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Effects of Solar Photovoltaic Size on Grid-Connected Power System in Savannakhet Province, Lao People's Democratic Republic

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ABSTRACT

The trends of renewable energy system and clean energy have become increasingly worldwide to reduce greenhouse gas emission which is the important effect of global climate change. The electricity generation in Lao people's democratic republic (PDR) more than 70% is hydropower plants in 2017, which is not sufficient in the dry season. Therefore, solar photovoltaic (PV) system is suitable to integrate grid connection system with hydropower plants. In this paper, the analysis of solar PV installation with optimal size and location for grid-connected distribution system is proposed. The electrical parameters for estimating the electrical effects are the active power (P), reactive power (Q), voltage (V), current (I), active power loss, and reactive power loss. In addition, PV installation was explored with 5 cases: 25, 50, 75, 100 and 125% of the peak load in Nongdern substation (22 kV and the 2nd feeder). The system was simulated by DIgSILENT PowerFactory software. The optimal capacity size of PV installation connected in the bus Phonxay substation is 75% of installed capacity. The minimum value of active power and reactive power loses are 0.11 MW and 3.32 MVAR, respectively. Moreover, the voltage increases from 0.976 to 1.003 p.u. The outcome in this project to subsidize the clean energy resource and the best planning in power system for PV installation in Savanakhet Province. The power system will be reliability and stability for supply power energy to customers. Moreover, it achieves the one target of policy’s Ministry of Energy and Mine to promote and develop the solar energy.

Keywords: PV generation, Power loss, Voltage profile

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Introduction

The greenhouse gas (GHG) emissions are increased by human activities, such as coal burning, fuel oil combustion and chemicals transpiring. Those are released into the atmosphere. The radiation of the sun cannot reflect back in the right amount, because some part of infrared rays will be attracted in atmosphere covered the earth by GHG. In addition, the average of global surface temperature in the end of century will rise in the range of 1.6^{o}C up to 5.8^{o}C since it effects to the climate change, more severe natural disasters, floods, severe earthquakes and storms [1-2]. Moreover, the hot weather is very dangerous to all the living thing. Therefore, renewable and alternative energies are constructed for reducing GHG emission: solar energy, wind turbine, hydropower, biomass and bioenergy, geothermal electricity, ocean energy and tidal power etc.

In the worldwide, the installed capacity of solar PV rapidly increases from 9.26-295.93 GW in 2007 to 2016 [3] because of lower price of PV silicon cell–the price of PV modules has decreased from 4,394 to 1,388 USD/kW [4]. In addition, the governments in any country have policy regulation to support fund and feed-in tariff [5-6]. According report of renewable energy statistic in 2017 of International Renewable Energy Agency (IRENA), the large capacity of PV was installed at 77.8, 41.6, 38.7 and 34.7 GW in China, Japan, Germany and USA, respectively [3]. Currently, the biggest solar farm in Lao PDR was installed in Vientiane capital of 3 MW with grid connected power substation. Therefore, the government of Lao PDR defined the strategy and policy for development of renewable energy. These aims are to enhance the renewable energies: small hydropower, solar energy, wind energy, biomass, biogas, biodiesel and other alternative sources of energy for transportation to 30% of the total energy consumption in 2025. Accordingly, the solar PV must be produced of 22, 36 and 48 MW with electricity generation by solar cells in 2015, 2020 and 2025, respectively [7].

The increasing population and economic growth in Lao PDR are significant to enhance the energy consumption. Accordingly, the report of Ministry of Energy and Mine with Electricite Du Laos (EDL) forecasted the electricity energy in Laos PDR. It will be increasing 5 times or 5,892 MW in 2030 when compared to 2016 [8]. For lack of energy in the Central-II part, it is not enough in dry season because of the most of electricity generation from hydropower plant [8]. Especially, Savannakhet Province has the largest area, the most population of Lao PDR and large manufacturing industry. There is the main problem of the energy consumption with the peak load higher than supply. The report in 2017 presented the peak load in Savannakhet Province of 220.8 MW, meanwhile the total installed capacity is 8 MW [9]. The solar radiation areas are high in the western region and the highest in the south of the country of 17-18 and 18-19 MJ/m^{2}-day, repressively as presented in the Fig. 1 [10]. However, the solar radiation is low in the east and the high mountain areas.

The analysis of PV generation in distribution systems with electrical parameter analysis of the power flow active power and reactive power in distribution networks was proposed in Ref. [11]. The PV was installed in distributed generation to minimize loss and improve voltage [11-13]. Many researches evaluated the impact of the PV generation connected to the power system. The load flow calculation was used to analyze the voltage profile, power losses, fault characteristics and short-circuit current [14-16]. On the other hand, the increasing size of PV installation has negative impact in distribution system such as rising voltage, phase unbalance, increasing power losses and harmonic distortion in power system [17-18].

Therefore, this paper mainly studies the electricity effects of PV installation on grid-connected to medium voltage at 22 kV. It is examined for comparison between traditional grid with and without PV on grid in Savannakhet Province. The power flow electrical system with varying size of PV installation is computed by Newton Rapson method. The power system was simulated by DIgSILENT PowerFactory software. This work is organized as follows: section 2 proposed modeling and simulation power system, Newton Rapson method and data information in distribution networks. In section 3, the results and discussions show the effects of the PV installation in each case study. Finally, conclusion is in the section 4.

