KKU RESEARCH JOURNAL (GRADUATE STUDIES)
Vol. 19 NO. 4: October-December 2019

Electrical Effects of Wind Energy Generation on Power System in Area of the Central II Part, Lao People's Democratic Republic

Kanthanachuck Vorabout* Chayada Surawanitkun** Arkom Kaewrawang[1]***

(Received: *October 5, 2018*; Revised: *January 22, 2019*; Accepted: *January 27, 2019*)

ABSTRACT

Currently, the hydropower plants are the important energy resources in Lao People's Democratic Republic (Lao. PDR). However, the hydropower plants may have some disadvantages of generation and capacity depending on the water volume during the rainy season; therefore, the government has promoted the utilization of other renewable energy resources to increase the power stability. One project is the construction of the wind farm for renewable energy source to supply energy in Central II part, Lao PDR. In this paper, the electrical effects of wind energy generation on the power system were analyzed for installation in an area of Central II part, Lao PDR. The DIgSILENT software based on load flow analysis with the installed capacity at 20, 40, 60, 80, 100 and 120 % of energy lacking demand was used for the analyzer. The results indicated the dependence of the power flow, voltage, power factor and power loss of the system on the different installed capacities. The total power generation and power loss in this area of 126.24 MW and 5, respectively. The increased wind power generation of 40 % of energy demand can cause increment of power supply of 215.56 MW and power loss of 6% of total power generation. However, it can be reduced the import energy of 77.17 MW.

Keywords: Wind power generation, Voltage stability, Renewable energy

[1]*Correspondent author: arkom@elec.kku.ac.th, arkom.kaewrawang@gmail.com*

** Student, Master of Engineering Program, Energy Engineering, Faculty of Engineering, Khon Kaen University, Thailand*

*** Assistant Professor, Faculty of Applied Science and Engineering, Khon Kaen University, Nong Khai Campus, Thailand*

**** Associate Professor, Department Electrical of Engineering, Khon Kaen University, Thailand*

Introduction

At the present, most of energy supply is from burning fossil for electric generation. Then, the results are carbon dioxide emission (CO_2) and global warming. That is the big problem on our world today because the CO_2 emitted from burning fossil fuel released CO_2 amount of 32,294 Mton in 2016 [1]. The target to reduce the CO_2 emission in 2050 is below 50% [1]. Among the renewable energy resources, wind energy is a clean energy resource, less of greenhouse gas emission and growing quickly [2].

The wind energy plants are expanded worldwide, especially, in the developed countries such as the United states of America (USA), Germany and Canada, etc. The globe has potential for wind source with the onshore wind power and off shore wind power [3]. The onshore wind power is developed by wind power installation more than 95 TW and the offshore wind power is developed because of suitable location and few impacts of the environment [4]. The wind energy based on the recent reports is 1988 EJ/year as well as 1226 and 762 EJ/year from onshore and offshore wind power, respectively [4]. The number of wind power generation potential to produce electricity has increased every year. In 2017, the total capacity of installation was 539,123 MW that increases by 11% compared with 2016 [5]. Several researches have forecasted the electrical consumption from wind energy in the future; the estimation expects 1,245,000 MW and investment cost is approximately around 692 billion Euros by 2020 [6].

The wind power generation depends on wind speed. The wind speed over 3.5 m/s is sufficient to rotate the wind turbine blades. There are three periods of electrical generation for wind potential [7-8]. The first period is the cut-in period with the turbine begins to produce power at wind speed of 3-4 m/s. Secondly, the period is the rising power and wind speed with maximum of power generation to reach the high capacity at wind speed of 12-17 m/s. Finally, the last period is cut-off period - the turbine is not allowed to generate power at wind speed over 25 m/s because there is a risk of damage to the turbine and the consequent system [3].

The influence on damage is more important of power system. When wind power generation is integrated with the grid utilities because the wind power is uncertainly generated and fed proper power size in to the electrical grid. Consequently, there are several instabilities in the electrical systems, i.e. voltage, current and power flow oscillation etc. The protection selectivity of the system can be investigated by load flow and electrical voltage analysis [9].

Based on the optimal placement to electric generation from wind farm, the geographic and the electrical power grid to the optimal location and size of wind farm to maximize potential of electric generation was studied [10]. Regarding the results, electric generation with wind energy and electric power transfer operation control are a long-term. Therefore, the unified power flow controller is inserted in to system for improving electrical quality. The integration of wind power system is modelled on DC network to achieve the optimal power flow approach to promote a performance of long-run power generation. The Monte-Carlo simulation was used to analyze load flow based on Weibull distribution for wind speed [11].

Lao People's Democratic Republic (Lao. PDR) government has policies to promote the renewable energy development. The one of aims is clean energy development to serve the domestic energy demand, as well as, being a plan for the country's development for a long term. This can increase energy consumption resulted from growth of population and economic. Thus, the main objective of energy development is research of power supply reliability, sustainable energy and improvement of energy resources. The biggest challenge of the development strategy plan is the rural electrification. In addition, electricity has also become an important key for development for several years to access electricity of household more than 90% by 2020 [12]. During the year 2015-2030, the government has planned to construct renewable energy resources especially, wind energy at installed capacity about 75 MW to reduce the domestic energy import in dry season [13].

