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Selection of Potential PV Locations: A Case Study in Bali

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Abstract: A 1 MW on grid photovoltaic system has been developed in regency of Bangli, Bali, Indonesia. The PV system is connected to a 20 kV distribution network, namely feeder "Bangli". The PV generated electricity is injected to the network by utilizing 5 transformers, each of them with a capacity of 250 kVA. The PV system accommodates land of about 1 ha. There are a number of feasible locations for placing the system, based on different criteria. This study discusses the selection of potential PV locations along the medium voltage distribution feeder. The study utilized bus sensitivity analysis as parameter in choosing five options of PV locations. In order to simplify the calculation complexity, the feeder is modeled by clustering the distributed load. The 5 alternative locations then were scored further based on 4 criteria which include power loss, land utilization and availability, bus minimum voltage and accessibility to the 20 kV network. Based on the given criteria, it was found that the simple approach is very useful to assist in deciding the best location for the PV system.

Key words: Distributed generation, PV system, power loss, sensitivity analysis, Bangli

INTRODUCTION

Bali is a small province with an area of about 5,600 km^2 and a population of approximately 3.8 millions. The local capacity of Bali electricity generating system is about 796.5 MW with a peak load of 730 MW (MEMR Republic of Indonesia, 2013). Most of the generated electricity comes from oil-fired power plants. Only small portion of the generated power come from various renewable resources, such as solar, wind and hydro power with a total capacity of a few MW. A small capacity of electricity generation from biogas and domestic waste are also available (Kumara *et al*., 2014).

The very small fraction of the utilization of renewable resources despite of the abundant potential availability has became an attention to the government of the Republic of Indonesia in implementation of renewable energy policy. The Indonesia energy policy states that the new and renewable energy resources should contribute to 17% of national energy mix by 2025 (MEMR Republic of Indonesia, 2013). The target has driven an increased utilization of renewable energy resources in energy sectors, including electrical power sector.

In relation to the government energy policy, on grid photovoltaic system has been developed in regency of Bangli, Bali, Indonesia. Details of the location's characteristics and the technical specifications of the PV system have been discussed by Kumara *et al*. (2013). The PV system is connected to a 20 kV distribution network, namely "Bangli" feeder. The Bangli feeder delivers power from Gianyar Sub-Station to customers in Bangli region. The feeder is operated radially with a total length of 79.02 km. The day peak load of this feeder is approximately 3.3 MVA while the night peak load is about 6.5 MVA. Note that the PV system is not equipped with batteries hence the system only supplies electrical energy to the grid during daytime. Figure 1 shows the PV panels composing 1 MWp solar power generating system.

The PV system; nevertheless was built merely based on the land availability, hence the contribution to the grid may be not optimal. This study discusses the selection of alternative PV locations along the distribution feeder. The study utilized bus sensitivity analysis as parameter in

Fig. 1: The PV system

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choosing five options of PV locations. In order to simplify the calculation complexity, the feeder is modeled by clustering the distributed load. The 5 alternative locations then were scored further based on 4 criteria which include power loss, land utilization and availability, bus minimum voltage and accessibility to the 20 kV network. A comparison of the used parameters to the existing location is also discussed in this study.

MATERIALS AND METHODS

Selection of potential PV locations: A simple selection process is utilized to determine other potential locations of the PV system. The selection process is begun with the calculation of the sensitivity analysis of a number of feasible points within the distribution feeder. In order to simplify the calculation process, the load points are clustered into a number of lumped load points. Five potential locations with the five highest sensitivity values are chosen for further analysis. The five alternative locations then are scored further based on 4 criteria which include power loss, land utilization, feeder minimum voltage and accessibility to the MV network.

Sensitivity analysis: The sensitivity analysis used in this study is based on feeder power loss changes due to an increase in demand at a particular load point. The sensitivity value for each bus is calculated by using the following mathematical expression:

$$y_p = \frac{\Delta L}{\Delta P_p} \tag{1}$$

Where:

y_p = Sensitivity of bus P
AL = Change in power loss (kW)
Ap_p = Change in load at bus P (kW)

A large value of the bus sensitivity indicates that a small injected power into the particular node will decrease a significant amount of power loss of the system. Therefore, potential PV locations with high sensitivity values are chosen subsequently.

Parameter weighting: The parameters used for scoring approach include feeder power loss, land availability and current utilization, minimum bus voltage after PV penetration, and the accessibility to the 20 kV distribution network. The four parameters are weighted as shown in Table 1. The feeder power loss and land utilization at the potential locations are given a high weight because of the important of two parameters.

