	13.75

2.2. Integration of the renewable energy plants

Currently, all renewable energy plants are integrated into the existing power network. The current 110 kV power network of Binh Dinh province consists of 14 substations and 481.891 kilometers of transmission line. Three large-scale solar power plants including the Fujiwara plant with a peak capacity of 50 MWp, Cat Hiep plant with a peak capacity of 49.5 MWp, and Dam Tra O plant with a peak capacity of 50 MWp are integrated into the current 110 kV power network. In addition, three large-scale wind power plants including the Nhon Hoi plant with a capacity of 60 MW, Phuong Mai 1 plant with a capacity of 26.4 MW, and Phuong Mai 3 plant with a capacity of 20.7 MW are integrated into the current 110kV power network. Some of the substations and 110 kV lines of the current power network of Binh Dinh province are upgraded and shown in Tables 3 and 4 respectively. The diagram of the current 110 kV power network of Binh Dinh province using PSS/E is shown in Figure 2.

The Nhon Hoi wind power plant, Phuong Mai 1 wind power plant, or Phuong Mai 3 wind power plant has the general model of a type 3 wind turbine. The grid-connected wind turbine system based on the doubly-fed induction generator (DFIG) is shown in Figure 3 [25]. The grid-connected PV system diagram of the Fujiwara plant solar power plant, Cat Hiep solar power plant, and Dam Tra O solar power plant is illustrated in Figure 4 [26].

Table 3. Parameters of the substations of the current 110 kV power network of Binh Dinh province

Name	No.	Nominal capacity (MVA)	Name	No.	Nominal capacity (MVA)
Quy Nhon 2	2	2*40	Phu My	2	25 + 40
Dong Da	1	63	My Thanh	1	40
Nhon Hoi	2	40 + 63	Hoai Nhon	2	2*25
Quy Nhon	2	2*40	Tam Quan	2	25 + 40
Long My	2	25 + 40	Nhon Tan	2	2*25
Phuoc Son	1	25	Don Pho	1	25
An Nhon	2	25 + 63	Tay Son	1	40
Phu Cat	2	2*25			

Table 4. Parameters of the 110 kV lines of the current 110 kV power network of Binh Dinh province

No.	From bus	To bus	Type	L (km)	No.	From bus	To bus	Type	L (km)
1	DAMTRAO	PHU_MY	AC-240	10.42	21	TAM_QUAN	HOAI_NHON	AC-185	17.81
2	PHUOC_AN	QUY_NHON	ACSR-400	5.74	22	PHU_MY	PHUMY220	AC-185	0.97
3	PHUOC_AN	AN_NHON	AC-300	10.53	23	PHU_MY	PHUMY220	AC-300	6.25
4	PHUOC_AN	NHON_TAN	AC-240	9.40	24	PHU_MY	PHUMY220	AC-240	5.42
5	FUJIWA	NHON_HOI	AC-185	4.30	25	MY_THANH	PHU_CAT	AC-185	32.42
6	CAT_HIEP	PHU_CAT	AC-185	5.52	26	MY_THANH	PHUMY220	AC-185	19.50
7	CAT_HIEP	PHU_CAT	AC-185	5.52	27	HOAI_NHON	PHUMY220	AC-185	29.12
8	DG_P_MAI3	DONG_DA	AC-240	34.40	28	HOAI_NHON	VINH_SON	AC-185	46.92
9	DG_P_MAI3	DG_P_MAI1	AC-240	0.34	29	DON_PHO	AN_KHE	AC-185	6.84
10	DG_N_HOI	DG_P_MAI1	AC-240	9.54	30	PHU_CAT	AN_NHON	AC-185	16.67
11	DG_N_HOI	NHON_HOI	AC-240	3.05	31	QUY_NHON2	QUY_NHON	AC-240	9.95
12	DONG_DA	QUY_NHON	AC-240	13.30	32	QUY_NHON2	QUY_NHON	AC-240	9.95
13	SONGCAU	QUY_NHON	AC-300	26.30	33	QUY_NHON	AN_NHON	AC-240	12.67
14	SONGCAU2	LONG_MY	AC-300	7.73	34	QUY_NHON	PHUOC_SON	AC-240	13.24
15	KENLUTHA	DON_PHO	AC-185	29.80	35	QUY_NHON	LONG_MY	AC-300	5.90
16	KENLUTHA	TRA_XOM	AC-185	13.40	36	PHUMY220	TD VSON 5	AC-300	43.45
17	TAY_SON	DON_PHO	AC-240	14.42	37	VINH_SON	TD VSON 5	AC-185	11.89
18	TAY_SON	NHON_TAN	AC-240	16.00	38	TD VSON 5	TRA_XOM	AC-185	7.16
19	MO_DUC	TAM_QUAN	AC-240	48.70	39	NHON_HOI	PHUOC_SON	AC-240	13.75
20	DUC_PHO	TAM_QUAN	AC-240	22.30					

