Study of Alternatives Dynamic Feed-In Tariff for Photovoltaic Power Plant in Indonesia

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Abstract: ***The evolution of the electrical energy demand and supply system's variation requires that electricity tariff not be determined by a conventional, traditional transaction method. The complexity of the numbers and types of power plants contributing to the grid system and the variation of consumer's load behavior creates the electricity market system. It requires the dynamic tariff method to keep demand and supply nearly at a stable condition. Some consumers become producers by installing the photovoltaic panel and producing electricity that contributes, as a supplier, to the grid system.The Dynamic Feed-In Tariff method can accommodate this consumer type. At present, the authority electricity regulator or government in most countries commonly establish the electricity tariff for renewable energy toencourage renewable energy development and contribution. They regulate the Feed-In Tariff of photovoltaic (PV) connected to the grid electricity system and apply intensive or remuneration to support PV use. Based on the literature study, there is a possibility to seek a new design method of PV electricity tariff by determined a few method schemes and analytical mathematics models considering the condition of the power plants, including PV, entering the grid system, such as characteristics of each power plant and the energy contribution to the system. The load curve and other assumptions apply at the beginning to calculate the amount of energy supply. The PV tariffs could be dynamically change based on the realization load curve supply comparing to the unit commitment load curve. This studyexplores the PV tariffs (termed Dynamic Feed-In Tariff) for PV connected to the grid system with several simulation conditions with power plants connected to the grid system as a baseload, frequency follower, and backup. This study will develop the Dynamic FIT tariffs formula for the PV power plants connected to the grid system with an individual unit commitment load curve. Some simulations conduct using conditions and available data in North Sulawesi Grid System in Indonesia. The result will compare the current tariffs that are already applied and the regulated prices (Indonesia Government Regulation). The result of this study could be an appropriate alternative design dynamic feed-in tariff of the PV power plant of the government or electricity regulator to determine the PV power plant tariffs that connect and supply energy to the grid system.***

Keywords: photovoltaic power plant, PV, PV tariffs, unit commitment load curve, Dynamic Feed-In Tariff, FIT, load curve, grid operator, balance cost, back-up cost, electricity production cost, peaker, follower, base load, PLN, Indonesia.

1. Introduction

The photovoltaic power plant (PV) has been applied since 1980 and is increasingly in line with the need for green energy. At this time, the implementation of electricity tariffs for PV is a policy mechanism to encourage green energy generation investments. Some countries have implemented Feed-In Tariffs (FIT) as part of the green energy policies (Mayer et al., 2015). FIT has rules, calculations, and design tariffs that are different from the standard electricity tariffs. FIT is a long-term contract that can guarantee a return on investment from renewable energy power plant producers. The investment costs for renewable energy plants are still relatively expensive compared to thermal or hydro-power plants.

Most European countries have adopted FIT policies since the year 2010 and followed by more than 50 countries in the world[1] (Haas et al., 2011). Based on (Haas et al., 2011), countries in Europe have applied the FIT mechanism for PV plants that enter the grid system. In the FIT model, the investment cost component is still the largest in determining the electricity tariff for PV (Mayer et al., 2015). PV has relatively higher investment costs compared to fossil fuel power plants. Therefore, the mechanism of implementing FIT in most countries in Europe still includes elements of long-term subsidies (Zhang et al., 2014). The application of long-term contributions in Europe aims to achieve renewable energy use (including PV) of 20% of the total energy mix by 2020 (Haas et al., 2011).Some European countries faced this sustainability policy's challenges, including a subsidy factor in their FIT components with various tariff designs. Incentives, subsidies, and remuneration in the FIT component are generally aimed at social and environmental cost adjustments (externalities) compared to power plants with fossil energy. Some examples of externalities factors arising from the use of fossil plants include the greenhouse effect, environmental pollution factors, and social cost factors that result from the use of fossil energy (Hoppmann, Huenteler, and Girod 2014). For example, Germany and the United Kingdom have implemented FIT. Still, Germany provides a better energy policy than the United Kingdom by providing a guaranteed investment guarantee for renewable energy investors to achieve long-term sustainability for green energy (Mitchell, Bauknecht, and Connor 2006). Germany's FIT policy continues to experience various challenges, especially the German government's sustainability policy in carrying out subsidies and incentives for PV investors and providing remuneration for electric power system operators.

[1]Countries that have implemented FIT policies include Algeria, Australia, Austria, Belgium, Brazil, Canada, China, Cyprus, Chech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Iran, Republic of Ireland, Israel, Italy, Kenya, Republic of Korea, Lithuania, Luxembourg, Netherlands , Pakistan, Portugal, South Africa, Spain, Switzerland, Tanzania, Thailand, Turkey and United Kingdom.

Several country's applied dynamic FIT models, such as Australia, which uses a dynamic FIT model in New South Wales based on the calculation of Return of Investment (ROI) of the investment costs of PV and electricity production from PV. FIT adjustments are made the following year after considering electricity production and investment costs. It means the dynamic FIT scheme is adjusted every year (Oliva and MacGill 2013). (Hayat, Shahnia, and Shafiullah 2018) conducted a dynamic FIT analysis with shorter (daily) periods with the Fuzzy method. This regular dynamic FIT also considers location factors (related to sunlight intensity), energy consumption, load curves, and the amount of PV that enters the grid system. In line with the dynamic FIT model in Australia, China also implements annual period dynamic FIT by considering periodic changes in investment cost components and applying regionalization based on sunlight intensity (Yang and Ge 2018).

In Indonesia, The Government of Indonesia has launched regulations related to FIT through Minister of Energy and Mineral Resources Regulation Number 50 the Year 2017 concerning Utilization of Renewable Energy Sources for Electric Power Supply, including Solar Power Plants (Photovoltaic – PV). In this regulation, there is no element of subsidy or incentive for PV entering the grid system. Also, there is no remuneration for grid operators (termed PLN in Indonesia) when utilizing PV. The regulation only provides a maximum FIT price limit determined by the grid operator (PLN) influenced by the magnitude of production cost for a particular power system (termed BPP in Indonesia). Furthermore, the PV electricity transaction mechanism is carried out based on an agreement between the two parties, namely PLN and the PV power plant (ESDM, 2017).The regulation aims to reduce the cost of electricity production (termed BPP in Indonesia) of generation in the local electricity system when PV connects to the grid system. Suppose the Generating BPP in the regional electricity system is above the national average BPP Generating. The purchase price of electricity from the PV power plant is the highest at 85% of the Generating BPP in the local electricity system. If the Generating BPP in the regional electricity system is the same as or below the national Generating BPP, the purchase price of electricity from the PV plant is the same as the Generating BPP in the local electricity system. Thereforethe current implementation of PV power plants in Indonesia is still challenging to implement because providing electricity (marginal cost) from PV power plants is always above the National and Regional Basic Production Costs (termed BPP). PV power plants cannot compete with fossil energy power plants in terms of their economic level. Although the Indonesian government has accommodated the determination of tariffs for PV power plants, the government has not intervened in establishing this FIT in subsidies or other incentive elements.

FIT modeling in the generation of PV for grid systems requires a load curve plan. The grid system operator can prepare a backup load if the PV has a change/loss of capacity due to its nature depending on weather conditions. The grid system's load curve plan to anticipate the PV generator's intermittent kind needs to be evaluated first by the grid system operator.

Based on the literature review, the author could not find a comprehensive study regarding determining an optimal FIT for PV power plants suitable for Indonesia's electricity system. Therefore, this study is needed to determine the optimal FIT for PV plants that penetrate the interconnection system, both large and small systems. This study's scope includes the tariffs of electricity energy without PV batteries interconnected and supplies energy to the grid system. This study's limitation is that a PV power plant without batteries does not supply electrical energy continuously, but only at a specific time under possible weather conditions following the unit commitment of the PV power plants (intermittence characteristic). The PV power plant's intermittent nature will cause a unique pattern in the supply of electricity for PV over a certain period, including daily and seasonal load patterns.