Model and Simulation

1. Analysis of the Power Flow and Solar Efficiency

Load flow analysis in power system is important to evaluate power flow problems and planning. The relation of node current and voltage in the power system on the linear network can be presented by Newton-Raphson equation [19]

$$I = Y_{bus}V \tag{1}$$

or

$$I_i = \sum_{j=1}^{N} Y_{ij}\dot{V}_j \qquad (i = 1, 2\ldots n) \tag{2}$$

where I_i is the injected current for bus i and V_j is the voltage for bus j. The Y_{ij} is the element of the admittance and *n i*s the total number of nodes in the power system.

The solution of load flow problem by used the equation, should be used the relation between the node power and the current, which can be calculated by

$$I_i = \frac{P_i - jQ_i}{\widehat{V}_i} \qquad (i = 1, 2\ldots n) \tag{3}$$

where P_i is the active power and Q_i is the reactive power at node i, in case node i is a load node in the system. Therefore, P_i and Q_i are take the negative values and $\widehat{V}_i$ is the conjugate of the voltage vector at node i in the network. The injected current can be summarized as eq. (4).

$$\frac{P_i - jQ_i}{\widehat{V}_1} = \sum_{j=1}^{N} Y_{ij}\dot{V}_j \qquad (i = 1, 2\ldots n) \tag{4}$$

Improvement of the active power of each generator can be calculated by eq. (5) [20]

$$P_i = P_{i\text{-dispatch}} + \Delta P_i \tag{5}$$

where P_i, $P_{i-\text{dispatch}}$ and ΔP_i are the modified active power, the initial active power dispatch and the active power change, respectively, for generator i

$$S_i = \sum_{k=1}^{n} |V_i||V_k|\, e^{j\theta_{ik}}(G_{ik} - jB_{ik}) \tag{6}$$

$$= \sum_{k=1}^{n} |V_i||V_k|\,(\cos\theta_{ik} + j\sin\theta_{ik})(G_{ik} - jB_{ik}) \qquad (i = 1, 2, \ldots, n)$$

where S_i is the apparent power and θ_{ik} is the phase angle between bus i and bus [19]

$$P_i = \sum_{k=1}^{n} |V_i||V_k|\,(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \tag{7}$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k|\,(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$

where P_i is the active power and Q_i is the reactive power at node i, the $\widehat{V_i}$ and $\widehat{V_k}$ is the conjugate of the voltage vector at node i and k in the network, respectively. The G_{ik} and B_{ik} are called conductance and susceptance, respectively.

For analysis of the power losses in distribution systems, there are two major sources that are in the power lines and transformers.

$$\text{Active power loss} = I^2R \tag{8}$$

$$\text{Reactive power loss} = I^2X \tag{9}$$

where R, I and X is resistance, current and reactance of the conductor, respectively.

Solar Efficiency

$$\eta = \frac{P_e t/A_1}{It/A_2} \quad (10)$$

where η is the efficiency of solar panel, P_e is the power electricity generation, t is the time duration per day, A_1 and is the area of solar panel and A_2 is reference area of the solar radiation which it is equate $1m^2$. Finally, I is the solar radiation.

2. Power System Modelling

2.1 Distribution System

The 115/22 kV distribution network located in Savanakhet Province of the central part II of Lao PDR was selected to model. The information provided by Savanakhet Provincial Electricity was the load point, capacity of transformer and cable data. The data collection of 22kV power system was surveyed by using GPS mark point to build the map taken into AutoCAD program. Then, the power system was modelled in DIgSILENT PowerFactory software as distribution network in the AutoCAD program, data base in Excel, and some information in substation taken into simulation. Nongdren substation is in Kaisonephomvihan District at latitude of 16.62 N and longitude of 104.78 E. Its rating voltage is 115/22 kV included one transformer step down of 115/22 kV, size of 50 MVA and 7 feeders. However, the 2nd feeder was selected to simulate because the peak load at 9.13 MW and 3.3 MVAR in this feeder is highest in this substation. It consists of one main feeder used to transfer from the 2nd bus to the 3rd bus. There are two sub-feeders and 202 loads point to simulate the system as shown in Fig. 1.

2.2 Electrical Load

The load sizing was divided into twelve contents according to the capacity of transformer as the rated of 30, 50, 100,160, 250, 315, 400, 500, 630, 1000, 1250, and 2000 kVA. Then, these value were used by of 0.285 times for defining percent load of the transformer and rated voltage referred to the annul peak load in 2017 as shown in the table 1 and table 2.

2.3 Cable Specification

The conductor cables used for power system had two types; Aluminum Conductor Steel Reinforced (ACSR) and Space Aerial Cable (SAC). The parameters of these cable were shown in table 3. The main feeder was the cable size of 240 mm^2 to transfer from bus 2 to bus 3 with length of 9 km. In addition, this one was used in sub-feeder 1 and 2 about 7.647 km. Finally, the size of 150, 50 and 35 mm^2 were used for distribute cables.