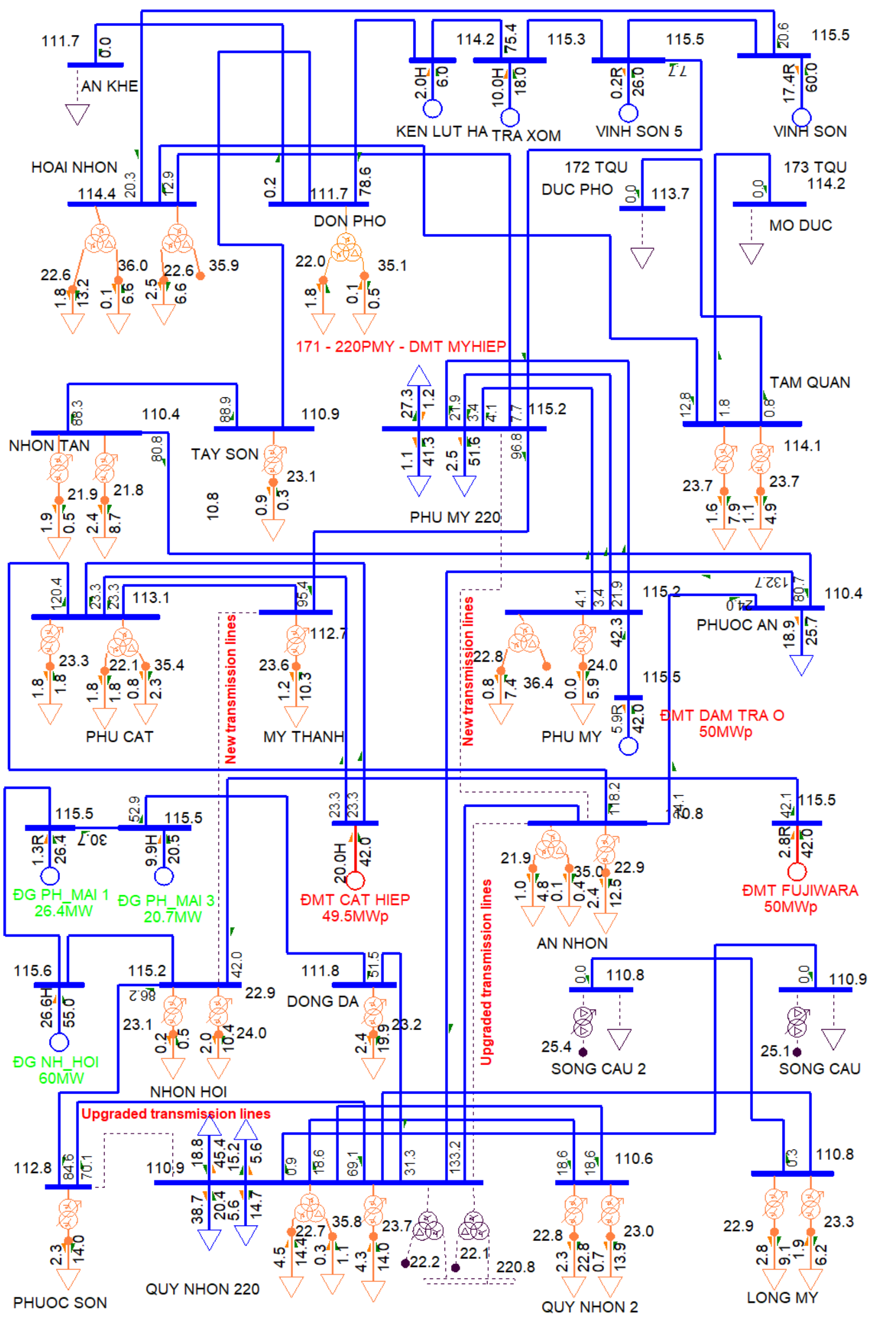

Figure 2. The current 110 kV power network of Binh Dinh province

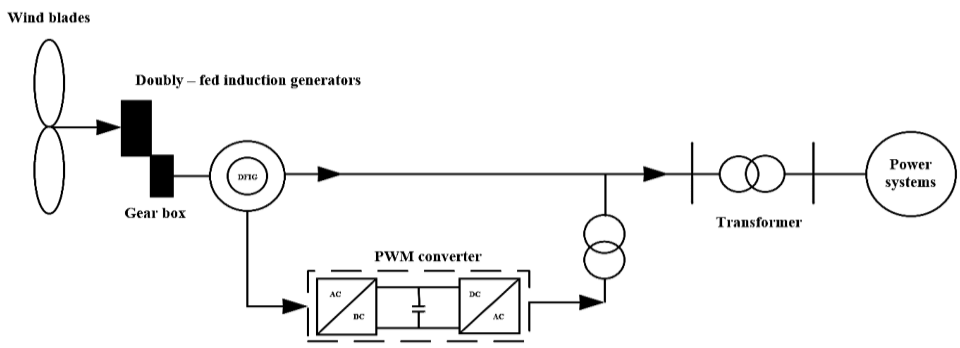

Figure 3. DFIG-based wind turbine system diagram

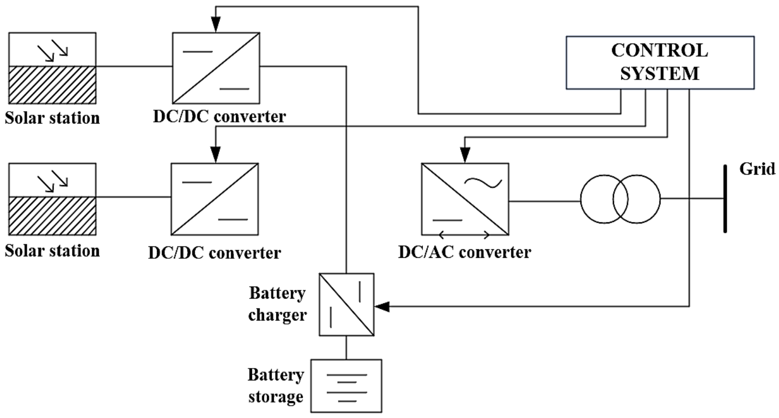

Figure 4. Grid-connected PV system diagram

3. SIMULATION RESULTS AND DISCUSSION

As large-scale wind power plants and large-scale solar power plants are integrated into the electrical power system, the power flow in the grid may significantly change. In order to investigate the impact of three large-scale solar power plants and three large-scale wind power plants on the tie-line loadings of the 110 kV power network of Binh Dinh province, the PSS/E software is used to run the load flow solution. The Newton–Raphson algorithm is applied to solve the load flow solution. The percentage of loadings of these transmission lines is used to examine the loadings capacity since each transmission line has a different loadings capacity.

3.1. Before integrating the renewable energy plants

The simulation results of the 110 kV power network of Binh Dinh province without these large-scale renewable energy plants in May 2019 using PSS/E as shown in Figure 1 are shown in Table 5. As shown in Table 5, the percentage of loadings of these transmission lines is rather small. The average percentage of loadings of the transmission lines in this power network is 16.4%. The QUY_NHONAN_NHON transmission line has the maximum percentage of loadings (55.8%). The DON_PHO– AN_KHE transmission line has the minimum percentage of loadings (0.2%).