2. PV Load Curve Planning

This section explains the planning of PV load curves in the application of dynamic FIT. The load curve plan is the main requirement for the PV that will connect to the grid system so that the grid system operator (PLN) can plan the power plant that will enter the grid system.

Some factors such as solar radiation, reflectivity, PV cell temperature stimulation, and inverter efficiency influence PV load curve planning. The selection of input variables and horizon prediction affects the accuracy of the developed power curve plan model. In general, relevant variables available as input from solar prediction models include but are not limited to the following factors (Bizzarri, et al. 2013):

- Historical data from PV measurements.
- Historical data measurement the results of variables that affect the PV output power such as temperature, solar radiation level, humidity, and other meteorological data.
- Other weather forecast data.

The Planning PV load curve uses several models whose application depends on the needs, for example, planning one hour, daily, monthly, or yearly with the model used, among others (Wan, et al., 2015) as shown below:

- Statistical models based on historical climatology data include the persistence approach, Auto Regressive Moving Average (ARMA), Auto-Regressive Integrated Moving Average (ARIMA), Autoregressive Moving Average Model with Exogenous Inputs (ARMAX).
- Artificial Intelligence (AI) models. For example, Artificial Neural Networks (ANN), Radial Basis Function Neural Networks (RBFNN), and Wavelet Recurrent Neural Networks (WRNNs).
- Physical models include Sky Image and Numerical Weather Prediction (NWP).
- Combined models. For example, a combination of Auto Regressive Moving Average (ARMA) and Nonlinear Autoregressive Neural Network (NARNN), combined Auto Regressive Moving Average (ARMA), and Time Delay Neural Network (TDNN).

This load curve plan's result is a unit commitment of the PV as a reference for grid operators (PLN) to prepare power plants to be operated.

The unit commitment for renewable energy, including a PV power plant, has been applied in several countries. In case studies in Afghanistan, although not individually for each renewable energy but in the form of a combination including a pump storage power plant that serves as a counterweight to other renewable energy sources with intermittent characteristics. (Sediqi, et al. 2017).

The application of unit commitments PV power plant that connected and supplied energy into the grid system can be made by planning obligations for one day ahead based on weather forecast predictions. During a day, the PV owner can revise the commitment based on weather forecast predictions every hour. It can also be called a commitment for a one-hour future (Wu, et al. 2015).

3. Proposed Dynamic Feed-in Tariff Methodology

The methodology proposed by the author is related to Dynamic FIT, which aims to analyze the determination of electricity tariffs for PV power plants that supply electricity into an interconnection grid system with a case study of the Indonesian electric power system, specifically in North Sulawesi. In determining the optimal electricity tariffs for PV power plants, it needs to consider the balance load between producers and consumers, especially for the isolated system in some regions in Indonesia. The dynamic FIT calculationrequires detailed forecasts of the PV load curve (unit commitment PV) as a reference. The unit commitment of PV power plants, including energy lost due to intermittence (as part of the PV load pattern planning), will be used as a reference in determining FIT and becomes a challenge in modeling dynamic FIT. The realization of the energy supply to the grid system will calculate based on the PV load curve forecast.

Figure 1 shows the grid system's modeling by considering merit orders and PV power plants' availability. The FIT model proposed in this study finds the availability of generators in the power system based on its loading characteristics as follows:

- A baseload (load follower) power plant is a power plant that must operate continuously as a baseload bearer for the grid system.
- The frequency follower power plant is a power plant that has a function to balance the grid system.
- A backup/peaker power plant is a power plant that must operate at any time if there is a significant loss of load on the grid system so that the grid system cannot blackout.
- PV power plant that has an intermittent characteristic.

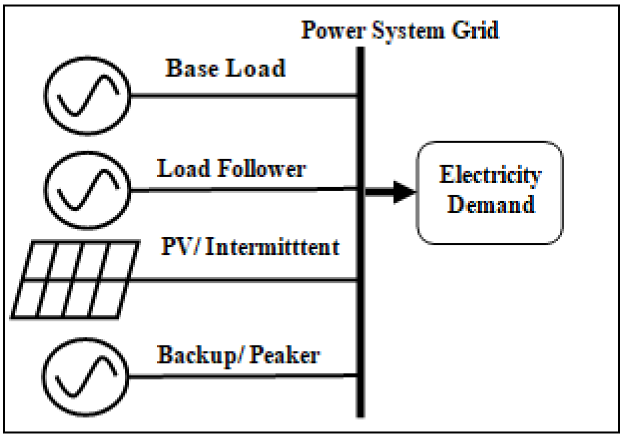
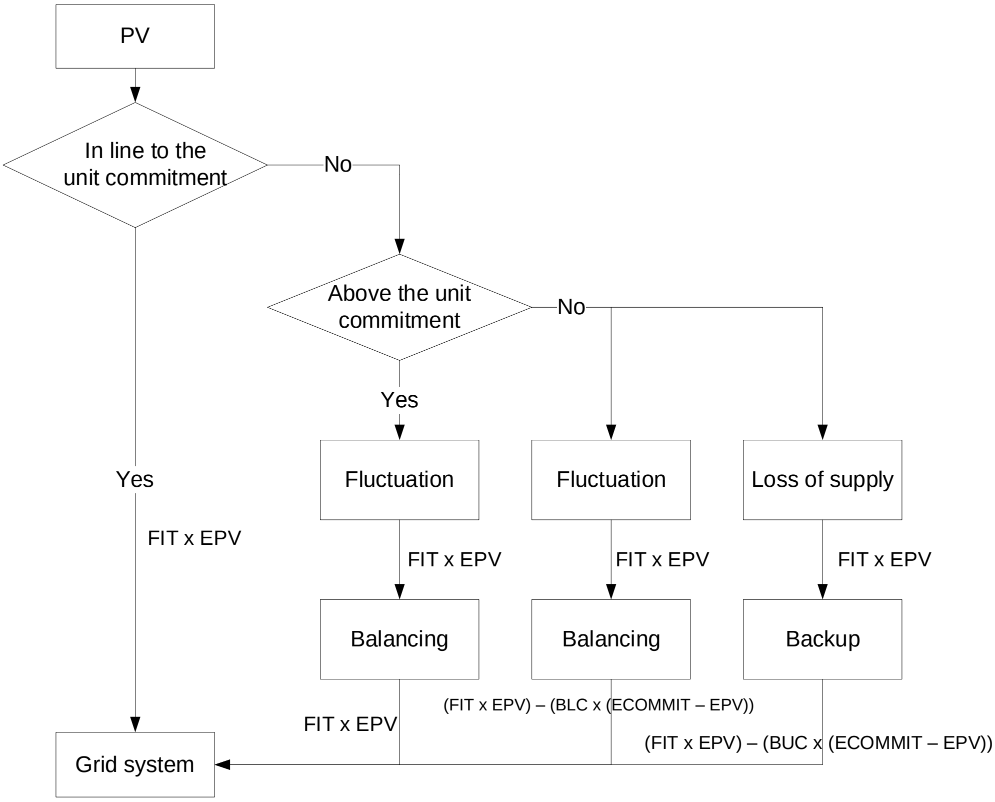


