# Economic Analysis and Optimization of Micro Grid considering Incentive Oriented Demand Response Programme

**Sarabjeet Singh, Saurabh Chanana**

***Abstract: In this paper, Economic Analysis and Optimization of Micro Grid (MG) considering Incentive oriented Demand Response Programme (DRP) is proposed. To minimize levelized cost of energy, net present value and to maximize return on investment, incentive oriented Demand Response Programme is implemented using Hybrid optimization model of electric renewables (HOMER). Assessment of this work targets end users having installed net energy meters/smart meters with flat rate. This DRP also encourage end users to reduce their peak load. Simulations are carried by Hybrid optimization model of electric renewables. Results show that MG with incentive oriented DRP can be utilized for optimizing the bidding, utility savings to minimize levelized cost of energy, net present value and maximize Return on Investment(ROI).***

***Keywords: Demand Response Programme, Return on investment, Levelized cost of energy, Micro Grid, HOMER.***

## SECTION I
## INTRODUCTION

As a developing nation, growing demand of energy is exerting enormous pressure on already highly priced conventional energy sources. Many countries make it mandatory for power utilities to serve the major part of load demand with renewable sources of energy. Due to intermittent generation renewable energy system having PV components with energy storage units have been presented widely in recent years [1].Energy system based on renewable sources, seriously concerned in recent times as they are generating electricity without emission. [2] Presents simulation tool to design and operate an integrated energy system having photovoltaic generation and energy storage system. Grid connected hybrid energy system with design and cost effectiveness is discussed in [3]. High potential of HOMER in simulating a micro-power system attracts the researchers, various designs of Hybrid energy system are configured using HOMER software is presented in [4-9] for sensitive analysis and optimization. Demand Response Programme (DRP) may be best utilized in state like Punjab where unbundling of Punjab State Electricity Board in 2010 leads to two new power corporations Punjab State Power Corporation limited (jurisdiction of generation and distribution) and Punjab State Transmission Corporation limited (jurisdiction of transmission system) [10].

Manuscript published on November 30, 2019.
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Due to disparity between generation and demand there may be acute shortage of energy during peak load hours that may cause system failure [11].With deregulation in power sector smart grids with DR component may lead to maximize the profits in electricity market. Electricity markets become more competitive as restructuring of power sector equip the market with open access[12].Competition in power sector rises day by day due to increase rush of participants in electricity market. Such an environment develops concept of social welfare maximization[13].Transition of power sector from vertically integrated system to restructured system create atmosphere of competition, in which customers are getting price rates and respond to them accordingly. Customers are shifting their peak load demands to off peak load hours when power prices are cheap. Hence electricity crisis can be tackled by independent system operator by appropriately using DRP [14].Various types of DRPs are designed by independent system operators to benefit electricity market consumers. Different types of Demand response programme with their cost components and their benefits are highlighted in [15].From various available DRPs, incentive based programme is one in which consumer get incentives by voluntary curtailment in their load demand during peak load hours [16].This incentive based programme is alike, when a consumer get reward by maintaining power factor of his premises within certain specified limits [17]. To reduce the peak demand and to minimize the utility cost, load shifting approach in hour wise mode is presented in [18]. Operational benefits and improvement in microgrid is evaluated using solar estimation and Demand response programme [19]. This paper presents various factors analyzed above and their potential impact on the proposed energy system. The main intent of this work can be summarized as follows:

- Economic analysis, Optimization and implementation of incentive based Demand response programme on grid connected Renewable hybrid energy based system.
- Finding Return on investment of system with least Net Present Value (NPV) while minimizing levelized cost of energy (COE) and total Annualized cost of the system.
- Appropriately deciding the energy system while performing sensitive analysis with or without different demand response incentives.
- Compare the utility with annualized bill savings, net present bill savings and annualized demand charge savings.

This paper is categorized in V sections: Section I outline economic analysis, Optimization and various aspects of Demand response programme on grid connected Renewable hybrid energy based system. Section II presents the problem formulation. Section III briefly explained grid connected system having PV and storage based facilities and data required.

Section IV presents different incentive based DRs considering grid connected renewable energy system, results are presented and discussed. Section V accommodates the conclusion and future scope followed by references.