3. Solar Radiation Data

In this section, the data of solar radiation and power system simulation are presented. The area of power network in this case is Savannakhet Province in Laos PDR. The solar power meter "SPM-1116SD" was used to measure the solar radiation in every 1-hour by a data logger. The location of Nongdeun substation at the latitude of 16°37'16.17"N and the longitude of 104°47'21.92"E was selected for measurement. The time duration for recording data of solar radiation was April 2018 – September 2018.

Results and Discussions

The proposed simulation model in this paper has been analyzed power flow in the 2nd feeder at the Nongdern to Phonxay substation which the PV installation was connected in the 3rd bus (Phonxay substation). This method was varying capacity of PV installation which was compared the effect on grid-connected power system. The simulation results were proposed the active and reactive power flow from the 2nd bus to 3rd bus (Nongdern to Phonxay). When the PV was connected the 3rd bus of 25, 50, 75, 100 and 125% of the peak demands. The active power transfer from the 2nd bus to 3rd bus was decreased from 9.48 to 7.02, 4.58, 2.17, -0.21 and -2.56 kW (the negative value represent the reversion of power flow) because the active power is response to end use electrical energy. Meanwhile, the PV installed of 100 and 125% had the active power flow reversely to the 2nd and 1st bus because of the capacity over the load consumption as shown in Fig. 3(a). In the same way, the reactive power was highest without PV at 4.02 MVAR and lowest at 3.48 MVAR with 100% PV penetration due to the impedance was reduced in the transmission line. It increases when 125% of PV was connected to the grid. It was 3.52 MVAR because the power generation over the load in this area presented in the Fig. 3(b).

Figure 4 shows the voltage in original case (0%). on the 101st bus is lowest voltage at 0.976 p.u. because of the end of feeder. it increases on the 102nd bus at 0.995 p.u. because this bus direct connects with the 4th bus. In addition, on the 133rd bus the voltage value rises to 0.997 p.u. because it is branch of the 3rd bus and it is the first bus on the sub-feeder. In the final bus of the 2nd sub-feeder the voltage drops to 0.982 p.u. after that, the PV at 25, 50, 75, 100, and 125% of the peak capacity was in the 3rd bus. The voltage in the 101st bus was increased from 0.976 p.u to 0.984, 0.991, 0.997, 1.003 and 1.008 p.u, respectively. While, the voltage the 102nd bus is the first bus of the sub-feeder 2 effected to increase the voltage on this bus. On the other hand, the voltage at the 1st bus is constant value since the rated voltage has different the value such as 115 kV and 22 kV. Although, the voltage rises in the almost bus but it is still in the standard range of rated voltage. The normal operating and emergency conditions are defined rang of ±5% and ±10% of the voltage deviation.

The current in transmission line was reduced when the PV was installed at the 3rd bus. The electric energy was transferred from the 3rd bus to the load resulted to reduce the current in the 2nd to the 3rd bus. The current was reduced from 0.26 to 0.2, 0.15, 0.1 and 0.09 kA according to PV variation from 25 to 100%. On the other hand, the current of the generation at size 125% is over the total summation of load in this area that it is reversed to the 2nd bus. Therefore, the current in the transmission line on the 2nd to the 3rd bus increases compared to size of 100% as shown in Fig. 5.

The PV was established and connected to grid. The voltage was improved and the current was reduced in the system. The results of program simulation displayed various of the total power loses reduction according PV size from 25, 50, 75, and 100% in the both active power and reactive power: the total power loss of active power reduce from 0.32 to 0.22, 0.16, 0.12 and 0.11 MW, respectively. The total power losses of reactive power reduce from 0.96 to 0.64, 0.41, 0.29

and 0.25, respectively. However, it is increased at 125% of the PV installation since the current increase in the system and the generation is over the load. This affects to increase the both cases: active power loss and reactive power loss are 0.12 MW and 0.3 MVAR, respectively, compared with 100% of the PV installation as shown in the Fig. 6(a) and 6(b).

In the suitable case, the case of 75% is the best because the voltage variable in the 22 kV system is near 1 p.u during minimum to maximum values at 0.996 and 0.018 p.u, respectively. The both power flow-active and reactive power unreversed to the external. Moreover, the current in the external grid to the 3rd bus reduced from 0.26 to 0.1 kA and the current of the PV generation is 0.18 kA. In addition, the power loss is close tendency the minimum value. Therefore, this case is the better than each case.

The solar radiation was measured by the solar power meter, the report showed the highest and lowest values of total energy of 6916 Wh/m^2-day in April and 2823.9 Wh/m^2-day in July, respectively, as shown in the Fig. 7. The average of solar radiation in April, May, June, July and August 2018 was 532, 438.5, 357.7, 217.2 and 275.6 W/m^2, respectively. Therefore, the average of radiation of 5 months was 364.2 W/m^2. This value was used for simulation in the DIgSILENT PowerFactory software. The area of PV panel installation could be calculated size according to eq. (10). The total area of the PV Panel was 209,040.22 m^2 according to efficiency of solar panel is 11.468% with power electricity generation at 100% of 9.46 MW.

