

Impact of high WPPs penetration on the Vietnam Power System

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ABSTRACT

Wind power installed capacity is expected to reach 1,000 MW and 6,200 MW in the Vietnam Power System (VPS) in 2020 and 2030, respectively. But detailed dynamic analysis of the wind power plants' (WPPs) integration into the VPS is still scarce. In this paper, first, the impact of WPPs' integration on the dynamic voltage performance and the wind turbine generator (WTG) low-voltage-ride-through (LVRT) requirement in the VPS for the year 2020 is studied. Then, case studies on the VPS for the year 2020 with different levels of wind penetration and different values of WTG's maximum allowable voltage sag are studied. Simulation results show that the 2020 VPS can lose as much as 1,000 MW (100%) of WPP's generated power following a severe contingency if the WTG's LVRT capability is not considered. In some scenarios, the loss of WPPs' generated power can cascade into a power system islanding situation which in turn could cause massive load shedding (15%) in the load-rich subsystem and result in wide variations of the electrical parameters of generators near the islanding boundary.

Keywords: Wind Power Plants, Vietnam Power System, Transient Stability, Low Voltage Ride Through, Power System Islanding

1. INTRODUCTION

VIETNAM Master Plan VII [1] has set targets to develop 1,000 MW of WPPs by 2020 and 6,200 MW of WPPs by 2030. The most updated and detailed official research on wind integration into the Vietnam Power System (VPS) is [2] based on a cooperation between Vietnam Electricity (EVN) and the International Copper Association Southeast Asia Ltd (ICASEA). In the research conducted in [2], the dynamic studies on wind integration were not considered and a fixed maximum level of wind penetration was assumed (WPPs penetration was assumed to be less than 5%).

Fig. 1 depicts the 2020 VPS where the system can be viewed as two subsystems (A and B) connected

by a double-circuit 500 kV tie line. References [3] and [4] show that the registered WPPs at the end of 2012, with a total capacity of 4,296 MW, are located in the south central and the southern provinces of Vietnam. Combining this information with the data from [1] - [2] all the interconnection points of WPPs in the VPS are found in subsystem B. Hence, the percentage penetration of WPPs in subsystem B is higher than in the VPS as shown in Table 1.

Table 1: Total Projected WPPs capability in the VPS.

Description	MW	% of the 2020 VPS Installed Capacity	% of the Subsystem B in the 2020 VPS Installed Capacity
Target for 2020	1,000	1.3	2.7
Registered WPPs for 2012	4,296	5.7	11.6
Target for 2030	6,200	8.2	16.8

This paper is aimed at studying the impact of WPPs on the VPS by analyzing the transient stability of the 2020 VPS for four cases of different installed capacities of WPPs: Base Case - 1,026 MW of WPPs; Case 1 - 0 MW of WPPs; Case 2 - 4,471.5 MW of WPPs; and Case 3 - 6,216 MW of WPPs.

The motivation for this paper is based on the following reasons: 1) There has been no published transient stability study on the VPS with WPPs' penetration; 2) There have been cases of the VPS's separation into islands in the past five years [5] (In these separation cases, the penetration of WPPs in subsystem B could have been higher than that assumed in [2]); 3) The percentage of WPPs penetration was calculated using the installed capacity (Thus, under conditions of minimum load and maximum generated power from WPPs, the percentage of WPPs penetration can be higher than that shown in Table 1); 4) The amount of generated power from WPPs varies in a wide range depending on weather conditions; 5) Cases 2 and 3 are chosen with the intent of studying the impact of higher WPPs penetration on the transient stability of the VPS. Case 2 represents the interconnection of all registered WPPs in 2013. Whereas Case 3 represents the interconnection of all WPPs targeted for 2030.

The remainder of this paper is organized as follows. Section 2 presents the main characteristics of the 2020 VPS. Section 3 details the development plan and the

