# Study on FIP Policy Design by Using Multi-agent Based Electric Power Market Simulation Model

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A multi-agent based electricity market simulation model is used to study the possible effects of variable renewable technologies on the electricity market and the implications for the design of the feed-in premium (FIP) policy, which is being discussed by government committees in the context of revision of the current feed-in tariff mechanism in Japan. The paper focuses on the impact of solar PV in Kyushu. The results suggest that under a FIP price of 10 yen/kWh, the breakeven cost of solar PV (in Kyushu) is under 150,000 yen/kW. However, if the amount of solar PV increases from 7,850 MW to 16,673 MW, the monthly average market value of solar PV would decrease by 3–4 yen/kWh and cheaper solar PV cost would be required to achieve breakeven. Although batteries can help to increase solar PV' revenue from electricity market, to make the investment on batteries economically make sense, the cost of batteries need to be below 15,000/kWh.

***Key words***: FIP, renewable energy, electric power market simulation

## 1. Background and purpose

The Japanese government is currently considering revising the feed-in-tariff system for renewable energies (renewables), and has indicated a policy of migrating solar PV and wind power to the feed-in premium (FIP) system[1).]

The FIP system is expected to promote the integration of renewables into the electricity market. However, the problem is that an influx of solar PV and wind power (variable renewable energy (VRE) power sources) that have a low marginal cost could drive down the market price of wholesale electricity market, and thus the negative impact on the revenue of VRE itself (Referred to as "cannibalism")[2),3)].

By a case study of Kyushu, which leads Japan in terms of installed solar PV capacity, this study focuses on the following topics: possible impact on market price when there is an influx of solar PV into the wholesale electricity market (cannibalism), the effect of installing batteries on easing the cannibalism phenomenon, economic efficiency of solar PV and batteries under the FIP system, and implications for a better design of the FIP system and for solar PV to become independent from subsidies in the future.

## 2. Methodology and key assumptions

### 2.1 Assumptions for the FIP system mechanism

Under the FIP system, the revenues for renewable power sources consist of two parts: revenue from selling electricity in the wholesale market, and the premium (subsidies) that is added onto the market prices. The FIP design can be classified into the variable-premium type and fixed-premium type depending on how the premium is determined (**Fig. 1**). Japan is considering a hybrid FIP design between the two in which the reference price changes at a given interval, a system similar to the German FIP system. The analysis of this study is carried out based on this type of FIP design (details elaborate later).

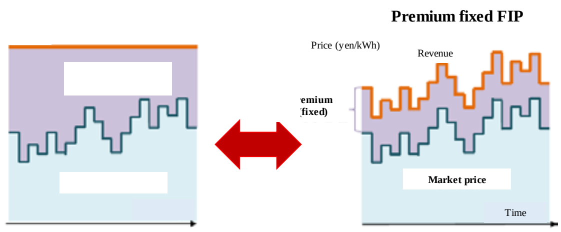


**Fig. 1** Illustration of two different FIP types

Source: Material for the first meeting of the Subcommittee on System Reform for Renewable Energy as a Main Power Source[1)]

A premium is the difference between the FIP price (purchasing price paid to the VRE developer) and the reference price. The FIP price for solar PV is assumed to be 10 yen/kWh, which is in line with the lowest successful bidding price at the

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fourth auction for solar PV (10.5 yen/kWh[4]).

In the German FIP system, the method of calculating the reference price depends on the power source. According to the German FIP design the reference price for renewable technologies is assumed as follows: the reference price for a renewable power source with stable output (biomass, geothermal, and hydropower) is set to the average wholesale electricity market price[5]. Meanwhile, the reference price for VRE is technology specific average market price, which is calculated based on the market price at the time of successful VRE sale and the VRE generation, given by:

$$\text{Reference price } (VRE_i) = \frac{\sum_{t=1}^{n}(market\ price\ of\ hour\ t * VRE_i's\ market\ settled\ amount\ of\ hour\ t)}{monthly\ generation\ of\ VRE_i} \quad \textbf{(1)}$$

where, $n$ is the number of hours in a month and $i$ is the type of VRE technology. In this study, the reference price is set to the monthly technology specific average wholesale electricity market price, and the premium of the relevant month (which is the difference between the FIP price and the month's reference price) is calculated after the month's trading.