Conclusions

This paper presents the effects of size PV installation with utility grid connected on PV power distribution system in Savannakhet Province, PV installation was varied PV size with increasing 25, 50, 75, 100 and 125% of the peak demand by DIgSILENT PowerFactory simulation software. The simulation results showed that the power generation was exported by PV to system with the effect positive way: voltage profile improvement from 0.97 p.u. to 1.03, total power losses reduction on active power 57.1% and 85% for reactive power. This leads to guideline for increasing the energy source in Savannakhet Province area. This can reduce the power loss in the transmission lines and distribution systems.

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Table 1 The loads in the system

Load points	Load	
	Active power (MW)	**Reactive power (MVAR)**
L11, L23, L24, L39, L43, L56, L105, L108, L110, L119, L148, L153, L154, L156, L157, L159, L162, L168, L170, L171, L172, L173, L174, L181, L183, L186, L195, L198, L199, L201, L202	0.009	0.003
L2, L4, L6, L13, L25, L29, L30, L32, L33, L34, L35, L36, L37, L50, L62, L65, L66, L69, L72, L74, L76, L79, L80, L86, L97, L98, L100, L103, L107, L109, L111, L112, L113, L126, L134, L141, L142, L143, L144, L145, L146, L150, L155, L158, L161, L163, L164, L167, L169, L175, L178, L180, L182, L187, L188, L190, L192, L193, L194, L197	0.014	0.005
L14, L15, L16, L27, L44, L48, L49, L51, L52, L54, L57, L59, L61, L71, L75, L82, L89, L94, L102, L115, L125, L127, L130, L132, L137, L138, L139, L140, L147, L149, L151, L152, L165, L184, L191, L200	0.028	0.010
L5, L7, L8, L10, L17, L18, L21, L22, L26, L41, L45, L58, L70, L73, L77, L81, L83, L84, L90, L101, L114, L117, L120, L124, L131, L133, L136, L160, L176, L179, L189	0.046	0.026
L1, L3, L9, L12, L19, L20, L28, L38, L40, L53, L55, L64, L78, L96, L99, L104, L106, L116, L118, L121, L166, L177, L185, L196	0.071	0.0
L31, L42, L47, L60, L63, L68	0.090	0.032
L67, L87, L95, L128, L135	0.114	0.041
L129	0.142	0.051
L46	0.179	0.065
L123	0.285	0.103
L88	0.355	0.129
L91, L92, L93	0.570	0.206

Table 2 Bus voltage in the system

Bases	Rated voltage		remark
	kV	(p.u.)	
1	115	1.05	External grid
2	22	1.05	Load bus
3-202	22	1	Sub load bus

Table 3 Impedances and line charging of the cable [21]

Size (mm^2)	Z_1 (Ω/km)		Z_0(Ω/km)		B_0 (μS/km)	B_1 (μS/km)	Rating (A)
	R_1 (Ω/km)	X_1 (Ω/km)	R_0 (Ω/km)	X_0 (Ω/km)			
ACSR 25	1.138	0.4818	1.3158	1.9333	1.49	3.45	145
ACSR 35	1.11	0.4129	1.2582	1.6397	1.26	2.97	126
ACSR 50	0.556	0.3912	0.7042	1.6180	1.29	3.15	190
ACSR 150	0.1830	0.3281	0.3312	1.5550	1.34	3.47	335
ACSR 240	0.1343	0.3179	0.2825	1.5448	1.36	3.60	560
SAC 240	0.125	0.327	0.2732	1.5538	1.34	3.48	525