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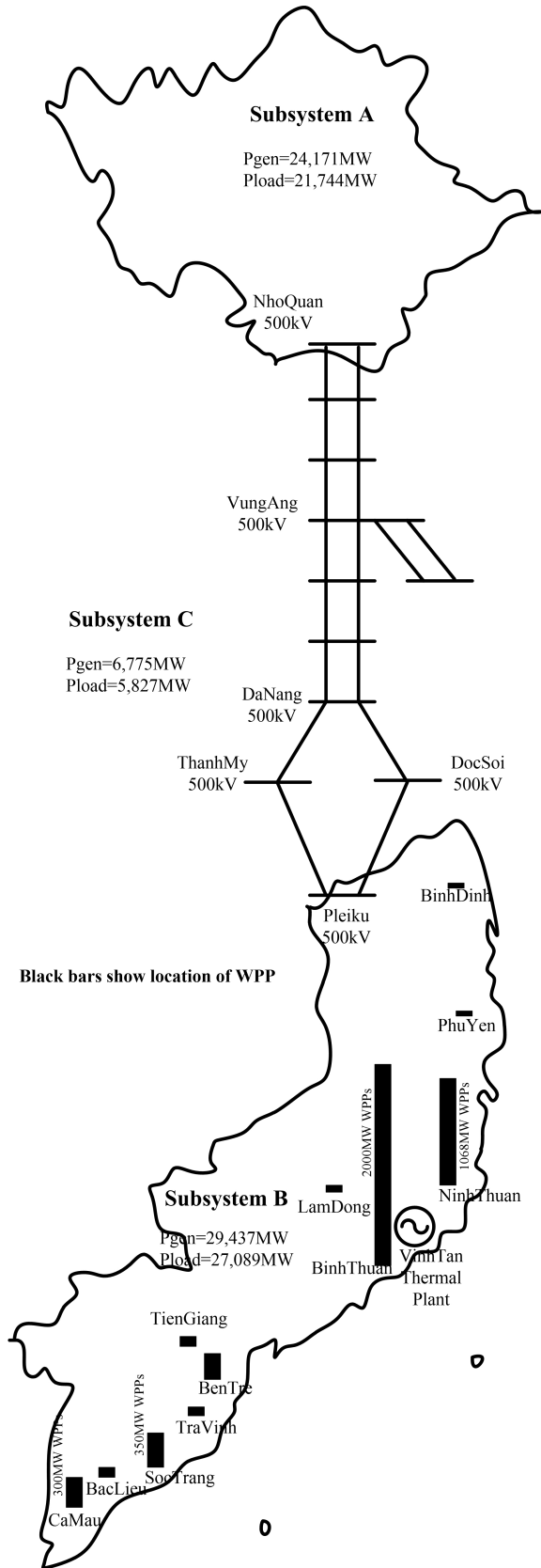


Fig.1: The 2020 VPS with WPPs' distribution.

Table 2: Details of the 2020 VPS.

	System Characteristic	Total	Sub. A	Sub. B	Sub. C
	Number of 500kV buses	68	23	36	9
	Installed capacity for 2020, MW	75,621	28,721	36,927	9,973v
	Installed capacity for 2018, MW	60,383	24,171	29,437	6,775
Base Case	Generated Power from Conventional Sources, MW	55,551	22,732	26,219	6,601
	Generated Power from WPPs, MW	1,000	0	1,000	0
	Load, MWv	54,691	21,774	27,089	5,827
Case 1	Generated Power from Conventional Sources, MW	56,551	22,732	27,219	6,601
	Generated Power from WPPs, MW	0	0	0	0
	Load, MW	54,691	21,774	27,089	5,827
Case 2	Generated Power from Conventional Sources, MW	55,572	22,728	26,238	6,605
	Generated Power from WPPs, MW	4,360	0	4,360	0
	Load, MW	58,133	22,870	29,142	6,121
Case 3	Generated Power from Conventional Sources, MW	55,718	22,875	26,238	6,061
	Generated Power from WPPs, MW	6,061	0	6,061	0
	Load, MW	59,881	23,420	30,192	6,268

interconnection model of WPPs in Vietnam. Section 4 studies and analyzes the impact of high WPPs penetration on transient stability of the VPS. Conclusions are drawn from the analysis and presented in section 5.

2. CHARACTERISTICS OF THE 2020 VPS

According to [1] and [5], the 2020 VPS is projected to include about 11,810 km of 500 kV tie-lines and 24,439 km of 220 kV transmission lines. The total installed capacity of the 2020 VPS is projected to be 75 GW. However, the construction of some power plants has been slower than expected as referred to in [6]. Thus, in this paper, the 2020 VPS includes the planned 500 kV and 220 kV networks for the year 2020 and the planned power plants for 2018.

The VPS is geographically divided into three parts: the northern, southern and central parts. However, in the paper, the VPS is represented by subsystems A and B connected by 500 kV and 220 kV transmission lines which are referred to as subsystem C (Fig. 1). This representation of the VPS is more convenient for the 2020 VPS transient stability study. The subsystem A includes the 500 kV and 220 kV networks in the north to the connection point at NhoQuan 500 kV substation. The subsystem B includes 500 kV and 220 kV networks in the south to the connection point at Pleiku 500 kV substation. Both the 500 kV networks inside subsystems A and B are built as multi-

ple closed loops. Subsystems A and B are connected mainly by a double-circuit 500 kV tie-line and two 220 kV lines as shown in Fig. 1.