### 2.2 Electricity market simulation model

The analysis in this study needs to have market price changes under various circumstances as inputs for assessing the impact of large amount of solar PV on the market price, and the economic efficiency of solar PV and the installation of batteries under a market price-linked FIP system. As the historical market price data of Japan Electric Power eXchange (JEPX) alone is not sufficient for this purpose, we built a multi-agent-based model to simulate the electricity market.

Both the sellers and the buyers are treated as an agent. A market bidding block is generated for each agent (both the buyer and the sellers) using a program, and the market settling price and the trade volume are calculated based on a market trading mechanism (**Fig. 2**) similar to that of JEPX.

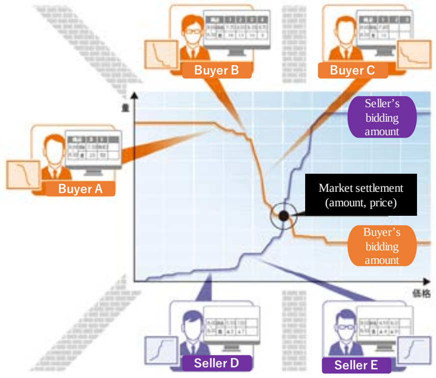


**Fig. 2 Image of market trading and market settlement**

Source: JEPX[6]

JEPX has a day-ahead (spot) market and real time market. This study assumes that VRE sources participate only in the day-ahead market. In the JEPX the day-ahead market is traded at a 30-minute interval, however, because only hourly power generation output data is available 1-hour interval market trade is calculated in the simulation model.

The precondition for the simulation is that the entire electricity demand and supply in Kyushu Electric's service area is traded in the electricity market, and the agent assumption is that one agent as the buyer and multiple agents for each power generation technology. The bidding block for the buyer agent is generated using the demand function shown in **Fig. 3**. Here, β is set to −0.05 and the bidding price cap to 85 yen/kWh. $Q_0$ is the actual hourly electricity demand (2017) disclosed by Kyushu Electric[7]. For the buyer's bidding block, the bidding amount is 3MW and the bidding price (p) is calculated by the demand function with the input as the demand that decreases in units of 3 MW (q) down to $Q_0$. The base price ($P_0$) is set to 5 yen/kWh.

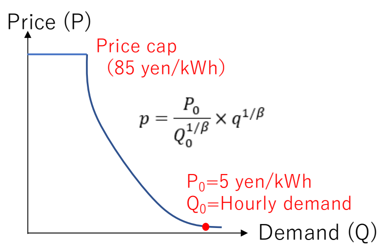


**Fig. 3 Relationship between electricity demand and market bid price**

The market bidding price for the seller agents is assumed to be the sum of marginal generation cost of each technology and the profit (α). The value of α is selected from among the 21 options predefined using an enhanced learning method called

Q-learning based on the objective to maximize the agent's revenue from market trading. The range of α is from 0 to 80. Marginal cost for each power generation technology is set based on the calculation results from Power Generation Cost Verification Working Group[10] (**Table 1**). Fuel costs are considered to be constant over the simulation period. As this study assumes that the seller's minimum bidding price equals to its marginal cost, the market price does not become 0.

The bidding amount of each seller agent is set based on the installed capacity for non-VRE technologies For VRE technologies, the capacity that can be offered at a certain hour is calculated based on the installed capacity and the output curve (which is estimated from the historical output data). The installed capacity is from the data disclosed by Kyushu Electric Power Company (**Table 1**).

For simplification, we assume no inter-region electricity trading between Kyushu and other areas and balancing by pumped hydro power is not considered either.