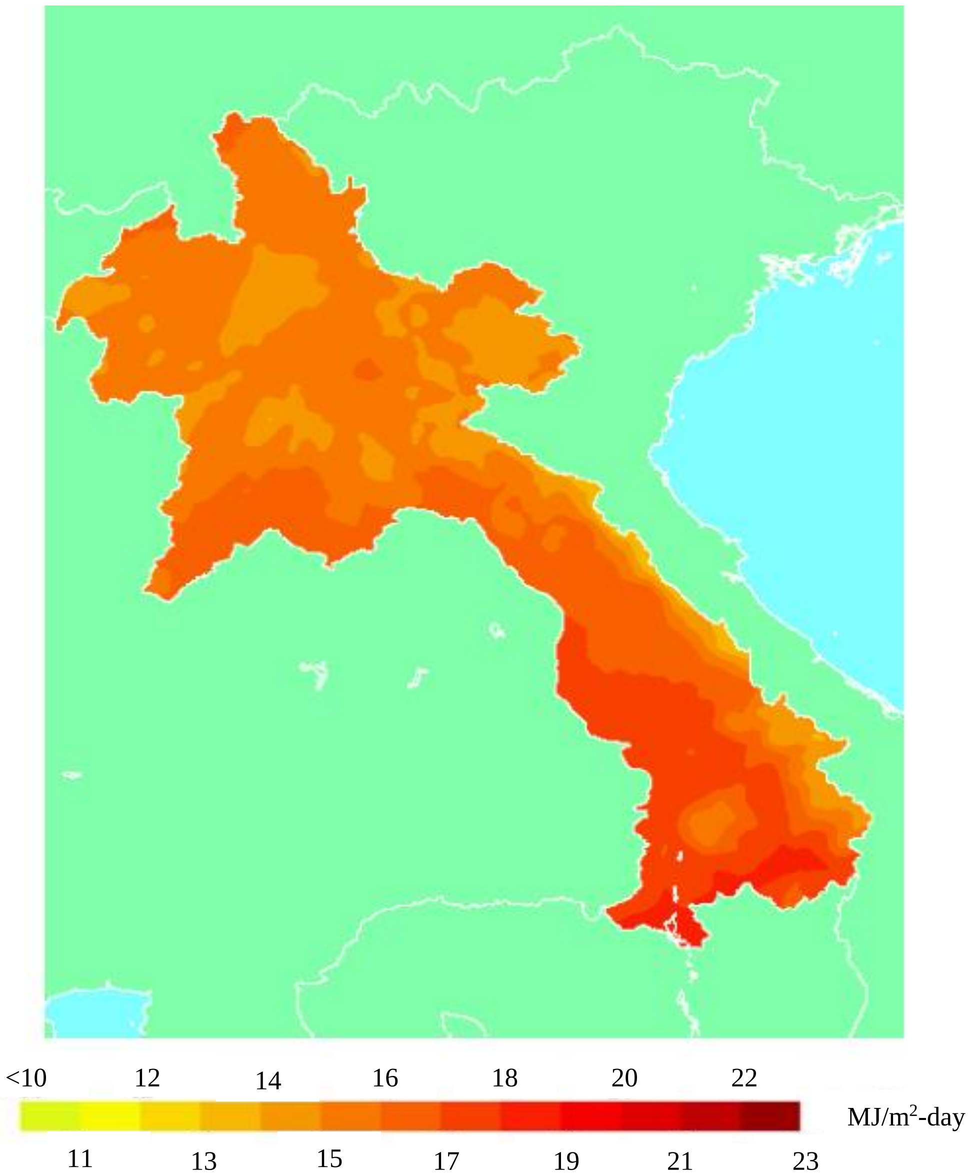
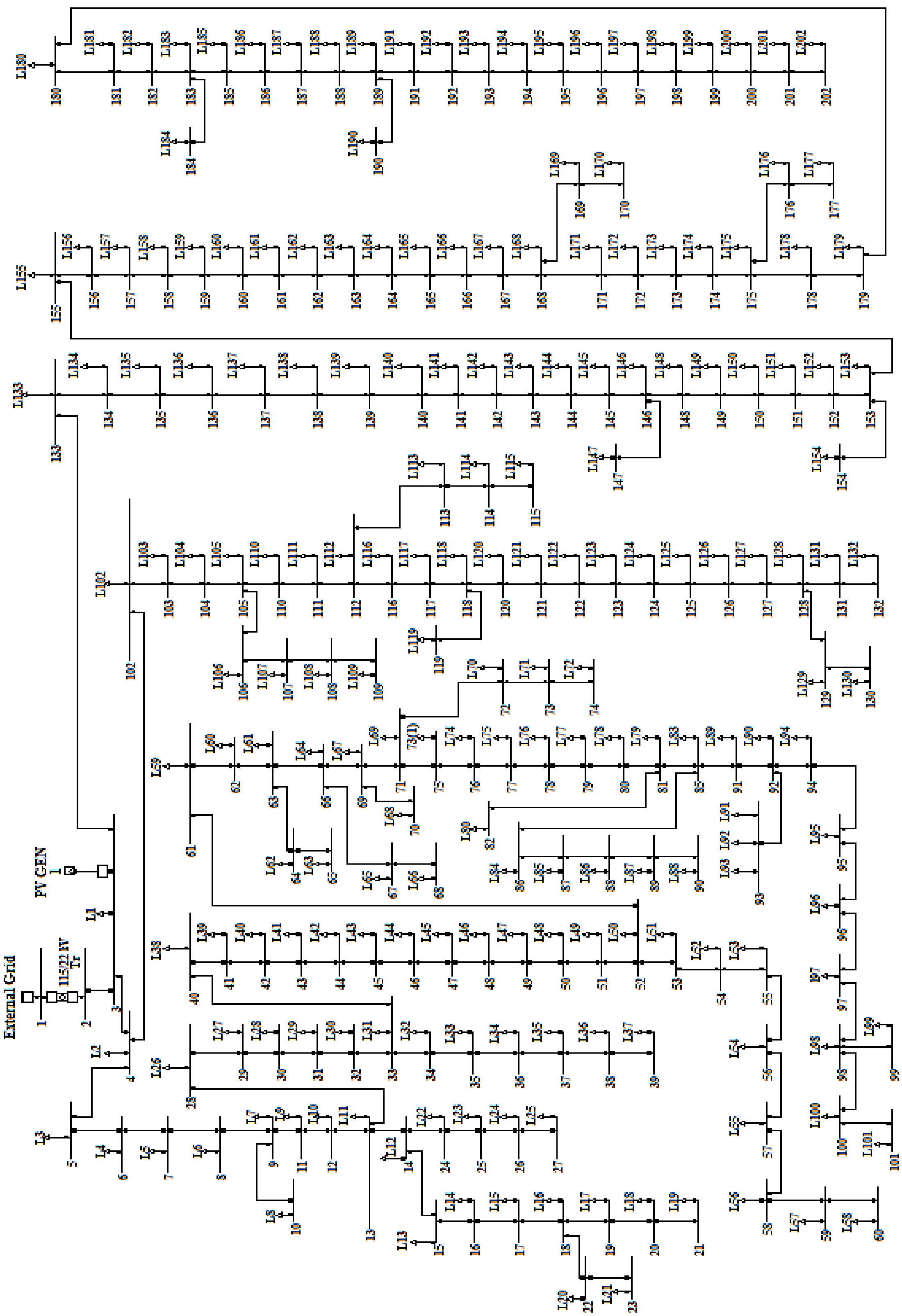


