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Techno-economic Evaluation of Utilizing a Small-Scale Microgrid

Yuli Astriani^{a,b}, GM Shafiullah^{a*}, Martin Anda^a, Hamzah Hilal^b

^a*School of Engineering and Information Technology, Murdoch University, Perth, Australia*

^b*National Laboratory for Energy Conversion Technology, BPTT, Jakarta, Indonesia*

Abstract

Microgrid deployment has offered technical and economical benefits such as improving grid reliability, maximizing penetration of intermittent renewable energy sources, reducing the cost of energy production, etc. However, to realize those advantages, the costs of microgrid implementation may be bloated as microgrid need additional investment for the enabling technologies. Therefore, an appropriate approach to determine the economic viability of microgrid to quantify the values of microgrid benefits is needed. This study performs a techno-economic analysis of a small-scale grid-connected microgrid deployment which consists of photovoltaic (PV) and energy storage system. The analysis is done by considering the possible bussines models available in Indonesia where the microgrid test case is located, i.e, net metering for electricity bill, feed-in tariff for utilizing renewable energy, demand response (DR) implementation by exploiting battery roles in response of price variation during peak and off-peak period and assuming compensation is given every time microgrid is in islanded mode due to fault event occur in the main grid. The feasibility of each model is indicated by the microgrid's net present value (NPV) and internal rate of return (IRR). The results show that further incentives from the utility or Government is required to make the small-scale microgrid deployment economically sustainable.

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* Corresponding author. Tel.: +61-8-9360-6417; fax: +61-8-9360-6346.

E-mail address: g.shafiullah@murdoch.edu.au

1. Introduction

Alongside with the emerging development of modern control, information, and communication technology, microgrid, a small and localized power system is introduced to solve some of conventional grid's problems. Being localized, microgrid is expected to be able to manage its distributed energy resources (DERs) and connected loads. The microgrid will be operated in islanded mode in cases of fault in the main grid so that its load will still be supplied. Moreover, if it is needed, a demand management may be implemented to ensure the system stability or minimize the cost of energy in microgrid. It is also expected that deployment of microgrid could contribute to the maximization of the penetration of intermittent renewable energy sources. However, to enable the islanding operation or DR in microgrid require additional investment for the enabling technologies [1-4]. Therefore, a techno-economic analysis on microgrid is essential to determine whether the deployment of a microgrid is economically feasible to be implemented.

Ref. [5] mentioned that the costs of microgrid development are consist of 50% for the generation, 15% for the controller, and 35% for the other remaining costs. Meanwhile, the benefits of microgrid deployment has been addressed in [6], which are; reducing the overall load baseline; avoiding peak energy costs and adding revenue by exporting microgrid's energy to the main grid; participating in the DR program to reduce energy cost and improving supply reliability trough islanding capability. Many studies have been done to calculate costs and benefits ratio of microgrid deployment. In the Electric Research Power Institute (EPRI) technical report, it is stated that different approach is needed for analyzing cost-benefit of the smart grid as microgrid offer new benefits beyond basic services [7]. Two different approaches for modeling microgrid business case based on the perspectives of microgrid owner's interest either technical value or energy cost reduction benefits have been presented in [8]. The study in ref. [9] has performed an assessment for technical and economic potential of microgrids in California which resulted that the deployment of microgrid is economically viable for customers with peak loads higher than 1MW, while for the customers with peak loads below 1MW it may be feasible if there is any external funding available. A techno-economic model based on the different combinations of microgrid's services has been proposed in [10] considering reliability service and price signals. Meanwhile in [11], a Monte Carlo methodology is used to perform techno-economic analysis for solar PV prosumer of Swedish residential sector and resulted that PV investor will likely have 71% chance to get 3% real return on investment, but the chance drops to 8% without subsidies. It also has been proved in [12] that market regulation affecting the benefits value in expanding microgrid deployment.

Based on above-mentioned studies, it can be deduced that predicting the economic feasibility of microgrid deployment is affected by the approach for the business model and the size of microgrid capacity. However, most of the current studies considered medium to large-scale microgrid (a capacity of higher than 1MW) and deployed in the developed countries where incentive is given for the deployment of renewable energy sources. On the other hand, this study evaluates the performance of a small scale microgrid considering technical, economical and environmental benefits based on a real test microgrid. This study will calculate IRR and NPV for a small scale microgrid considering few scenarios, i.e., with and without implementing DR based on the price variation; including the quantification value of reliability improvement; considering incentive is given for producing electricity from renewable energy including and assuming carbon tax is implemented.