The VPS 500 kV and 220 kV networks are incorporated by upgrading the working 2012 VPS to the 2020 VPS based on the information from the Vietnam Master Plan [1]. All the existing generator interconnections to the VPS network are modeled from the generators' terminal nodes to the corresponding 110 kV or 220 kV connection points as in the real 2012 VPS. All the planned generators' connections in [1] to the VPS network are modeled from generators' terminal nodes to the planned high-voltage connection points based on the information in [1]. Low-voltage load nodes are reduced to the 110 kV and 220 kV nodes. Values of loads are corrected based on the information from the Institute of Energy [5], from [1] and from the real 2012 VPS. All the WPPs are modeled as groups of wind turbines with 1.5 MW-590 V doubly fed induction generators (DFIG) connected to the VPS through the 22 kV and 110 kV networks to the 220 kV connection points as depicted in Fig. 2.

As a result, the 2020 VPS contains 1,145-buses including 68 buses at 500 kV and 343 buses at 220kV. The generators are modeled using conventional GENROU models for the thermal plants, GENSAL models for the hydro plants, and the IEEE generic WTG model - WT3 in [7]-[8] for WPPs. Hence, there are 163 GENROU, 181 GENSAL and 83 WPPs type WT3 generators represented in the 2020 VPS.

The details of the 2020 VPS are presented in the first three rows of Table 2. The last twelve rows of Table 2 show the loads and the powers generated by conventional power plants and WPPs of the 2020 VPS for the base case, Case 1, Case 2 and Case 3. The generated powers are lower than the installed capacities because spinning-reserves are considered for all the cases.

Table 3: WPPS project development [3]-[4]

Province	No of Project	Installed Capacities MW	% of Total Capacity
Binh Thuan	20	2,000	44.8
Ninh Thuan	13	1,068	23.9
Soc Trang	4	350	7.8
Ca Mau	2	300	6.7
Ben Tre	2	280	6.3
Tien Giang	1	100	2.2
Bac Lieu	1	99	2.2
Tra Vinh	1	93	2.1
Lam Dong	2	70	1.6
Binh Dinh	2	51	1.1
Phu Yen	1	50	1.1
Total	49	4,461	100.0

In the base case, the values of loads are chosen equal to the values for the maximum load condition under normal operation in 2020 [5]. All generators planned in [1] for 2018 including WPPs, excepting

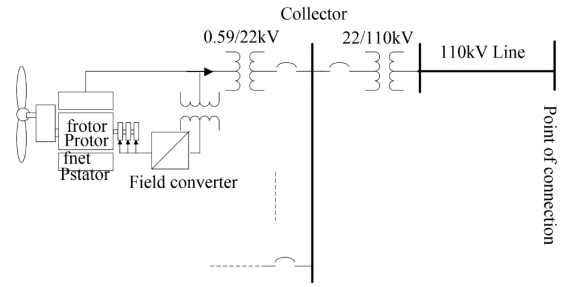


Fig. 2: WPP's connection topology in the 2020 VPS.

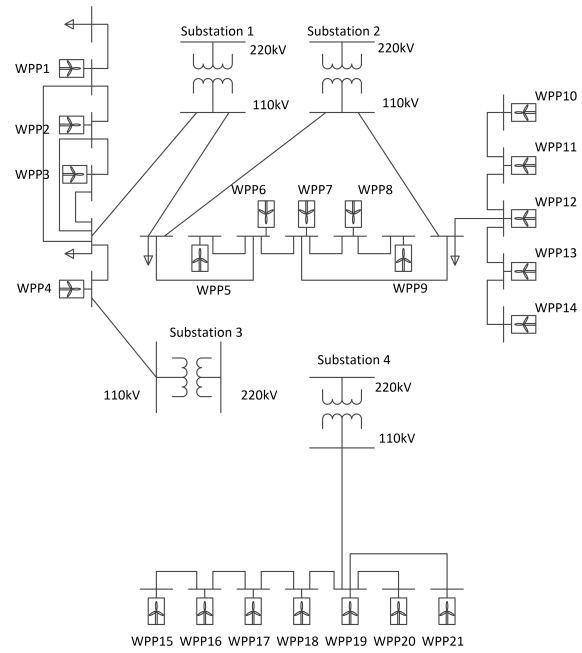


Fig. 3: Schema of WPPs' connection to the 2020 VPS (Base Case).