Fig. 1 The map of the average solar radiation over Lao PDR [10]


External Grid
115/22 kV
Tr
PV GEN

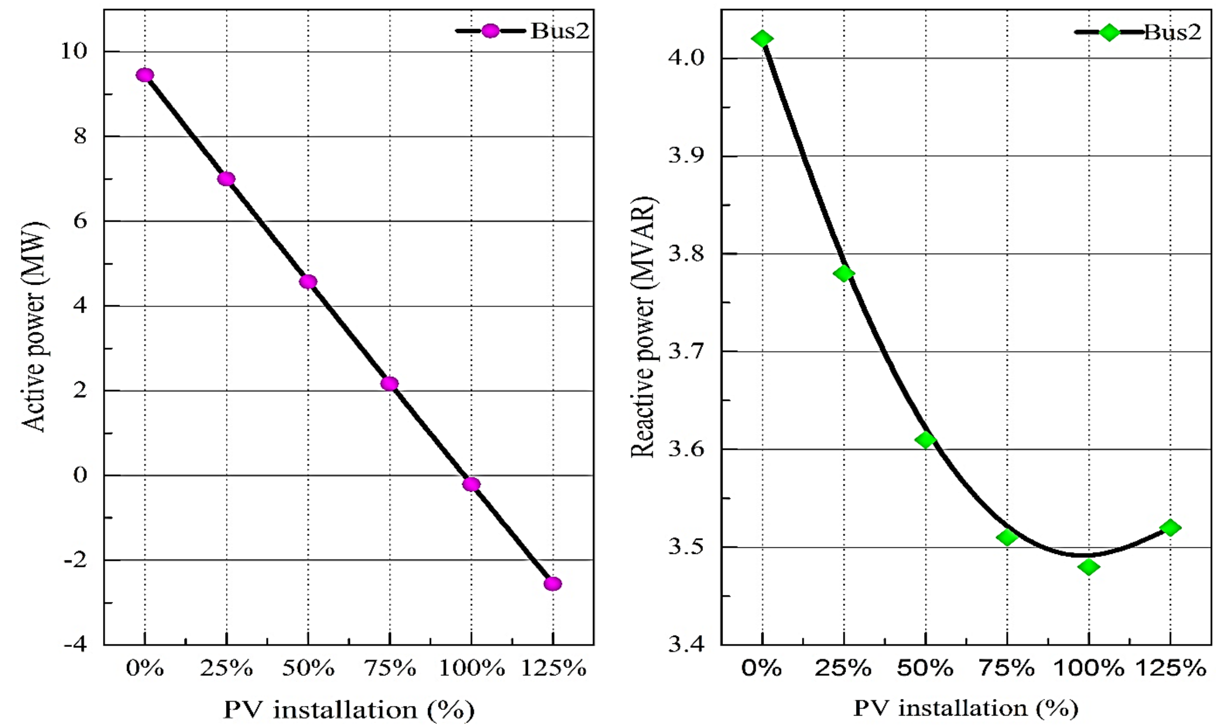


Fig. 3 Active and reactive power flow at different percentages of the PV installation