2. Methodology

The microgrid test case in this study is a 10kW PV integrated microgrid located at the office of Agency for The Assessment and Research of Technology (BPPT)'s office in Serpong, Indonesia. The microgrid is connected to 380VAC three phase system and consists of 10kWp PV array with a grid-tied inverter, SCADA and PLC system as microgrid controller, weather station, and 10kWh battery lithium connected to 3 bidirectional battery inverters to form three phase AC system as shown in Fig.1. The battery inverter can be operated in on-grid and off-grid system and providing voltage reference for the grid-tied PV inverter during islanded mode. Meanwhile, the loads consist of lighting system, wall socket for supplying electrical equipment as well as microgrid controller instrumentation.

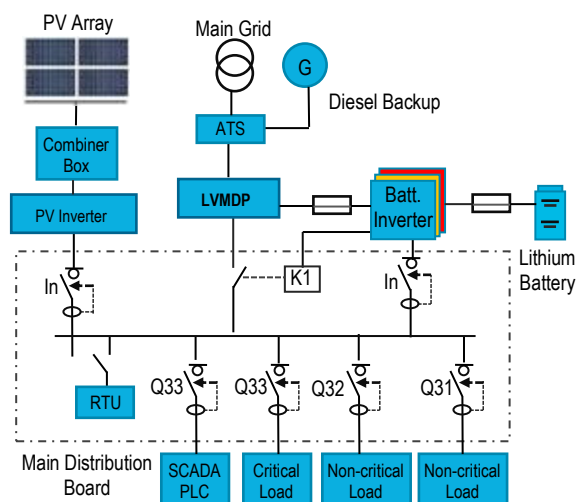


Fig. 1. Single line diagram 10kW PV Microgrid.

2.1. Estimation of PV Power

The PV system output power is computed based on [13] and using a yearly solar irradiations data of the studied location. The total energy is cumulated for 25 years based on the PV module lifetime and considering its degradation level, i.e. 2.5% in the first year and 0.5% for the following years [14].

2.2. Estimation of microgrid total cost and revenues

The deployment costs consist of the initial, operation and maintenance, and replacement costs. The initial cost is counted based on the total price of the purchased equipment, installation, and the software development cost. As the value of money differs with time, the calculation of the predicted operation and maintenance costs and the electricity price took the consideration of the inflation rate, i.e., 3.53% [15]. The replacement cost is calculated by assuming that the equipment price decreases around 15% per year, averaging from the report in [16]. Meanwhile, the salvage value is ignored because most of the equipment are used until the end of their lifespan.

On the other hand, the microgrid revenues are defined as follows:

- Two approaches are used to calculate the income from the PV system, i.e., net metering and feed-in tariff. In the net metering method, the generated electricity from the PV system will be rated same as the customer's electricity price, i.e., \$0.08 per kWh [17] for the BPPT building. Meanwhile, feed-in tariff method is used to simulate the effect if incentive is given. To generalize solar energy tariff, this study uses regulation [18] which stated that feed-in tariff for the solar power plant located in Java Island is 14.5 cents/kWh.
- The revenue from battery system is calculated by assuming that DR program is implemented based on the price variation. Battery system is assumed to be charged during off-peak period and discharged during peak period. PT. PLN as the national electricity grid operator in Indonesia applies higher tariff during peak period with multiplication factor $K = 1.5$ [17]. The peak period is from 5 to 10 PM.
- The reliability improvement revenue is calculated assuming that compensation is provided to the customer who faced supply interruption. Based on [19] it is stated that PLN is obliged to provide 35% reduction from consumer's minimum electricity bill if the realization of power service quality level exceeds 10% above the level of standardized electricity service quality. However, as the microgrid capacity is much smaller compared to the BPPT building total loads so that the microgrid can't be considered to represent BPPT class customer, therefore, the compensation refers to [20], i.e., value of service \$2.5/kWh non-delivered energy (NDE). This reliability revenue then calculated based on the average interruption occurrence [21], i.e., 5 times interruption with total duration is 5 hours per month.
- The last revenue is derived by assuming that carbon tax is yet implemented. It is suggested that for the initial

implementation of carbon tax in Indonesia is \$10/ton CO₂ [22]. Based on [23], the emission factor for electricity generation in the studied location is 0.877 ton CO₂/MWh.

2.3. Calculate cost-benefit ratio

Based on the predicted cash flow for 25 years, the microgrid's NPV and IRR is calculated with considering the discounted rate, i.e., 7.5% [24]. The calculation of NPV and IRR will be simulated following the variation of the calculated costs and benefits in Section 2.2.

3. Results and Discussion

3.1. Energy from the PV system

The output energy from the PV system is calculated based on the solar irradiation data extracted from the pyranometer at BPPT in 2016. The predicted output power from the PV system of the microgrid is shown in Fig. 2 and the predicted generated energy from the PV system is 16232 kWh/yr. The total predicted output energy of the PV system for 25 years lifespan is presented in Fig. 3 assuming the same solar irradiation.