Table 4: Sets of generators dynamic data.

	Hydro Unit	Fossil Steam Unit	Cross-Compound Unit	WTG
$P_{gen} < 150\text{MW}$	1: GENSAL			
$150\text{MW} < P_{gen} < 400\text{MW}$	2: GENSAL			
$400\text{MW} < P_{gen}$	3: GENSAL			
$P_{gen} < 200\text{MW}$		4: GENSAL		
$200\text{MW} < P_{gen} < 400\text{MW}$		5: GENSAL		
$400\text{MW} < P_{gen} < 600\text{MW}$		6: GENSAL		
$600\text{MW} < P_{gen}$		7: GENSAL		
$P_{gen} < 350\text{MW}$			8: GENSAL	
$350\text{MW} < P_{gen}$			9: GENSAL	
$P_{gen} = 1.5\text{MW}$				10: WT3

Table 5: *LDS3AL relay's setting.*

	Step 1	Step 2	Step 3	Step 4	Step 5
Load Shed Point, Hz	49	48.8	48.6	48.4	48.2
Pickup Time, s	0	2	4	6	8
Breaker Time, s	0.02	0.02	0.02	0.02	0.02
Fraction of Load Shed	0.1	0.05	0.05	0.05	0.05

Table 6: *WTGS' voltage dips during the contingency.*

Eterm, pu	Base Case			Case 2			Case 3		
	NO	Pgen		NO	Pgen		NO	Pgen	
		MW	%		MW	%		MW	%
< 0.55	0	0	0	3	224	5	4	243	4
0.55 ÷ 0.6	4	154	15	0	0	0	0	0	0
0.6 ÷ 0.5	4	171	17	5	145	3	6	224	4
0.65 ÷ 0.7	5	412	41	4	221	5	6	241	4
0.7 ÷ 0.8	8	263	26	12	917	21	14	1,120	18
0.8 ÷ 0.85	0	0	0	9	462	11	10	310	5
0.85 ÷ 0.9	0	0	0	23	1,849	42	32	3,244	54
>0.9	0	0	0	23	1,849	42	32	3,244	54
Total	21	1,000	100	63	4,360	100	83	6,061	100

two diesel generators (750 MW each) at O-Mon thermal plant, are generating a total of 56,551 MW of power. The spinning-reserve is 6.3%.

In Case 1, loads are at the same level as in the base case. All the WPPs are not generating power. Instead of the WPPs, the two 750 MW generators at the O-Mon thermal plant are generating 1,000 MW.

In Case 2, 3,360 MW of WPPs are added to the base case to increase WPPs' generated power to 4,360 MW. Similarly, 5,061 MW of WPPs are added to the base case to increase WPPs' generated power to 6,061 MW in Case 3. Twenty percent of the generated power from the newly added amount is used for supplying local loads. The other 80% is used for supplying the remaining base case load incremented by 5% and 7.6% in Case 2 and Case 3, respectively. The spinning-reserves are 6.0% and 5.6% in Case 2 and Case 3, respectively.

3. WPPS IN THE 2020 VPS

In this section, the issue of WPPs penetration and interconnection to the 2020 VPS is examined. Then, the detailed simulation model of the WPPs in the 2020 VPS is presented.

3.1 WPPs Penetration in the 2020 VPS

The targets for WPPs development in Vietnam are 1,000 MW and 6,200 MW for years 2020 and 2030, respectively [1]. Based on the information in Table

2 from [3]-[4], all the registered WPPs in 2013 are located in subsystem B (Fig.1).

Table 3 shows that Binh Thuan and Ninh Thuan are the two provinces with the highest installed capacities of WPPs with 44.8% and 23.9% of the newly added capacity, respectively. The approved WPPs development plans for 2020 for Binh Thuan and Ninh Thuan have targets of about 700 MW and 220 MW installed capacities of WPPs respectively as per [2] and [9]. The detailed information about WPPs projects in Binh Thuan can be found in [2], but a similar data for Ninh Thuan is not available. Thus, for the base case, detailed data of some WPPs projects in Binh Thuan [2] are used for modeling the WPPs in Ninh Thuan. Consequently, the installed capacities of the WPPs in Binh Thuan and Ninh Thuan in the base case are 742.5 MW and 283.5 MW, respectively.

