

Feed-in Tariff Premium for Optimal Solar PV Allocation: Case of Phitsanulok 1st Substation

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Abstract. *Solar Photovoltaics (PVs) are famously known as green technology devices. The devices are commonly used to feed electric energy into the distribution systems worldwide; including Thailand. In addition, lower prices of solar PVs lead to more popular in installation of solar PV grid-connected power stations. However, erroneous allocation of grid-connected solar PVs systems leads to power loss increasing in the power distribution systems. This consequently affects the increment of the power distribution system investment cost. To connect solar PVs in the power distribution system, the power loss of the system is important to consider with the system stability. Therefore, to promote the solar PVs installation, the optimal allocation of solar PVs with the Feed-in Tariff (FiT) premium price was proposed and implemented in this research. The analytical results from the simulation showed that the net present value (NPV) and the internal rate of return (IRR) were increased from the normal FiT scheme. Therefore, the FiT premium could create motivation for investment in the future installation and connection of the solar PVs at the optimal allocation.*

Keywords:

Solar photovoltaics, renewable energy, feed-in tariff, distribution system, allocation

1. Introduction

Grid-connected solar PVs system has been known as one of the most famous technologies in the world [1]. This is because of various benefits and advantages such as reducing CO₂ emission, ease for installation, relatively low investment cost, electricity support possibility during peak demand and power loss reduction in distribution systems [2]. As reported in [3], the solar PVs installation capacity has been dramatically increased around the world. To promote solar PVs energy, the feed-in tariff (FiT) scheme has been implemented in many countries such as Germany, USA, Japan, China, Malaysia and also Thailand [4]. Moreover, the FiT premium models have been effective to

promote the solar PVs energy [5]. Anyway, the improper installation capacity and placement of solar PVs in power distribution systems can cause a reverse power flow, power losses and poor voltage profiles [6]. Consequently, many reports have been analyzed the optimal sizing and placement of solar PVs in the distribution systems [7] - [9]. Analytical expressions are popular to identify the optimal sizing and placement of the solar PVs in distribution systems because these techniques are easy and can be analyzed with the MATLAB software. Analytical expression techniques based on a single objective can be used for distributed generation planning to reduce power loss in the distribution system, as presented in [10]. Then, the multi-objective index (IMO) was used to identify the optimal allocation for grid-connected solar PV [11]. The indices for optimal allocation analysis consist of active power loss index, reactive power loss index and voltage deviation index. Also, the IMO can identify the solar PVs location with reducing the power loss more than a single objective.

Although, the optimal allocation of solar PVs has been solved and identified, the policy to promote solar PV with considering the optimal allocation still needs. Thus, in this work, the FiT premium was investigated for the extra revenue from the energy loss reduction at the optimal location. The data for local power substation at Phitsanulok province in Thailand was used for simulation with the IMO technique to allocate the optimal sizing and placement of the solar PVs. Moreover, the net present value (NPV) and the internal rate of return (IRR) with the FiT premium has evaluated the project. The evaluation results show the NPV and the IRR was increased. Consequently, this FiT premium scheme can be considered to promote the optimal allocation of the solar PVs installation project.

2. Modeling and Problem Formulation

The solar PVs grid-connected power system has been installed with one feeder of Phitsanulok 1st substation distribution system, where is the Thailand local power substation in Phitsanulok province at total load demand of

4.52 MW and 1.53 MVar. A single line diagram and the load demand at each location are shown in Fig.1 and Fig.2, respectively.

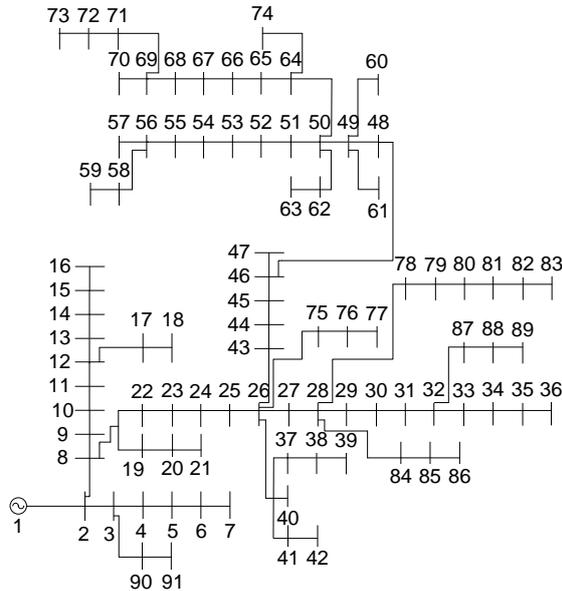


Fig. 1 Single line diagram of Phitsanulok 1st substation for the radial distribution system [12].