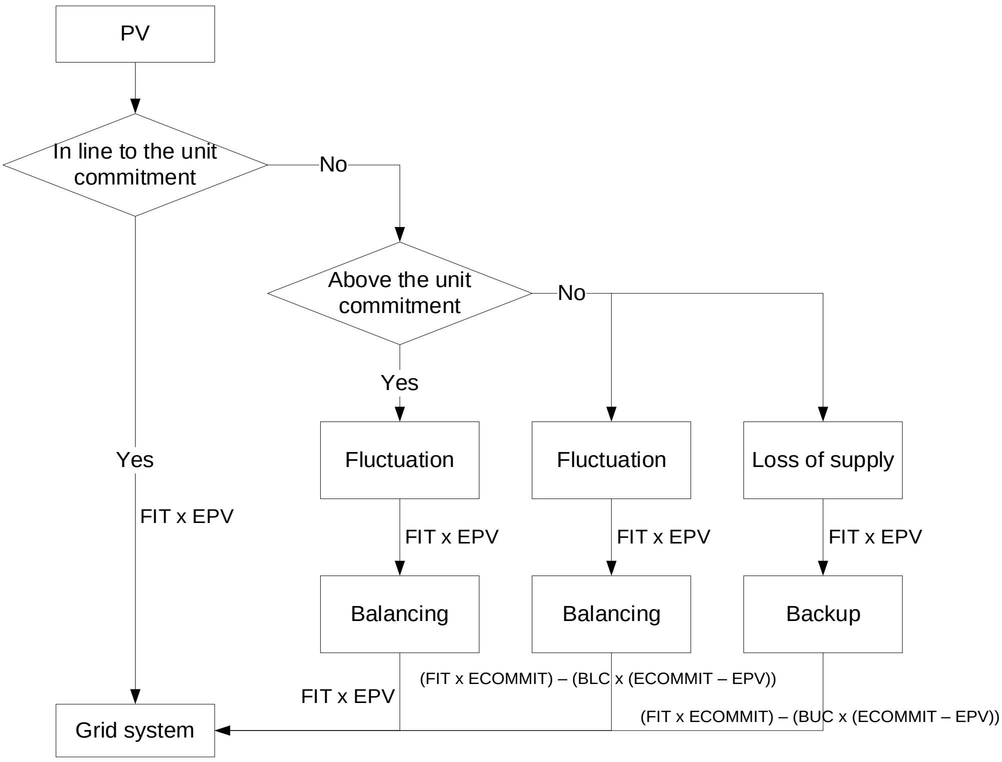
Figure 1: Grid System Model

Each power plant connected to the grid system has its tariff (termed BPP in Indonesia). The grid operator (PLN) regulates the power plant's determination that enters the grid system based on merit orders according to system requirements except for the PV power plant.
The proposed FIT algorithm for PV powerplant connected to the grid system, as shown in Figure 2 below, can be described as follows:

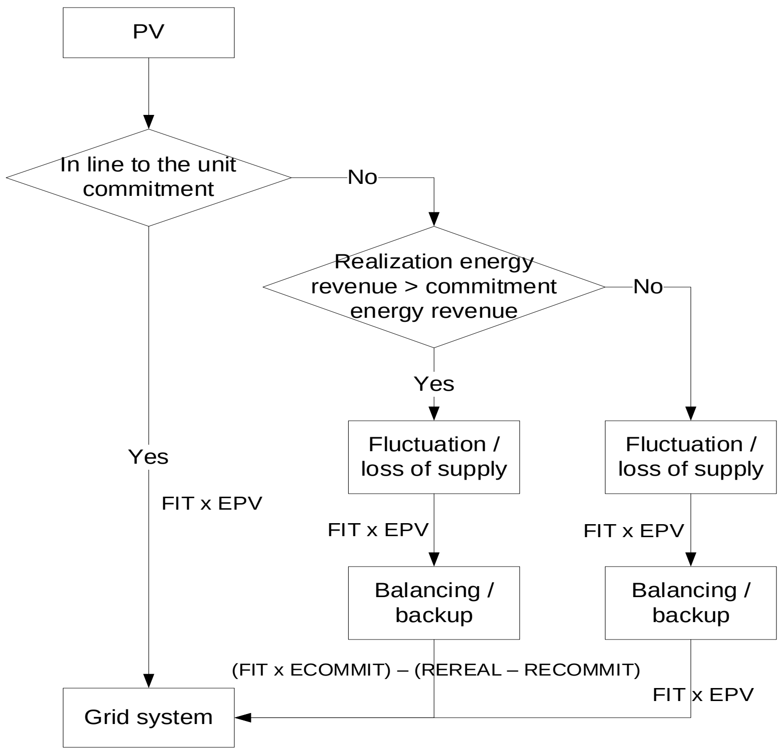
- Assume that each power plant connected to the grid system already has a tariff based on cost production (termed as BPP).
- A PV power plant that will enter the grid system should have the unit's commitment to generate electricity (the load curve) for an established specific time. This unit commitment may different for a different time depend on the weather prediction.
- FIT is a tariff for electricity energy supply by the PV power plants to the grid system. In Indonesia, the government establishes FIT.
- BLC is BPP ofthe frequency follower power plants to maintain the establishment of the grid system. BPP of BLC is calculated based on the production costs of power plants that electricity energy supply into the grid system and serves as a frequency balancer.
- BUC is BPP of backup/peaker power plants that shall start when the grid system loss the load significantly and the frequency follower power plant could not compensate it. BPP of BUC is calculated based on the cost of production of power plants that enter the grid system and serves as a substitute for the lost electrical energy supply.
- A PV tariff is if the PV power plant could supply the electricity according to the load curve's unit commitment (EPV). However, suppose the PV power plant's supply is not following the unit commitment (outside the allowable tolerance level). In that case, the FIT of the PV power plant will be subject to a penalty.


PV
In line to the unit commitment
No
Above the unit commitment
No
Yes
Fluctuation
Fluctuation
Loss of supply
Yes
FIT x EPV
FIT x EPV
FIT x EPV
FIT x EPV
Balancing
Balancing
Backup
(FIT x EPV) – (BLC x (ECOMMIT – EPV))
FIT x EPV
(FIT x EPV) – (BUC x (ECOMMIT – EPV))
Grid system

(a)


PV
In line to the unit commitment
No
Above the unit commitment
No
Yes
Fluctuation
Fluctuation
Loss of supply
Yes
FIT x EPV
FIT x EPV
FIT x EPV
FIT x EPV
Balancing
Balancing
Backup
(FIT x ECOMMIT) – (BLC x (ECOMMIT – EPV))
FIT x EPV
(FIT x ECOMMIT) – (BUC x (ECOMMIT – EPV))
Grid system

(b)



(c)

Figure 2: Proposed Dynamic FIT

Figure 2(a) shows the first proposed FIT algorithm that PV power plants supply electrical energy to the grid system with particular unit commitments, and grid operators (PLN) admit it. These FITsare applied when the load curve PV supply is equal to or above the unit commitment.When the amount of electric energy of the PV power plant is not following the unit commitment delivered (due to load fluctuations), the prescribed tariff is reduction FIT with BPP of BLC (BPPof the frequency follower power plants for balancing the system frequency). When the amount of electrical energy is not following the commitment of units delivered since the supply is lost, the prescribed tariff is reduced FITwith BPP of BUC (BPP of the backup power plants for replacing the loss of electrical energysupply). The application of BPP of BUC and BLC reductions to FIT can apply both for the agreed period of unit commitment between the PV power plant owner and the grid operator (PLN). Here, FIT is less than BPP of BLC and BUC, and they are flat BPP.

Figure 2(b) shows the second proposed FIT algorithm and similar to Figure 2(a). The difference is in Figure 2(a); the PV power plant owner will bear a penalty equal to all the additional energy costs due to PV energy under commitment. In Figure 2(b), the PV power plant owner will bear a penalty on the number ofexpenses that PLN should not pay.

Figure 2(c) shows the third proposed FIT algorithm and similar to Figure 2(b). The difference is in Figure 2(c), BPP of BLC and BUC are dynamic BPP that depends on the cost of components A (investment), B (fixed operation and maintenance), C (fuel), and D (variable operation and maintenance). Therefore, there are possibilities that BPP of BLC and BUC are less or more or equal to FIT.

Figure 3 below shows illustrations of the load curve unit commitment PV power plant for a specified period (in the example, the picture is from 6:00 to 17:00) indicated by the blue color curve.The red color curve describes the realization of the load curve PV (fluctuated load curve), while the green color curve is the realization of PV, which is a lost supply of energy from 13:00 to 17:00.