Table 5. Load flow solution of the 110 kV lines of the Binh Dinh power network in May 2019

No.	From bus	To bus	Rating (MVA)	Percent	No.	From bus	To bus	Rating (MVA)	Percent
1	SONGCAU	LONG_MY	99	0.3	14	DON_PHO	NHON_TAN	116	8.6
2	KENLUTHA	DON_PHO	99	22.2	15	DON_PHO	AN_KHE	99	0.2
3	KENLUTHA	TRA_XOM	99	15.4	16	PHU_CAT	AN_NHON	99	23.9
4	MO_DUC	TAM_QUAN	99	1.6	17	QUY_NHON2	QUY_NHON	116	23.7
5	DUC_PHO	TAM_QUAN	99	0.8	18	QUY_NHON2	QUY_NHON	116	23.7
6	TAM_QUAN	HOAI_NHON	99	18.1	19	QUY_NHON	AN_NHON	99	55.8
7	PHU_MY	PHUMY220	99	8.3	20	QUY_NHON	PHUOC_SON	116	25.2
8	PHU_MY	PHUMY220	99	6.0	21	QUY_NHON	LONG_MY	99	27.1
9	PHU_MY	PHUMY220	99	6.8	22	QUY_NHON	NHON_TAN	99	18.2
10	MY_THANH	PHU_CAT	99	6.3	23	PHUMY220	TD VSON 5	116	39.1
11	MY_THANH	PHUMY220	99	13.2	24	VINH_SON	TD VSON 5	99	13.9
12	HOAI_NHON	PHUMY220	99	3.6	25	TD VSON 5	TRA_XOM	99	4.8
13	HOAI_NHON	VINH_SON	99	45.8	26	NHON_HOI	PHUOC_SON	116	13.8

3.2. Integration of the renewable energy plants

The simulation results of the current 110 kV power network of Binh Dinh province with these large-scale renewable energy plants by using PSS/E as shown in Figure 2 are shown in Table 6. As shown in Table 6, the percentage of loadings of these transmission lines with the integration of these large-scale renewable energy plants has increased in comparison with the power network without the integration of these large-scale renewable energy plants. The average percentage of loadings of the transmission lines in this power network is 37.22%. The PHU_CAT–AN_NHON transmission line has the maximum percentage of loadings (118.6%). The DON_PHO – AN_KHE transmission line and SONGCAU2 – LONG_MY transmission line has the minimum percentage of loadings (0.2%). The percentage of loadings of the KENLUTHA–DON_PHO transmission line increases from 22.2% to 78.3%. The percentage of loadings of the KENLUTHA–TRA_XOM transmission line increases from 15.4% to 72.7%. The percentage of loadings of the TAY_SON–DON_PHO transmission line increases from 1.6% to 75.7%. The percentage of loadings of the TAY_SON–NHON_TAN transmission line increases from 0.8% to 76.0%. The percentage of loadings of the MY_THANH PHU_CAT transmission line increases from 6.3% to 83.7%. The percentage of loadings of the MY_THANH–PHUMY220 transmission line increases from 13.2% to 93.9%. The percentage of loadings of the PHU_CAT–AN_NHON transmission line increases from 23.9% to 118.6%. The percentage of loadings of the QUY_NHON–PHUOC_SON transmission line increases from 25.2% to 59.1%. The percentage of loadings of the TD VSON 5–TRA_XOM transmission line increases from 4.8% to 57.2%. The percentage of loadings of the NHON_HOI–PHUOC_SON transmission line increases from 13.8% to 71.1%. Obviously, the percentage of loadings of most transmission lines in the existing transmission power network considerably increases.

Table 6. Parameters of the 110 kV lines of the current 110 kV power network of Binh Dinh province

