Application of behind the meter battery storage system integrated with net metering in Indonesia

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Abstract. Indonesia’s energy supply system is experiencing a transition towards more sustainable energy generation with an increased amount of Rooftop Solar photovoltaic (PV). However, the daily variability of the solar resource, in addition to intermittent arising from moving cloud cover becomes shading. To enable Net zero energy home and optimize power management for future homes, Behind The Meter (BTM) battery storage as one solution to solve intermittent energy production, so as an improvement the energy saves. The objective of this paper is to analyze the financial metric of rooftop solar PV and Behind The Meter (BTM) battery storage in the rural sector so that the decision to integrate the rooftop solar PV and BTM battery storage can be solution for Net-zero energy home. Solar PV and BTM battery storage framework was designed to supply continuous and uninterrupted power to a typical house in Indonesia. Step by step method for financial simulation and implementation of the rooftop solar PV and BTM battery storage framework was done. System Advisor Model (SAM) is used for economic investigation. The economics of solar PV and BTM battery storage get LCOE real was $ 10.26 cents/kWh and total reduction CO₂ around 7116 kg.

1. Introduction
The application of solar photovoltaic (PV) in the form of rooftop solar is growing and getting popular in Indonesia. However, as the cost of solar cells getting cheaper over time, with the support of the right policies and/or incentives, rooftop solar PV installation will be increasing shortly soon. Responding to the increasing demand, the Ministry of Energy and Mineral Resources (MEMR) issued, MEMR Regulation No. 49/2018 jo. MEMR Regulation No. 13/2019 jo. MEMR Regulation No 16/2019 on rooftop solar PV. Current ministerial regulation only allows 1:0.65 ratio (each kilowatt-hour exported to the grid is credited with the equivalent of 0.65 units of PLN electricity) [1]. Energy conservation in the building sector has interested in and concern about the world community concerning environmental conservation. Indonesia's tropical climate provides the potential for the development of Net Zero Energy Home integrated with the solar PV module [2].

Solar PV module generated the power and supplied to the grid utility depending on solar irradiance and weather patterns in an inconstant generation. To overcome this barrier and optimize electricity usage of the solar PV modules, an energy storage system (ESS), such as a battery can install at home.

A Behind The Meter (BTM) battery storage system absorbs surplus power from solar PV and then discharged it later when solar sources are not available, e.g., at nighttime for energy saving in a home [3].

In rooftop PV application, no dynamic charge for battery energy storage, was an economic benefit for BTM battery storage to be setting up for cut solar PV power and store it for later use?
To evaluate, this problem will use the System Advisor Model (SAM) has developed by NREL (National Laboratory of the U.S Department). A Case study of a model of a BTM battery energy storage system connected with a rooftop solar PV array will be analyzing [4].

2. Net Zero Energy Home
The basic concept of a Net Zero Energy Home is one that can meet its energy needs from cheap sources, is clean, easy to produce, and renewable. A more precise definition states that a Net Zero Energy Home produces in-place renewable that is sufficient to meet or even exceed annual energy consumption. By applying solar PV modules, electric consumption can also be reduced significantly. The electric power generated by the solar PV modules can also be exported to the power grid, thus cutting electricity bills through BTM battery storage integrated with the net-metering incentive scheme.

Implementation Net Zero Energy Home used BTM battery storage connected with a solar PV array, and the solar PV will feed power to a battery through DC/DC power converters and the inverter will send power to the electric load or charging from the grid. The model is shown in Figure 1[5].

2.1. Solar Photovoltaic
Solar Photovoltaic modules are the key element in Net-zero energy Home systems. Current photovoltaic technology-dominated with crystalline silicon (c-Si) and thin-film solar cell (TFSC). More than 90% in the market silicon-based installed at home, commercial, and utility. These types of cells have the advantage of using a photoactive absorber material that is stable. They also produce more power in low sunlight [6]. The characteristic of solar PV is shown in Figure 2. The curve has a unique point called Maximum Power Point (MPP). MPP point will give the highest power outputs.

![Figure 1. Schematic BTM Battery Storage](image1.png)

![Figure 2. PV Characteristic](image2.png)

2.2. Inverter
The Function of Inverters was converted the solar PV direct current (DC) output into alternating current (AC) which is the standard use of commercial appliances. Therefore, an inverter is the “gateway” between the solar PV system and the utility load. Standalone and grid-connected types inverters are generally used in the solar PV arrays system are the main power source for grid-connected inverters and power rating depends on array size. String inverters are connected into the multiple solar PV strings where panels are connected in series.

The solar PV production and system profitability depend on this conversion ratio. Therefore, maximum power point tracking (MPPT) is a critical function of an inverter which states the inverter operation on the maximum power point of the system. PV modules have a voltage-current (I-V) characteristic curve that includes a short-circuit current value at 0 Volt (DC) and an open-circuit voltage value at 0 A and the “knee” point known as MPP which is the maximum power producing point from the highest product of voltage and current [7].
Inverter performance is vital for the PV system as the usable AC power is produced from this conversion. Standard specifications for all inverters can be identified from four main parameters: AC power output ratings, conversion efficiency, DC input voltage, and AC output voltage. Inverter manufacturers published data provides conversion efficiency in the range of 92% - 95%, these efficiencies assume optimum operating conditions for a system in which the array is properly sized for the inverter.

