ECONOMIC PERFORMANCE OF FUSION POWER PLANT ON FUTURE DEREGULATED ELECTRICITY MARKET

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Abstract

Conventional metrics such as Levelised Cost of Electricity (LCOE) may not be able to represent the market value of power plants on future deregulated electricity markets. As such, the operation of future fusion power plants has to be discussed in terms of how to maximize the monetary value of the plant through the deregulated market mechanisms. The paper quantitatively analyzes the economic performance of steady-state fusion power plants on future deregulated electricity markets for the first time with a newly constructed Simplified PJM Market Model. The results show that (1) the economic performance of fusion power plant showed higher sensitivity to the unplanned outage frequency on deregulated electricity market and that (2) the unplanned outage (including plasma disruption) frequency target should be lowered to 0.3 times/year on deregulated market to achieve economic rationality of fusion power plants. The paper pioneers a vital new area for the economic assessment of fusion power plant: the economic performance on the future deregulated electricity market.

1. INTRODUCTION

Conventionally, a significant portion of the development strategies for future fusion power plants have been based on the extrapolation of the historical experiences of fission power plants. For instance, the disruption frequency target of the Japanese DEMO, 0.5 times/year, was adopted from the historical statistics of early fission plants. Essentially, this 'extrapolation' strategy planning thinking assumes the continuity of the environment, both for the electricity market and the power plant. However, a) due to the rapid transformations of electricity markets around the world, including deregulation, the future electricity markets are envisioned to be significantly different from that of half a century ago; and b) there're significant differences to the characteristics of fission and fusion power plants, including the possibility of unplanned outages, due to including but not limited to plasma disruptions [1]. Therefore, the authors believe that the fusion development strategies shall be reviewed accordingly, without the extrapolating the historical experiences in fission.

More specifically, the economic performances of future nuclear fusion power plants have traditionally been discussed with conventional metrics like Levelised Cost of Electricity (LCOE) [2, 3]. However, this may no longer accurately represent the market value of fusion power plants in the near future due to the discontinuous transformations of the electricity markets taking place around the world. Instead, the operation of future fusion power plants has to be discussed in terms of how to maximize the monetary value of the power plant through the deregulated market mechanisms [4]. Such study is also essential in planning the future fusion power plant operation.

Therefore, the purpose of this paper is to quantitatively analyze the economic performance of fusion power plants on deregulated future electricity markets. While there are numerous studies that estimated the LCOE of fusion power plants, this is the first study of its kind to take the deregulation into account.

2. METHOD

For reasons stated in the introduction, to quantitatively analyze the economic performances of fusion power plants, future deregulated electricity markets have to be assumed and modeled. The authors constructed Simplified PJM Market Model that simulates three Energy Market models (Year Forward, Day Ahead and Real Time), Imbalance Fee model and Ancillary Service Market model based on statistics of PJM, a U.S. a regional transmission organization (RTO), as illustrated in Fig. 1 [5].