The Central II part in Lao PDR needs more energy to support the increasing demand with the industry area and the population growth [13]. In 2017, the total demand of this area is 281 MW whereas the total power supply is 165 MW. Thus, wind energy is the possible resource to supply electricity to the system based on energy lacking of 116 MW. In the basic research of geographic in Central II part and Southern part, the suitable areas of wind turbine installation are Savanhnakhet, Khammuan and Sekong provinces to construct the wind farm because of wind speed average of 5.8 m/s with the height above 50 m.

In this paper, the main work is investigation of electrical effect of wind energy generation on power system in the Central II part of Lao PDR by DIgSIENT power factory software based on Newton-Rapson method. Therefore, power system analysis is investigated at before and after wind power installation. The results of power system simulation showed the direction of power flow dispatch, power generation capacity, peak load, current and voltage.

Model and Simulation

1. Overview of electrical power systems

The electrical power systems of Lao PDR depend on geography with 4 areas: Northern, Central I, Central II and Southern parts. The electrical power is transferred by overhead transmission line composed of 115, 230, and 500 kV. In addition, there are 115/22, 115/230 and 500/230 kV substations. Currently, the national grid of Lao (northern-southern parts) is 115 kV overhead transmission line. However, 230 and 500 kV are extending to cover over all country.

Electricite du Lao (EDL) have established the performant standard grid code to support the power system expansion planning in the future. The grid code become a significant due to the AC electric power system is sensible variation of voltage and frequency. Consequently, the independent power producer, the small power producer and the customer who will connect with the electric power grid that should be followed Lao grid code. The variable frequency in the normal condition allowed from 49.5-50.5 Hz [14]. The variable voltage in the normal condition allowed period of 95-105%; Voltage limited during emergency condition allowed period of 90-110% [14]. EDL has planned to developed the electric power system to be the smart grid that proposed for management, remote monitoring and power system control to ensure high security based on IEC 61850 "the communication networks and System in substations" [15].

2. Modeling

The power system with condition of peak load and total power generation is investigated because it shows ability of power transmission in the system. Therefore, the first study is investigation of power system without the integration with the wind farm. After that, the combination between the hydro power plant and the wind power generation is selected to supply total electrical demand in the area. It is necessary to analyze the electrical effects after the wind farm power generation connected to the power grid as shown in Fig 1. In order to achieve the main objective, the DIgSILENT program is used to simulate the power flow that is the helpful software tool for analysis and advance investigation of electrical power system. The electrical effect of substations number of 1, 2, 8, 9, 10 were selected for this study because these substations were the path ways of power flow and the connection points an electricity transfer to other parts. The wind farm was connected to the 10^{th} substation by 115 kV overhead transmission because it near located to connect with distance around 55 km. The power system analysis and wind farms installation are followed by:

Step 1: The study of Central II part was chosen, then collect the basic data of power system and single line diagram as shown in Table 2 and Table 3.

Step 2: Existing power system was modelled that include bus bars, transformers, transmission lines and loads.

Step 3: The power system without wind power generation was analyzed by DIgSILENT power factory software based on Newton-Rapson method as below formula.

The power balance equations are followed [16-19].

$$\left.\begin{aligned} P_{G_i}+P_{w_i}-P_{D_i} &= V_i \sum_{j=1}^{NB} V_j Y_{j,i} \cos(\theta_i-\theta_j-\gamma_{i,j}) \\ Q_{G_i}+Q_{w_i}-Q_{D_i} &= V_i \sum_{j=1}^{N_B} V_j Y_{j,i} \sin(\theta_i-\theta_j-\gamma_{i,j}) \end{aligned}\right\} \quad (1)$$

where P_{G_i} is active power of generation, P_{w_i} is active power of wind farm, P_{D_i} is active power, Q_{G_i} is reactive power of generation, Q_{w_i} is reactive power of wind farm, Q_{D_i} is reactive power of demand. voltage magnitude and angle at but i, j are V_i, V_j, θ_i, θ_j, $\gamma_{i,j}$, respective and NB is a number of the buses.

Active power, reactive power and voltage should be allowed range of control:

$$P_{G_i}^{min} \leq P_{G_{sl}} \leq P_{G_i}^{max} \quad ,\forall i = sl \quad (2)$$

$$Q_{G_i}^{min} \leq Q_{G_{sl}} \leq Q_{G_i}^{max} \quad ,\forall i \in N_G \quad (3)$$

$$V_i^{min} \leq V_{i,s} \leq V_i^{max} \quad ,\forall i \in N_B \quad (4)$$

Power flow equations are

$$P_k-jQ_k=V_k \sum_{i=1}^{n} Y_{ki} V_i \quad (5)$$

$$P_k=|V_k| \sum_{i=1}^{n} |Y_{ki}||V_i| \cos(\theta_k-\theta_i) \quad (6)$$

$$Q_k=-|V_k| \sum_{i=1}^{n} |Y_{ki}||V_i| \sin(\theta_k-\theta_i) \quad (7)$$

where P_k and Q_k are active power and reactive power at the k bus, V_k, V_i, θ_k, θ_i are voltage magnitudes and voltage angles that are elements of admittance matrix.