In Case 2, new WPPs are added to all provinces to reach the given installed capacities in Table 3. Installed capacities of WPPs are chosen to be equal in each province and ranging from 51 MW to 100.5 MW depending on the number of the 220 kV substations in that province which are assumed to be located at the interconnection points of the VPS.

In Case 3, new WPPs are added equally to all provinces listed in Table 3 to reach a total value of WPPs' installed capacity in the VPS equal to 6,216 MW.

3.2 Technical Data for Connecting WPPs to VPS

As per [1], all the large wind turbines operating in Vietnam are primarily DFIG machines. In the year 2000, wind turbines with DFIG emerged in many countries with a capacity of about 1 MW to 2 MW. Thus, in the paper, all WPPs are modeled as groups of 1.5 MW - 590 V doubly-fed asynchronous generators using the generic wind turbine generator (WTG) type 3 (WT3) [7]-[8] with the technical parameters from [10].

As for the proposed recommendations in [2], each WT3 has its own 0.59/22 kV transformer which is connected to the collector of a WPP. The collector is connected to a 22/110 kV step-up transformer, then the 110 kV bus is connected to the connection point via either a single circuit or double circuit line as shown in Fig. 2.

Based on the data from [2], the diagram of WPPs' connection to the 2020 VPS for the base case used in this paper is presented in Fig. 3.

With the proposed detail and model representation, the impact of WTG LVRT's capability on the 2020 VPS is studied in Subsection 4.2. In subsection 4.3, the impact of high WPPs penetration on the transient stability of the VPS is studied.

4. IMPACT OF WPPS' PENETRATION ON THE 2020 VPS

The intent of this section is first to determine the possibility that a contingency in the 2020 VPS can lead to tripping WPPs because of their WTG LVRT's violation, and then to study the impact of losing a large amount of generated power from WPPs on the transient stability in the 2020 VPS.

The simulations in this section are carried out for the four proposed cases using the PSS/E 33.4 software. The details of the input data for simulation of the 2020 VPS is provided in Subsection 4.1. In Subsection 4.2, the impact of WPPs penetration on WTG LVRT's requirement is studied by comparing the simulation results of the base case and Case 1. In Subsection 4.3, the impact of high WPPs penetration on the VPS's transient stability performance is studied by comparing Cases 2 and 3 with the base case.

4.1 Input Data

The operating condition data for power flow calculation is presented in Table 2. Because of the lack of actual generator dynamic data for the 2020 VPS, parameters are chosen from actual data of available similar generators derived from data in [10]-[11]. In order to minimize the deviation on the results, caused by using generic generator dynamic data, ten different sets of generator dynamic data are used for ten different groups of generators (Table 4). In the 2020 VPS, the most, second most and least popular types of conventional generator are fossil steam, hydro and cross-compound, respectively. Hence, four sets, three sets and two sets of generator dynamic data are used for fossil steam generators, hydro generators and cross-compound generators, respectively, with different ranges of installed capacities.

Hydro units are modeled as GENSAL with exciter AC7B and turbine governor HYG0V. Fossil steam units are modeled as GENROU with exciter AC7B and turbine governor TGOV2. Cross-compound units are modeled as GENROU with exciter AC7B and turbine governor GAST. WPPs are modeled as groups of WT3G2 with electrical control model WT3E1, mechanical control model WT3T1 and pitch control model WT3P1 according to [7], [8] and [10].

All load buses are equipped with under-frequency load shedding relay LDS3AL [10] with five load shedding steps. The LDS3AL relay's setting is presented in Table 5, knowing that the nominal frequency in the VPS is 50 Hz. Twelve out-of-step relays are equipped on the tie lines connecting subsystems A and B: six relays on 500 kV lines and six relays on 220 kV lines. Over and under frequency relays FRQTPAT, over and under voltage relays VTGTPAT are provided on all generators near the boundary between the two subsystems. These generators are the most vulner-

able during the transient stability study conducted in this paper.

4.2 Impact on WTG LVRT's Requirement

Several contingencies were tested and the most severe contingency was chosen for presentation and analysis. The chosen contingency includes two events: first a trip of one 500 kV tie-line from Pleiku to Thanh My, then a three-phase short circuit on the 220 kV bus at Vinh Tan thermal plant which is cleared after 0.08 s by tripping one generator-transformer connected directly to the faulted bus. The Vinh Tan 220 kV bus in Binh Thuan province is tightly coupled with the 220 kV connection points of all WPPs in the base case (Fig. 1). Hence, a short circuit on Vinh Tan 220 kV bus has significant influence on voltage dips at many of the WPPs.

