The investigation impact of variable installed capacity wind farm on the power system

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Abstract

Penetration of wind power generation into the power system has greatly affected the electrical power system because the increment of installed capacity of wind farms (WFs) causes the variable power flow in the system. This paper presents assessment of an electrical effects depending on the installed capacity of WFs. Firstly, a scenario is analysed power system before and after WFs connected into power system of the Central II-part of Lao PDR by DIgSILENT power factory software. Secondly, the installed capacity WFs is inserted into simulation with the two located. The propose of this study is comparative the result of electrical effects based on the ratio installed WFs each location. It has been demonstrated variable power flow and current flow into substations on the power transmission. In addition, the result shown limited performance of installed WFs power generation in the system. The outcome of a novel scenario is considering the power system to determine an electrical effect when the increment installed capacity of power generation also that is a planning extension of power generation in the Central II part, Lao PDR.

Keywords: Renewable energy, power flow, power loss, wind power generation

1. Introduction

Currently, a number of the energy consumption on worldwide is increment based on a result of the strong economic growth rate around 3.7% in 2017 [1]. The height of energy consumption has impact to environment because the main energy resources for supplying demand is 79.5% of non-renewable energy (fossil energy resources) such as coal, petroleum, natural gas [1]. Although, fossil fuels are mainly to supply energy demand of countries on worldwide, However, fossil fuels are run-off in nearly future. Meanwhile, burning fossil fuels are the cause of greenhouse gas emission that has been become a greatly environmental concern. The main gas from burning fossil fuel composes Carbon dioxide, Sulfur dioxide and Nitric dioxide. These gases are not friendly for human and environment, it caused global climate change and global warming. According to the renewable's global status report, Carbon dioxide emission in 2017 expands 1.4% from energy consumption section [1-2].

The increment of electricity consumption occurred in Asia due to the several countries are developing in the region that resulted a high electricity requirement. The estimation of world electrical consumption will be increased 31,657 TWh by 2030 [3]. Consequently, several countries have planned to improve energy resources with a priority environmental impact because both are acceleration to solve the problem [4]. Renewable energy becomes a significant for supplying energy demand since it is friendly for environment. The renewable energy has been promoted by government of other countries especially the developed country in Europe, America and Asia that propose to reduce an energy consumption from fossil [5-6]. Renewable energy has been developed toward sustainable energy, modern technology and clean energy. Among a various renewable energy resources, wind energy is one of fast expansion installed capacity because wind energy is free energy, never ending and long-life cycle. In addition, the energy conversion from wind energy is less pollution impact for environment [7-8]. According to a recent annual report 2017, wind energy is the third of strong growing with a growth rate 11% compared to 2015

[8]. The top countries installed capacity of wind farm compose of China, United states, Germany, India, United Kingdom, Brazil etc. The installed capacity of wind farm increases 52 GW that was result total installed capacity of 539 GW at end 2017 [1].

The wind turbine is device for convert kinetic wind energy into electricity, it composes of horizontal and vertical axis wind turbine. However, horizontal-axis wind turbine is manufactured for a commercial electricity generation since it is designed bigger, higher and more efficiency with three blades are position up wind turbine on the tower [9]. According to a rising of modern wind turbine, it has installed on onshore and offshore where a location has a potential of wind energy. Although an electricity generation from wind farm is less impact environment when compare electricity generation from fossil. However, there is a visual and noise impacts also a large installed wind farm is requirement a lot place that is a limited of wind installation near community. The offshore wind sector was fascinated to install wind turbine cased a strong condition of wind speed is a viable at coast area more than wind on land. Offshore wind turbine has planned and installed more than twice since 2000 [8, 10]. Currently, United Kingdom is the first of installed capacity offshore wind farm that is 36% of world share, Germany is the second with 28.5% and China comes the third of installed capacity under 15%. As a several research, offshore wind farm is high cost of installation, maintenance and repair than onshore wind farm about 30-50% that is between 0.027-0.048 USD/kWh. A cost of maintenance for onshore wind farm is between 0.01-0.025 USD/kWh [1, 11].