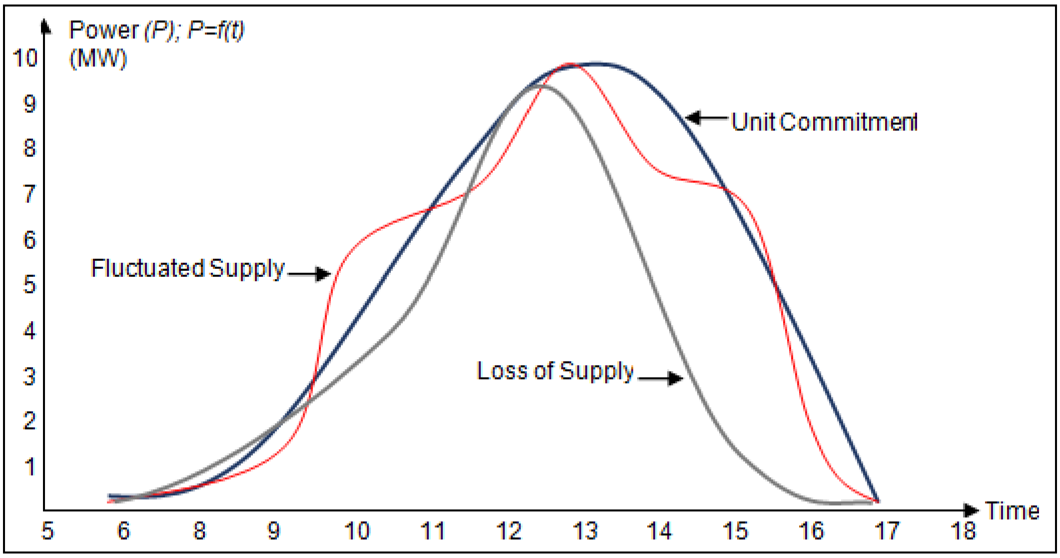


Figure 3: PV Load Curve

The plant energy supply (E) of the PV based on the unit commitment shown in Figure 3 with a blue curve can be calculated in the T period from *1* to a specific time k, then it can be described in the equation:

$$E = \int_{T=1}^{k} P = \sum_{t=1}^{n} P(T_t)\Delta(T_t) \quad (1)$$

where:
E : Energy supply (kWh)
P : Power output PV in a specific time (kW),$P = f(t)$
t : The time is in hours (h)

When the prescribed tariff is FIT, and the PV power plant can supply energy following the unit commitment, the PV power plant owner will gain revenue (R) according to equation 2.

$$R = FIT \times E_{PV} \quad (2)$$

where:
R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
E_{PV} : PV energy supply (kWh)

3.1 First Proposed FIT Algorithm

In cases where the PV power plant energy supply fluctuates (as shown by the red curve in Figure 4), another power plant (frequency follower power plant) is needed to balance the system load.In the first proposed FIT algorithm, when PV power plant energy is more than the unit commitment, then the PV power plant owner will gain revenue according to equation 2. However, when PV power plant energy is less than the unit commitment, then the PV power plant owner will earn income according to equation 3.

$$R = (FIT \times E_{PV}) - \left(BLC \times (E_{COMMIT} - E_{PV})\right) (3)$$

where:
R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
BLC :BPP of the frequency follower power plants (IDR/kWh)
E_{PV} : PV energy supply (kWh)
E_{COMMIT} : Committed PV energy (kWh)

In case PV loses the supply of energy required of backup power plants as replacement energy supply into the system. The owner of the PV power plant will gain revenue according to equation 4.

$$R = (FIT \times E_{PV}) - \left(BUC \times (E_{COMMIT} - E_{PV})\right) (4)$$

where:
R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
BUC : BPP of the backup power plants (IDR/kWh)
E_{PV} : PV energy supply (kWh)
E_{COMMIT} : Committed PV energy (kWh)

Example:
Committed PV power plant energy = 10 kWh
FIT of committed PV power plant energy = IDR 100,000

Realized PV power plant energy = 4 kWh
FIT of realized PV power plant energy = IDR 40,000

Additional energy of gas engine power plant (PLTMG) as frequency follower power plant (PLN) = 10 kWh – 4 kWh = 6 kWh
BPP of additional energy of PLTMG (PLN) = IDR 80,000

PV power plant energy revenue with dynamic FIT
= IDR 40,000 – IDR 80,000
= - IDR 40,000 (minus means the owner of the PV power plant will pay IDR 40,000 to PLN)

3.2 Second Proposed FIT Algorithm

In the second proposed FIT algorithm, when PV power plant energy is more than the unit commitment, then the PV power plant owner will gain revenue according to equation 2. However, when PV power plant energy is less than the unit commitment, the PV power plant owner will earn income according to equation 5.

$$R = (FIT \times E_{COMMIT}) - \left(BLC \times (E_{COMMIT} - E_{PV})\right) \quad (5)$$

where:

R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
BLC : BPP of the frequency follower power plants (IDR/kWh)
E_{PV} : PV energy supply (kWh)
E_{COMMIT} : Committed PV energy (kWh)

In case PV loses the supply of energy required of backup power plants as replacement energy supply into the system. The owner of the PV power plant will gain revenue according to equation 6.

$$R = (FIT \times E_{COMMIT}) - \left(BUC \times (E_{COMMIT} - E_{PV})\right) \quad (6)$$

where:

R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
BUC : BPP of the backup power plants (IDR/kWh)
E_{PV} : PV energy supply (kWh)
E_{COMMIT} : Committed PV energy (kWh)

Example:
Committed PV power plant energy = 10 kWh
FIT of committed PV power plant energy = IDR 100,000

Realized PV power plant energy = 4 kWh
FIT of realized PV power plant energy = IDR 40,000

Additional energy of PLTMG (PLN) = 10 kWh – 4 kWh = 6 kWh
BPP of additional energy of PLTMG (PLN) = IDR 80,000

PV power plant energy revenue with dynamic FIT
= IDR 40,000 – (IDR 80,000 – (IDR 100,000 – IDR 40,000)), PLN should pay IDR 60,000 for energy of 6 kWh
= IDR 20,000 (the owner of the PV power plant will gain IDR 20,000 from PLN)

3.3 Third Proposed FIT Algorithm

In the third proposed FIT algorithm, when PV power plant energy is more or less than the unit commitment or lose the energy supply, the PV power plant owner will gain revenue according to equation 7.

$$R = (FIT \times E_{PV}) - (RE_{REAL} - RE_{COMMIT}) \quad (7)$$

where:

R : Revenue (IDR)
FIT : Feed-In Tariff (IDR/kWh)
E_{PV} : PV energy supply (kWh)
RE_{COMMIT} : Committed energytariff (IDR)
RE_{REAL} : Realized energy tariff (IDR)

Example:
FIT = USD 0.15 /kWh = IDR 2,137.50 /kWh
BPP of PLTMG = cost of component A + cost of component B + cost of component C + cost of component D

$$cost\ A = \frac{installment\ \left(\frac{IDR}{month}\right)}{P_{NETT}(kW) \times 24\left(\frac{hours}{day}\right) \times 30\left(\frac{days}{month}\right) \times capacity\ factor\ (\%)} \quad \ldots\ 8$$

$$cost\ B = \frac{fixed\ operation\ and\ maintenance\ costs\ \left(\frac{IDR}{month}\right)}{P_{NETT}(kW) \times 24\left(\frac{hours}{day}\right) \times 30\left(\frac{days}{month}\right) \times capacity\ factor\ (\%)} \quad \ldots\ 9$$

$$cost\ C = SFC\left(\frac{liter}{kWh}\right) \times fuel\ cost\left(\frac{IDR}{liter}\right) \quad \ldots\ 10$$

$$cost\ D = \frac{variable\ operation\ and\ maintenance\ costs\ \left(\frac{IDR}{month}\right)}{P_{NETT}(kW) \times 24\left(\frac{hours}{day}\right) \times 30\left(\frac{days}{month}\right) \times capacity\ factor\ (\%)} \quad \ldots\ 11$$