An analysis of WTGs' terminal voltage dips during the specified contingency is carried out. The results of this analysis are presented in Table 6 involving the number (No.) and generated power (Pgen) of WPPs which have their WTGs' terminal voltages (Eterm) within a specified voltage range.

According to Table 6, all the WPPs in the base case undergo voltage dips ranging from 0.55 p.u. to 0.8 p.u. Moreover, WPPs with voltage dips between 0.65 p.u. and 0.7 p.u. contribute 41% of all WPPs' generated power which is equal to 412 MW. Whereas, 42% of generated power is from WPPs with voltage dips higher than 0.9 p.u. (or no voltage dip) in Case 2. The respective number for Case 3 is 54%.

Table 7: Accuracy Comparison of Two Service Areas.

Sag voltage V_x , pu	Base Case	Case 1	Case 2	Case 3
0.65	Stable	Stable	Stable	Stable
0.7	Unstable (Scenario 1)	Stable	Stable	Stable
0.8	Unstable (Scenario 2)	Stable	Stable	Stable
0.85		Stable	Stable	Stable

Table 8: Accuracy Comparison of Two Service Areas.

	Base Case	Case 1	Case 2	Case 3
No of Islands	2	1	1	1
No of tripped 500kV lines from out-of-step relays	1	0	0	0
No of tripped 220kV lines from out-of-step relays	2	0	0	0
No of tripped generators	2	0	0	0
No of generators with deep fluctuation	19	0	0	0
% of Load Shedding in subsystem B	15	0	0	0

It can be seen that if WTG LVRT's requirements are set to a value of maximum allowable voltage sag

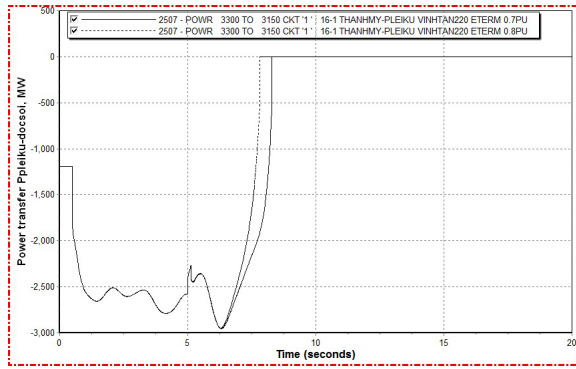


Fig.4: Power transfer on the 500 kV tie-line from Pleiku to DocSoi for scen. 1 & 2. (Solid line - scen.1; dot line - scen. 2)

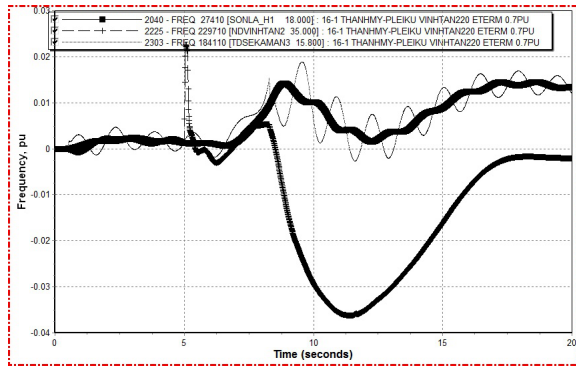


Fig.5: Frequencies for scenario 1. (Line with square marks - in sub. A; line with cross marks - in sub. C near the boundary; dot line - in sub. B)

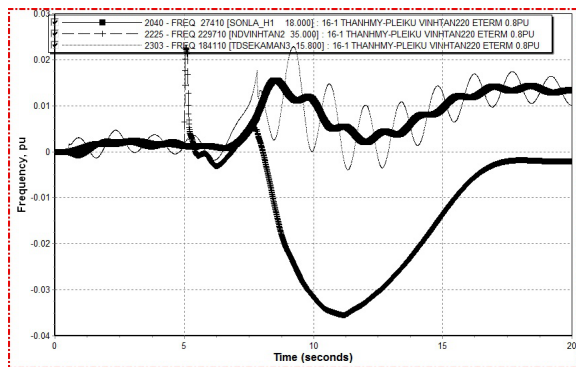


Fig.6: Frequencies for scenario 2. (Line with square marks - in sub. A; line with cross marks - in sub. C near the boundary; dot line - in sub. B)

