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Distribution company investment cost reduction analysis with grid-connected solar PV allocation in power distribution system

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Abstract

Currently, the solar PV is an important renewable energy because of an advantage for environment including the power distribution systems. Optimal sizing and placement of grid-connected solar photovoltaic (PV) are important for power loss reduction in distribution system because it also leads to the cost reduction. To promote the solar PV energy, feed-in tariff (FiT) policy was used in many countries. However, due to the FiT still higher than normal wholesale, the distribution company (DisCo) can absorb and leads to increase electricity retail price in the future. Therefore, the DisCo investment cost related to the power loss reduction was analyzed in this work by considering sizing and placement of grid-connected solar PV on the IEEE 33 bus and IEEE 69 bus distribution systems. To explore optimal solar PV placement, profit-cost ratio (PCR) was estimated with parameters of the reduced cost due to reduction of power loss and the DisCo investment to absorb FiT cost. The results show the DisCo cost depending on the solar PV sizing and the reduced cost due to installation of solar PV placement in power distribution system. Although the maximum power loss reduction is an optimal location, the maximum reduction of the DisCo absorbing FiT cost was achieved at the maximum PCR location. Thus, the optimal placement relating to the PCR is an important to explore the solar PV allocation in distribution system.

Keywords: Feed-in tariff, renewable energy, solar PV, grid-connected, investment cost analysis, power systems

1. Introduction

Solar energy has become an important energy source for electricity generation due to significant environmental benefits [1,2]. Currently, there is an increment of the power generation capacity with grid-connected solar photovoltaic in distribution system because solar PV module's prices have fallen roughly 75% since 2006 [3,4]. Moreover, in the power distribution systems, optimal sizing and placement of grid-connected solar PV are important to improve the voltage profile and to reduce the peak load demand and the power loss [5]. This is because it leads to the cost reduction. In contrast, improper sizing and placement of solar PV grid-connected is cause of the reverse power flow, the power loss and the poor voltage profile [6,7]. Consequently, many researchers have proposed the analysis to identify the optimal placement and size of the solar PV for installing in system. The analytical expression is a method for DG planning based on a single objective to reduce power loss [8,9]. Recently, the multi-objectives index (IMO)-based analytical expression can be used to consider the size and placement of solar PV-based DG relating to the parameters active power loss, reactive power loss, and voltage deviation [10].

However, the economic and investment cost are not mentioned in this IMO-bases analytical expression.

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Generally, distribution system improvement and investment cost minimization of electrical grids are the main target of the distribution company (DisCo) [11]. The aim of DG owner is the maximize revenue by selling electricity to the electrical grid with Feed-in Tariff (FiT) price which higher than the wholesale price to promote the solar PV installation [12]. According FiT scheme, this different cost was absorbed by DisCo. When considering absorbed cost effect in distribution systems, the investment cost significant increases and leads to the electricity retails price which is expensive than the normal scheme.

Therefore, this work purposes the solar PV allocation using the IMO-based analytical expression with considering the DisCo profit-cost ratio (PCR). Results can identify the optimal placement and sizing of solar PV with analysis of investment cost related the solar PV sizing. The optimal placement can reduce DisCo absorbing FiT cost and cause reduction of the electricity retails in the future.

2. Model and Problem Formulation

2.1. Analysis of optimal solar PV size in redial distribution systems

The distribution systems for analysis of optimal PV placement have presented with IEEE radial distribution systems for 33 bus and 69 bus. The sizing of solar PV at each bus for average load level was achieved by the muti-objective index (IMO) based analytical expression [10]. For estimating the solar PV output in this work, the solar PV capacity factor (CF) is defined as the ratio of the actual annual energy output to the quantity of the maximum possible energy generate from the solar PV systems (*InsCap*), as reported that the average CF is about 15% [12]. The average solar PV output (PV_{out}) for this CF can be calculated by (1).

$$PV_{out} = InsCap \times 0.15 \tag{1}$$

2.2. Distribution company profit analysis

Installation of the PV in distribution system leading to energy loss reduction in system can reduce the DisCo cost. The DisCo annual energy loss saving cost can estimate by (2).

$$C_{loss} = E_{loss} \times E_{price} \tag{2}$$

where C_{loss} is cost of energy loss reduction ($/Year), E_{loss} is energy loss reduction (kWh/Year) and E_{price} is wholesale energy price ($/kWh).