Committed energy
= committed PV power plant energy + PLTMG energy
= 15 MWh + 100 MWh
= 115 MWh

BPP of committed energy
= (FIT x committed PV power plant energy) + (BPP x PLTMG energy)
= (IDR 2,137.50 /kWhx(15x10^3) kWh) + (5 x(18x10^3) kWh x (0.8 / (18 MW / 20 MW) xIDR 374 /kWh + 0.8 / (18 MW / 20 MW) xIDR 80 /kWh + IDR 7,287.84 /liter x (8 x10^{-6}) liter/kWh x (18 MW / 20 MWx100)^2 – 0.0014 liter/kWh x (18 MW / 20 MWx 100) + 0.2894 liter/kWh) + 0.8 / (18 MW / 20 MW) xIDR 80 /kWh)
= IDR 32,062.50 x 10^3+ IDR 192,397.64 x 10^3
= IDR 224,460.14 x10^3

Realized energy
= realized PV power plant energy + realized PLTMG energy
= 15.85 MWh + (100 – 0.85) MWh
= 115 MWh

BPP of realized energy
= (FIT x realized PV power plant energy) + (BPP x realized PLTMG energy)
= (IDR 2,137.50 /kWh x (15.85 x 10^3) kWh) + (5 x ((18 – (0.85 / 5)) x10^3) kWhx (0.8 / ((18 – (0.85 / 5)) MW / 20 MW) xIDR 374 /kWh + 0.8 / ((18 – (0.85 / 5)) MW / 20

MW) xIDR 80 /kWh + IDR 7,287.84 /liter x ((8 x10^{-6}) liter/kWh x ((18 – (0.85 / 5)) MW / 20 MW x 100)^2– 0.0014 liter/kWh x ((18 – (0.85 / 5)) MW/ 20 MW x 100) + 0.2894 liter/kWh) + 0.8 / ((18 – (0.85 / 5)) MW / 20 MW) xIDR 80 /kWh)
= IDR 33,880.23 x 10^3+ IDR 190,965.01 x 10^3
= IDR 224,845.24 x 10^3

Because BPP of realized energy is more thanBPP of committed energy, soPV power plant energy revenue with dynamic FIT
= FIT of realized PV power plant energy – (BPP of realized energy – BPP of committed energy)
= (IDR 33,880.23 – (IDR 224,845.24 – IDR 224,460.14)) x 10^3
= IDR 33,495.13 x 10^3 (the PV power plant owner will gain less revenue from PLN than the realization, even though the realized PV power plant energy is more than committed PV power plant energy because the BPP of PLTMG (cost of component A + cost of component B + cost of component C + cost of component D) has increased)

4. Simulation

The simulation was carried out using data from the North Sulawesi grid system (termed Sulutgo) in Indonesia. The Sulutgo system, as shown in Figure 4 below, there is a Likupang PV power plant with a capacity of 15 MWp and other power plants as follows:

- Hydroelectric power plant.
- Diesel power plant.
- Gas engine power plant.
- Steam turbine power plant.
- Geothermal power plant.
- Gas turbine power plant.

Figure 4: North Sulawesi Grid System (Sulutgo)

The simulation was performed on March 20 – 24, 2020, where he had a different variation of the load curve with simulation conditions as follows:

- Tariffs for the current Likupang PV power plant used to refer to the terms that currently apply and government regulation.
- There is no unit commitment applied to the LikupangPV power plant. The revenue gain is based on the realization of the energy supply to the grid system.
- The proposed PV tariffs used unit commitment for the Likupang PV power plant based on the weather's reasonable condition.
- The BLC (heat reserve tariffs for load balancing) and BUC (capacity tariffs to replace lost electricity supply) depend on power plants connected to the Sulutgo system. The BUC is applied if the Likupang PV power plant load fluctuation is below the follower power plant's ability to anticipate it, so a backup generator is needed. In this simulation, set 10 MW according to the conditions that occur in the Sulutgo system.

The simulation usesAmurang Leasing Marine Vessel Power Plant (AmurangLMVPP) as the frequency follower and backup power plants. The Amurang LMVPP has6 PLTMG units, with each unit capacity is 20 MW (6 x 20 MW). According to economic dispatch, if the Amurang LMVPP (PLTMG) has to be on standby more than 10 MW and has to have a spinning reserve of 10 MW, so

- 1 PLTMG unit as the backup power plant.
- 6 PLTMG unitsas the frequency follower power plants with each the unit capacity is 18 MW (5 x 18 MW).

Figure 5shows the Specific Fuel Consumption (SFC) assumptionofthe PLTMGthat can be formulated, such as equation12.

$$y = (8)(10)^{-6}x^2 - 0.0014x + 0.2894 \qquad (12)$$

where:
y : SFC (liter/kWh)
x : PLTMG power (%)

According to equation 8, when output of the PLTMG is 80%, so
SFC = $(8)(10)^{-6}(80)^2$– (0.0014)(80) + 0.2894 = 0.2286 liter/kWh

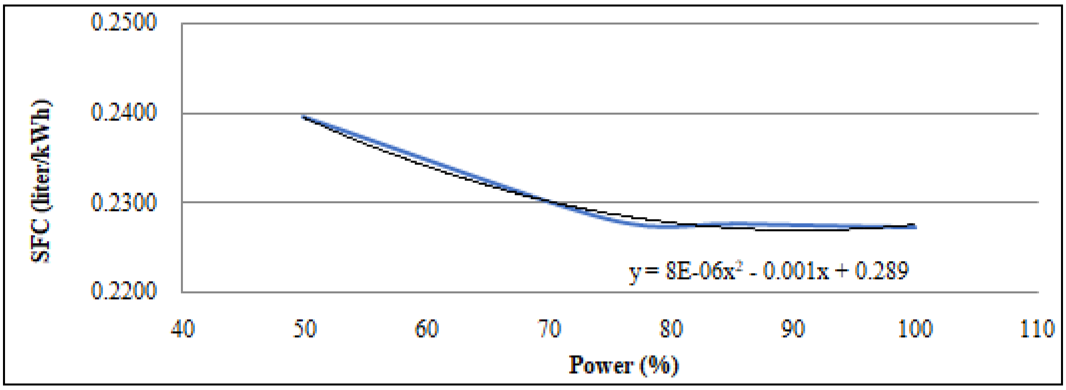


Figure 5: SFC of Amurang LMVPP

The BPP of the PLTMG as the frequency follower power plant is IDR 2,220, andthe PLTMG as the backup power plant is IDR 2,300. Table 1 shows the cost of components A, B, C, and D of power plantsby assuming the interest and term investment are 7%/year and ten years, respectively.According to Table 1, the cost of components of the PLTMG as the frequency follower power plant is

Cost of component A = 2 x IDR 187 = IDR 374 /kWh
Cost of component B = 2 x IDR 40 = IDR 80 /kWh
Cost of component D = 2 x IDR 40 = IDR 80 /kWh
Cost of fuel
= (BPP of BLC – (cost A + cost B + cost D)) / SFC
= (IDR 2,200 /kWh – (IDR 374 /kWh + IDR 80 /kWh + IDR 80 /kWh)) / 0.2286 liter/kWh
= IDR 7,287.84 /liter

The cost of components of the PLTMG as the backup power plant is
Cost of component A = 2 x IDR 187 = IDR 374 /kWh
Cost of component B = 2 x IDR 40 = IDR 80 /kWh
Cost of component D
= BPP of BUC– (cost A + cost B + (cost of fuel x SFC))
= IDR 2,300 /kWh – (IDR 374 /kWh + IDR 80 /kWh + (IDR 7,287.84 /liter x 0.2286 liter/kWh))
= IDR 180 /kWh