## SECTION II
## PROBLEM FORMULATION

In this paper incentive oriented Demand Response Programme (DRP) is categorized into two programmes one is Normal Relief Programme (NRP) other is Commercial Relief Programme (CRP). NRP event triggered by congestion of network that may have a potential for an outage. In NRP, calling an event to occur needed advance 2 hours notification. Utility will pay Rs.300/kW to consumer for his reduction in load. Any number of events can be called on any day between 01 May to 30 September between 7:00 AM to 19:00 PM for four hours. On the other hand, CRP event triggered by forecast of day ahead peak demand system while reaching 90% of overall peak demand forecast in summer. In CRP, calling an event to occur needed advance 21 hours notification. Utility will pay Rs.100/kW to consumer for his reduction in load. Any number of events can be called on any day between 01 May to 30 September between 00:00 AM to 19:00 PM for four hours.

HOMER [20] is used for various system configurations that have been classified in the optimization results on total net present cost. HOMER calculate total annualized cost of the system , levelized cost of energy (LCOE) and Net present cost (NPC) of system by adding the total deducted cash flows in each year of the project lifetime. Significant economic output feature of HOMER is Net Present Cost of system, which is the present value of all the costs like initial investments, replacement costs, operation and maintenance costs and other miscellaneous costs in a system, the system incurs over its lifespan and subtracts the present value of all the profits it earns. HOMER also computes Return on investment (ROI) by doing difference in nominal cash flow over the project lifespan divided by capital cost difference. The total annualized cost is calculated using the annualized value of the total net present cost, which can be evaluated as follow:

$$C_{ann,tot} = CRF(i, R_{proj}) C_{NPC,tot} \quad (1)$$

where:

$C_{NPC,tot}$ the total net present cost of system[Rs.]

$i$ the annual real discount rate [%]

$R_{proj}$ the project lifetime [yr]

$CRF$ a function returning the capital recovery factor.

HOMER calculates the annual real discount rate from the “Nominal discount rate” and “Expected inflation rate” inputs as shown by (2). It uses this real discount rate to calculate discount factors and annualized costs.

$$i = \frac{i' - f}{1 + f} \quad (2)$$

where:

$i'$ nominal discount rate (the rate at which you could borrow money)

$f$ expected inflation rate.

The capital recovery factor function as given by expression (3) used to calculate the present value of annuity.

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (3)$$

where:

$N$ number of years.

The expression for Levelized cost of energy (COE), is given in (4).

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (4)$$

where:

$C_{ann,tot}$ total annualized cost of the system[Rs./yr]

$E_{served}$ total electric load served[kwh/yr]

Return on investment (ROI) is given by equation (5)

$$ROI = \sum_{i=0}^{R_{proj}} \frac{C_{i,ref} - C_i}{R_{Proj}\,(C_{cap} - C_{cap,ref})} \quad (5)$$

where:

$C_{i,ref}$ nominal annual cash flow for base system.

$C_i$ nominal annual cash flow for current system.

$R_{Proj}$ project lifetime in years

$C_{cap}$ capital cost of current system.

$C_{cap,ref}$ capital cost of base system.

## SECTION III
## SYSTEM ILLUSTRATION

Proposal of this plan is for a small Restaurant Jaggi Resorts located, at Sirhind in Punjab having coordinates of $30^0$ 36 N latitude and $76^0$ 22 E longitude is presented in this paper. The proposed location has average load of 25.08 kW and peak load of 37.95 kW. Total average energy consumption of resort is 601.89 kwh/day. Proposed micro grid with PV and battery energy system is grid connected as shown in figure 1.

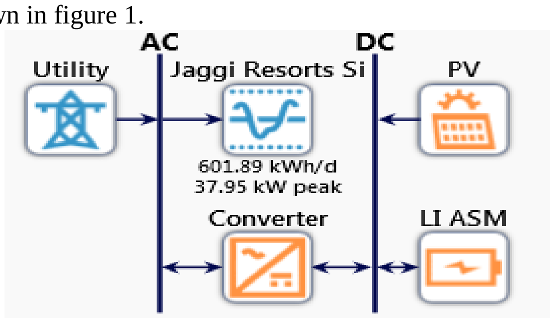


**Fig. 1 Available Portfolio of System**

### A. Solar resource

For the proposed site plan, solar resource data is taken from NASA surface metrology website [23]. For this region, the annual average radiation is 5.44 kWh/m$^2$/day. Average Solar radiation for whole year and clearness index of this location is shown in fig. 2