No.	From bus	To bus	Rating (MVA)	Percent	No.	From bus	To bus	Rating (MVA)	Percent
1	DAMTRA0	PHU_MY	116	34.8	21	TAM_QUAN	HOAI_NHON	99	12.5
2	PHUOC_AN	QUY_NHON	158	83.7	22	PHU_MY	PHUMY220	99	21.2
3	PHUOC_AN	AN_NHON	135	17.7	23	PHU_MY	PHUMY220	135	2.4
4	PHUOC_AN	NHON_TAN	116	69.4	24	PHU_MY	PHUMY220	116	3.4
5	FUJIWA	NHON_HOI	99	40.5	25	MY_THANH	PHU_CAT	99	83.7
6	CAT_HIEP	PHU_CAT	99	22.9	26	MY_THANH	PHUMY220	99	93.3
7	CAT_HIEP	PHU_CAT	99	22.9	27	HOAI_NHON	PHUMY220	99	8.1
8	DG_P_MAI3	DONG_DA	116	43.7	28	HOAI_NHON	VINH_SON	99	19.9
9	DG_P_MAI3	DG_P_MAI1	116	25.2	29	DON_PHO	AN_KHE	99	0.2
10	DG_NHOI	DG_P_MAI1	116	4.1	30	PHU_CAT	AN_NHON	99	118.6
11	DG_NHOI	NHON_HOI	116	46.3	31	QUY_NHON2	QUY_NHON	116	16.0
12	DONG_DA	QUY_NHON	116	26.7	32	QUY_NHON2	QUY_NHON	116	16.0
13	SONGCAU	QUY_NHON	135	0.6	33	QUY_NHON	AN_NHON	116	67.9
14	SONGCAU2	LONG_MY	135	0.2	34	QUY_NHON	PHUOC_SON	116	59.1
15	KENLUTHA	DON_PHO	99	78.3	35	QUY_NHON	LONG_MY	135	11.3
16	KENLUTHA	TRA_XOM	99	72.7	36	PHUMY220	TD VSON 5	135	5.4
17	TAY_SON	DON_PHO	116	75.7	37	VINH_SON	TD VSON 5	99	40.7
18	TAY_SON	NHON_TAN	116	76.0	38	TD VSON 5	TRA_XOM	99	57.2
19	MO_DUC	TAM_QUAN	116	1.5	39	NHON_HOI	PHUOC_SON	116	71.1
20	DUC_PHO	TAM_QUAN	116	0.7					

3.3. The proposed scenarios

In order to decrease the high percentage loadings of these transmission lines in the current 110 kV power network of Binh Dinh province, different scenarios are proposed by Binh Dinh Power Company. In the first scenario, some of the current transmission lines will be upgraded. In the second scenario, some new transmission lines will be installed. The last scenario is the combination of the two above scenarios.

3.3.1. First scenario

In the first scenario, two transmission lines (i.e., QUY_NHON–AN_NHON transmission line and QUY_NHON – PHUOC_SON transmission line) with AC – 240 will be replaced by AC – 300 as shown in Figure 2. The load flow results of the 110kV lines of the Binh Dinh power network with the upgraded transmission lines by using PSS/E are shown in Table 7. As shown in Table 7, the average percentage of loadings of these transmission lines in this scenario has slightly decreased from 37.22% to 36.8%. The percentage of loadings of the QUY_NHON–AN_NHON transmission line decreases from 67.9% to 57.4%. The percentage of loadings of the QUY_NHON–PHUOC_SON transmission line decreases from 59.1% to 50.7%.

3.3.2. Second scenario

In the second scenario, two new transmission lines (PHUMY220–AN_NHON with AC 300 and MY_THANH–NHON_HOI with AC 240) are installed as shown in Figure 2. The load flow results of the 110 kV lines of the Binh Dinh power network with the new transmission lines by using PSS/E are shown in Table 8. As shown in Table 8, the percentage of loadings of these transmission lines in this scenario has considerably decreased. The average percentage of loadings of the transmission lines in this power network is 29.39%. The NHON_HOI–PHUOC_SON transmission line has the maximum percentage of loadings (78.0%). The DON_PHO–AN_KHE transmission line and SONGCAU2–LONG_MY transmission line has the minimum percentage of loadings (0.2%). The percentage of loadings of PHU_CAT–AN_NHON transmission line decreases from 118.6% to 56.4%. The percentage of loadings of MY_THANH–PHUMY220 transmission line decreases from 93.3% to 42.1%. The percentage of loadings of MY_THANH–PHU_CAT transmission line decreases from 83.7% to 16.6%. Obviously, the percentage of loadings of most transmission lines in the existing transmission power network considerably decreases.