Table 1: Cost of Components of Power Plants

Type of Power Plant	Capacity (MW)	Cost of Component A (IDR/kWh)	Cost of Component B (IDR/kWh)	Cost of Component C (IDR/kWh)		Cost of Component D (IDR/kWh)
Combine cycle power plant	800	148 – 200	14 – 22	525 – 1033 (Natural gas)	1006 – 1394 (HSD)	27 – 40
Combine cycle power plant	60	188 – 246	97 – 147			40 – 54
Gas turbine power plant	250	80 – 123	15 – 22	774 – 1476 (Natural gas)	1484 – 1992 (HSD)	40 – 54
Gas turbine power plant	60	134 – 184	32 – 55			54 – 68
Coal fired steam turbine power plant with reheat	800	324 – 432	29 – 41	280 – 352 (Coal)		34 – 47
Coal fired steam turbine power plant without reheat	60	269 – 370	194 – 295	344 – 516 (Coal)		68 – 108
Nuclear power plant	1250	539 – 926	62 – 106	Unknown		27
Biomass fired steam power plant	30	539 – 770	194 – 295	0 – 947 (Biomass)		68 – 108
Gas engine power plant	10	187 – 237	40 – 60	573 – 1028 (Natural gas)		40 – 60
Diesel power plant	10	175 – 230	40 – 60	994 – 1291 (MFO)	1224 – 1614 (HSD)	40 – 60

The simulation results compare the revenue obtained by the Likupang PV power plant according to the current realization with the proposed formula. It means comparing the payment cost of PLN as a grid operator. In the current conditions, PLN must pay only according to the energy supply without considering the expenses incurred by PLN if the PV loses a sudden load or fluctuation in the capacity that occurs in the PV because there is no commitment of the PV unit. In this condition, the PLN must bear the costs for load balancing and replacement costs lost due to PV's intermittent nature. The price is equivalent to BPP of the frequency follower power plants for load balancing and BPP of the backup/peakerpower plants to replace lost loads to maintain the grid system's stability. The simulation results are described in the Attachment.

5. Conclusions

This study proposes a method of determining electricity tariffs for PV power plants without batteries within a specified period, taking into account the characteristics of Indonesia's existing grid system. The proposed Dynamic FIT contains deduction tariffs when the PV power plant could not fulfill the unit commitment and exceeding tolerance.

Implementing the proposed dynamic FIT model in this study has many advantages compared to the flat FIT. The dynamic FIT model presented in this study considers the unit commitment of the PV power plant. Therefore, PV's unit commitment becomes a reference for power system operators to prepare the power system reliability. This dynamic FIT model includes the prediction of the cost of electricity production based on merit orders that incorporate the PV unit's operation. The grid system operator (PLN) prepares the power plant to enter the grid system so that the dispatcher system can predict the account. It means PV and other power plants have the same treatment.

The Advantages:

- The grid operator can anticipate the possibility of loss or fluctuation of supply due to PV's characteristics.
- The governmentis not necessary to give incentives or subsidies.

The disadvantages:

- PV owners should estimate the electrical energy to be supplied into the system within a particular time (unit commitment).
- PV owners should predict accurately before entering the grid to minimize the penalties.
- The grid operator should make the correct prediction to accept PV come to the grid system.

Attachment

<u>Case 1</u>

The following parameter conditions:

FIT of Likupang PV power plant (15 MWp) (according to the contract) = USD 0.15/kWh

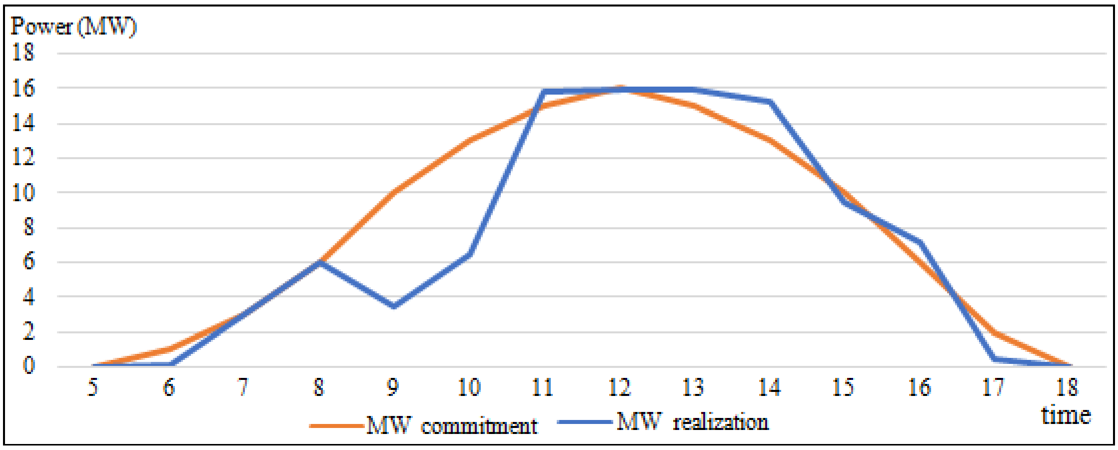
= IDR 2,137.5/kWh (USD 1 = IDR 14,250)

BPP of BUC (Amurang LMVPP) = IDR 2,300/kWh (as backup/peaker power plants)

BPP of BLC (Amurang LMVPP) = IDR 2,200/kWh (asfrequency follower power plants)

BPP of Sulutgo grid system = IDR 1,918/kWh

BPP of BUC is applied if the PV load is below 10 MW from the unit commitment.



20/03/2020	Realization (IDR x 1000)			Commitment (IDR x 1000)			Realization (as the First Proposed Formula) (IDR x 1000)			Realization (as the Second Proposed Formula) (IDR x 1000)			Realization (as the Third Proposed Formula) (IDR x 1000)		
Time	MW	MWh	PV (IDR)	MW	MWh	PV (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)
5	0			0											
6	0.12	0.12223	261.27	1	1	2,137.50	0.00	0.00	-1,669.83	0.00	0.00	206.41	0.00	0.00	261.27
7	2.95	2.95312	6,312.29	3	3	6,412.50	0.00	0.00	6,209.16	0.00	0.00	6,309.36	0.00	0.00	6,312.29
8	6.05	6.04826	12,928.16	6	6	12,825.00	12,928.16	0.00	0.00	12,928.16	0.00	0.00	12,906.51	0.00	0.00
9	3.49	3.48651	7,452.42	10	10	21,375.00	0.00	0.00	-6,877.26	0.00	0.00	7,045.32	0.00	0.00	7,452.42
10	6.44	6.44375	13,773.52	13	13	27,787.50	0.00	0.00	-650.23	0.00	0.00	13,363.75	0.00	0.00	13,773.52
11	15.85	15.8504	33,880.23	15	15	32,062.50	33,880.23	0.00	0.00	33,880.23	0.00	0.00	33,495.13	0.00	0.00
12	15.92	15.9164	34,021.31	16	16	34,200.00	0.00	0.00	33,837.39	0.00	0.00	34,016.08	0.00	0.00	34,021.31
13	15.96	15.9609	34,116.42	15	15	32,062.50	34,116.42	0.00	0.00	34,116.42	0.00	0.00	33,680.71	0.00	0.00
14	15.22	15.2212	32,535.32	13	13	27,787.50	32,535.32	0.00	0.00	32,535.32	0.00	0.00	31,513.13	0.00	0.00
15	9.52	9.51817	20,345.09	10	10	21,375.00	0.00	0.00	19,285.06	0.00	0.00	20,314.97	0.00	0.00	20,345.09
16	7.17	7.16986	15,325.58	6	6	12,825.00	15,325.58	0.00	0.00	15,325.58	0.00	0.00	14,793.78	0.00	0.00
17	0.46	0.46372	991.20	2	2	4,275.00	0.00	0.00	-2,388.61	0.00	0.00	895.18	0.00	0.00	991.20
18	0			0											
							128,785.70	0.00	47,745.67	128,785.70	0.00	82,151.08	126,389.26	0.00	83,157.09
Payment by PLN (IDR)			211,942.79			235,125.00	176,531.37			210,936.78			209,546.35		