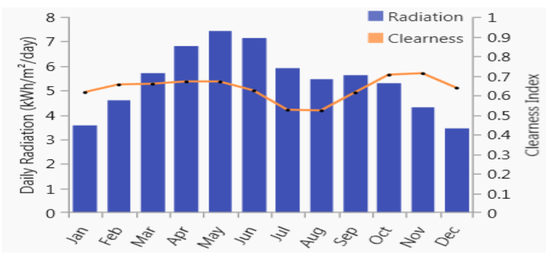


**Fig. 2: Solar Radiation Profile of Proposed Site**

Average solar radiation and clearness index for each month is given in Table-I for the proposed site plan. With change in season there is variation in average solar radiation, minimum daily radiation 3.450 kwh/m$^2$/day occurs in the month of December and maximum daily radiation 7.420 kwh/m$^2$/day occurs in the month of May.

**Table-I: Average solar radiation and clearness index profile**

| Month | Daily Radiation (kwh/m$^2$/day) | Clearness index |
|---|---|---|
| January | 3.570 | 0.614 |
| February | 4.610 | 0.653 |
| March | 5.710 | 0.656 |
| April | 6.810 | 0.668 |
| May | 7.420 | 0.668 |
| June | 7.120 | 0.623 |
| July | 5.890 | 0.524 |
| August | 5.460 | 0.520 |
| September | 5.620 | 0.612 |
| October | 5.290 | 0.703 |
| November | 4.320 | 0.710 |
| December | 3.450 | 0.636 |

## B. Component Costs

**Table-II: Component Costs**

| Component | Capital cost per kw | Replacem-ent cost per kw | Maint-enance cost per kw | Lifetime |
|---|---|---|---|---|
| PV module [22] | Rs.70000 | Rs.63000 | Rs.0/yr | 25 yr |
| Converter [21] | Rs.47000 | Rs.47000 | Rs.135/yr | 15 yr |
| Battery [21] | Rs.10000 | Rs.10000 | Rs.135/yr | 10 yr |

Cost of PV module, converter and battery in terms of capital cost per kw, replacement cost per kw and maintenance cost per kw, are presented in Table-II. Lifetime of each component in years/hours is also presented in the same.

## SECTION IV
## RESULTS AND DISCUSSIONS

Table III presents system configuration with different energy systems. Sensitive analysis of Normal Relief Programme and Commercial Relief Programme with the cost of incentives are presented. Four configurations having variation in their size capacity and numbers are shown,all configurations are compared in same order in table IV-VII.

**Table- III: System Architecture with DR**

| NRP Rs. | CRP Rs. | PV/ KW | Battery /No. | Utility/ KW | Converter /KW |
|---|---|---|---|---|---|
| 0 | 0 | 137 | 14 | 50 | 81.1 |
| 0 | 100 | 136 | 15 | 50 | 80.8 |
| 300 | 0 | 139 | 20 | 50 | 81.0 |
| 300 | 100 | 137 | 22 | 50 | 82.1 |

Table IV presents cost comparison of all configurations in terms of net present cost (NPC),Cost of energy (COE) , and Operating cost.This table shows that the configuration no. 4 with NRP Rs 300 and CRP Rs.100 has minimum cost of energy i.e Rs.4.60 with minimum NPC and minimum operating cost.

**Table- IV : Cost Comparison with DR**

| NRP Rs. | CRP Rs. | NPC Rs. | COE Rs. | Operating Cost Rs./ Yr |
|---|---|---|---|---|
| 0 | 0 | 19.6M | 4.74 | 4,67,676 |
| 0 | 100 | 19.4M | 4.72 | 4,60,653 |
| 300 | 0 | 19.0M | 4.61 | 4,09,389 |
| 300 | 100 | 18.9M | 4.60 | 4,02,924 |

**Table –V: System Metrics with DR**

| NRP Rs. | CRP Rs. | IRR % | ROI % | Simple payback Yrs |
|---|---|---|---|---|
| 0 | 0 | 8.5 | 5.7 | 9.6 |
| 0 | 100 | 8.6 | 5.8 | 9.5 |
| 300 | 0 | 8.9 | 6.0 | 9.4 |
| 300 | 100 | 9.0 | 6.1 | 9.3 |

Table V discuss about system metrics considering DR programmes NRP and CRP ,which shows that with incentive of Rs. 300 in NRP and Rs.100 in CRP , percentage internal rate of return (IRR) and ROI increases and simple year pacback time decreases as compared to other configurations.