Power loss equation is

$$P_{loss}=I^2R=\frac{P^2+Q^2}{V^2}R \quad (8)$$

Step 4: Power system analysis with wind power generation was investigated.

Step 5: The electrical effects such as active power, reactive power, voltage and current, etc. were analyzed.

Step 6: Repeat step 3 with installed wind farm capacity of 40% until 120%.

Step 7: A number of wind turbines were investigated to supply lacking energy demand.

1) C_P is coefficient that resulted calculation of available power output of turbine using eq. (9)

$$P = C_p \frac{1}{2} \rho S V^3 \quad (9)$$

where P is the power generation of wind speed directly (W), C_p is coefficient, ρ is mass of air condenses (kg/m^3), S is the blade sweep circular surface m^2 and V is the speed of wind (m/s).

2) Calculated a number of wind turbine to install in area using eq. (10) - (12)

$$T_n=\frac{P_D}{P_{av}} \quad (10)$$

$$P_{av}= \sum_{i=1}^{N} \frac{P_{out,i}}{N} \quad (11)$$

where P_D is lacking power demand, P_{av} is power output of wind turbine convert to electrical power on average, P_{out} is available power of wind flow per months and N is number of month in the year.

Results and Discussions

1. Voltage, current and power loss assessment of substations

Figure 2 shows a variable voltage level ride up/down of the substations based on installed capacity of wind farm in the Central II part. Firstly, the wind farm was installed 20% of lacking demand that results increment of voltage level. After that, the capacity was continuously increased wind farm of lacking demand and the result showed the maximum voltage at the 40% of lacking demand, especially the substation is nearby generation. When the capacity installed more than 40% of lacking demand, the voltage of substations decrease. We have found that the peak voltage drops at installed capacity of 120 % . Therefore, voltage drop is solved by connected external grid control voltage at the 8th and the 13th substations. The result after connecting external grid is voltage under control in standard [14].

Figure 3 (a) shows the current value of substations with installed capacity of the wind farm. The increment of domestic power generation to supply extension of energy potential leads to power flow through substation resulted increment of current. It is clearly shown that the current of the 10th substation is higher than other substations because it was connected with the hydro and the wind power generations. In addition, the 9th substation has current lower than other substations caused power flow through this substation less than others.

Figure 3 (b) shows the power loss of power system based on installed capacity of wind farm in the Central II area based on power flow analysis. The power loss can be estimated by eq. (8). Therefore, the scenario was calculated before wind farm installation resulted total 8.6 MW. Then, installed capacity of wind power is inserted 20, 40, 60, 80, 100 and 120 % of lacking demand resulted power loss of 10.8, 14.93, 20.23, 26.82 and 34.64 MW, respectively. The result showed trend of increased power loss based on the increment of active power and reactive power flow. In addition, the increment of current causes of power loss in the system.

2. Power flow

The increment of installed capacity of wind power generation reaches to increase of power flow in power system that is significant of expanded energy potential in domestic and reducing import energy. However, one disadvantage of wind power generation was limited on location because the suitable location with wind potential is far from residential area (Load center). Therefore, this is a problem of power transfer because a long transmission line is a cause of power loss. The wind farm in Bualapha district, Khammuan province-55 km of distance is connected the 10th substation by ACSR of 300 mm^2.

Figure 4 (a) and (b) show the active power flow of substations with installed capacity of the wind farm. The power flow increases with respect to installed capacity of the wind farm as eq. (1), especially the 10th substation is the highest value of active power flow because it is the nearest substation connected wind farm and center of power transfer. Furthermore, the 9th substation is lowest power flow in substation because it is alternative way of power transfer from the 10th to the 8th substations. Since the power is used to support the demand of substation and the exceed power is transferred. The highest active power flow out is the 10th substation because this substation carries load only 4.38 MW whereas power active flow in is more than 73 MW. Therefore, excessive energy flows out to other parts.

Figure 4 (c) and (d) show the result of reactive power flow with installed capacity of wind farm. As the result, the 1st and the 8th substations are the highest effect of reactive power flow in the substation because substations are a connection point of other parts. Consequently, there is the reactive power flow through the substations to enhance voltage under control. The maximum of reactive power flow in and out of the 1st station is 83.1 and 56.38 MVar, respectively. In addition, the 10th substation is high for reactive power flow out because this substation is nearly power resources. Moreover, it has installed big size of capacitor blank. Therefore, exceed reactive power is transferred through other parts.