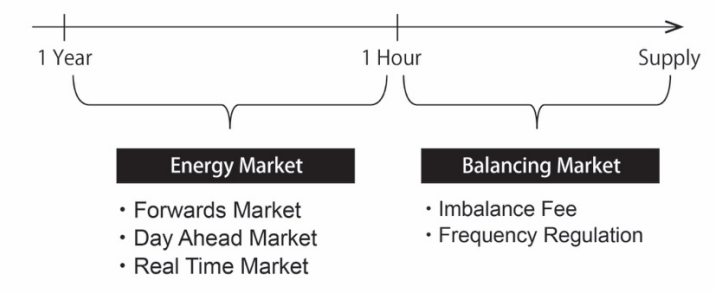
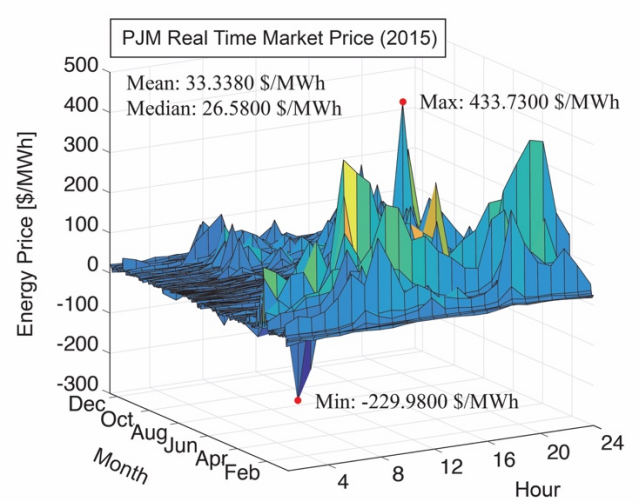
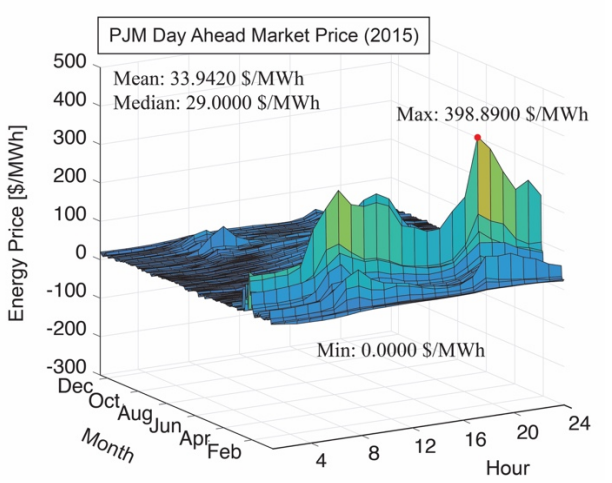


Fig. 1 Illustration of the Simplified PJM Market Model [5].

The structure of Simplified PJM Market Model shown in Fig. 1 indicates that future nuclear fusion power plants have to monetize the generated electricity via various markets through bidding processes. It is possible for future fusion power plants to sign individual contracts for long-term fixed electricity selling prices even on deregulated electricity markets, e.g. CfD: Contract for Difference. However, these long-term fixed price contracts in many cases virtually work as subsidies, therefore the contracts may not represent the actual market value of the power plants. For this reason, this in this study, the nuclear fusion power plants are assumed to sell the entire electricity through bidding. The market prices are taken from the historical data of PJM between 2011-2015 (Fig. 2) [6-8].



(a) Real Time Market



(b) Day Ahead Market

Fig. 2 PJM LMP Historical Data of Energy Market (PJM Node), 2015.

A steady-state fusion power plant with 1,200 MW electrical output (2,801 MW fusion output) was assumed, and the average cash-flows of the plant were calculated with Monte Carlo method of 125,000 calculations per case. The net present values (NPV) of 40 years of plant operation were calculated the discount rate of 1.7%. The sensitivity analyses were conducted for the unplanned outage frequency from 0.001 to 0.00001 hours-1. (A 10-day downtime was assumed per outage.) Table 1 summarizes the major parameters assumed for the nuclear fusion power plant.

TABLE 1. FUSION POWER PLANT SCENARIO PARAMETERS.

System Parameter	Value
Operation Mode	Steady-state
Electricity Output (sending-end)	1,200 GW
– Major Radius	7.728 m
– Minor Radius	2.208 m
– Beta Value	4.274
– Fusion Output	2,801 MW
Frequency of Plasma Disruption (and other interruptions)	0.001 – 0.00001 $hour^{-1}$
Service Time before Plasma Restart	10 days
Scheduled Maintenance (incl. replacements)	61 days (Nov. & Dec.) / 2 years
Bidding Market	Real-time or Day-ahead or Year-Forward

3. RESULTS

The average revenue for selling the electricity varied significantly depending on the bidding market as illustrated in Fig. 3 and Table 2. These results show that when the unplanned outage frequency is low, it maximizes the revenue for fusion power plants to bid on the Year Forward market.