Table 1: Weight of parameter

Parameters	Weight (%)
Power loss	40
Minimum voltage	20
Land utilization	30
MV network access	10

Table 2: Individual score for total power loss

Power loss (kW)	Score
P_L<103.5	100
103.5≤P_L<105	75
105≤P_L<106.5	50
106.5≤P_L<108	25
108≤P_L	5

Table 3: Individual score for land utilization

Land utilization	Score
Empty land	100
Plantation	80
Commercial plantation	70
Rice field	60

Table 4: Individual score for feeder minimum voltage

Minimum voltage (kV)	Score
19.39≤V_{min}	100
19.34≤V_{min}<19.39	75
19.29≤V_{min}<19.34	50
19.24≤V_{min}<19.29	25
V_{min}<19.24	5

Individual score: The individual score for power loss is illustrated in Table 2. The power loss variation was calculated using power flow simulation software. It was found that the variation of the feeder power loss lies between 103 and 109 kW. The highest individual score is given to the potential PV location with the lowest total power loss, and vise versa.

Table 3 shows the individual score for land utilization. The PV project should not occupy productive land particularly that for rice field. With this regards, the rice field is given the lowest score and the empty land is given the highest individual score.

Penetration of PV to the grid should improve the voltage profile of the primary distribution network. Simulation of bus minimum voltage has indicated that the minimum voltage varies between 19.2 and 19.4 kV. The individual score for minimum voltage at a load point within the analyzed feeder can be seen in Table 4. It is clear that the lower the voltage, the lower the individual score for a particular location.

The individual score for network accessibility is determined by the distance of the potential location to the nearest 20 kV distribution line. The lowest distance is given the highest score. Table 5 shows the individual score for network accessibility.

Table 5: Individual score for network accessibility

Distance (m)	Score
D<5	100
5≤D<10	75
10≤D<15	50
20≤D	25

Total score: The total score can be calculated by summation of the individual score times weight, and divided by the total weight, or mathematically can be expressed as:

$$TS = [(S_1\times W_1)+(S_2\times W_2)+\ldots+(S_N\times W_N)]/[W_1+W_2+\ldots+W_N] \quad (2)$$

where, TS is the total score while S_n and W_n consecutively are the individual score and the weight of each parameter. N is the total number of decision parameters.

RESULTS AND DISCUSSION

Load clustering: The "Bangli" feeder supplies 147 distribution transformers with different capacity and load demand. The PV system injects power to the feeder through 5 units of 250 kVA transformers. The daily feeder load variation can be seen in Fig. 2. The night peak demand is close to 6.5 MVA while the day peak demand is about 3.3 MVA. The feeder services mostly residential customers. Typical increased in energy consumption occurs during evening time, when people arrive home, turn the light on and begin the evening activity. A slight increased in energy consumption can be seen during early morning, when people prepare for the day activity.

The 147 load points of the feeder then are clustered into 13 load points. The clustering process follows a simple method where a number of load points are grouped into lumped load attached to the main branch of the feeder. The feeder's topology after clustering process is shown in Fig. 3.

Sensitivity analysis: The sensitivity analysis then is applied to the system with clustered load points. The bus sensitivity analysis follows Eq. 1 and the five highest sensitivity values are shown in Fig. 4. The five buses then are defined as potential locations of the PV system. All the potential locations are located within sub-region of "Tembuku", region of "Bangli" with the following details:

- Site option 1 is located in sub village of "Banjar Metra". The bus code is TK0041
- Site option 2 is in sub-village of "Banjar Kaler", village of "Bangbang" with a bus code of TK0019
- Site option 3 with a bus code of TK0017 is located in sub-village of "Banjar Bangkiang Sidem"

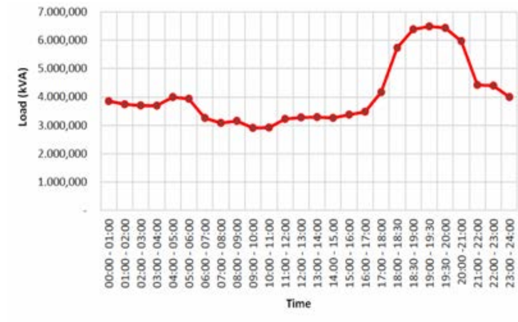

Fig. 2: Daily load curve of the feeder

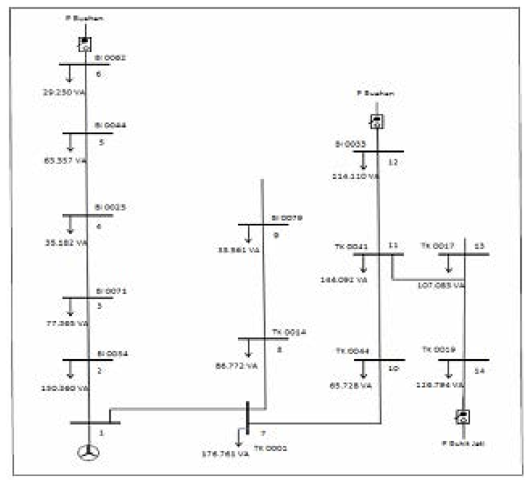

Fig. 3: Topology of the feeder after clustering process

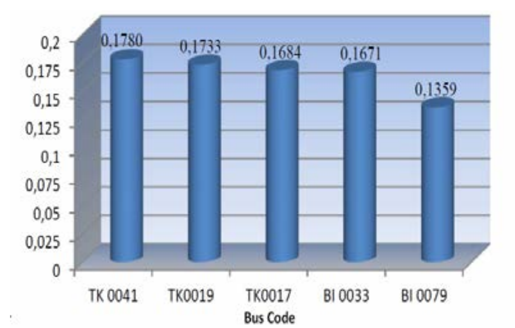

Fig. 4: Senstivity values of the 5 busses

- Site option 4 is located in sub-village of "Banjar Penaga" with a bus code of BI0033
- Site option 5 with a bus code of BI0079 is located in sub-village of "Banjar Landih Selatan"