A large scale of the wind farm becomes a concern on the electrical power system due to the variable level of natural wind speed is a fluctuation of power output from wind turbine which is a cause of unreliability in the power system network for instance the increment installed capacity of wind farm has related a variability of voltage, active power and reactive power [12] because the total power generation depended on specification of wind generator design, installed capacity of wind turbine and potential of wind speed. Consequently, the power system stability is urgent analysis to influence transient stability after connected the wind farm to the power system [3]. The new technology has been used in the power system to manage the variable power flow.

A penetration of wind power generation is considered reactive power reserve management scheme by optimal power flow to improve voltage stability margin. The doubly fed inductor voltage control feature was a technic to control voltage stability under wind farm penetration. It is a significant component in the power system due to an effect from rotor speed and torque of wind turbine based on wind speed that is directly for flexible active and reactive power generation [13]. Reactive power is importance for power system control because its response for controlling a variable power factor and voltage. Usually, the capacitor bank is installed in the power system to serve reactive power into the system that is improvement power quality [14-16].

In this paper, the main work investigates electrical impact of variable installed capacity of wind power generation on the power system in the Central II part of Lao People's Democratic Republic (Lao PDR). The DIgSILENT power factory software was used for simulation the existing system. There is input real data into software to analyze power system after connected the 2 regions of the wind farm to the power system. The propose is assessment variable power flow, voltage and current based on the ratio of the installed capacity both regions.

2. Model and Simulation

2.1 Power flow analysis

Power flow analysis is an important of electrical power system due to it was a basic calculation of power system stability such as steady-state, transient, dynamic stability, etc. The analysis becomes a commonly part of AC-power system operation and planning. The AC-power flow solution methods have been developed for solving the electrical problem such as Newton-Rapson, Gauss-Seidel, Jacobian matrix methods. However, The Newton-Rapson become the most powerful and acceptation algorithm. Power flow analysis is investigated the non-linear problem of the injected power into the system because of the variable power flow, power demand and voltage of substations. The basis of parameter assessment

composes active power flow, reactive power flow, voltage magnitude and current of each substation.

The non-linear solution is considered the investigation of power flow analysis by Newton-Raphson method that can be estimated by an iterated function [17-18].

$$f(x) = f(x^0) + (x^0)(x-x^0) + \frac{f''(x^0)}{2}(x-x^0)^2 + \ldots + \frac{f^n(x^0)}{n}(x-x^0)^n \tag{1}$$

$f(x)=0$, x is a variable and x^0 is a primary value to estimate the solution. Therefore, we will get

$$f(x) = f(x^0) + f(x^0)(x-x^0) = 0 \tag{2}$$

From the eq. 2, we can estimate the iteration about first value

$$x^{(1)} = x^{(0)} + \frac{f(x^0)}{f'(x^0)} \tag{3}$$

From the eq. 3, the equation can be written in the normal form, the estimated value x of each iterated k. shown as:

$$x^{(k+1)} = x^{(k)} + \frac{f(x^k)}{f'(x^k)} \tag{4}$$

The power balance equations are followed [14].

$$\left. \begin{array}{l} P_{G_i} + P_{W_i} - P_{D_i} = V_i \sum_{j=1}^{N_B} V_j Y_{j,i} \cos(\theta_i - \theta_i - \gamma_{i,j}) \\[3mm] Q_{G_i} + Q_{W_i} - Q_{D_i} = V_i \sum_{j=1}^{N_B} V_j Y_{j,i} \sin(\theta_i - \theta_i - \gamma_{i,j}) \end{array} \right\} \tag{5}$$

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 $V_i, V_j, \theta_i, \theta_j, \gamma_{i,j}$, respective, N_B is a number of the buses. Active power, reactive power and voltage should be allowed range of control, using eq. (6) -(8)

$$P_{G_i}^{\min} \le P_{G_{SL}} \le P_{G_i}^{\max} \qquad , \forall i = SL \tag{6}$$

$$Q_{G_i}^{\min} \le Q_{G_{SL}} \le Q_{G_i}^{\max} \qquad , \forall i \in N_G \tag{7}$$

$$V_i^{\min} \le V_{i,s} \le V_i^{\max} \qquad , \forall i \in N_B \tag{8}$$

Power flow equation are followed by [16]