**Table-VI : System Savings With DR**

| NRP Rs. | CRP Rs. | Utility Bill Savings Rs./Yr | Total Bill Savings Rs. | Demand Charge Savings Rs./Yr |
|---|---|---|---|---|
| 0 | 0 | 1.44 M | 18.6M | 57,330 |
| 0 | 100 | 1.44M | 18.6M | 66,924 |
| 300 | 0 | 1.48M | 19.2M | 94,477 |
| 300 | 100 | 1.49 M | 19.3 M | 1,06,958 |

Table VI shows that the Utility Bill Savings, Total Bill Savings and Demand Charge Savings are highest in configuration with NRP Rs 300 and CRP Rs.100.

**Table - VII:Utility Economics with DR**

| NRP Rs. | CRP Rs. | Demand Cost Rs. | Energy Purchased (KWH) | Energy Sold (KWH) |
|---|---|---|---|---|
| 0 | 0 | 2,66,305 | 1,08,413 | 99,442 |
| 0 | 100 | 2,54,797 | 1,08,232 | 98,642 |
| 300 | 0 | 2,12,506 | 1,06,696 | 99,163 |
| 300 | 100 | 1,99,333 | 1,06,433 | 98,370 |

Table VII discuss utility economics with demand response,which shows that demand cost reduced with large margin in fourth configuration. Energy Purchased and energy sold are moderately comparable to above three configurations.

**Table–VIII : NRP events for optimized bidding**

| NRP Event Date | Optimize demand reduction bid KW | Load Peak During event KW | Actual Demand Peak KW | Demand reduction Revenue Rs. |
|---|---|---|---|---|
| 20-08-19 | 10.1 | 34.5 | 24.5 | 3016 |
| 26-08-19 | 33.9 | 34.5 | 0.605 | 10162 |
| 1/6/2019 | 33.7 | 35.4 | 1.73 | 10104 |
| 16-09-19 | 36.5 | 36.6 | 0.0544 | 10951 |
| 27-09-19 | 34.2 | 37.1 | 2.88 | 10252 |

**Table-IX: CRP Events for optimized bidding**

| CRP Event Date | Optimize demand reduction bid KW | Load Peak During event KW | Actual Demand Peak KW | Demand reduction revenue Rs. |
|---|---|---|---|---|
| 13-06-19 | 35.9 | 35.9 | 0 | 3588 |
| 06-08-19 | 34.9 | 34.9 | 0 | 3488 |
| 29-09-19 | 7.85 | 15.9 | 8.01 | 785 |
| 09-09-19 | 3.23 | 30.4 | 27.2 | 323 |
| 12-08-19 | 18.9 | 32.2 | 13.3 | 1895 |

Table VIII and IX presents the summary of DR events timing with optimized demand reduction bid, load peak during event, actual demand peak and demand reduction revenue.Their detailed outputs are discussed from figs. 3-12.

Renewable Load Utility Bid Limit

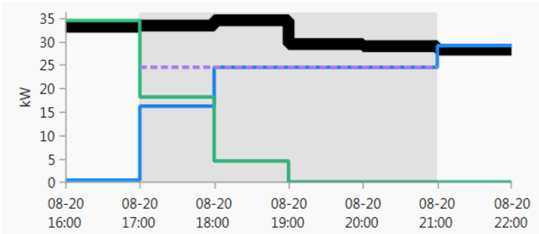


**Fig. 3**

Fig. 3 presents the Demand response event on dated 20 August occuring for 4 hours between 17:00 hrs to 21:00 hrs where the Load Peak During event is 34.5 KW and Actual Demand Peak is 24.5 KW.Hence an Optimized demand Reduction Bid is about 10.1 KW and Demand reduction Revenue is about Rs.3016.