3. Investigation of installed wind turbine

The kinetic wind power is converted into electrical power by the wind turbine. The main cause of variable electrical power output depends on the wind speed and the swept area of the wind turbine. Consequently, the electrical power generation management of the wind farm planning is necessary to know the expected power output. As the Betz theory, the maximum of wind turbine efficiency is 59% of wind energy conversion. However, wind energy efficiency value is commonly 35-45% of the best designed wind turbine.

The wind turbine size of 2.5 MW, hub height of 110 m and area swept of 11,304 m^2 was chosen for the electrical generation to supply the lacking energy of demand at 124 MW in the area. Furthermore, the installation of wind farm was separated 6 cases: 20, 40, 60, 80, 100 and 120% of lacking energy. Consequently, it is necessary to calculate a number of wind turbine based on these installed capacities. The calculation of wind power output is followed by eq. (9). The data information of wind turbine is blade length of 60 m, power coefficient C_p of 0.45, air density ρ of 1.23 kg/m^3. According to the statistic of wind speed in 2011, power output of wind turbine converts electrical power on average which is calculated by eq. (10) and (11). The result of power out per month and average power is shown as Table 1. According to the calculation shown that the wind farm was not able electric generation during June to September course of low wind speed. Therefore, the way to serve lacking of the power is development another renewable energy resources such as small hydro power, biomass also that should be development of the high voltage level power transmission line as 230 kV to improve ability of the power transfer to the Central II part. Consequently, it can be calculated a number of wind turbine based on wind farm installed capacity: 20, 40, 60, 80,100 and 120%; a number of wind turbine these cases is 17, 34, 50, 87, 84 and 101 turbines, respectively.

Conclusions

In this paper, the electrical effects of wind energy generation on the power system were investigated by DIgSILENT power factory software. Load flow was used to analyze the penetration levels of wind power generation on power system. The basic factors in this study conclude active power, reactive power, voltage, current and power loss of substations. It found that the long distance of transmission line from wind power generation to the energy consumption is the cause of voltage drop. The increment of installed capacity is the cause of increased power generation in the area. The total installed capacity of wind power generation was 120% of lacking power that resulted more power flow through substations especially the 1^{st}, 2^{nd}, 8^{th}, 9^{th} and 10^{th} substations. The increment installed capacity of wind power generation is the increment of power flow in the system. However, there is one disadvantage because the distance between generation and load is quite far so that was the cause of power loss.

The result from this study is significant for power system because it was the simulation of power flow analysis with the installation of wind farm. In addition, this study will improves the power reliability and the power control that will be useful planned the power system of Lao PDR in the future.

Acknowledgments:

This project is funded by cooperation of Electricite du Lao (EDL) and Electrical Authority Generation of Thailand (EGAT). In this scenarios, DIgSILENT factory software is supported by EDL. I would like to thank Ministry Energy and Mine of Lao for the supporting data and information. In addition, we thank Electrical Engineering Department, Khon Kaen University.

References

1. International Energy Agency IEA. Technology Roadmap 2014 [Internet]; Cited 2018 Aug 15. Available, from http://www.iea.org/temsadconditionsuseadcopyright.
2. Novaes Menezes EJ, Araujo AM, Bouchonneau da Silva NS. A review on wind turbine control and its associated methods. Journal of Cleaner Production. 2018; 174: 945-953.
3. Dupont E, Koppelaar R, Jeanmart H. Global available wind energy with physical and energy return on investment constraints. Apply Energy. 2018; 209: 322-338.
4. Wang X, Zeng X, Li J, Yang X, Wang H. A review on recent advancements of substructures for offshore wind turbines. Energy Convers management. 2018; 158: 103-119.
5. Global wind energy report [Internet]. Annual marketing update 2017; Cited 2018 Aug 20. Available, from http://www.researchgate.net/publication/324966225.
6. Kokturk G, Tokuc A. Vision for wind energy with a smart grid in Izmir. Renewable and Sustainable energy reviews. 2017; 73: 332-345.
7. Mohseni-Bonab SM, Rabiee A, Mohammadi-Ivatloo B. Voltage stability constrained multi-objective optimal reactive power dispatch under load and wind power uncertainties. Renewable energy. 2016; 85: 598-609.
8. Oliveira CC, Bonini Netto A, Miussi CR, Alves DA, Castro CA. New representation of PV buses in the Current injection Newton power flow. International Journal of Electrical Power & Energy Systems. 2017;90: 237-244.
9. Feilat EA, Azzam S, Al-SAlaymeh A. Impact of PV and Wind power plants on voltage and frequency stability of Jordan's national grid. Sustainable cities and Society. 2018; 36: 257-271.
10 Katinas V, Gecevicius G, Marciukaitis M. An investigation of wind power density distribution at location with low and high wind speeds using statistical model. Apply Energy. 2018; 218: 442-451.
11. Gupta N. A review in the inclusion of wind generation in power system studies. Renew Sustain Energy. 2016; 59: 530-543
12. Baloch MH, Kaloi GS, Memon ZA. [Internet]. Current scenario of the wind energy in Pakistan challenges and future perspectives a case study. Energy Reports. 2016; 2: 201-210. Available from http:// dx.doi.org/10.1016/j.egyr.2016.08.002.