$$P_k - jQ_k = V \sum_{i=1}^{n} Y_{ki} V_i \tag{9}$$

$$P_k = |V_k| \sum_{i=1}^{n} |Y_{ki}||V_i| \cos(\theta_k - \theta_i) \tag{10}$$

$$Q_k = -|V_k| \sum_{i=1}^{n} |Y_{ki}||V_i| \sin(\theta_k - \theta_i) \tag{11}$$

where P_k and Q_k are active power and reactive power at but k, $V_k, V_k, \theta_k, \theta_i$ are voltage magnitudes and voltage angles that are elements of admittance matrix.
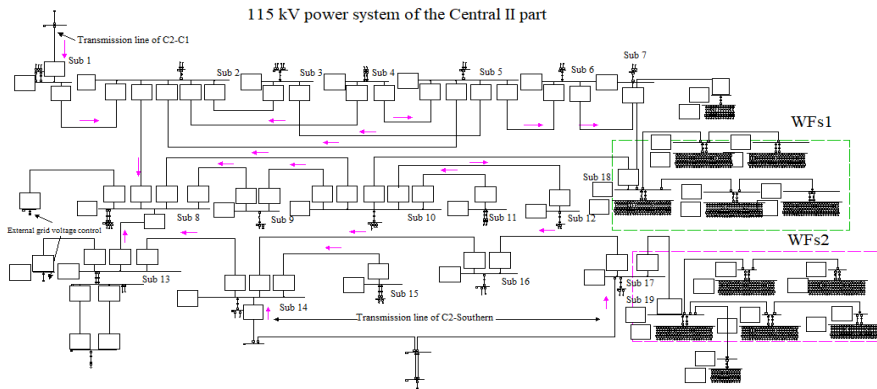
2.2. Power system investigation

Fig. 1. Existing power system with connected wind farm 1 and 2 modelling

In this study, the DIgSILENT power factory software was used to model and simulate the power system of the Central II part. This area includes 115/22 kV with 17 substations, 115/22 kV of the 1st substation was the connection point and the hub of an electricity transfer between the Central I and II parts. 14th and 17th substations are the electricity transmission between the Central II and Southern parts. The main power generation in this area composes of 2 resources: Nam Thuen 2 and Nam Nguan hydro power plants with total capacity around 165.24 MW that included sugar power plant of 3 MW.

The configuration model chose the existing power system the Central II part of Lao PDR. In addition, the power transmission network is connected by aluminum conductor steel reinforced (ACSR). The specific of conductor is maximum cross area of 1×240 mm2, temperature of 90 °C, current of 1.5 kA, voltage of 115 kV. Wind farms 1 and 2 are connected to the 10th and 17th substations, respectively by 115 kV overhead transmission because both substations are near to connect the wind forms with distance around 55 km, as shown in Fig. 1. 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

Step 2: Existing power system was modelled that include bus bars, transformers, transmission lines and loads then input the data of each parameter into the DIgSILENT power factory software

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

Step 4: Power system analysis with wind power generation was investigated to estimate power balance between power generation and demand.

Step 5: The investigation of the electrical effects after connected wind farm into the power system such as active power, reactive power, voltage and current, etc.

Step 6: At first, the combination between power generation domestic and wind power generation within the installed capacity of the wind farm 1 and 2 were 100% and 0%, respectively.

Step 7: The installed capacity of the wind farm 1 was decreased each 20% and increased installed capacity of wind farm 2 each 20%. The total installed of both wind farm must be equal 100% of lacking demand.

Step 8: A number of wind turbines were investigated to supply lacking energy demand.

The relation between wind energy and power production based on wind speed is followed as below equation [19]:

$$P_{out} = \frac{1}{2} C_P \rho S V^3$$ (12)

where P_{out} 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 m2, V is the speed of wind (m/s).

Calculated a number of wind turbine to install in area using eq. (13) - (14)

$$P_{av} = \sum_{i=1}^{N} \frac{P_{out,i}}{N} \tag{13}$$

$$T_n = \frac{P_D}{P_{av}} \tag{14}$$

where P_{av} is power out of wind turbine convert of wind turbine into electrical power on average, P_{out} is available power of wind flow per months, N is mount of the year, T_n is a mount of wind turbine and P_D is a peak demand.