Total score: The scores given for each parameter for site option 1 are summarized in Table 6. Note that the power loss and the minimum voltage are calculated using power

Table 6: Score for site option 1

Parameters	Quantity/Description	Score
Power loss	103.1 kW	100
Minimum voltage	19.34 kV	75
Land utilization	Less productive plantation	80
MV network access	<5 m	100

Table 7: Score for site option 2

Parameters	Quantity/Description	Score
Power loss	104.5 kW	75
Minimum voltage	19.39 kV	100
Land utilization	Rice field	60
MV network access	<5 m	100

Table 8: Score for site option 4

Parameters	Quantity/Description	Score
Power loss	106.4 kW	50
Minimum voltage	19.38 kV	75
Land utilization	Less productive plantation	80
MV network access	5≤D<10	75

Table 9: Score for site option 5

Parameters	Quantity/Description	Score
Power loss	109.5 kW	5
Minimum voltage	19.30 kV	50
Land utilization	Less productive plantation	80
MV network access	<5 m	100

flow simulator for the given day peak demand. The reason is to look at the effect of the PV penetration to the system voltage and power loss profile. Figure 5 shows the associated land condition and the available MV network. It is clear that the MV network is available right next to the site.

Table 7 shows the scores given for each parameter for site option 2 of the PV system location. Different from that of option 1, the proposed site for option 2 is currently utilized as rice field, as shown in Fig. 6. Consequently the score for land utilization is lower than that for site option 1.

Details on the scores for Site Option 4 and 5 are described in Table 8 and 9 while the corresponding site conditions are depicted in Fig. 7 and 8. The distribution network for Site Option 4 is located about 8 m from the proposed site; hence the score for MV network access becomes 75. The score for site option 5, however, is significantly lower than that for Option 4. This is caused by a comparatively high power loss in the feeder due to PV injection in this site.

The total score for all the potential PV locations are summarized in Table 10. The result shows that site option 1, with a bus code of "TK0041", located in sub-village of "Banjar Metra" posses the highest score of 89. The lowest total score is for site option 5 with a total score of 46. The existing location of PV system has a total score of 47.

Table 10: Score for site option 5

Potential location	Total score
Site option 1	89.0
Site option 2	84.0
Site option 3	68.0
Site option 4	66.5
Site option 5	46.0
Existing	47.0

Fig. 5: Site condition and the MV network for site option 1

Fig. 6: Site condition and MV network for site option 2

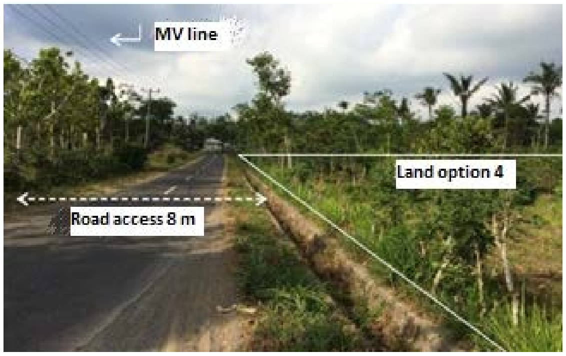

Fig. 7: Site condition and MV network for site option 4

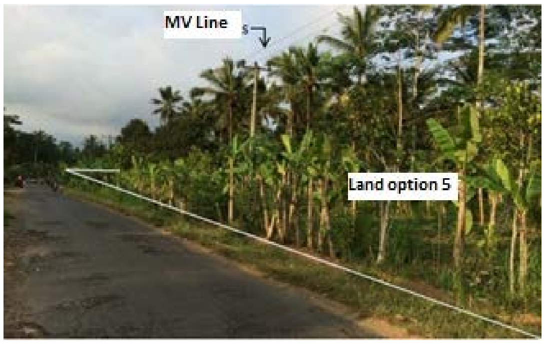

Fig. 8: Site condition and the MV network for site option 5

CONCLUSION

A simple approach in selecting the best options for PV location based on the power loss, land utilization and availability, bus minimum voltage and the accessibility to 20 kV network has been demonstrated in the paper. The location of PV system has a significant effect to the system voltage and power loss profile. The land utilization at the proposed PV site must also be considered in determining the best location for PV system.

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