Case 2

The following parameter conditions:

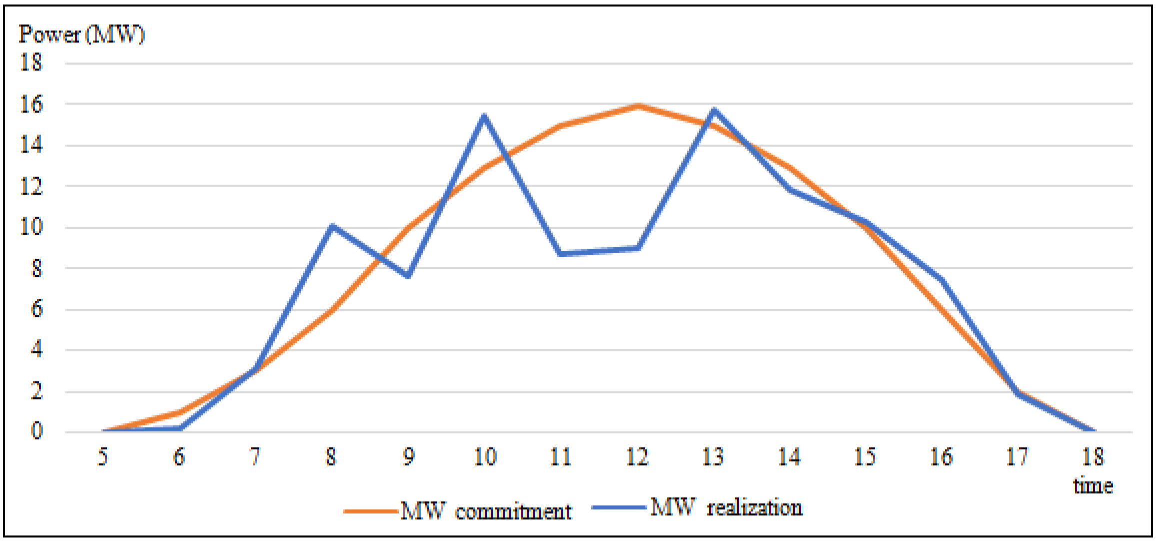
FIT of Likupang PV power plant (15 MWp) (according to the contract) = USD 0.15 /kWh = IDR 2,137.5 /kWh (USD 1 = IDR 14,250)

BPP of BUC (Amurang LMVPP) = IDR 2,300/kWh (as backup/peaker power plants)

BPP of BLC (Amurang LMVPP) = IDR 2,200/kWh (asfrequency follower power plants)

BPP of Sulutgo grid system = IDR 1,918/kWh

BPP of BUCis applied if the PV load is below 10 MW from the unit commitment.



24/03/2020	Realization (IDR x 1000)			Commitment (IDR x 1000)			Realization (as the First Proposed Formula) (IDR x 1000)			Realization (as the Second Proposed Formula) (IDR x 1000)			Realization (as the Third Proposed Formula) (IDR x 1000)		
Time	MW	MWh	PV (IDR)	MW	MWh	PV (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)
5	0			0											
6	0.21	0.20994	448.75	1	1	2,137.50	0.00	0.00	-1,289.39	0.00	0.00	399.37	0.00	0.00	448.75
7	5.32	5.31858	11,368.46	3	3	6,412.50	11,368.46	0.00	0.00	11,368.46	0.00	0.00	10,300.28	0.00	0.00
8	5.52	5.52015	11,799.32	6	6	12,825.00	0.00	0.00	10,743.65	0.00	0.00	11,769.33	0.00	0.00	11,799.32
9	12.97	12.9661	27,715.04	10	10	21,375.00	27,715.04	0.00	0.00	27,715.04	0.00	0.00	26,338.49	0.00	0.00
10	9.85	9.8455	21,044.76	13	13	27,787.50	0.00	0.00	14,104.86	0.00	0.00	20,847.60	0.00	0.00	21,044.76
11	15.62	15.6212	33,390.32	15	15	32,062.50	33,390.32	0.00	0.00	33,390.32	0.00	0.00	33,109.78	0.00	0.00
12	9	8.99709	19,231.28	16	16	34,200.00	0.00	0.00	3,824.88	0.00	0.00	18,793.60	0.00	0.00	19,231.28
13	7.96	7.9645	17,024.12	15	15	32,062.50	0.00	0.00	1,546.02	0.00	0.00	16,584.40	0.00	0.00	17,024.12
14	10.27	10.2703	21,952.77	13	13	27,787.50	0.00	0.00	15,947.43	0.00	0.00	21,782.16	0.00	0.00	21,952.77
15	9.69	9.68668	20,705.28	10	10	21,375.00	0.00	0.00	20,015.97	0.00	0.00	20,685.70	0.00	0.00	20,705.28
16	3.42	3.42313	7,316.94	6	6	12,825.00	0.00	0.00	1,647.83	0.00	0.00	7,155.89	0.00	0.00	7,316.94
17	0.79	0.7902	1,689.05	2	2	4,275.00	0.00	0.00	-972.51	0.00	0.00	1,613.44	0.00	0.00	1,689.05
18	0			0											
							72,473.82	0.00	65,568.74	72,473.82	0.00	119,631.48	69,748.55	0.00	121,212.26
Payment by PLN (IDR)			193,686.08			235,125.00	138,042.56			192,105.30			190,960.81		

CASE 3

The following parameter conditions:

FIT of Likupang PV power plant (15 MWp) (according to the government regulation, ESDM 50, 2017) = IDR 1,630.3/kWh (85% x IDR 1,918/kWh)

BPP of BUC (Amurang LMVPP) = IDR 2,300/kWh (as backup/peaker power plants)

BPP of BLC (Amurang LMVPP) = IDR 2,200/kWh (as frequency follower power plants)

BPP of Sulutgo grid system = IDR 1,918/kWh

BPP of BUC is applied if the PV load is below 10 MW from the unit commitment.

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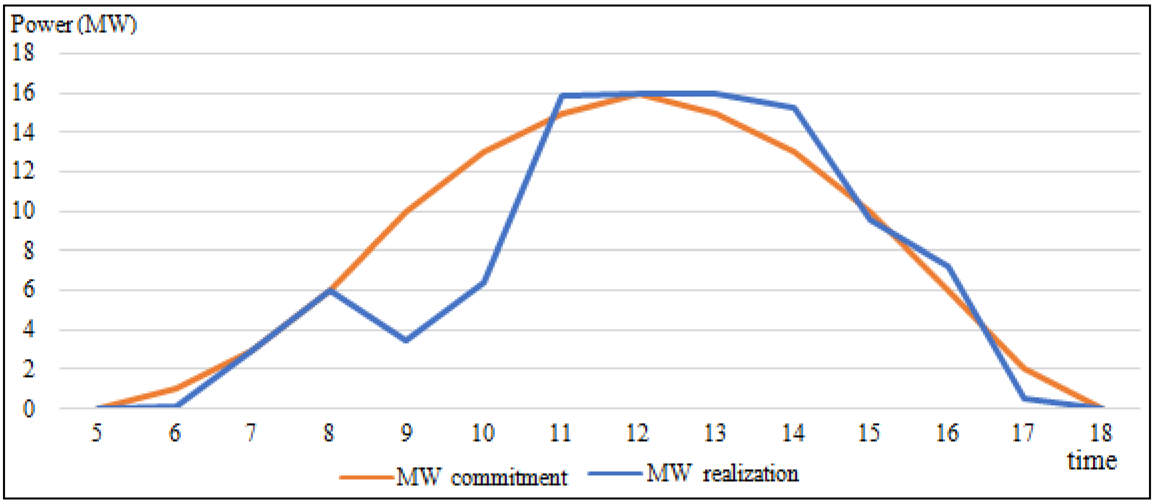