3 Results and Discussion

The electric power to support during the peak demand was divided 2 resources. The first one is power generation in the local area (hydro power) and the another one is imported electrical power from the Central I and Southern parts. In this study, the power system analysis of the Central II part composes of 7 cases. The main approach is observed variable power flow when the WFs1 and WFs2 were connected to the power system based on the condition of maximum installed capacity of 100% of lacking demand to investigate the electrical effects such as the variable power flow, voltage magnitude, current power loss and power factor.

3.1. Electrical power flow in and flow out area

The power system analysis without integrated wind farm is the case study before connected wind farm to the power system in the Central II part. In this case study, we found that the hydro power generation is the main electrical power for supporting in the area with capacity about 162 MW. However, that is not enough to supply in the during peak demand. Consequently, the electrical power was imported from the Central I and the Southern parts about 50 and 66 MW, respectively. In the second study case, the installed capacity of WFs1 was 0% and WFs2 was and 100% of peak demand that shown the increment of alterative internal power generation based on the installed capacity. Even though the installed capacity WFs2 was increased 100% peak demand, the electrical power was not enough to support the demand; there was import electrical power from the Central I around 32.6 MW due to the WFs2 was located near the Southern part. Therefore, mostly electric power generation from WFs2 was flow out to the Southern part around 44.3 MW. Then, the power system analysis with the installed capacity of WFs2 was decreased 80% while the installed capacity of WFs1 was increased 20% of lacking demand. we found that the remaining electric power flow out to the Southern part that was decrement. However, the increment installed capacity of WFs1 can be supported and reduced import electrical power form the Central I part. After that, the power system analysis with WFs1 and WFs2 were installed capacity of 40 and 60%, respectively. we found that electric power flow was imported form the Central I and electric power was exported to the Southern parts around 19.5 and 11.2 MW. When the installed capacity of WFs1 was increased to 100% while the WFs2 was decreased to 0% that was remaining electric power flow out to the Central I part and electric power was imported from the Southern part of 11.1 and 11.2 MW, respectively. Therefore, the power system analysis with the integration of WFs1 and WFs2 was shown the direction of electrical power flow based on the ratio installed capacity and the ability of electric supply.

3.2. Power flow investigations

The power generation development in the local area become a significant of the statistic energy development section due to that increase a potential of power generation to support the demand. In the fact, the increment of installed capacity potential was a concern of power stability for example There was a variable internal active power and reactive power flow through each substation.