KKU RESEARCH JOURNAL (GRADUATE STUDIES)
Vol. 19 NO. 4: October-December 2019

13. Planning System Office, Technical department, Electricite du Laos: Electrical demand forecast and power system planning of Laos. Power system development. 2017 April: 1-8.

14. Electricite du Laos, Ministry Energy and Mine The electric power transmission system in Lao PDR. Lao grid code. 2019 Jan: 1-100.

15. Hansch K, Naumann A, Wenge C, Wolf M. Communication for battery energy storage systems compliant with IEC 61850. Electrical power and Energy systems. 2018; 103:577-586.

16. Rahmani S, Amjady N. A new optimal power flow approach for wind energy integrated power systems. Energy 2017; 134: 349-359.

17. Government of Lao PDR [Internet]. Renewable Energy Development Strategy in Lao PDR. 2011; 1-40. Available from http:// www.eepmekong.org /index.php/resources/country-reports/laos/57-laos-06/file.

18. Al Ameri A, Ounnissa A, Nichita C, Djamal A. Power loss analysis for wind power grid integration based on Weibull distribution. Energies. 2017; 10(4).

19. Magdi Ragheb, Adam M. Wind turbines theory-the Betz Equation and Optimal Rotor Tip Speed Ratio [Internet] 2011; Cited 2018 Aug 15. Available from: http://www.intechopen.com/books/fundamental-and-advanced-topicsin-wind-power/wind-turbines-theory-the-betz-equation-and-optimal-rotor-tip-speed-ratio

Table 1 The data of wind speed and power output on average of wind power

Place name	**year**	**Wind speed/Month (m/s)**												**Average**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Bualapha district Khammuan province	2011	12.6	7.8	11.2	6.8	4.3	2.7	2.4	2.2	2.9	7.5	9	13.1	6.875
		Power output [MW/Month]												**P_{av} (MW)**
		6.26	1.48	4.40	0.98	0.25	0.00	0.00	0.00	0.00	1.32	2.28	7.03	1.48

Table 2 The data of substations

Substation	Substation number	MVA	Voltage (kV)	Z(%)	Copper Loss (kW)	Vector Group	Remark
Pakxan	Sub.1	16	115/22	14.76	88	YN/YN	2 Unit
Khonsong	Sub.2	20	115/22	9.97	121	YN/YN	1 Unit
Lanxang	Sub.3	20	115/22	9.97	121	YN/YN	1 Unit
Nam ngaung	Sub.4		11/115				
Thasala	Sub.5	20	115/22	10.63	88.75	YN/YN	1 Unit
Pompik	Sub.6	30	115/22	13.94	121	YN/YN	1 Unit
Nakadok	Sub.7	30	115/22	13.94	121	YN/YN	1 Unit
Thakhek	Sub.8	30	115/22	13.94	121	YN/YN	2 Unit
CM .Thakhek	Sub.9	20	115/22	10.12	102	YN/YN	1 Unit
Mahaxay	Sub.10	20	115/22	13.5	102	YN/YN	2 Unit
NTH2	Sub.11						
Xepon	Sub.12	50	115/22	10.53	186	YN/YN	3 Unit
Pakbor	Sub.13	20	115/22	9.71	102	D/YN	2 Unit
Nongdeun	Sub.14	50	115/22	10.24	194.2	YN/YN	1 Unit
Kengkok	Sub.15	10	115/22	8.6	53	D/YN	1 Unit
Xeno	Sub.16	20	115/22	10.12	102	YN/YN	1 Unit
M.Phim	Sub.17	10	115/22	8.6	53	YN/YN	1 Unit
Mitphon	Sub.18	4	6.3/22				
WFs1	Sub.19		11/115				

Table 3 The data of peak load, power generation and transmission line

Substation	Voltage (p.u.)	Current (kA)	Peak load (MW)	Generation (MW)	Transmission Line	Resistance (Ω/km)
Sub.1	0.95	0.15	38.27		Sub.8-Sub.10	2.60
Sub.2	0.95	0.45	6.85		Sub.8-Sub.9	3.09
Sub.3	0.95	0.39	13.47		Sub.2-Sub.5	5.84
Sub.4	0.96	1.44		88	Sub.4-Sub.5	0.95
Sub.5	0.96	2.88	15.3		Sub.14-Sub.15	5.57
Sub.6	0.93	0.81	15		Sub.2-Sub.4	6.89
Sub.7	0.92	0.3	15.3		Sub.13-Sub.14	0.44
Sub.8	0.93	0.93	46		Sub.13-Sub.18	2.73
Sub.9	0.94	0.45	7.45		Sub.2-Sub.8	12.71
Sub.10	0.95	2.46	4.38		Sub.11-Sub.12	13.52
Sub.11	1	1.2		74.24	Sub.1-Sub.2	10.69
Sub.12	0.89	0.6	29.89		Sub.8-Sub.10	5.69
Sub.13	0.92	0.63	25.59		Sub.8-Sub.13	10.34
Sub.14	0.92	1.98	22.38		Sub.10-Sub.11	3.34
Sub.15	0.89	0.39	17.13		Sub.5-Sub.6	4.40
Sub.16	0.93	0.87	14.8		Sub.6-Sub.7	2.14
Sub.17	0.96	1.23	9.4		Sub.10-Sub.19	4.93
Sub.18	0.92	1.08		3	Sub.2-Sub.3	3.33
Sub.19						