Table 7. Load flow solution of the 110 kV lines of the Binh Dinh power network with two upgraded transmission lines

No.	From bus	To bus	Rating (MVA)	Percent	No.	From bus	To bus	Rating (MVA)	Percent
1	DAMTRA0	PHU_MY	116	34.8	21	TAM_QUAN	HOAI_NHON	99	12.5
2	PHUOC_AN	QUY_NHON	158	84.5	22	PHU_MY	PHUMY220	99	21.1
3	PHUOC_AN	AN_NHON	135	17.9	23	PHU_MY	PHUMY220	135	2.4
4	PHUOC_AN	NHON_TAN	116	69.4	24	PHU_MY	PHUMY220	116	3.4
5	FUJIWA	NHON_HOI	99	40.6	25	MY_THANH	PHU_CAT	99	83.6
6	CAT_HIEP	PHU_CAT	99	23.0	26	MY_THANH	PHUMY220	99	93.2
7	CAT_HIEP	PHU_CAT	99	23.0	27	HOAI_NHON	PHUMY220	99	8.1
8	DG_P_MAI3	DONG_DA	116	44.1	28	HOAI_NHON	VINH_SON	99	19.8
9	DG_P_MAI3	DG_P_MAI1	116	25.7	29	DON_PHO	AN_KHE	99	0.2
10	DG_NHOI	DG_P_MAI1	116	4.3	30	PHU_CAT	AN_NHON	99	118.7
11	DG_NHOI	NHON_HOI	116	46.0	31	QUY_NHON2	QUY_NHON	116	16.0
12	DONG_DA	QUY_NHON	116	27.2	32	QUY_NHON2	QUY_NHON	116	16.0
13	SONGCAU	QUY_NHON	135	0.6	33	QUY_NHON	AN_NHON	135	57.4
14	SONGCAU2	LONG_MY	135	0.2	34	QUY_NHON	PHUOC_SON	135	50.7
15	KENLUTHA	DON_PHO	99	78.4	35	QUY_NHON	LONG_MY	135	11.3
16	KENLUTHA	TRA XOM	99	72.7	36	PHUMY220	TD VSON 5	135	5.4
17	TAY_SON	DON_PHO	116	75.7	37	VINH_SON	TD VSON 5	99	40.7
18	TAY_SON	NHON_TAN	116	76.0	38	TD VSON 5	TRA XOM	99	57.2
19	MO_DUC	TAM_QUAN	116	1.5	39	NHON_HOI	PHUOC_SON	116	71.1
20	DUC_PHO	TAM_QUAN	116	0.7					

Table 8. Load flow solution of the 110 kV lines of the Binh Dinh power network with two new transmission lines

No.	From bus	To bus	Rating (MVA)	Percent	No.	From bus	To bus	Rating (MVA)	Percent
1	DAMTRA0	PHU_MY	116	35.3	22	PHU_MY	PHUMY220	99	21.3
2	PHUOC_AN	QUY_NHON	158	70.1	23	PHU_MY	PHUMY220	135	2.5
3	PHUOC_AN	AN_NHON	135	31.4	24	PHU_MY	PHUMY220	116	3.4
4	PHUOC_AN	NHON_TAN	116	39.1	25	MY_THANH	PHU_CAT	99	16.6
5	FUJIWA	NHON_HOI	99	41.1	26	MY_THANH	PHUMY220	99	42.1
6	CAT_HIEP	PHU_CAT	99	22.7	27	HOAI_NHON	PHUMY220	99	10.0
7	CAT_HIEP	PHU_CAT	99	22.7	28	HOAI_NHON	VINH_SON	99	31.3
8	DG_P_MAI3	DONG_DA	116	46.8	29	DON_PHO	AN_KHE	99	0.2
9	DG_P_MAI3	DG_P_MAI1	116	28.6	30	PHU_CAT	AN_NHON	99	56.4
10	DG_NHOI	DG_P_MAI1	116	6.8	31	QUY_NHON2	QUY_NHON	116	16.0
11	DG_NHOI	NHON_HOI	116	44.4	32	QUY_NHON2	QUY_NHON	116	16.0
12	DONG_DA	QUY_NHON	116	29.8	33	QUY_NHON	AN_NHON	116	72.4
13	SONGCAU	QUY_NHON	135	0.6	34	QUY_NHON	PHUOC_SON	116	65.9
14	SONGCAU2	LONG_MY	135	0.2	35	QUY_NHON	LONG_MY	135	11.3
15	KENLUTHA	DON_PHO	99	43.8	36	PHUMY220	TD VSON 5	135	22.6
16	KENLUTHA	TRA XOM	99	38.0	37	VINH_SON	TD VSON 5	99	28.6
17	TAY_SON	DON_PHO	116	46.1	38	TD VSON 5	TRA XOM	99	22.3
18	TAY_SON	NHON_TAN	116	46.3	39	NHON_HOI	PHUOC_SON	116	78.0
19	MO_DUC	TAM_QUAN	116	1.5	40	MY_THANH	NHON_HOI	116	15.1
20	DUC_PHO	TAM_QUAN	116	0.7	41	PHUMY220	AN_NHON	135	64.3
21	TAM_QUAN	HOAI_NHON	99	12.6					