Fig. 2 (a-e) show the active power flow through the substations based on the ability of power transmission from primary substation of power generation resources. The power flow is increment based on installed capacity of the wind farm as eq. (5), especially the substation was connected the WFs and the substation on the power transfer such as the 1st, 8th, 10th, 13th, 17th substations. The 17th substation was the highest active power flow through due to it is a central substation hub of electrical power generation from both of hydro power plant and wind power generation resources. That resulted the 10th substation has electric power flowing in and flow out more than 73 MW.
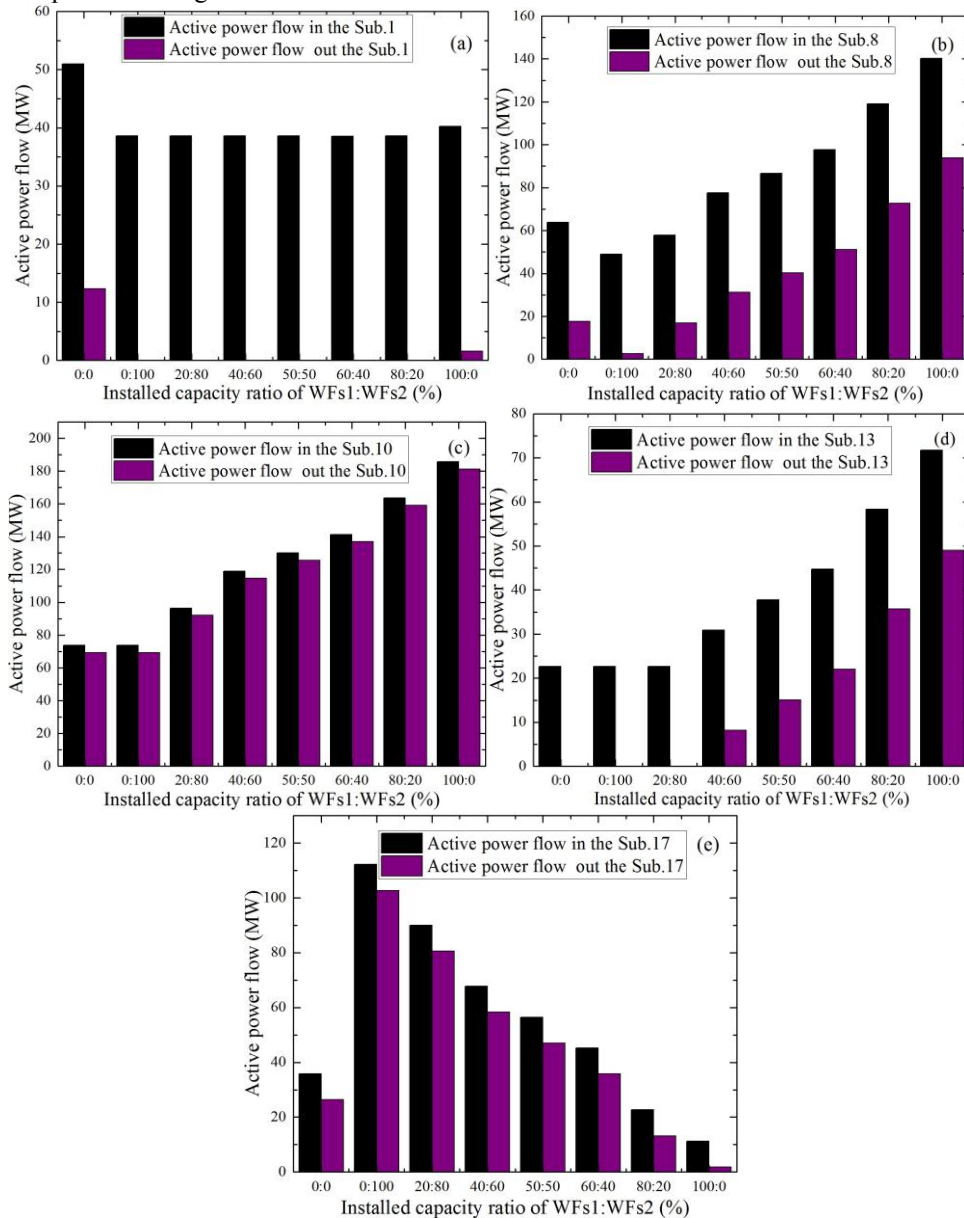

Fig. 2 (a-e). Active power flowing in and flowing out of substations

Fig. 3 (a-e) show the reactive power flowing in and out of the substations. The increment installed capacity of WFs has effect of the variable reactive power. The 8th substation was reactive power flow through 26.49 MVar when the WFs1 was installed capacity of 100%. In addition, the 14th, 16th, 17th of substations were electrical reactive power flowing in and flow out. The peak of reactive power flowing