**Table 1** Marginal cost and current installed capacity for each power generation technology

| | Hydro | Nuclear | Coal | Gas | Oil | Biomass | Geothermal | Solar PV | Wind | PV + battery |
|---|---|---|---|---|---|---|---|---|---|---|
| Marginal cost (yen/kWh) | 2.3 | 5.4 | 7.2 | 11.4 | 26.7 | 25.2 | 12.5 | 3.34 | 4.15 | 3.34 |
| Capacity (MW) | 1,901 | 1,780 | 3,983 | 4,981 | 3,560 | 52 | 192 | 7,850 | 500 | Scenario |

Source: Power Generation Cost Verification Working Group[10], Kyushu Electric Power Company[7),11)]

### 2.3 Setting the simulation cases

An increase in solar PV that has a low marginal cost is expected to lower the day-time market prices and drive down the revenue from electricity market of solar PV itself. Solar PV developers are able to increase their market sales revenues by installing batteries and selling the power when the market price is high, but this would require additional investment for battery installation. Whether there will be sufficient incentive for developers to install batteries depends on whether the increase in market sales revenue is enough to at least cover the additional battery investment. Under the FIP mechanism, installing batteries could also cause the change of the reference price because of the shift of the overall output pattern of solar PV. As a result, the premium paid to all the developers will also change, which will affect the revenue of the developers without batter installation.

Simulation cases in this study are shown in **Figure 4.** Focuses of the analysis include: impact of solar PV on the electricity market, price benefit of revenue increase by installing batteries, the economic viability of solar PV and batteries under the FIP mechanism, implications for better FIP design and future subsidy phase-out conditions.

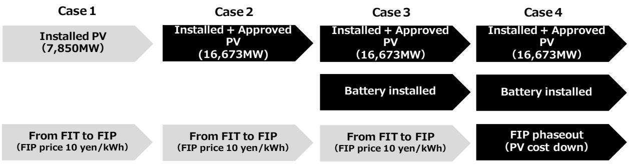


**Fig. 4** Simulation cases

### 2.4 Output pattern: solar PV + batteries

The power output pattern of the combined solar PV and battery system is given as an exogenous variable. Five cases of battery/solar PV capacity from 1 kWh battery /kW solar PV to 5 kWh battery/kW solar PV are considered. Although there can be various operation patterns of batteries, for simplification reason this study assumes an pattern under which generation from solar PV is stored to the battery to its maximum capacity during day-time and the stored electricity is sold to the market in the evening hours (17:00–21:00) when price is high(**Fig. 5**).

As the amount of solar PV output that can be shifted to the evening varies depending on how much battery capacity is installed, the cost-effectiveness of batteries will vary depending on their installed capacity.

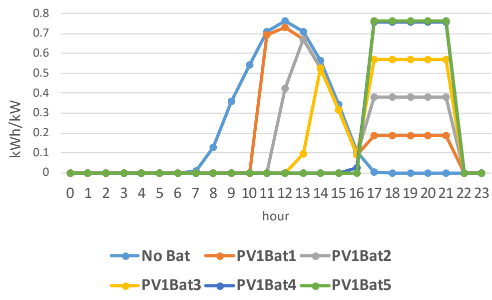


**Fig. 5** Image of solar PV + battery output

## 3. Results

### 3.1 FIP mechanism and the impact of influx of solar PV

As mentioned before, the influx of solar PV could result to market price falling down during day-time and in turn the reference price of solar PV (the monthly average market price of solar PV). For example, if the amount of solar PV traded at the electricity market were to increase from the current level (7,850 MW as of 2017) to the current approved FIT capacity (16,673

MW[1]), the reference price for solar PV would fall by 3–4 yen/kWh (**Fig. 6**).

As a result of the market price fall during day-time hours, the annual revenue from electricity sales in the market is estimated to decrease by approx. 5,000 yen per kW for solar PV developers (**Fig. 7**). To compensate possible revenue reduction from the market and make the new installed solar PV project economically viable more subsidies or faster system cost down are required.