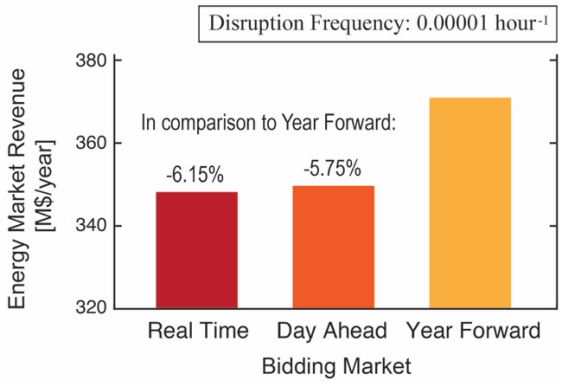


Fig. 3 Average Energy Market Revenues (Unplanned Outage Frequency = 0.00001/hour).

TABLE 2. ENERGY MARKET REVENUES (UNPLANNED OUTAGE FREQUENCY = 0.00001/HOUR).

		Energy Market Revenue
Bidding Market	Real Time	348.43 ± 59.27 M$/year
	Day Ahead	349.93 ± 60.75 M$/year
	Year Forward	371.27 ± 23.78 M$/year

The Imbalance Fees, i.e. the "penalty charge" for unplanned outages, were also calculated for each bidding market [4]. Based on the random 10,000 trials, the average Imbalance Fees for future fusion power plants per an unplanned outage (including but not limited to plasma disruption) were estimated as Table 3. This shows that when bidding on the Year Forward market, not only the revenues but also the imbalance fee would be larger.

TABLE 3. AVERAGE IMBALANCE PAYMENT PER UNPLANNED OUTAGE.

		Ave. Imbalance Payment
Bidding Market	Real Time	0.0887 M$/Disruption
	Day Ahead	1.6926 M$/Disruption
	Year Forward	50.080 M$/Disruption

The results show in Table 2 and 3 indicates that while the revenue can be raised by bidding through the Year Forward market, the potential penalty charges for the unplanned outages also increases by bidding through the Year Forward market. As a result, not just the net present value (NPV) of future nuclear fusion power plant, but also the optimal bidding electricity market showed sensitivity to the unplanned outage frequency as illustrated in Fig. 4.

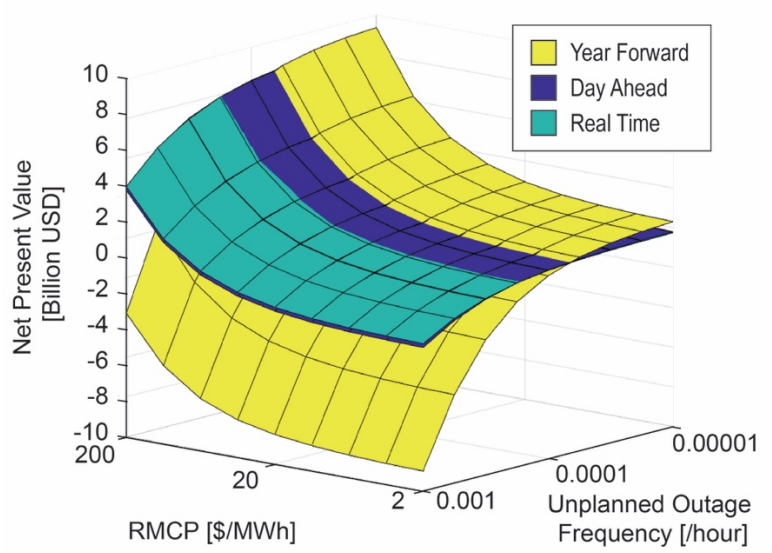


Fig. 4 Net Present Value of Fusion Plant on Deregulated Electricity Market (ESS Case).

4. DISCUSSION

The economic performance of fusion power plant showed higher sensitivity to the unplanned outage frequency on deregulated electricity market. Fig. 5 shows that the NPV of fusion plant would be devaluated from +368.3 million USD to -741.3 million USD when the unplanned outage frequency rise from 10-5 times/hour to 10-4 times/hour, while on conventional market, the devaluation would be only from 370.3 to 284.9 million USD.