20/03/2020	Realization (IDR x 1000)			Commitment (IDR x 1000)			Realization (as the First Proposed Formula) (IDR x 1000)			Realization (as the Second Proposed Formula) (IDR x 1000)			Realization (as the Third Proposed Formula) (IDR x 1000)		
Time	MW	MWh	PV (IDR)	MW	MWh	PV (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)
5	0			0											
6	0.12	0.12223	199.27	1	1	1,630.30	0.00	0.00	-1,731.82	0.00	0.00	-300.79	0.00	0.00	143.16
7	2.95	2.95312	4,814.47	3	3	4,890.90	0.00	0.00	4,711.34	0.00	0.00	4,787.76	0.00	0.00	4,811.69
8	6.05	6.04826	9,860.48	6	6	9,781.80	9,860.48	0.00	0.00	9,860.48	0.00	0.00	9,860.48	0.00	0.00
9	3.49	3.48651	5,684.06	10	10	16,303.00	0.00	0.00	-8,645.62	0.00	0.00	1,973.32	0.00	0.00	5,048.53
10	6.44	6.44375	10,505.25	13	13	21,193.90	0.00	0.00	-3,918.50	0.00	0.00	6,770.15	0.00	0.00	9,863.78
11	15.85	15.8504	25,840.91	15	15	24,454.50	25,840.91	0.00	0.00	25,840.91	0.00	0.00	25,840.91	0.00	0.00
12	15.92	15.9164	25,948.51	16	16	26,084.80	0.00	0.00	25,764.59	0.00	0.00	25,900.88	0.00	0.00	25,943.53
13	15.96	15.9609	26,021.06	15	15	24,454.50	26,021.06	0.00	0.00	26,021.06	0.00	0.00	26,021.06	0.00	0.00
14	15.22	15.2212	24,815.12	13	13	21,193.90	24,815.12	0.00	0.00	24,815.12	0.00	0.00	24,815.12	0.00	0.00
15	9.52	9.51817	15,517.47	10	10	16,303.00	0.00	0.00	14,457.45	0.00	0.00	15,242.97	0.00	0.00	15,487.74
16	7.17	7.16986	11,689.02	6	6	9,781.80	11,689.02	0.00	0.00	11,689.02	0.00	0.00	11,689.02	0.00	0.00
17	0.46	0.46372	756.00	2	2	3,260.60	0.00	0.00	-2,623.81	0.00	0.00	-119.22	0.00	0.00	652.05
18	0			0											
							98,226.59	0.00	28,013.61	98,226.59	0.00	54,255.08	98,226.59	0.00	61,950.48
Payment by PLN (IDR)			161,651.61			179,333.00		126,240.19			152,481.67			160,177.06	

CASE 4

The following parameter conditions:

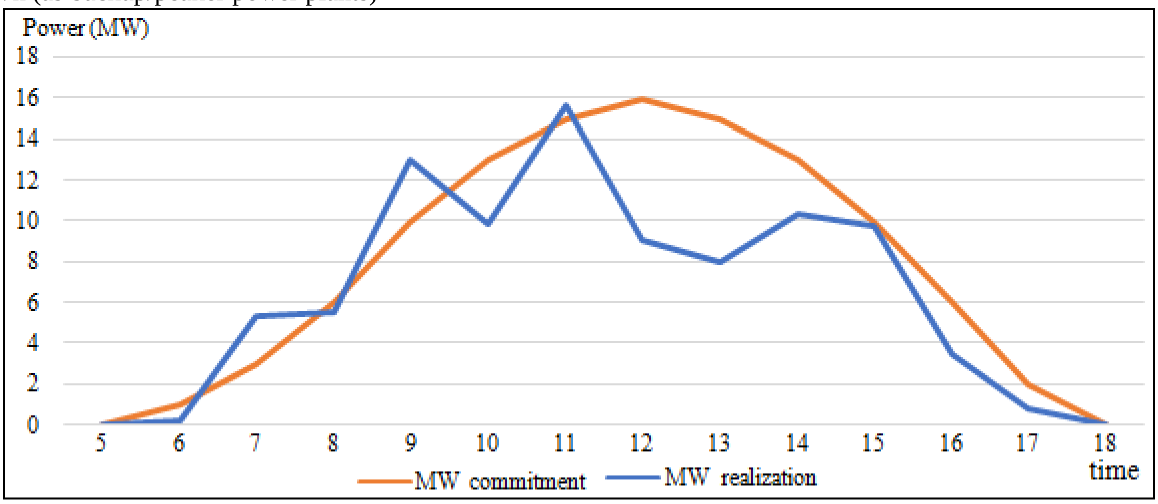
FIT of Likupang PV power plant (15 MWp) (according to the government regulation, ESDM 50, 2017) = IDR 1,630.3 /kWh (85% x IDR 1,918 /kWh)

BPP of BUC (Amurang LMVPP) = IDR 2,300/kWh (as backup/peaker power plants)

BPP of BLC (Amurang LMVPP) = IDR 2,200/kWh (as frequency follower power plants)

BPP of Sulutgo grid system = IDR 1,918/kWh

BPP of BUC is applied if the PV load is below 10 MW from the unit commitment.



24/03/2020	Realization (IDR x 1000)			Commitment (IDR x 1000)			Realization (as the First Proposed Formula) (IDR x 1000)			Realization (as the Second Proposed Formula) (IDR x 1000)			Realization (as the Third Proposed Formula) (IDR x 1000)		
Time	MW	MWh	PV (IDR)	MW	MWh	PV (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)	PV (IDR)	BUC (IDR)	BLC (IDR)
5	0			0											
6	0.21	0.20994	342.27	1	1	1,630.30	0.00	0.00	-1,395.87	0.00	0.00	-107.83	0.00	0.00	292.15
7	5.32	5.31858	8,670.88	3	3	4,890.90	8,670.88	0.00	0.00	8,670.88	0.00	0.00	8,670.88	0.00	0.00
8	5.52	5.52015	8,999.50	6	6	9,781.80	0.00	0.00	7,943.83	0.00	0.00	8,726.13	0.00	0.00	8,969.90
9	12.97	12.9661	21,138.63	10	10	16,303.00	21,138.63	0.00	0.00	21,138.63	0.00	0.00	21,138.63	0.00	0.00
10	9.85	9.8455	16,051.12	13	13	21,193.90	0.00	0.00	9,111.22	0.00	0.00	14,254.00	0.00	0.00	15,807.99
11	15.62	15.6212	25,467.24	15	15	24,454.50	25,467.24	0.00	0.00	25,467.24	0.00	0.00	25,467.24	0.00	0.00
12	9	8.99709	14,667.96	16	16	26,084.80	0.00	0.00	-738.45	0.00	0.00	10,678.40	0.00	0.00	13,962.99
13	7.96	7.9645	12,984.52	15	15	24,454.50	0.00	0.00	-2,493.58	0.00	0.00	8,976.40	0.00	0.00	12,274.82
14	10.27	10.2703	16,743.67	13	13	21,193.90	0.00	0.00	10,738.33	0.00	0.00	15,188.56	0.00	0.00	16,540.10
15	9.69	9.68668	15,792.19	10	10	16,303.00	0.00	0.00	15,102.89	0.00	0.00	15,613.70	0.00	0.00	15,773.16
16	3.42	3.42313	5,580.73	6	6	9,781.80	0.00	0.00	-88.39	0.00	0.00	4,112.69	0.00	0.00	5,390.86
17	0.79	0.7902	1,288.26	2	2	3,260.60	0.00	0.00	-1,373.30	0.00	0.00	599.04	0.00	0.00	1,208.65
18	0			0											
							55,276.76	0.00	36,806.70	55,276.76	0.00	78,041.08	55,276.76	0.00	90,220.62
Payment by PLN (IDR)			147,726.98			179,333.00	92,083.46			133,317.83			145,497.37		

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