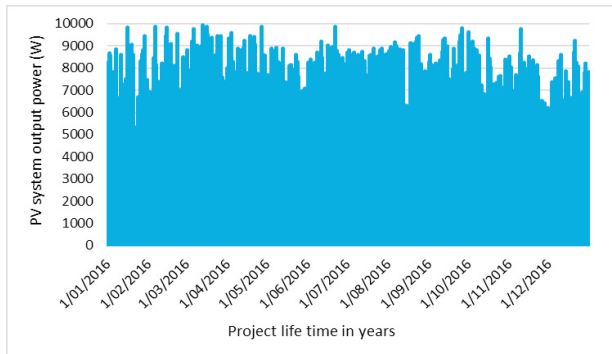


Fig. 2. The predicted output energy of the 10kWp PV array.

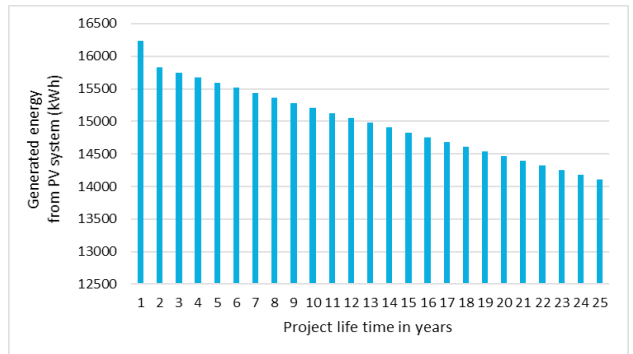


Fig. 3. The predicted energy from the PV system.

3.2. Microgrid costs and revenues

Table 1 shows the microgrid deployment costs, noting that the installation cost of the studied microgrid is \$46,803. The cost for battery system took almost 40% of the total deployment cost. It is mentioned in [25] that a bigger battery capacity may reduce customer dissatisfaction rate that also incurs a higher upfront cost which is not economically feasible. In this microgrid, battery system is needed to enable the islanding mode or could contribute to improving microgrid's income by exploiting price deviation between peak and off-peak period.

Table 1. Microgrid deployment costs.

Item	Price	Lifetime	Item	Price	Lifetime
PV Module	\$8,160	25 years	MDB panel, combiner box, support module, etc.	\$1,848	20 years
PV Inverter	\$2,789	12.5 years	SCADA system	\$2,414	-
Battery LiFePO ₄	\$11,734	20 years	PLC system	\$814	12 years
3 Battery Inverter	\$7,059	12.5 years	Additional uninterruptible power system	\$450	5 years
PC Server & Monitor	\$2,444	5 years	Installation cost & software development	\$7,235	
Weather Station	\$1,856	5 years	Total Cost	\$46,803	

Fig. 3 shows the cash flow of the microgrid running costs and revenues over 25 years. It can be seen from Fig. 3 that the revenue from carbon tax implementation is the smallest among other microgrid revenues. The revenue from battery system by implementing DR is also very small. This happens because of peak price period is only applicable in once allocated time per day, thus battery utilization as a response of price deviation between peak and off-peak period can also be done once a day and resulted in the small battery’s revenue. On the other hand, the biggest revenue is obtained with the feed-in tariff model.