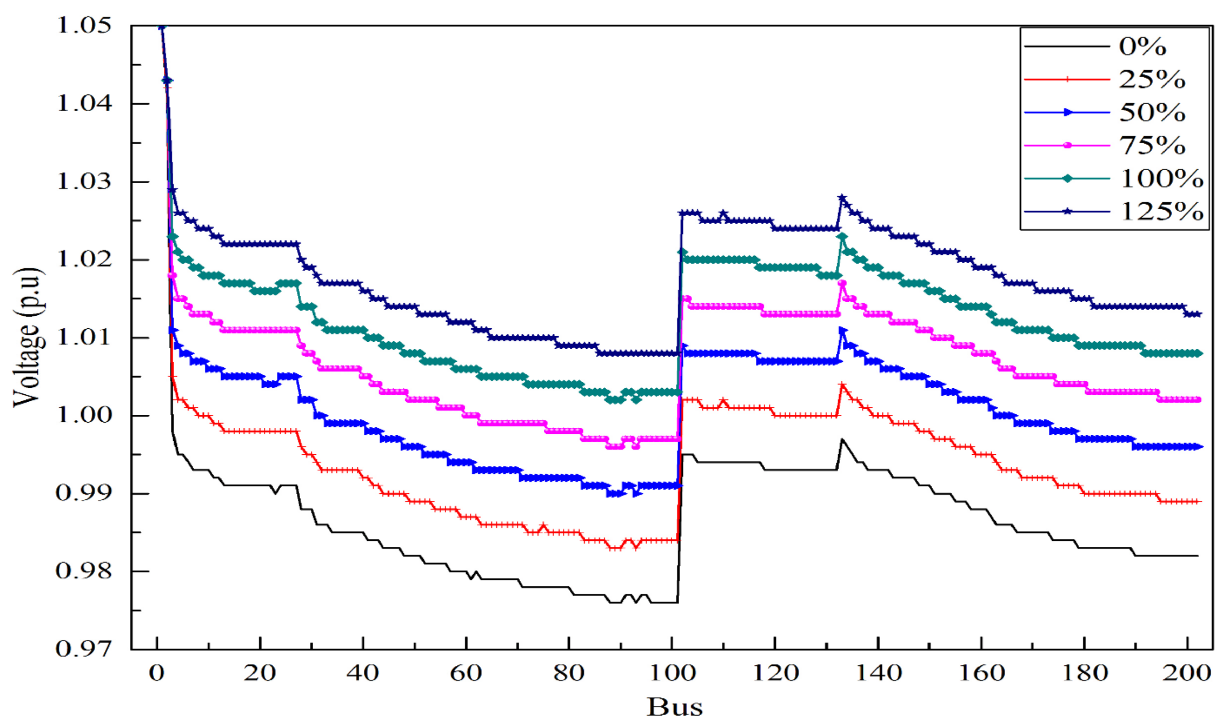


Fig. 4 The voltage variation in each buses when the PV connected to the grid

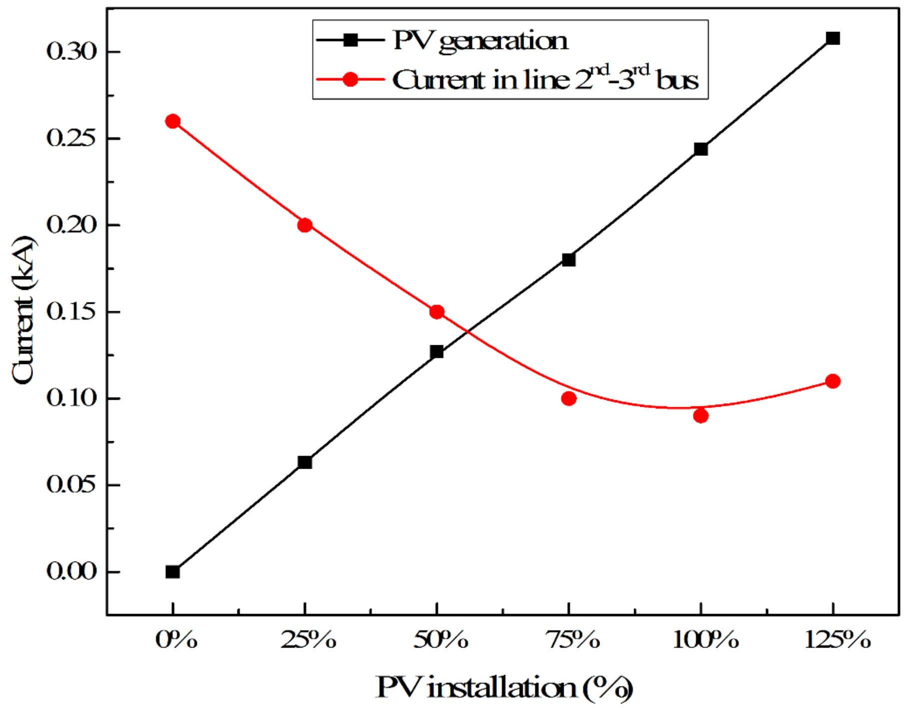


Fig. 5 The current in the transmission line bus 2 and bus 3 compared with PV generation.