3.3.3. Third scenario

This scenario is the combination of the two above scenarios. The load flow results of the 110 kV lines of the Binh Dinh power network in the third scenario by using PSS/E are shown in Table 9. As shown in Table 9, the percentage of loadings of these transmission lines in this scenario has considerably decreased. The average percentage of loadings of the transmission lines in the power network in this scenario is 29.0%. The NHON_HOI–PHUOC_SON transmission line has the maximum percentage of loadings (77.8%). The DON_PHO–AN_KHE transmission line and SONGCAU2–LONG_MY transmission line has the minimum percentage of loadings (0.2%). The reduction of loadings of the transmission lines is considerable since this scenario combines the advantages of the two above scenarios. In this scenario, the percentages of loadings of two transmission lines are less than 78%. The percentages of loadings of four transmission lines are less than 65%. The percentages of loadings of other transmission lines are less than 50%.

For comparison purposes, the percentage of loadings of the transmission lines of the existing power network and the percentage of loadings of the transmission lines of the upgraded power network in this scenario are demonstrated in Figure 5. As seen in Figure 5, most of the high percentage of loadings of the transmission lines can be significantly reduced. This shows the efficiency of the proposed scenarios in reducing the percentage of loadings of the transmission lines.

Table 9. Load flow solution of the 110 kV lines of the Binh Dinh power network in the third scenario

No.	From bus	To bus	Rating (MVA)	Percent	No.	From bus	To bus	Rating (MVA)	Percent
1	DAMTRA0	PHU_MY	116	35.5	22	PHU_MY	PHUMY220	99	21.5
2	PHUOC_AN	QUY_NHON	158	71.3	23	PHU_MY	PHUMY220	135	2.5
3	PHUOC_AN	AN_NHON	135	31.8	24	PHU_MY	PHUMY220	116	3.4
4	PHUOC_AN	NHON_TAN	116	39.2	25	MY_THANH	PHU_CAT	99	16.7
5	FUJIWA	NHON_HOI	99	41.5	26	MY_THANH	PHUMY220	99	42
6	CAT_HIEP	PHU_CAT	99	22.7	27	HOAI_NHON	PHUMY220	99	9.9
7	CAT_HIEP	PHU_CAT	99	22.7	28	HOAI_NHON	VINH_SON	99	31.3
8	DG_P_MAI3	DONG_DA	116	47.2	29	DON_PHO	AN_KHE	99	0.2
9	DG_P_MAI3	DG_P_MAI1	116	29	30	PHU_CAT	AN_NHON	99	56.6
10	DG_NHOI	DG_P_MAI1	116	7.3	31	QUY_NHON2	QUY_NHON	116	16
11	DG_NHOI	NHON_HOI	116	44.3	32	QUY_NHON2	QUY_NHON	116	16
12	DONG_DA	QUY_NHON	116	30.2	33	QUY_NHON	AN_NHON	116	61.3
13	SONGCAU	QUY_NHON	135	0.6	34	QUY_NHON	PHUOC_SON	116	56.4
14	SONGCAU2	LONG_MY	135	0.2	35	QUY_NHON	LONG_MY	135	11.3
15	KENLUTHA	DON_PHO	99	44	36	PHUMY220	TD VSON 5	135	22.6
16	KENLUTHA	TRA XOM	99	38.1	37	VINH_SON	TD VSON 5	99	28.6
17	TAY_SON	DON_PHO	116	46.2	38	TD VSON 5	TRA XOM	99	22.4
18	TAY_SON	NHON_TAN	116	46.5	39	NHON_HOI	PHUOC_SON	116	77.8
19	MO_DUC	TAM_QUAN	116	1.5	40	MY_THANH	NHON_HOI	116	15.1
20	DUC_PHO	TAM_QUAN	116	0.7	41	PHUMY220	AN_NHON	135	64.4
21	TAM_QUAN	HOAI_NHON	99	12.6					