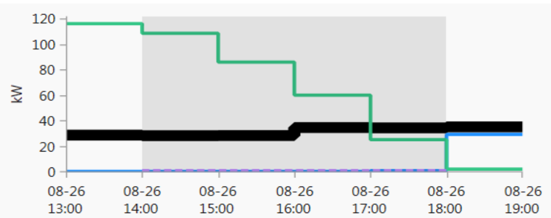


**Fig. 4**

Fig. 4 presents the Demand response event on dated 26 August occuring for 4 hours between 14:00 hrs to 18:00 hrs where the Load Peak During event is 34.5 KW and Actual Demand Peak is 0.605 KW .Hence an Optimized demand Reduction Bid is about 33.9 KW and Demand reduction Revenue is about Rs.10162.

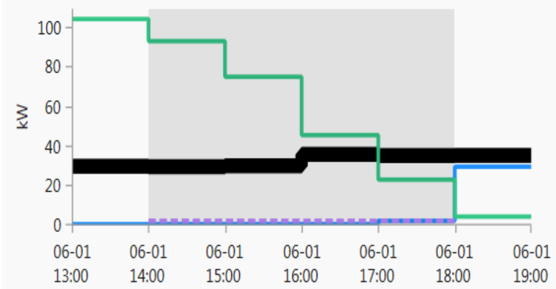


**Fig. 5**

Fig. 5 presents the Demand response event on dated 01 June occuring for 4 hours between 14:00 hrs to 18:00 hrs where the Load Peak During event is 35.4 KW and Actual Demand Peak is 1.73 KW. Hence an Optimized demand Reduction Bid is about 33.7 KW and Demand reduction Revenue is about Rs.10104.

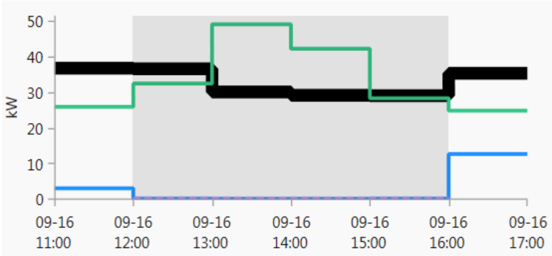


**Fig.6**

Fig. 6 presents the Demand response event on dated 16 September occuring for 4 hours between 12:00 hrs to 16:00 hrs where the Load Peak During event is 36.6 KW and Actual Demand Peak is 0.0544 KW .Hence an Optimized demand Reduction Bid is about 36.5 KW and Demand reduction Revenue is about Rs.10951.

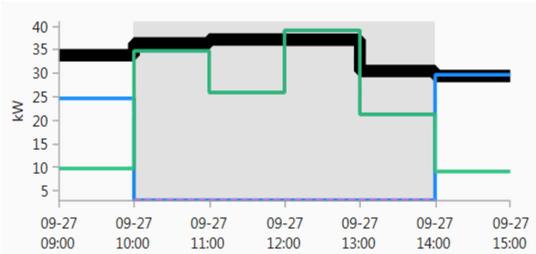


**Fig. 7**

Fig. 7 presents the Demand response event on dated 27 September occuring for 4 hours between 10:00 hrs to 14:00 hrs where the Load Peak During event is 37.1 KW and Actual Demand Peak is 2.88 KW. Hence an Optimized demand Reduction Bid is about 34.2 KW and Demand reduction Revenue is about Rs.10252.

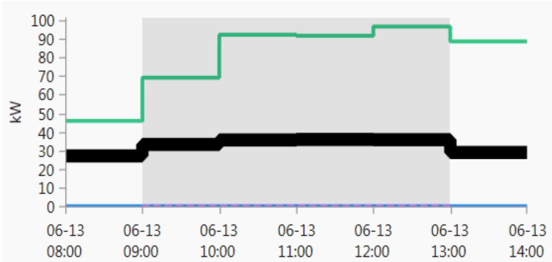


**Fig. 8**

Fig. 8 presents the Demand response event on dated 13 June occuring for 4 hours between 09:00 hrs to 13:00 hrs where the Load Peak During event is 35.9 KW and Actual Demand Peak is 0 KW. Hence an Optimized demand Reduction Bid is about 35.9 KW and Demand reduction Revenue is about Rs.3588.