All over the world, many countries use the feed-in tariff (FiT) policy to promote the solar PV installation capacity with the global Co_2 reduction [13, 14]. Each country has target with the electricity purchase by determining the higher solar PV price than normal wholesale price [12]. Actuality, the supporter is responsible for the financial from the different price between FiT and wholesale in each country. This depends on the government policy such as responsible by the government, customers even the distribution company (DisCo) [15]. In this work, the distribution company (DisCo) is responsible for the FiT financial supports cost. Similarly, the government or customers have to absorb the cost. This purpose method can apply as well. The annual different cost ($/Year) that the DisCo have to absorb (C_{DisCo}) can be written as (3)

$$C_{DisCo} = (FiT - E_{price}) \times E_{pv} \tag{3}$$

where *FiT* is the solar PV feed-in tariff price ($/kWh), E_{pv} is an annual electricity from the solar PV (kWh/Year) and E_{price} is the wholesale price ($/kWh).

The electricity price analyzed in this work which collects from Thailand current rate where in researched country. The FiT rate at 0.19 ($/kWh) while the electricity wholesale at 0.13 ($/kWh). The FiT is higher than the electricity wholesale because the government policy promotes the solar PV according the advantages for environment and reduced peak demand in distribution systems [12].

2.3. Profit cost-ratio analysis

The benefit cost-ratio (BCR) is an expression of the profitability of the project defined as the ratio of the profit of a project to its costs. The higher BCR illustrates a more profitable investment [16,17]. Our work applied this analysis method using DisCo profit cost ratio (PCR) to increase the DisCo profit from power loss reduction also control the FiT absorb cost. The PCR can indicate the optimal location where influence the DisCo increases the profitable with highest PCR define as the equation (4).

$$PCR = \frac{C_{loss}}{C_{DisCo}} \tag{4}$$

2.4. Computational steps

Computational steps have purposed to allocate solar PV by reduceing the DisCo absorb FiT cost while considering the power loss reduction cost in the distribution systems. The computational steps are summarized as follows.

Step 1: Run power flow to find the solar PV sizing as follows [10].

Step 2: Determine the solar PV output at each location follows capacity factor (1).

Step 3: Run power flow with the solar PV output from step 2 each location over all the systems to find the power loss.

Step 5: Determine the annual energy loss reduction cost for all locations by (2).

Step 4: Find the difference electricity cost between wholesale price and FiT price following (3).

Step 6: Calculate the profit cost ratio over the system by (4).

After computation by six steps, we can specify the DisCo PCR for all locations. This result can suggest the optimal location where the highest reduces FiT absorb cost including power loss in the system with the location has the maximum PCR.

3. Results and Discussion

The results of the solar PV outputs at 15% of CF with the solar PV sizing following the IMO based analytical expression method considered with the solar PV output pattern resemble with the solar PV sizing. However, the solar PV sizing is determined from the power flowing at each bus therefore the big size of solar PV can find at nearly source or substation then decreasing at next bus respective. The output is different in the rage from 20.25 to 329.57 kW and 1.95 to 347.07 kW shown in Fig. 1 for IEEE 33 bus and 69 bus, respectively.

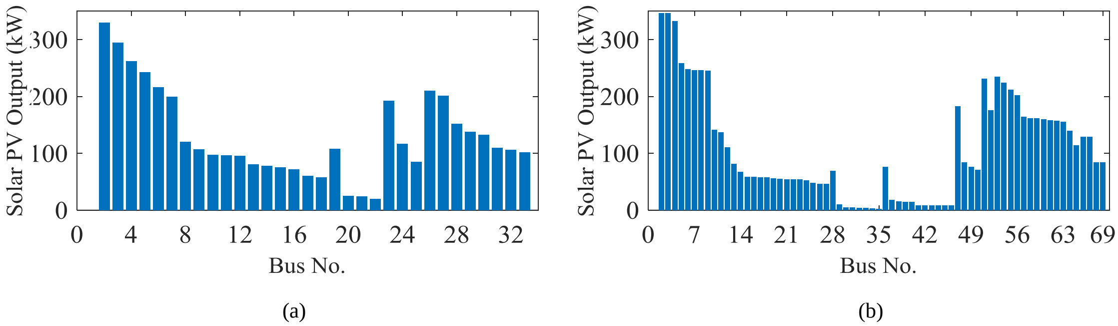

Fig. 1. Solar PV output for (a) IEEE 33 bus and (b) IEEE 69 bus.