2.3. Solar PV System Losses
Solar PV system losses will give actual energy production with realistic value; make an accurate technical and economic assessment. Types of PV system losses shown in Table 1

| PV System losses |
|------------------|
| Energy loss flow | Solar irradiation loss |
| Shading & soiling | Nominal DC energy loss |
| Module loss | Various inverter loss |
| DC wiring tracking | AC energy loss |
| Transformer curtailment | Final energy output (kWh-ae) |

2.4. BTM Battery Storage
The main functionality of a battery in a BTM battery storage system integrated with net metering is to store excess energy to use during the hours when no energy is produced by solar PV. BTM battery storage technology allows more renewable integration into the grid. Solar PV production is highly dependent on the weathering profile, like many other renewable sources and these uncertain power fluctuations create stress on the grid. BTM Battery storage can act as an energy buffer in-between generation and load. And also can provide voltage and frequency support to help power quality improvement [9].

2.5. Net Metering
Net metering allows residential customers who generate their electricity from solar PV systems to feed electricity they do not use back into the grid. Net metering was a billing mechanism that credits PV system owners for the electricity they add to the grid.
In Indonesia, Net Metering has been mandated by MEMR in Regulation No 49/2018, which obliges PLN to ‘credit’ energy produced by solar to a customer’s account. To use Net Metering, the customer simply applies for the installation of a 2-way meter. Each kilowatt-hour exported to the grid is credited with the equivalent of 0.65 units of PLN electricity [1].

3. Financial Model Simulation
The Solar PV system model is made to evaluate the economic viability of grid-connected Solar PV-BTM battery storage system and Net metering services for residential customers. The solar PV-battery storage system is analyzed with the idea of a behind-the-meter solution. It introduces a local energy management system at the residential consumer by integrating innovative technologies. In the current system architecture, end consumers at each residential level are connected with an individual meter.

3.1. Input Parameter
3.1.1. Solar Resource. Solar resource data is enormously important for the solar PV system to make an accurate estimation of the solar PV electricity generation and proper site selection. SAM uses TMY (Typical Meteorological Year) weather data at Jakarta from its solar resource library which is
originated from Climate.OneBuilding.org, data source. Figure 3 represents the variation of annual Global Horizontal Irradiance (GHI) for Jakarta [10].

3.1.2. Solar PV System Design. The Canadian Solar Inc. CS3-410MS modules were selected for the simulation, the characteristic data take from the Sandia PV array performance database. This characteristic provides the I-V curve parameter shown in Figure 4. The module type was single-crystal silicon cells with a size of only 1.92 m². The power rating of the panel is 410 W (dc) and nominal efficiency is 21.37%. Multiple modules are connected by wires to form an array. Available area constrains the installation of a larger PV system on the rooftop. In this study, the PV-battery system is initially modeled with a small array size and varied with a range with all other input parameters. A 5.74 kWdc (peak) PV system consisting of 2 strings and 14 modules and occupying 26.9 m² is found practical for a rooftop PV system after the simulation and parametric analysis.

In the system design, a PV module and inverter model Ningbo Ginlong, Solis 3.6K-2G-US ; 3.59 kWac with characteristic is shown in Figure 5, for the test system, and array size is selected. Therefore, the final system profile is observed in SAM. In this study, the system is designed as a single array system means that PV modules are in the same area with a fixed orientation.

The battery input parameters are shown in Figure 6. The capacity of the battery around 15 kWhdc

3.1.3. System Cost. Solar PV energy project economic feasibility depends on the realistic cost analysis. In this report, the PV system cost in Indonesia is analyzed. The system cost input data is taken from the study on PV market cost analysis from Indonesia solar photovoltaic, inverter, and battery storage supplier’s data sheet and prices. The capital installed cost is further divided into direct and indirect
capital costs. Solar PV module price, inverter, battery, and balance of system (BOS) cost are included indirect investment. Figure 7 shows the detailed cost breakdown of the designed system.

![Figure 7. System Cost](image)

**3.1.4. Financial assumption.** The financial parameters are important to define the system Net Present Value (NPV) for the analysis period which is the primary indicator for an investment decision. In this case, the debt ratio is selected as 100% which means that the net capital cost of the project money is borrowed and equity is zero. Finance takes from debt with an interest rate. The Financial analysis period is twenty-five years. The inflation rate refers to the annual rate of change of cost which depends on the consumer price index. In Indonesia, the inflation rate expects to keep it at 3.3%. SAM uses the inflation rate to calculate system cost and project cash flow for the total analysis period.

**3.2. Simulation Result**
The present simulation has demonstrated the photovoltaic electricity output based on SAM’s real-life simulation performance. It has also been shown that SAM is an excellent tool for estimating economic and electricity prediction from solar PV rooftop and BTM Battery Storage. Figures 8, 9 represent results from SAM simulation.

![Figure 8. Financial Metric](image)

![Figure 9. Annual Energy Production](image)

From Figures 8 and 9, Annual energy production around 7619 kWh with a capacity factor was 15.1%. During periods life cycle along 25 years, solar PV generation will degradation to 6800 kWh around 11%.

**4. Conclusion**
Application of Rooftop Solar PV and BTM Battery storage give the NPV positive with a payback period 11.3 years, It’s feasible to implement in Net Zero Energy Home with Levelized Cost of Energy (LCOE) real consumer prices was $ 10.26 cents/kWh. The designed system calculates the electricity bill savings from the difference of system cost without any PV and with PV-battery with Net saving year1 around $ 921. From total annual energy generation by the system around 7,619 kWh was equal
CO₂ reduction with 1 KWh of energy generated by any solar photovoltaic power plant = 0.934 kg, the total reduction was 7116 kg CO₂.

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