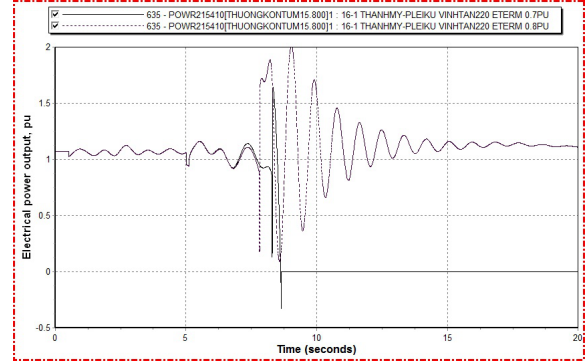


Fig.7: P_e of a hydro generator near the boundary (Thuongkontum) for scen. 1 & 2. (Solid line - scen.1; dot line - scen. 2)

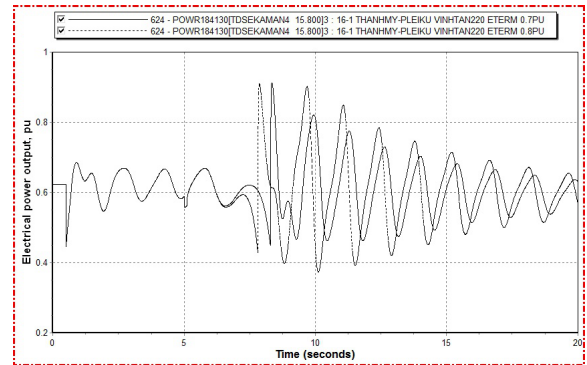


Fig.8: P_e of a hydro generator near the boundary (Sekaman4) for scen. 1 & 2. (Solid line - scen.1; dot line - scen. 2)

of 0.8 p.u., after the contingency, 100% of the WPPs in the base case will be tripped, while the numbers for Cases 2 and 3 are 66% and 70%, respectively. If the voltage sag limit is set to 0.7 p.u., 74%, 13% and 12% of WPPs' generated power will be tripped in the base case, in Case 2 and in Case 3 respectively.

In conclusion, the higher WPPs' penetration in the 2020 VPS, the lower the percentage of tripped generated power from WPPs because of the voltage dips during contingencies. Besides, studying details of LVRT's requirement for the VPS close attention should be paid to the value of the voltage sag ranging from 0.55 p.u. to 0.8 p.u. because all WPPs in the base case undergo voltage dips in this range.

4.3 Impact on VPS's Transient Stability

The impact of losing a large amount of generated power from WPPs on VPS's transient stability is analyzed in this subsection. The reason for losing generated power from WPPs is associated with the tripping of WPPs' due to the violation of the LVRT capability, following a three-phase short circuit at the Vinh Tan 220 kV bus. The value of the WTG LVRT's maximum allowable voltage sag (V_x) is supposed to be

equal to 0.65 p.u., 0.7 p.u., 0.8 p.u. and 0.85 p.u. for each of the considered cases. For each value of V_x , all the WPPs have voltage dips during contingency lower than V_x and are tripped. The considered disturbance is as follows.

- at $t=0.50$ s: trip the 500 kV tie-line from Pleiku to Thanh My;
- at $t=5.00$ s: a three-phase fault is located at Vinh Tan 220 kV bus;
- at $t=5.08$ s: the short-circuit is cleared by tripping a 600 MW generator-transformer connected to the 220 kV bus;

Simulations are carried out for all four cases of WPPs' penetration and for all four chosen values of voltage sags.

According to the simulation results of the base case (1,000 MW generated power of WPPs) shown in Tables 6 and 7, the 2020 VPS is stable when 32% (325 MW) of WPPs' generated power is tripped with $V_x=0.65$ p.u. The system becomes unstable when 74% (736 MW) or 100% (1,000 MW) of WPPs' generated power is tripped with $V_x=0.7$ p.u. in Scenario 1 or 0.8 p.u. in Scenario 2, respectively.