After implement the solar PV at each location, the results show a comparison of the power loss with the base case without solar PV. The result illustrates that the maximum power loss reduction is in the range from 0.16 to 10.52 kW and 0 to 15.00 kW. The maximum power loss reduction is bus No.6 and No.61 in IEEE test system 33 bus and 69 bus, respectively. Also, the results show the power loss reduction at location, which is different due to resource availability and geographic limitations. The annual energy loss reduction cost (C_{loss}) can determine from the power loss reduction with wholesale electricity price as the result in Fig. 2.

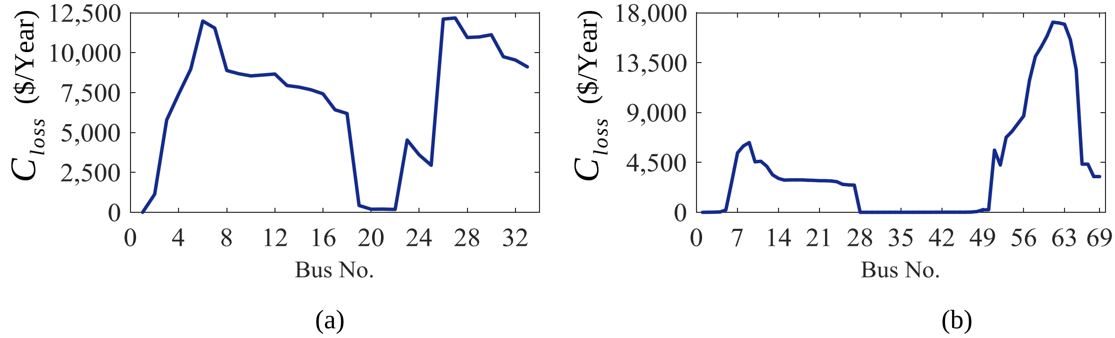

Fig. 2. Annual energy loss reduction cost at each location in IEEE 33 bus and 69 bus systems.

The DisCo financial absorb FiT cost (C_{DisCo}) was found when the DisCo purchase electricity from solar PV. The highest C_{DisCo} find at bus No.2 for both IEEE test systems due to the biggest solar PV sizing and output as follows Fig. 3. Similarly, at the location where find the maximum energy loss reduction, the C_{DisCo} still higher than other locations due to their output. This absorb cost is one of the investment cost for DisCo and distribution system then affect to society with electricity retails price. Thus, the solar PV scheme would be promoted with FiT relating the reduced cost due to power loss reduction. The PCR is an interest to consider identifying the optimal allocate solar PV.

Fig. 4 illustrates that the optimal placement with highest profit-cost ratio is at locations of bus No.18 and bus No.65 for IEEE test systems 33 bus and 69 bus, respectively. Although, following systems at bus No.6 and bus No.61 have the maximum energy loss reduction cost. Therefore, this can identify the placement and sizing of the solar PV grid-connected by considering the DisCo profit-cost ratio and it is more effective to reduce the financial support FiT cost.

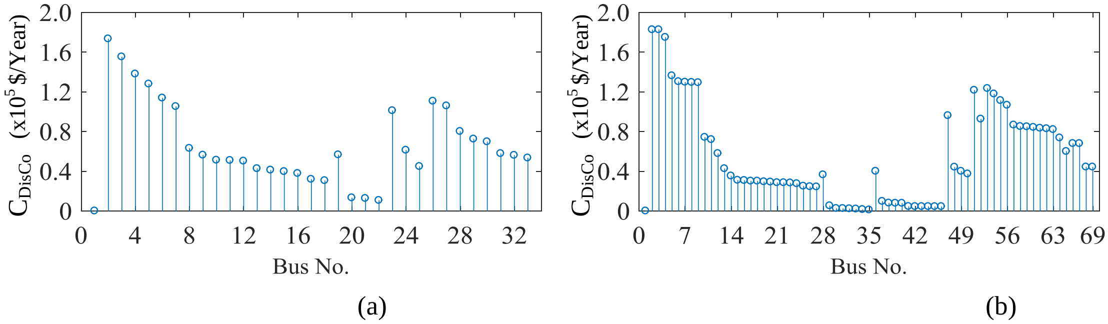

Fig. 3. Annual cost of DisCo absorb FiT scheme at each location in IEEE 33 bus and 69 bus systems.