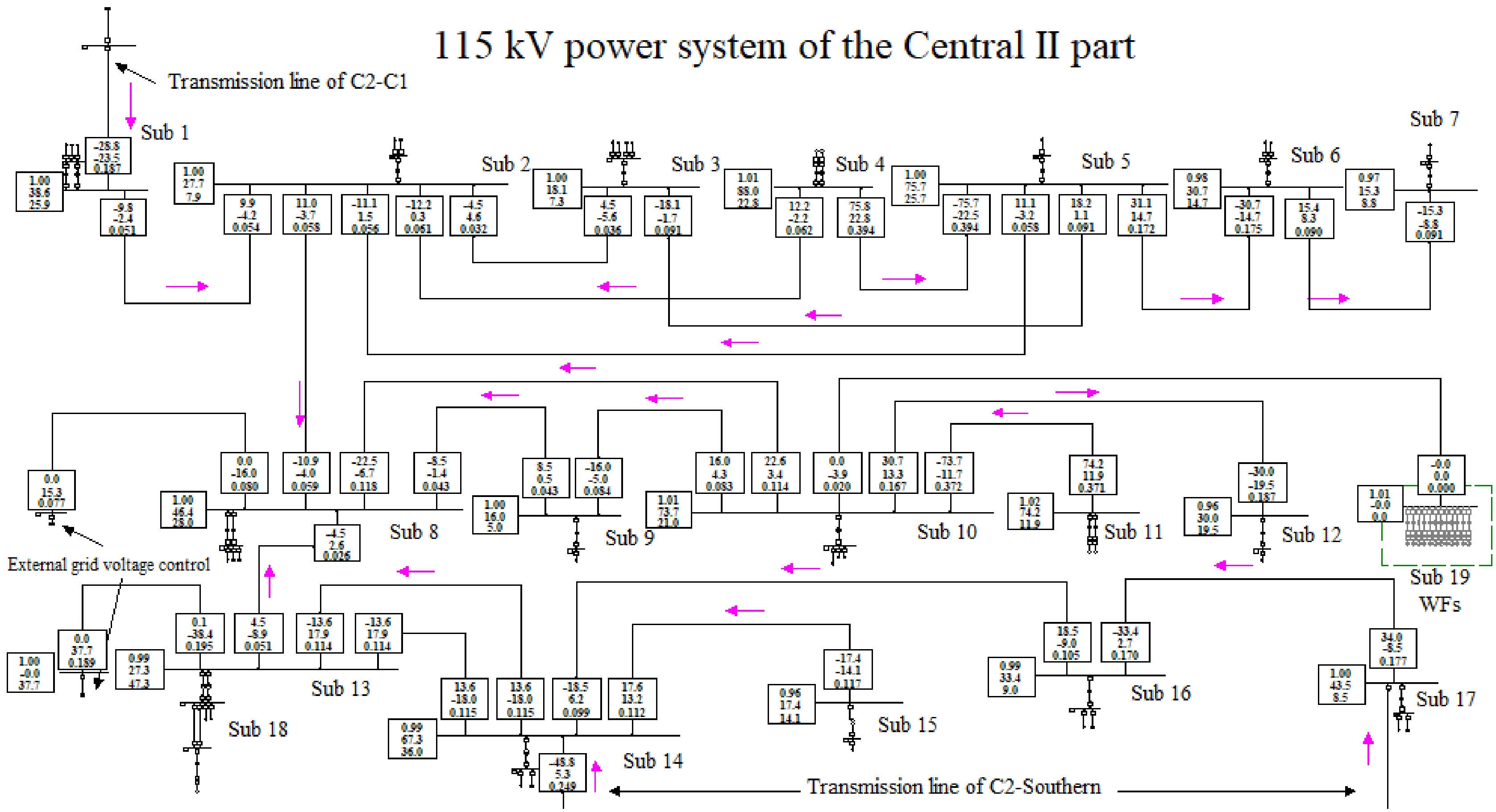

Fig 1 Wind farm installation in the Central II part