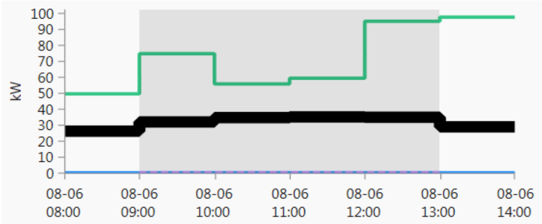


**Fig. 9**

Fig. 9 presents the Demand response event on dated 06 August occuring for 4 hours between 09:00 hrs to 13:00 hrs where the Load Peak During event is 34.9 KW and Actual Demand Peak is 0 KW.Hence an Optimized demand Reduction Bid is about 34.9 KW and Demand reduction Revenue is about Rs.3488.

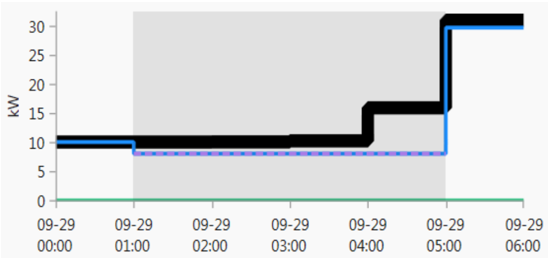


**Fig. 10**

Fig.10 presents the Demand response event on dated 29 September occuring for 4 hours between 01:00 hrs to 05:00 hrs where the Load Peak During event is 15.9 KW and Actual Demand Peak is 8.01 KW .Hence an Optimized demand Reduction Bid is about 7.85 KW and Demand reduction Revenue is about Rs.785.

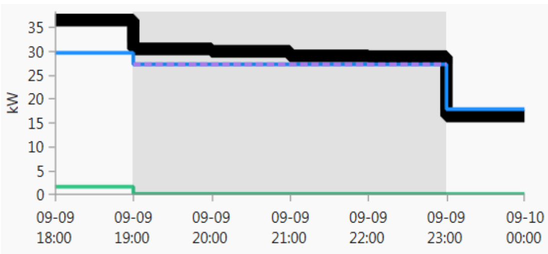


**Fig. 11**

Fig.11 presents the Demand response event on dated 09 September occuring for 4 hours between 19:00 hrs to 23:00 hrs where the Load Peak During event is 30.4 KW and Actual Demand Peak is 27.2 KW.Hence an Optimized demand Reduction Bid is about 3.23 KW and Demand reduction Revenue is about Rs.323.

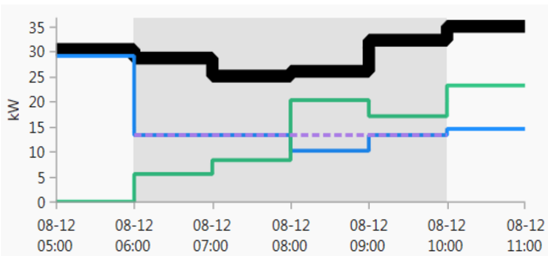


**Fig. 12**

Fig. 12 presents the Demand response event on dated 12 August occuring for 4 hours between 06:00 hrs to 10:00 hrs where the Load Peak During event is 32.2 KW and Actual Demand Peak is 13.3 KW .Hence an Optimized demand Reduction Bid is about 18.9 KW and Demand reduction Revenue is about Rs.1895.

## SECTION V
## CONCLUSION

This paper presents the optimization and economical feasibility for a utility connected MG having PV and battery storage energy system. A comparative study for four different Demand Response incentive sensitivities with NRP and CRP is carried out. For optimization and least cost combination renewable energy alternative PV is considered in the microgrid plan. For case study, HOMER software is used for Simulation, Optimization and Sensitivity Analysis.

Results show that configuration plan having both incentive of Rs.300 in NRP and incentive of Rs.100 in CRP, significantly optimizing the bidding by calling an event and has least net present cost and minimum levelized cost of energy This system can achieve the demand at a cost of Rs.4.60/kWh. The plan is able to increase the IRR and ROI and significantly reduces years of payback. Utility bill savings, total bill savings and demand charge savings are convincingly increase in the system. Significant reduction in demand cost is also analysed in this proposed plan.

In future, incentive based DRP can be compared with other grid connected PV-Biomass and Hydel hybrid energy systems and can also be compared with other DRP techniques which may improve not only energy crisis but also excess energy of the system can be sold out.

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