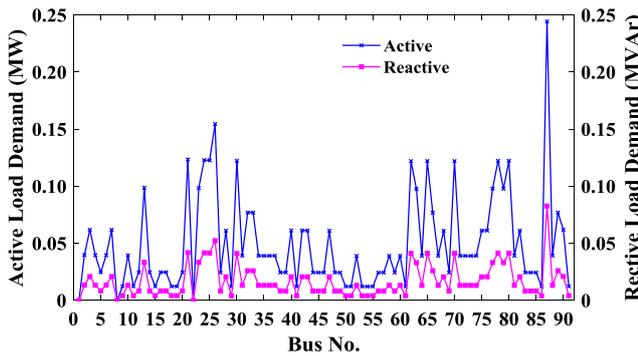


Fig. 2 Load demand at each location in Phitsanulok 1st substation [12].

2.1 Analysis of optimal solar PVs sizing

To determine the optimal solar PVs sizing, the formulation and objective function was presented in this research by the IMO technique with solar PVs sizing analysis.

2.1.1 Multi-Objective Index

To analyze the optimal solar PVs sizing in distribution systems, the active power loss index, the reactive power loss index and the voltage deviation index were considered with the IMO analysis. Regarding [11], the IMO is defined as:

$$IMO = \sigma_1 \frac{P_{LPV}}{P_L} + \sigma_2 \frac{Q_{LPV}}{Q_L} + \sigma_3 \frac{VD_{PV}^2}{VD^2} \quad (1)$$

; where σ_1, σ_2 and σ_3 are the weights of the active power loss index, reactive power loss index and voltage deviation index, respectively. These indices are σ_1 of 0.5, σ_2 of 0.25 and σ_3 of 0.25 and depend on the priority. P_L is an active power loss without solar PVs case, P_{LPV} is an active power loss with a grid-connected solar PVs, Q_L is a reactive power loss without solar PVs case, Q_{LPV} is a reactive power loss with a grid-connected solar PVs, VD^2 is a voltage deviation without solar PVs case and VD_{PV}^2 is voltage deviation with a grid-connected solar PVs.

2.1.2 Solar PVs Sizing

There are the various benefits for optimal allocation of the solar PVs. This is the power loss reduction includes a voltage profile improvement, which can be defined as equation (1) by the IMO. Therefore, to estimate the optimal solar PVs sizing with the minimum IMO value, the partial derivative of (1) with respect to P_{PVn} becomes zero as presented in (2):

$$\frac{\partial IMO}{\partial P_{PVn}} = \sigma_1 \frac{\partial P_{LPV}}{P_L \partial P_{PVn}} + \sigma_2 \frac{\partial Q_{LPV}}{Q_L \partial P_{PVn}} + \sigma_3 \frac{\partial VD_{PV}^2}{VD^2 \partial P_{PVn}} = 0 \quad (2)$$

; where P_{PVn} is the optimal solar PVs sizing at bus n. The P_{PVn} can be solved by using the objective function. The objective function in this work was formulated as the maximum power loss reduction after implementing solar PVs in the distribution system, which defined as follows:

$$\text{Maximize } F = \max (P_{LR}^{PV}) \quad (3)$$

where P_{LR}^{PV} is an active power loss reduction in the system with grid-connected solar PVs.

2.2 Feed-in Tariff price (FiT)

The Feed-in Tariff (FiT) policy has been implemented in Thailand since 2007 for promoting renewable energy including solar PVs energy [13]. As reported in [14], the total capacity of solar PVs in Thailand has increased significantly. Moreover, the FiT premium policy was adopted to some areas because the government would like to improve the distribution systems stability, such as Yala, Pattani and Narathiwat provinces [15]. Therefore, this work estimated the FiT premium to suggest for promoting the optimal allocate of solar PVs in the distribution system. The FiT premium will be returned to investor every year from the extra revenue of the energy loss reduction after grid-connected with optimal allocate of the solar PV.

2.3 Financial Indicators

Many reports presented the important financial indicators to evaluate the projects including the solar PVs energy project [16] - [19]. These indicators are the NPV and the IRR.

2.3.1 Net Present Value

The NPV is different between the present value of cash outflow and the present value of cash inflow over the project lifetime. The positive NPV value can indicate the profitable project while the negative NPV value it is noticed that it is a net loss [20] - [21]. For this work, the NPV calculation was used to evaluate the profitability of the solar PVs projected investment.

2.3.2 Internal Rate of Return (IRR)

The IRR is a discount rate that makes the net present value of all cash flow become to zero. The project with the high IRR would probably be accepted [22]. As same as the NPV, the IRR index was used to indicate the profitability of the solar PVs in the report [23]. Therefore, this work will be applying this indicator to evaluate the solar PVs allocation with FiT premium scheme.