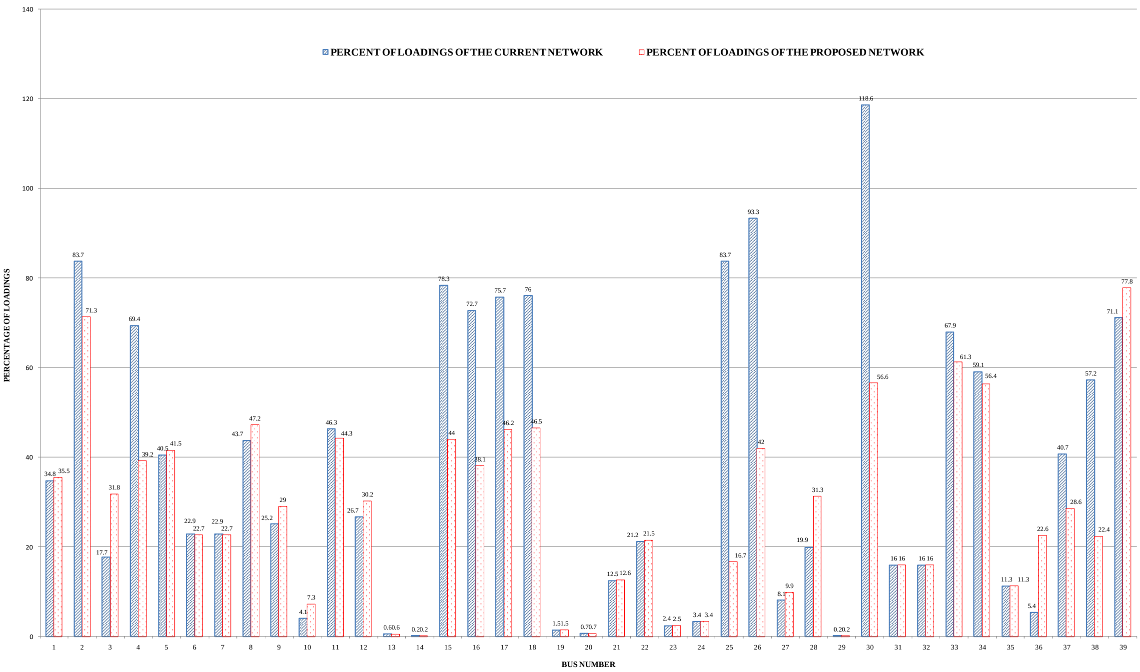

Figure 5. The comparison of percentage of loadings of transmission lines

4. CONCLUSION

The 110 kV transmission power network of Binh Dinh province, Vietnam with the integration of large-scale solar and wind power plants have been modeled by using PSS/E software. The loadings of all transmission lines of the power network before integrating the large-scale renewable energy plants are calculated. In addition, the loadings of all transmission lines of the power network with the integration of the large-scale renewable energy plants are determined. Based on the simulation results, the percentages of loadings of most of the transmission lines of the power network with the integration of the renewable energy plants increased considerably in comparison with the power network before integrating the renewable energy plants. Consequently, three different scenarios are proposed to reduce the high percentages of loadings of the transmission lines. The final results show that the percentages of loadings of the transmission lines with the proposed scenarios can be significantly reduced.

For further studies, the two large-scale solar plants will be integrated at the PHU_CAT bus and LONG_MY bus. The large-scale wind power plant will be integrated at the TAM_QUAN bus. The impact of these renewable energy plants will be investigated. Moreover, the uncertain generation of the renewable energy plants will be considered. Furthermore, the impact of the large-scale wind and solar power plants on the voltage stability of the 110 kV transmission power network of Binh Dinh province, Vietnam will be investigated. Finally, the small signal stability of the existing transmission power network with the integration of large-scale renewable energy plants will be analyzed.

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