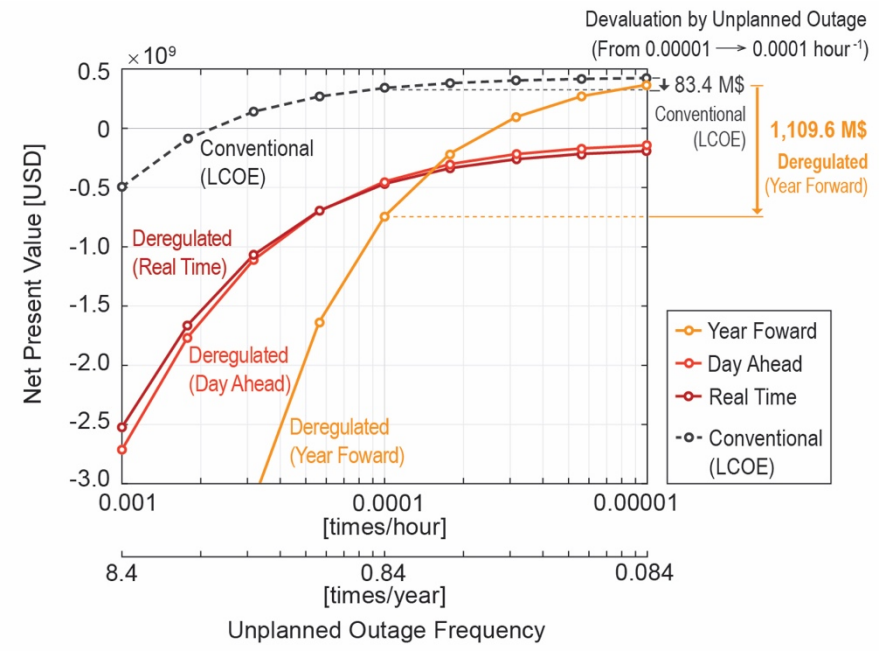


Fig. 5 Net Present Value of Fusion Power Plant on Deregulated Electricity Market vs. Conventional Market.

This is mainly due to the fact that imbalance fees would be imposed on top of the opportunity loss on deregulated markets. The imbalance fee is a "penalty charge" that will be imposed when a plant cannot deliver the contracted amount of electricity to the market: in the case of fusion plant, one unplanned outage would cost on average 50.1 million USD on year forward market, 1.69 million USD on day ahead market and 0.089 million USD on real time market. Opportunity loss is the cost of not being able to sell electricity while unplanned outage, which is on average 9.60 million USD per outage, regardless of conventional or deregulated market.

The results also indicate there are thresholds of unplanned outage frequency as to when the fusion plant should bid for each market to maximize its profit. Fig. 6 summarizes the thresholds, in which it is suggested that the unplanned frequency target should be lowered to less than 0.3 times/year on deregulated market to achieve economic rationality (NPV > 0).

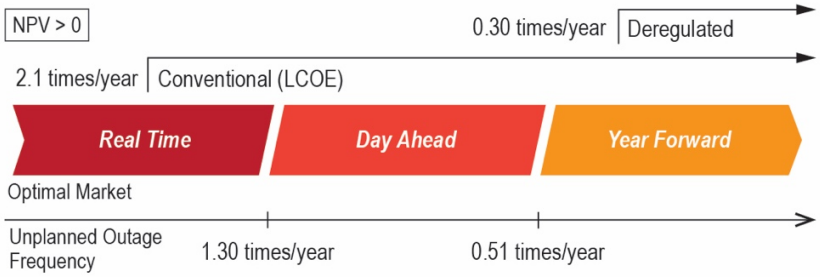


Fig. 6 Optimal Bidding Market for Fusion Power Plant vs. Unplanned Outage Frequency.

This study pioneered a vital new area for the economic assessment of fusion power plant: the economic performance on the deregulated electricity market. Results show that (1) discussions based on simple LCOE would be inapplicable to deregulated markets and (2) the unplanned outage frequency target should be lowered to 0.3 times/year on deregulated market to allow fusion plant to bid on electricity futures (year forward) market to maximize its revenue.

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