2.4 Computational Steps

The maximum reduction of power losses in a distribution system was estimated and identified as computational steps to the optimal sizing and placement of the solar PVs. This proposed method applied the analysis of [11] can identify the optimal sizing and placement of the solar PVs with minimizing IMO. The computational steps are as follows:

- Step 1** Run the power flow for the base case without solar PVs by MATPOWER [24] in MATLAB software.
- Step 2** Find the solar PVs sizing with the minimum IMO from the solution of (2).
- Step 3** Implement solar PVs with the sizing derived in step 2 at each location over the system. Then, estimation of the power flow and the power loss in the system at all locations. The minimum power loss is the optimal location.
- Step 4** Estimate the extra revenue from energy loss reduction then return this revenue to solar PVs owner every year over the project lifetime.

After these steps, the optimal solar PVs sizing and the placement with the maximum power loss reduction will be solved. Moreover, the optimal location will be promoted by FiT premium price suggestion.

3. Results and Discussions

The optimal solar PVs sizing and placement were tested in one feeder of Phitsanulok 1st substation distribution system. To estimate the solar PVs sizing with the minimum IMO at each location following step 1, the results for various sizes in the range from 0.24 MW to 4.21 MW are shown in Fig. 3. Regarding, bus No.1 will be not connected with the solar PVs because this location is the distribution substation. Thus, the maximum solar PVs sizing was found at bus No.2 and the minimum solar PVs sizing was found at bus No.91. This is because the power flow injected into a bus depends on the locations and load demand.

The result of solar PVs sizing with the minimum IMO at each location was implemented in each location for one feeder of the Phitsanulok 1st distribution system. Then, the power loss at each location was determined and collected following the computational step 3. According to the power loss reduction results shown in Fig. 4, the maximum power loss reduction was found at bus No. 26. The power loss reduction in the system is ranged from 1.23% at bus No. 91 to 64.08% at bus No. 26. This is because of the location limitations of the solar PVs connected to the distribution system. The low power loss reductions were found at locations near the substation. It was noticed that, in the case of a grid-connected solar PVs, a location near the source can be reduced the power loss less than other locations. Therefore, the optimal location for this system is at bus No.26.

Similarly, Fig.5 has presented the cost of the energy loss reduction as known as the cost of the extra revenue from energy loss reduction after implemented the solar PVs in the distribution system at each location. This extra revenue can be calculated from the power loss reduction after connected solar PVs in the distribution system using an average capacity factor of the solar PVs systems in Thailand at 15% of the installed capacity [13]. The extra revenue of energy loss reduction at the optimal location is about 6,840 \$/Year.

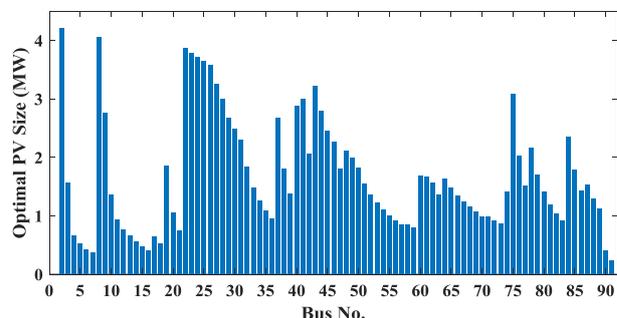


Fig. 3 Solar PVs sizing for the distribution system of Phitsanulok 1st substation.

Anyway, in the investor's point of view for solar PVs, the investor will invest to install the solar PVs by the criteria with the maximum revenue from energy selling

which depends on the solar PVs sizing. In this system, the maximum revenue from the energy was found at the different locations from the optimal location. Therefore, to promote the optimal location, this proposition is that the extra revenue of energy loss reduction returns to the investor via feed-in tariff premium price per year over the project lifetime.

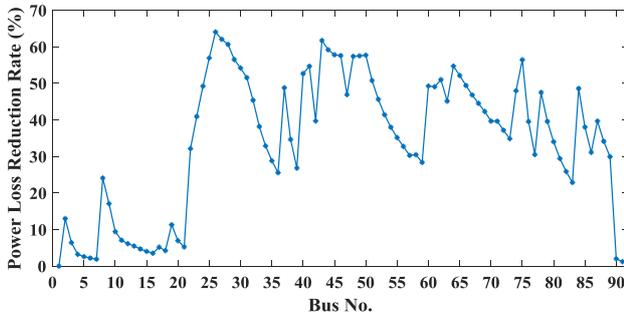


Fig. 4 Power loss reduction in the system after implemented solar PVs sizing at each location.