through was the 17th substation because the reactive to control local voltage was flowed from the Southern part to the 17th substation. However, the reactive power flow through the substation was continuously decreasing based on the decrement of installed capacity of WFs. The result of simulation was found that the decreased reactive power flow in the Central II from the southern with the ratio of WFs1 and WFs2 of 50:50%. Especially, the 16th substation was lower reactive power through because of the decreased reactive power on destination of power substation.
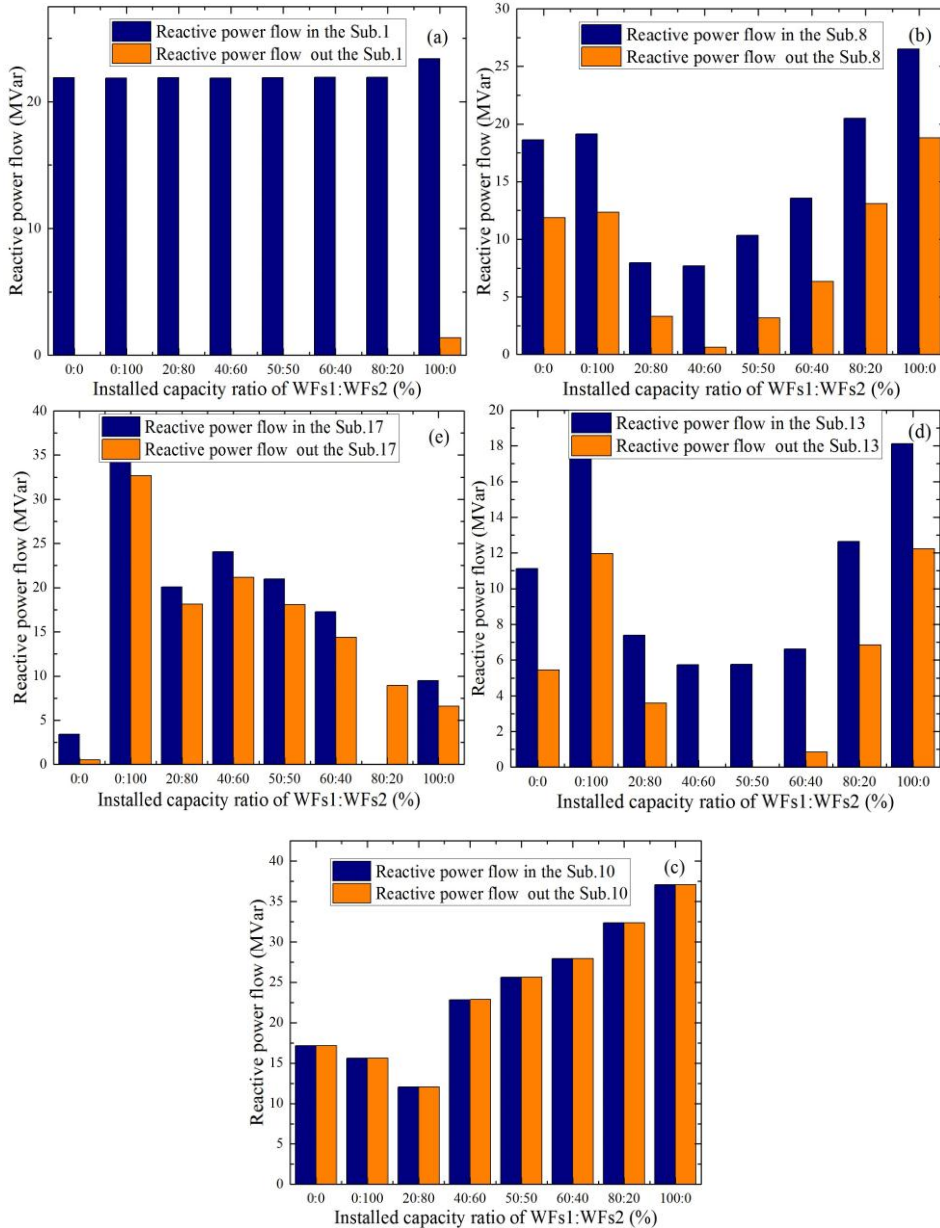

Fig. 3 (a-e). Reactive power flowing in and flowing out of the substations

3.3. *Voltage investigation of substations*

Table 1 shows the voltage value of substation based on ratio of installed capacity of WFs1 and WFs2 in the Central II part. The result of each case study have found that the ratio of installed capacity of WFs1 and WFs2 was not effect to other substations due to there was the national electrical power grid to connect the Central II part with the Central I and the Southern parts. In addition, the substations have

installed the capacitor bank to control the voltage quality based on the Lao grid code for instant the limit of variable voltage in the normal and emergency condition allowed period of 95-105% and 90-110%, respectively.