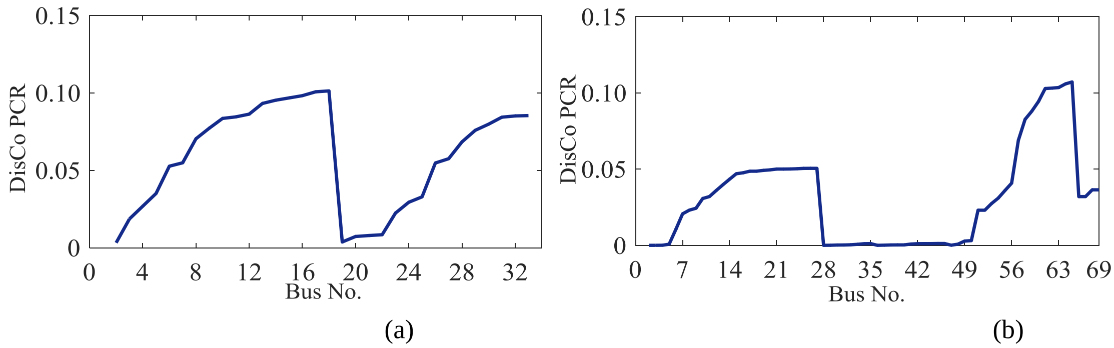

Fig. 4. DisCo profit-cost ratio at each location in IEEE 33 bus and 69 bus systems.

As table 1 shown a comparison of the DisCo profit between the IMO based analytical expression and the IMO based analytical expression considering DisCo profit-cost ratio. The result shows that the purposed method can reduces the DisCo cost which have to absorb the FiT scheme from the IMO without PCR considered at 73% and 28% with the annual energy loss reduction cost reduces from base case at 6,191.91 ($/Year) and 15,818.37 ($/Year) for IEEE 33 bus and 69 bus, respectively.

Table 1. Results comparison for methods and test systems.

	Optimal location bus No.		C_{DisCo} ($/Year)	
	33 bus	69 bus	33 bus	69 bus
IMO	6	61	113,687	83,338
IMO considered PCR	18	65	30,553	59,930
C_{DisCo} reduction	-	-	83,135	23,409
C_{DisCo} reduction rate (%)	-	-	73	28

4. Conclusions

Because Solar PV is an advantage for environment, mitigates conventional energy during peak demand also reduces the power loss in the distribution systems. Therefore, worldwide has the policy to promote the solar PV. The Feed-in tariff policy was successes in many countries. However, due to the FiT is higher than normal wholesale. Then, it affects to the DisCo absorbing the different price at the first time and leads to the investment cost increases. Moreover, the retails price will be increased in the future. Thus, this work purposes an analysis of the solar PV allocation with multi-objective index (IMO) based analytical expression by considering the PCR. This can reduce the power loss in the distribution systems and the DisCo investment cost for financial support at the FiT that higher than the wholesale. To identify the optimal placement and sizing of solar PV, the DisCo increases the profit with the maximum PCR. Thus, this purposes IMO method based on analytical expression considering the PCR is interesting to consider with suggestion to promote solar PV with optimal allocation. Moreover, the reduction of C_{DisCo} leads to the retail price of energy will be reduced in the future.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Katsarin Seepromting, Chayada Surawanitkun conducted the research, Rongrit Chatthaworn, Pirat Khunkitti, Anan Kruesubthaworn, Chayada Surawanitkun; analyzed the data; Katsarin Seepromting, Chayada Surawanitkun, Apirat Siritaratiwat, wrote the paper; all authors had approved the final version.

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