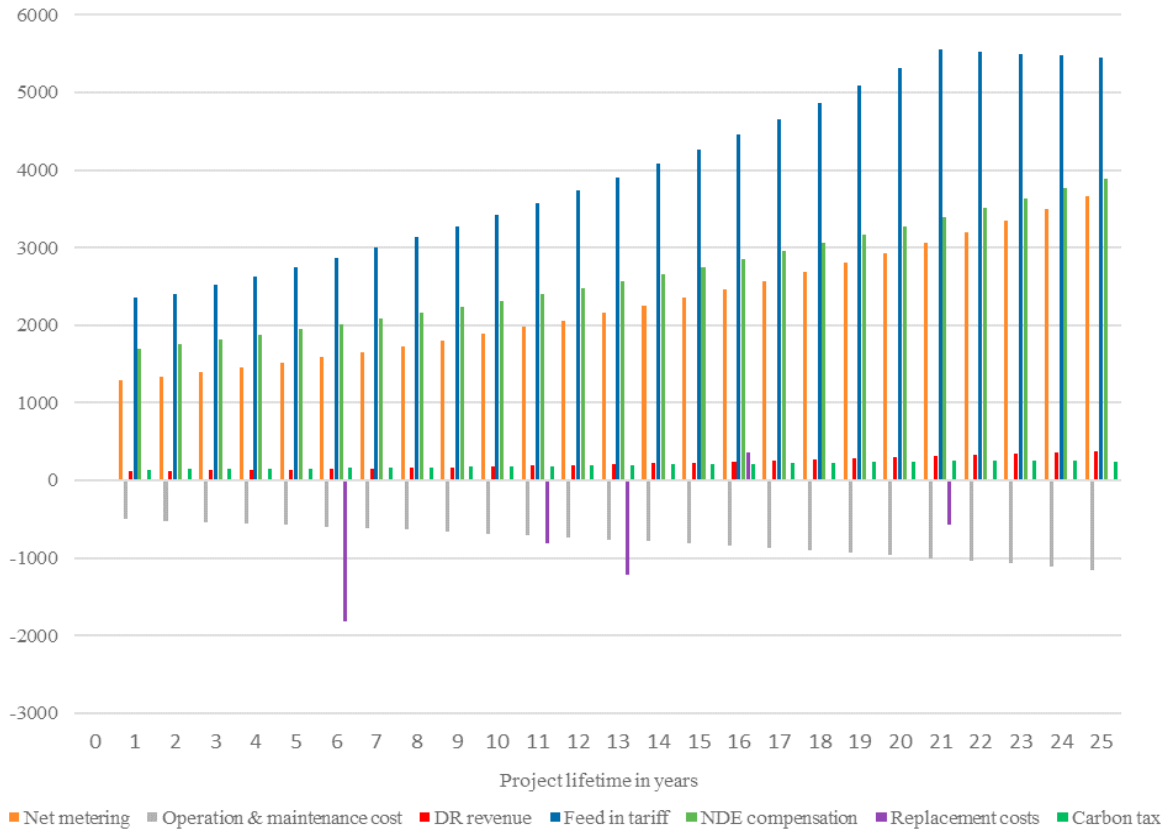


Fig. 3. Cash flow diagram for microgrid running costs and revenues.

3.3. Microgrid feasibility

This study calculates the NPV and IRR of the microgrid to estimate its techno-economic feasibility. Comparison between the different business cases is presented in Table 2. It can be seen from Table 2 that if the revenue from the PV system uses net metering model, it results in a negative value for the NPV, this means that the project is not feasible. Moreover, most of the business model with the net metering model is facing losses as indicated by the negative IRR. On the other hand, the positive IRR has observed with the feed-in tariff model which indicate that the studied microgrid will gain profit. Meanwhile, a positive NPV that signify the microgrid is economically feasible is obtained when both the feed-in tariff and reliability options were considered. The contribution of battery in DR program is insignificant as well as revenue from the carbon tax. The DR revenue only increased IRR 0.5% in average.

Table 2. Comparison of NPV and IRR based on the microgrid business cases.

Indicator	Net Metering	Net metering + DR	Net metering + carbon tax	Net metering + NDE	Net metering + DR + carbon tax	Net metering + DR + NDE	Net metering + NDE + carbon tax	Net metering + DR + NDE + carbon tax
NPV	-\$34,979.5	-\$32,897.2	-\$32,953.1	-\$8,954.2	-\$30,870.7	-\$6,871.8	-\$6,927.8	-\$4,845.4
IRR	-2.1%	-1.2%	-1.3%	5.6%	-0.4%	6.1%	6.0%	6.5%

Indicator	Feed in tariff	Feed in tariff + DR	Feed in tariff + carbon tax	Feed in tariff + NDE	Feed in tariff + DR + carbon tax	Feed in tariff + DR + NDE	Feed in tariff + NDE + carbon tax	Feed in tariff + DR + NDE + carbon tax
NPV	-\$17,996.5	-\$15,914.1	-\$15,970.1	\$8,028.9	-\$13,887.7	\$11,236.8	\$10,055.3	\$12,137.7
IRR	3.4%	4.0%	3.9%	9.1%	4.5%	9.6%	9.4%	9.8%

4. Conclusions and future work

The results of techno-economic analysis from this study shows that the deployment of a small scale microgrid equipped with modern control technologies for enabling microgrid services is not economically viable if only the net metering business model is considered. On the other hand, providing incentive for utilizing renewable sources such as in the feed-in tariff has significantly increased microgrid's NPV and IRR. Meanwhile, the absence of price variation reduces the opportunity of DR implementation so that installing large battery storage for the purpose to participate in DR program may causing losses to the microgrid. Therefore, in evaluating microgrid feasibility, adding other microgrid revenues such as by quantifying reliability improvement as the result of installing energy storage and microgrid controller or including carbon tax revenue will increase microgrid viability. In the future work, sensitivity analysis needs to be simulated by varying the technologies, DERs size, and exploring other benefits of the microgrid such as providing frequency or voltage restoration to the main grid by forcing the battery system to charge or discharge following the system variation.

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