Table 1. The voltage value of substations

Substation number	Sub.1	Sub.8	Sub.10	Sub.13	Sub.17
Without WFs1&2	1.02	1.00	1.02	1.00	1.02
WFs1&2 0:100%	1.02	1.00	1.02	0.99	0.99
WFs1&2 20:80%	1.02	1.00	1.02	1.00	1.00
WFs1&2 40:60%	1.01	1.00	1.02	1.00	1.01
WFs1&2 50:50%	1.01	1.00	1.02	1.00	1.01
WFs1&2 40:60%	1.01	1.00	1.01	1.00	1.02
WFs1&2 20:80%	1.01	1.00	1.01	1.00	1.02
WFs1&2 100:0%	1.01	0.99	1.00	0.99	1.02

3.4. *Current investigations of substations*

Fig. 4 shows the current value of the substations with the integration of WFs1 and WFs2. The expansion potential of wind farm is increment of local power generation lead to the electrical power transfer of substations. Consequently, the study followed power system analysis to investigate the variable current value of the substations. The primary substation connects with the WFs that will be increased current value due to there is a lot of power flow through. The 10th and 17th were the highest current than other substations because both substations were connected the WFs1 and WFs2 that have current value of 3.58 and 5.53 kA, respectively.
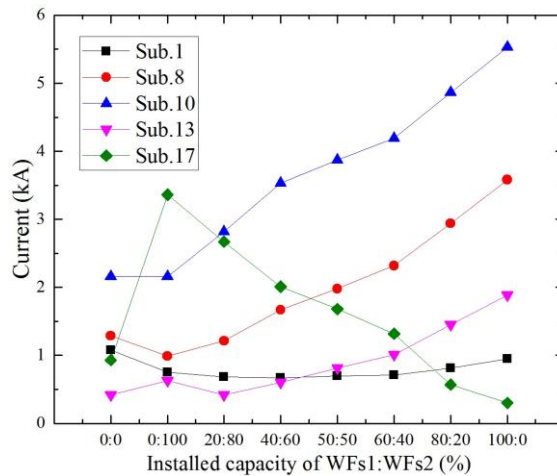

Fig. 4. Current of substation based on installed capacity of wFs1 and WFs

3.5. *Power loss investigation*

Fig. 5 shows the power loss value of the substations to study the variable power loss value in the Central II part. The power loss can be estimated by power system analysis. There was power loss of 5.6 MW in the case study without WFs connected to power system. The case study of WFs1 and WFs2 was installed capacity of 0 and 100% in the condition of peak demand resulted the power loss value of 11.38 MW. The reason of power loss is increment because there is increment of power, current and resistance of conductor. Particularly, there is power loss of 2.9 MW in the power transmission line between the 17th to WFs2 substations. However, if there is a suitable ratio of WFs1 and WFs2 that will make the electric

power to respond in the area. The installed capacity was a ratio of 50:50% of lacking demand; We have found that lower power loss than another ratio of installed WFs1 and WFs2. Finally, the installed capacity of WFs1 and WFs2 with the ratio of 100:0% of lacking demand became the highest power loss of 11.38 MW. Therefore, the installed capacity and ratio of WFs will affect the variable power loss.
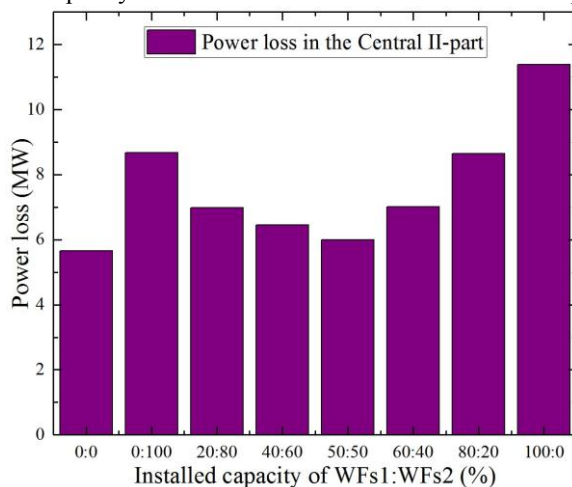

Fig. 5. Power loss in the Central-II part based on installed capacity of wFs1 and WFs2

3.6.   *Power factor investigation*

Table 2 shows the power factor value of the substations that were investigated by power system analysis with installed capacity of WFs. The result of case study has found that the ratio of installed capacity of WFs1 and WFs2 was effect of variable power factor because the increment installed capacity of WFs resulted the increment of reactive power flow in. Whenever, there is more reactive power flow into the substation that affect to reduce the power factor value. Therefore, the capacitor bank is stalled in the substation power to improve the power factor under standard control. The power factor was defined upward 0.875 based on the Lao grid code. Therefore, the investigation found that the ratio of installed WFs1 and WFs2 was 50:50% of peak demand resulted power factor value of substations better than other cases.