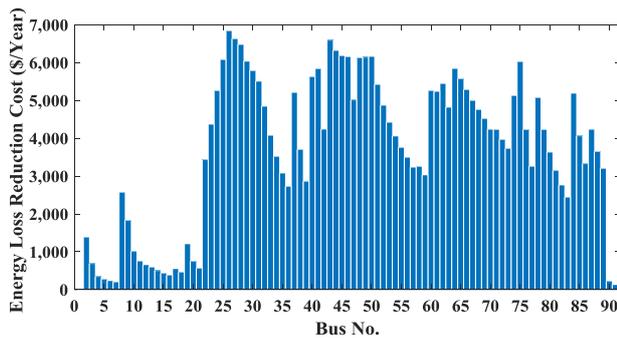


Fig. 5 Energy loss reduction cost per year in the system after implemented solar PVs sizing at each location.

Regarding the FiT premium price which returns to investor every year, the economic factors with NPV and IRR were analyzed. The results presented as Fig.6. To explore these results at bus No.26 where is the optimal location was promoted to connect the solar PVs, the FiT premium was varied from 10% to 100% of the extra revenue of energy loss reduction. The results have shown the NPV increased from the base case as well as the IRR. The maximum NPV is about 63,000 \$ and the maximum IRR is 12.16 % after using the FiT premium to promote this location. The NPV of this project was significantly increased and this can create motivation of the investor to install and connected the solar PVs in this optimal location.

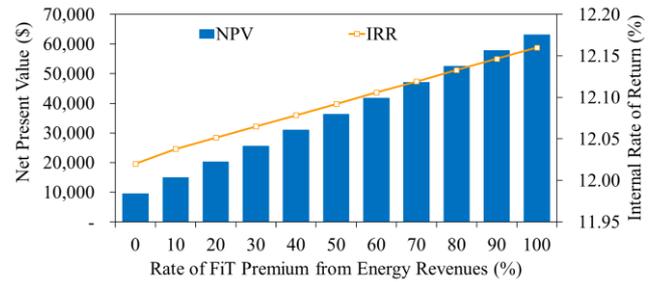


Fig. 6 Economic factor analysis after implement FiT premium price from the extra revenue of energy loss reduction per year in the system.

Moreover, after implementing the FiT premium results shown the NPV result at each location in Fig. 7. The maximum NPV at the base case was found at bus No.2 while the maximum NPV after implementing FiT premium was found at bus No.26 for all FiT premium rate. Thus, this suggestion is appropriate to promote the optimal location to connect the solar PVs.

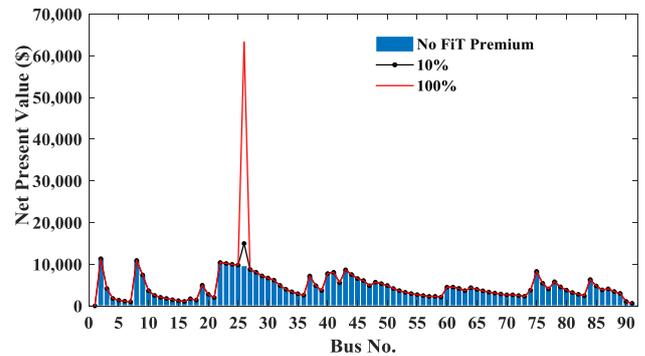


Fig. 7 A comparison of the NPV result at each location between No FiT premium scheme and FiT premium rate from extra revenue for 10% and 100% of energy loss reduction after implemented solar PVs.

4. Conclusions

Although grid-connected solar PVs systems can support the electricity during peak demand, the reduction of the power loss in the distribution systems and the improvement of the voltage profile are important with the optimal PVs location and sizing. Improper allocate of grid-connected solar PVs can lead to higher power losses and poor voltage profile in the systems. Therefore, to connect solar PVs in the distribution system, the optimal sizing and placement are important factors to consider. Consequently, this work proposed an analytical approach to allocate grid-connected solar PVs in a power distribution system with the case for Phitsanulok 1st substation. The objective is to minimize the power losses. The results showed that this proposed technique could be used to identify the solar PVs sizing and placement as well as the power losses reduction in these systems. Moreover, the FiT premium could be noticed that the NPV and the IRR were increased. Thus, the

optimal location is more interest than other locations to connected solar PVs in the system. Consequently, the FiT premium is the important suggestion to promote the optimal allocation of grid-connected solar PVs.

Acknowledgments

The author would like to express her gratitude to the Provincial Electricity Authority (PEA) and Khon Kaen University for their support of this research.

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Biography

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