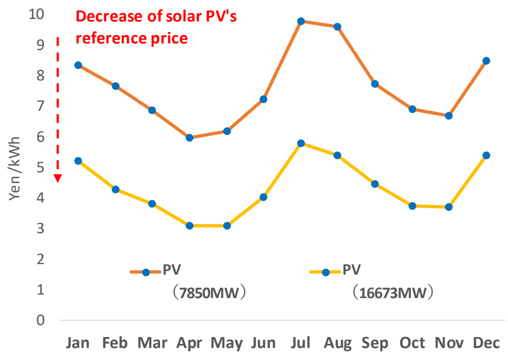


**Fig. 6** Change in the reference price of solar PV as the solar capacity increases in the market

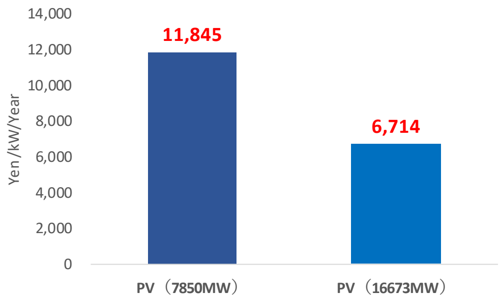


**Fig. 7** Change in revenue from sales in the market as solar PV increases

### 3.2 Effect of installing batteries to boost revenue

One way to improve solar PV's revenue from electricity market is to install batteries, which will enable selling the electricity at hours when the market price is high. The revenue-increasing effect of batteries is discussed based on the market simulation results from the case with 16,673 MW of solar PV (equal to the current licensed capacity) in the electricity market.

[1] As of May 2019.

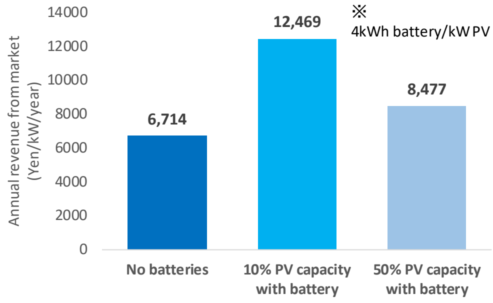


**Fig. 8** Change in market sales revenue from installing batteries

The result in **Fig. 8** shows that the annual market sales revenue is higher for solar PV with batteries than that without. In the case when batteries are installed to 10% of the solar PV capacity (4 kWh of battery capacity for 1 kW of solar PV), the annual revenue per kW (of solar PV) becomes 5,700 yen higher than that with no batteries (**Fig. 8**). However, if the capacity of solar PV with batteries becoming too much, more solar PV developers will choose to sell electricity during evening hours, that might drive down the market price in these hours, making the revenue of "solar PV + batteries" become lower (comparing to the case when the capacity of solar PV with batteries is smaller). Based on the simulation results it is found that if the percentage of solar PV capacity with batteries increases from 10% to 50% of the total, the revenue for "solar PV + batteries" system falls by approx. 4,000 yen/kW per year (**Fig. 8**).

### 3.3 Economic efficiency of solar PV and batteries

If FIP mechanism with a FIP price of 10 yen/kWh were applied to all the current solar PV capacity (7,850 MW as of 2017), the solar PV system cost need to be lower than 150,000 yen/kW to make the business viable. However, if the solar PV capacity increases to 16,673 MW (the approved solar PV capacity), because of the reduced market price and curtailment (the solar PV capacity exceeds the total demand), full-year revenue of solar PV will fall below the breakeven point (**Fig. 9**).

While installing batteries is expected to increase market sales revenue, the cost effectiveness of batteries largely depends on their cost. Under a FIP price of 10 yen/kWh and a solar PV system cost of 150,000/kW as in the case above, a battery cost of 90,000/kWh would worsen the deficit for the overall system (**Fig. 9**). A battery cost of 15,000/kWh or lower is required for the overall system cost to break even (in the case of 4 kWh of battery capacity for 1 kW of solar PV) (**Fig. 9**). Considering that the battery cost is around 40,000 yen/kWh ($380/kWh[12]) even in the United States where there is more experience for utility scale batteries a further reduction in battery cost is required to give solar PV developers an incentive to install batteries.