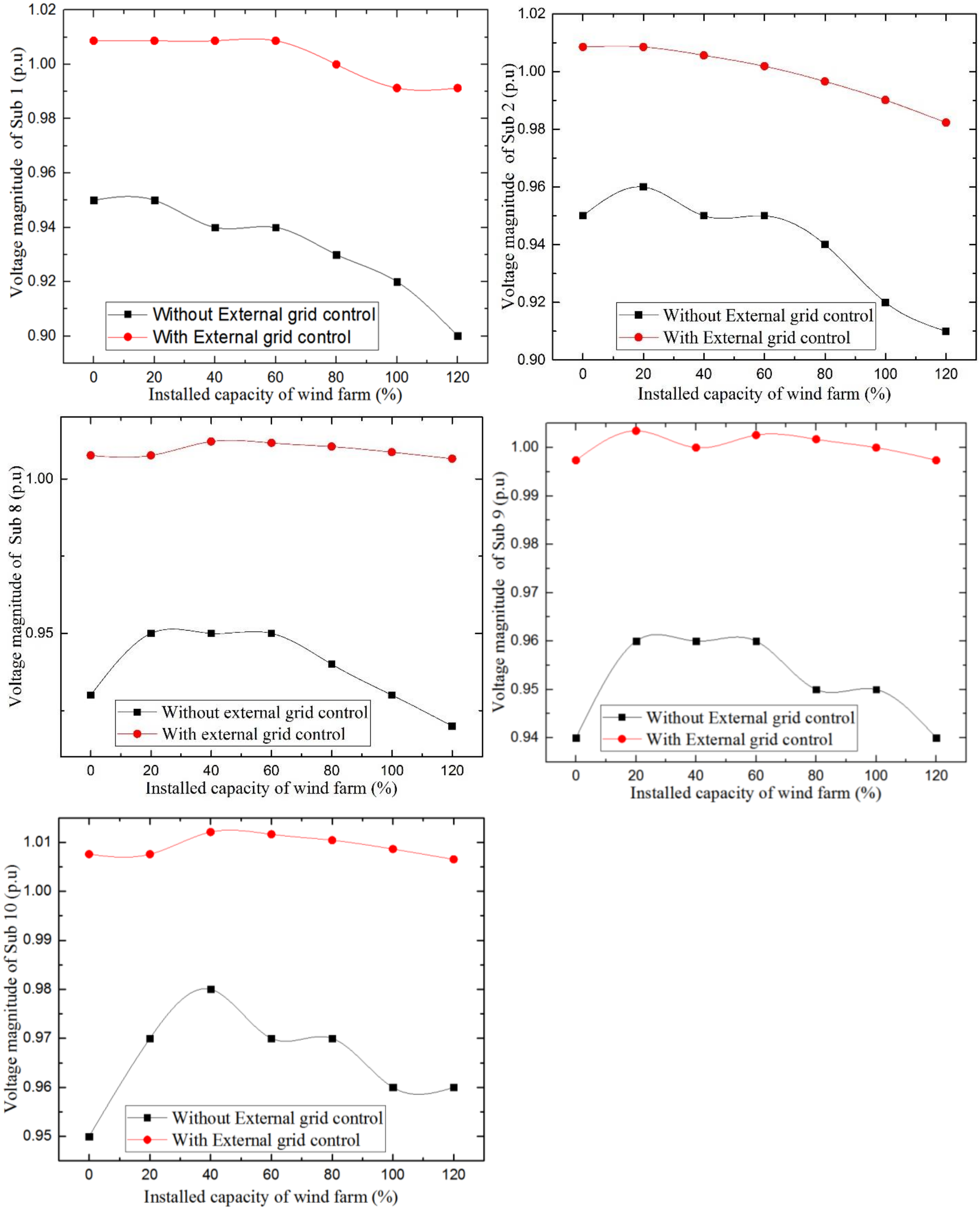

Fig 2 The percentage of voltage at substation in installed power capacity of the wind farm