Table 2. Power factor of the substation

Substation number	Sub.1	Sub.8	Sub.10	Sub.13	Sub.17
Without WFs1&2	0.55-1	0.74-0.98	0.94-1	0.66-0.85	0.99-1
WFs1&2 0/100%	0.7-0.9	0.95-1	0.91-1	0.7-0.84	0.83-0.99
WFs1&2 20/80%	0.8-0.96	0.97-1	0.92-1	0.98-1	0.76-9
WFs1&2 40/60%	0.93-0.98	0.96-1	0.92-1	0.97-1	0.69-0.99
WFs1&2 50/50%	0.85-0.99	0.92-1	0.93-1	0.95-1	0.9-1
WFs1&2 40/60%	0.5-1	0.72-1	0.94-1	0.94-0.99	0.96-0.99
WFs1&2 20/80%	0.98-1	0.79-0.99	0.95-1	0.94-0.99	0.25-0.77
WFs1&2 100/0%	0.55-1	0.74-0.98	0.94-1	0.66-0.85	0.99-1

3.7. *The installed wind turbine investigation*

The wind turbine is a device that is widely used to convert wind's energy into electrical power. The quantity of electric generation form wind turbine depends on the wind speed, wind turbine size and efficiency to convert the wind power into the electrical power. The horizontal axis wind turbine was used in study case with size of 2.5 MW, hub height of 110 m, area swept of 11,304 m^2, power coefficient C_p of 0.45, air density ρ of 1.23 kg/m^3 to calculate amount of wind turbines installation. Consequently, it is necessary to calculate a number of wind turbine based on the installed capacities of WFs1 and WFs2. According to the statistic of wind speed data in 2011 can be calculated electrical power on average and

amount of wind turbine to install by eq. **(12).** The result of power generation/month and power on the average is shown Table 2. Therefore, a number of wind turbine in the case study of 20, 40, 50, 60, 80 and 100% of peak demand is 12, 23, 29, 35, 47, 58, respectively.

Table 3. Power generation/Month and power on the average based on wind speed

Month	Wind speed (m/s)	Power output (MW/Month)
1	12.6	6.26
2	7.8	1.48
3	11.2	4.4
4	6.8	0.98
5	4.3	0.25
6	2.7	0
7	2.4	0
8	2.2	0
9	2.9	0
10	7.5	1.32
11	9	2.28
12	13.1	7.03
Average	6.875	2.00

4. Conclusions

In this paper, the power system of the Central II part was simulated by DIgSILENT to investigate the impact of WFs. According to the simulation and power system analysis as the ratio installed capacity of WFs1 and WFs2 has directed the relationship of each cases because that showed an electrical effects based on the power system analysis each cases. The increment installed capacity of WFs was determined the electrical effect such as the variation of power flow, voltage, current and power loss. The investigation showed the more power loss when the installed capacity of wind farm was increased. Especially, the case study of WFs1 and WFs2 is ratio of 100:0 that is a high-power loss than other cases because of the long distance of transmission line from wind power generation to the electrical consumption. Therefore, wind farm was separated into 2 locations to respond electrical power during peak demand in order to increase efficiency of electrical transfer and reduce power loss. Even though the increment installed capacity of wind farm is expected supplying. However, according to the calculation have shown that the wind farm was not able electrical generation during June to September course of low wind speed. Consequently, the sustainable and reliable energy that should be a development of various renewable energy resources such as small hydro power, biomass. In addition, that should be an improvement of high voltage level power transmission line as 230 kV to improve ability of the power transfer overall the Central II part. This study is significant of power system planning because it was simulated and analyzed in the condition of peak demand with the installation of wind farm to adjust the power reliability and power control.

Conflict of Interest

The authors declare no conflict of interest

Acknowledgements

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