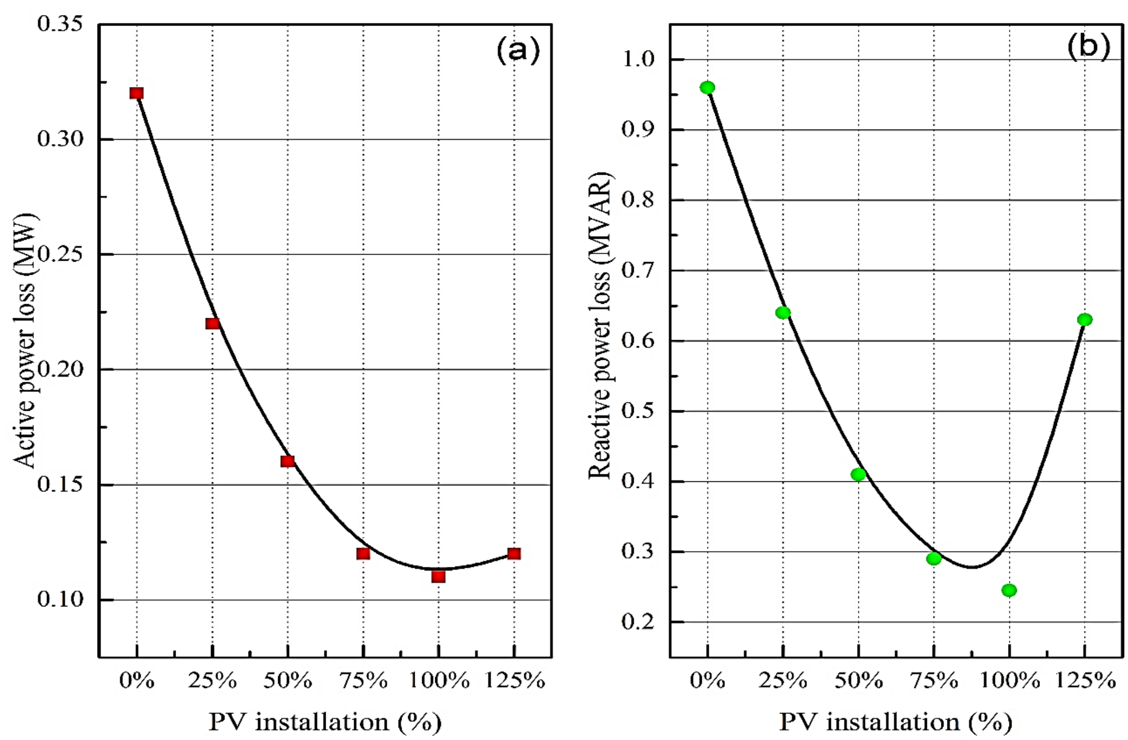


Fig. 6 Total power active power and reactive power in the electric power system at different percentages of the PV installation

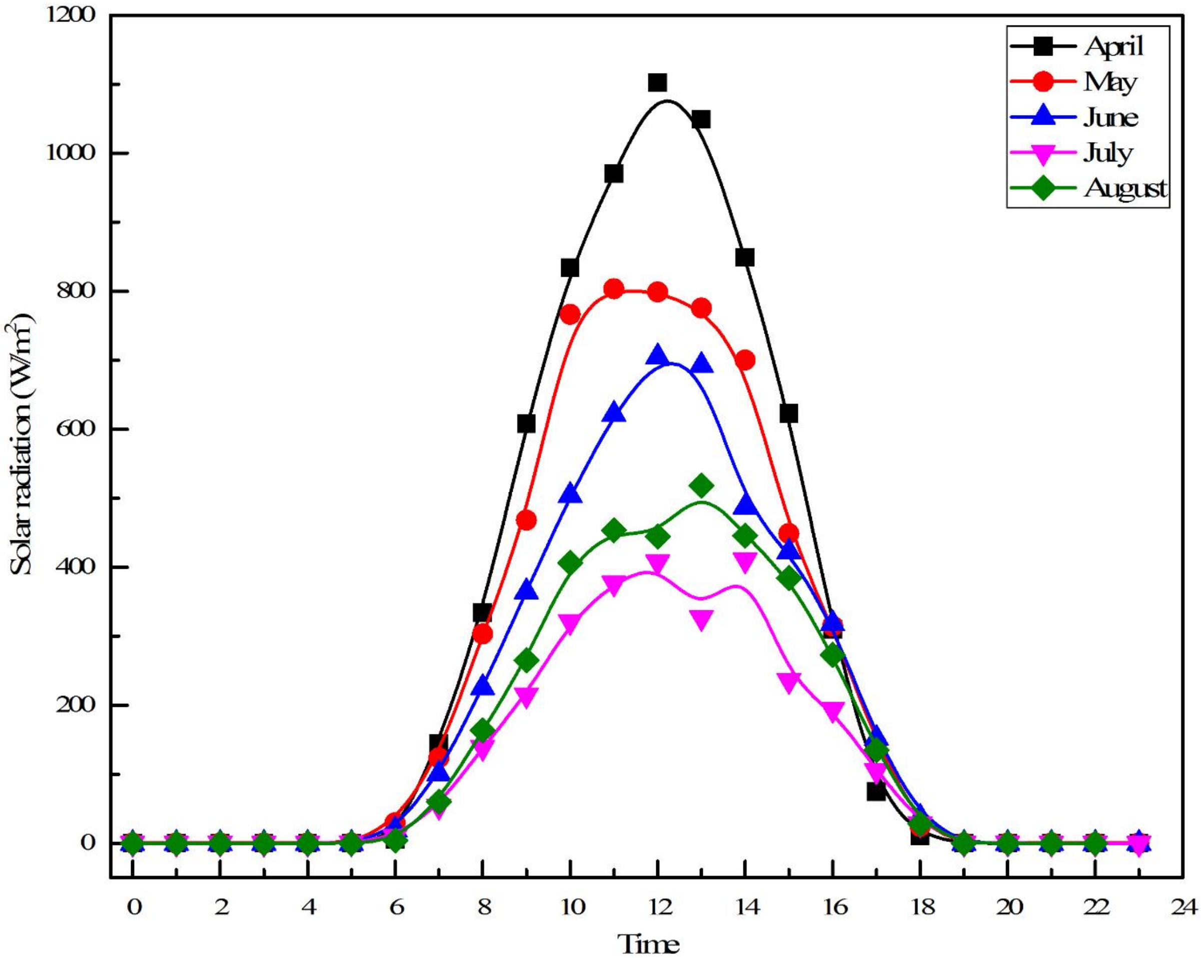


Fig. 7 The average solar radiation received from the solar power meter “SPM-1116SD in Savannakhet Province, Lao PDR, 2018