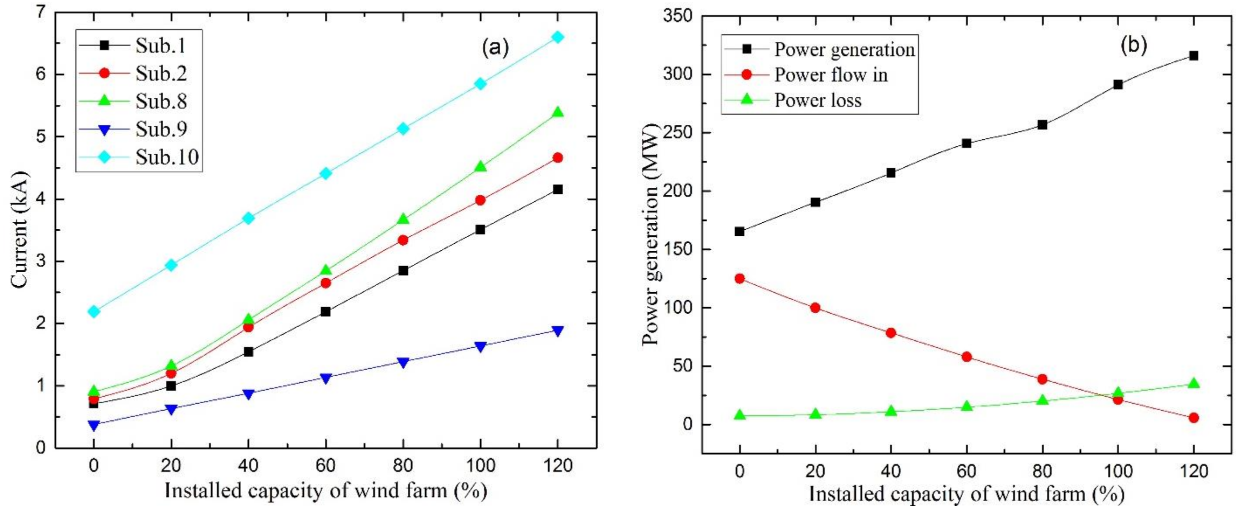

Fig 3 (a) and (b) the current of substation and power loss in the Central II part

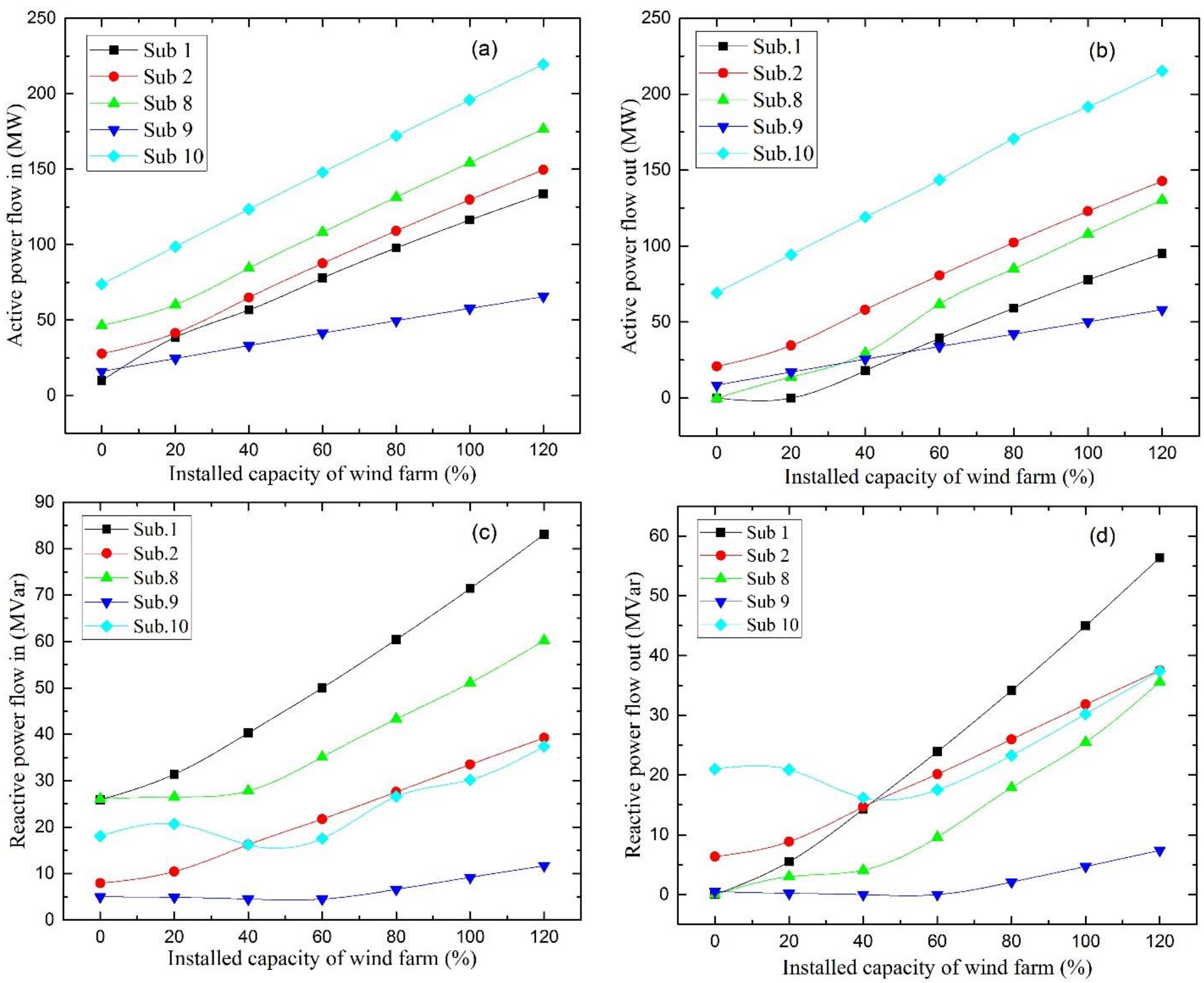

Fig 4 The active power (a), (b) and reactive power (c), (d) flowing in and out of the substations