In both Scenarios 1 and 2, the 2020 VPS loses transient stability at $t=6.3$ s when subsystems A, B and C start losing synchronism (Fig. 4). Power swings appear on the 500 kV transmission lines in subsystem C connecting subsystems A and B. The out-of-step relay on the 500 kV tie-line from Pleiku to DocSoi sends signals to trip the line and to transfer trip another two 220 kV transmission lines at $t=8.3$ s and 7.8 s in Scenarios 1 and 2, respectively. This action separates the 2020 VPS into two islands: subsystem B, subsystems A and C (Table 8, Fig. 4). In both scenarios, frequency in the load-rich island (subsystem B) starts to fall rapidly, and then under-frequency load shedding relays shed 15% of the total load in the subsystem B (Table 8, Figs. 5 and 6). In scenario 1, two small hydro generators near the boundary in subsystem B are tripped by out-of-step relays because of their electrical power output's swings (Fig. 7). The other 17 hydro generators in the generation-rich island (subsystems A and C) and 2 hydro generators in subsystem B near the boundary suffer severe fluctuations of electrical power output, rotor speed and rotor angle, however, they survive the disturbance and are not tripped from the network (Fig. 8). In Scenario 2, 17 hydro generators in the generation-rich island (subsystems A and C) and 4 hydro generators in subsystem B near the boundary, suffer severe fluctuations of electrical power output, rotor speed and rotor angle, however, they survive the disturbance and are not tripped from the network (Fig. 8).

Simulation results of Case 2 and Case 3 show that the VPS is stable even when 45% (1,958 MW) and 35% (2,138 MW) of WPPs' generated power is tripped with $V_x=0.85$ p.u. in Case 2 and Case 3, respectively.

Comparison of the results for the four cases with the same value of maximum allowable voltage sag, e.g. 0.7 p.u., are shown in Table 8.

5. CONCLUSION

The simulation results (Tables 6, 7, and 8) shows that an unexpected loss of a large amount of generated power from WPPs can cause transient instability in the 2020 VPS. Firstly, the issue of WTG LVRT should be taken in account carefully to avoid losing a large amount of WPPs' generated power following a contingency. However, with the higher penetration of WPPs, the percentage of lost generated power from WPPs because of the violation of the LVRT capability during the contingency is lower (Table 6). Secondly, the VPS is stable when even 32%, 45% and 35% of WPPs' generated power is tripped in the base case, Case 2 and Case 3, respectively.

In the dynamic study of the base case, the 2020 VPS cannot survive the contingency if 74% of WPPs' generated power is tripped which leads to the islanding of the VPS, shedding of 15% of total load in subsystem B and causing significant swings in generators.

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References

- [1] *Approval of the National Master Plan for the power development for the 2011-2020 period with the vision to 2030*, Decision No 1208/QĐ-TTg of the Prime Minister of the Socialist Republic of Vietnam, Hanoi, Vietnam, 2011.
- [2] *Technical manual for interconnecting wind power to Vietnam Power System*, Vietnam Electricity and International Copper Association Southeast Asia Ltd., Hanoi, Vietnam, 2013.
- [3] Pham Trong Thuc, *Wind Power Development in Vietnam*, presented at the EEP Mekong Third Regional Forum, Hanoi, Vietnam, 2012.
- [4] Nguyen Anh Tuan, *Wind Energy Market Development in Vietnam*, presented at the Forum on Wind Energy Development between Germany and Vietnam, HoChiMinh city, Vietnam, 2012.
- [5] *National Master Plan VII*, Institute of Energy, Hanoi, Vietnam, 2011, (In Vietnamese).
- [6] Tran Viet Ngai, *About the progress improvement of energy projects in Vietnam. Petition No 106/VBKN-VEA of the Vietnam Energy Association*, Hanoi, Vietnam, 2011, [Online], Available: <http://nangluongvietnam.vn/news/vn/hiep-hoi-nang-luong-viet-nam-vea/van-ban-phan-bien-kien-nghi/kien-nghi-giai-quyet-tien-do-cac->

du-an-nang-luong-cua-dat-nuoc.html,
(In Vietnamese).

- [7] Working Group Joint Report - WECC Working Group on Dynamic Performance of Wind Power Generation and IEEE Working Group on Dynamic Performance of Wind Power Generation, *Description and technical specifications for generic WTG models - a status report*, IEEE PES Power Systems Conf. Expo., 2011.
- [8] M. Asmine, J. Brochu, J. Fortmann and R. Gagnon, "Model Validation for Wind Turbine Generator Models," *IEEE Transactions on Power Systems*, Vol. 26, No. 3, pp. 1769-1782, 2011.
- [9] *Approval of the Provincial wind power development plan Ninh Thuan 2011-2020, Vision 2030*, Decision No 2574/QD-BCT, 2013, (In Vietnamese).
- [10] *PSSE 33.4. Program application guide*, Volume 2, Siemens Industry Inc., 2013.
- [11] P.M. Anderson and A.A. Fouad, *Power system control and stability*, 2nd ed., John Wiley & sons Inc., 2003.



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