**Figure 9** also shows that the cost effectiveness of batteries depends on the installed battery capacity.

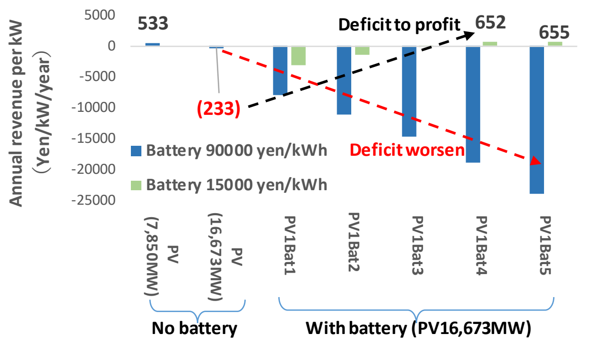


**Fig. 9** Economic efficiency of solar PV and batteries under a FIP price of 10 yen/kWh and a solar PV cost of 150,000 yen/kW (batteries installed for 10% of the solar PV capacity)

### 3.4 Gaining independence from subsidies

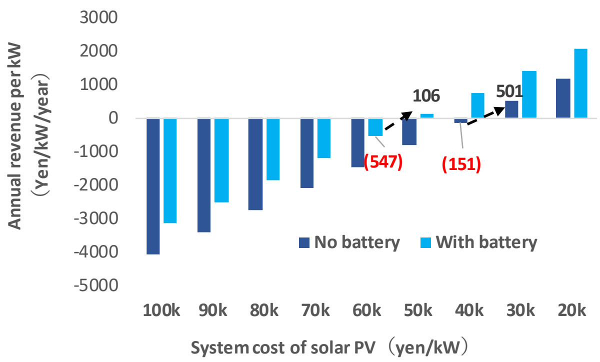


**Fig. 10** Comparison of annual revenues of unsubsidized solar PV (with and without batteries) (yen/kW/year)

As the revenue of solar PV from electricity market would decrease if large amounts of solar PV were to enter the market, a drastic reduction in system cost would be required for solar PV to become independent from subsidies. For example, if there is 16,673 MW of solar PV in Kyushu's electricity market, the system cost for solar PV must be below 30,000–40,000 yen/kW to make the business viable without subsidies (**Fig. 10**). If the battery cost can be lowered to 20,000 yen/kWh or less for the same conditions, the requirement for solar PV's system cost reduction becomes less strict, thanks to the revenue-increasing effect of batteries discussed earlier (3 kWh of battery capacity for 1 kW of solar PV). Thus, a reduction of battery cost can contribute to making solar PV graduate from subsidies sooner.

### 4. Conclusion and implications

Integrating solar PV into the electricity market under the FIP system could cause the "cannibalism," significantly affecting solar PV itself. The simulations in this study for Kyushu show that if the region's entire approved solar PV capacity (16,673 MW) were to enter the electricity market, the annual market sales revenue of solar PV will decrease by approx. 5,000 yen/kW. Installing batteries and shifting selling power during evening hours (when the market price is usually hither) would boost the revenue from electricity market, but the battery cost must be lowered significantly to ensure business viability. To encourage make solar PV more valuable to the electricity market, it is essential to accelerate efforts to drive down the battery cost. The study also found that if the battery cost falls to around 20,000/kWh, solar PV system with batteries may become independent from subsidies more quickly than that without batteries.

If the capacity of solar PV (with batteries) that are able to sell electricity in high market-price hours increases, the market prices for those hours will decline, which could in turn cause the of solar PV + battery systems' revenue from electricity market decrease. If renewable power generation is to be completely integrated into the market with batteries, dynamic battery operation responding to the change of market prices will be necessary to maximize the developer's revenue.

To address the issue of "cannibalism" that might occur when large amounts of VRE with low marginal costs enter the electricity market, a significant reduction of the cost of both the renewable technologies and batteries is required. At the same time, VRE developers can avoid the risk of revenue reduction from the electricity market due to "cannibalism" by securing alternative sales channels, such as corporate PPA (Power Purchasing Agreement).

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