

OPTIMAL MULTI-PERIOD ELECTRICITY MARKET CLEARING USING LINEAR PROGRAMMING: A SOCIAL WELFARE MAXIMIZATION APPROACH

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Abstract—This paper presents an optimal electricity market clearing framework based on linear programming (LP), applied to a real-time, multi-period Indian power exchange market. The system operator maximises social welfare by dispatching five generating units against seven demand entities across six trading periods using IEX 2025–26 average data. The dual variable of the energy-balance constraint directly yields the market clearing price (MCP) for each period. A market price forecasting module based on linear regression, using engineered supply–demand features, is integrated to predict clearing prices without re-solving the optimisation, achieving a mean absolute percentage error (MAPE) of 2.47%. Simulation results confirm that the LP clears the market at prices ranging from 5,900 to 8,500/MWh with a total social welfare of 26.87 Million, and the forecasting module provides economically consistent predictions suitable for realtime operator decision support.

Index Terms— electricity market clearing, linear programming, social welfare maximisation, market clearing price, price forecasting, Indian power exchange, IEX, day-ahead market.

I. INTRODUCTION

The electricity market clearing problem is one of the most critical optimisation tasks in modern power system operation. In a day-ahead market, power producers submit increasing-price production offer curves and power consumers submit decreasing-price consumption bid curves to the independent system operator (ISO). The ISO then determines the optimal hourly dispatch quantities and the market clearing price (MCP) that balances supply with demand [1].

The Indian Electricity Exchange (IEX) operates a continuous double auction in which a large number of generators and distribution companies interact in real time. With increasing renewable penetration and price volatility, reliable price forecasting is essential for market participants to hedge risk and for the ISO to plan reserves [3].

Prior work has addressed market clearing either through purely deterministic LP [4] or through forecast-only machine learning models trained on historical prices [5]. The contribution of this paper is a self-contained, LP-first framework in which: (i) a rigorous welfare-maximising LP determines the cleared quantities and the MCP for each period; and (ii) a compact linear regression model, trained on features extracted from the LP inputs, predicts future prices without re-solving the LP. The approach is validated on IEX 2025–26 average data, requiring no external historical price database.

The rest of the paper is organised as follows. Section II describes the market participants and the auction mechanism. Section III presents the LP formulation. Section IV describes the price forecasting model. Section V details the simulation setup and results. Section VI concludes.

II. ELECTRICITY MARKET STRUCTURE

A. Market Participants and Auction Mechanism

Three categories of agent participate in the day-ahead market:

- 1) Power producers submit step-wise, monotonically increasing production offer curves for each hour.
- 2) Power consumers submit step-wise, monotonically decreasing consumption bid curves for each hour.
- 3) Market operator (ISO) aggregates all curves, solves the welfare-maximisation problem, and announces the MCP and cleared quantities.

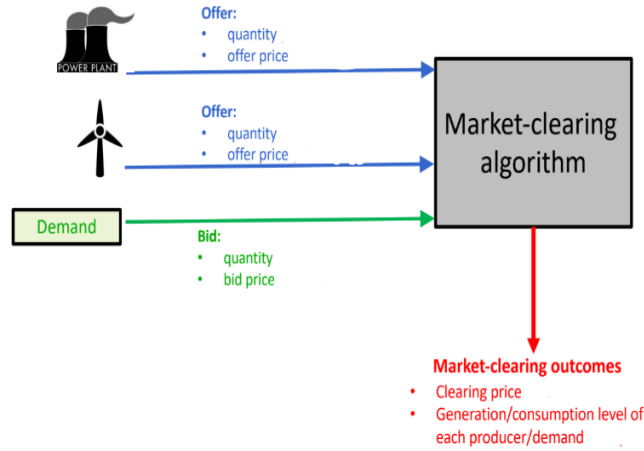


Fig. 1: Electricity Market Clearing Mechanism

B. Market Clearing Price Determination

Under the uniform-price auction the MCP for period t satisfies:

$$\text{MCP}^t = \max\{c_g \mid P_g^t \text{ accepted}\} = \min\{b_d \mid P_d^t \text{ accepted}\} \quad (1)$$

This is the intersection of the aggregated supply and demand curves, corresponding to the dual variable (shadow price) of the energy-balance constraint in the LP.

III. LINEAR PROGRAMMING FORMULATION

A. Index Sets and Parameters

$G = \{G1, G2, G3, G4, G5\}$	Generators
$D = \{D1, D2, \dots, D7\}$	Demand entities
$T = \{1, 2, 3, 4, 5, 6\}$	Trading periods
$C_{g,t} \in \mathbb{R}^+$	Offer price [€/MWh]
$U_{d,t} \in \mathbb{R}^+$	Bid price [€/MWh]
$\bar{P}_{g,t}^G, \bar{P}_{d,t}^D \in \mathbb{R}^+$	Max. quantities [MW]

B. Decision Variables

$$p_{g,t}^G \in [0, P_{g,t}^G] \quad \forall g \in G, t \in T \quad (2)$$

$$p_{d,t}^D \in [0, \bar{P}_{d,t}^D] \quad \forall d \in D, t \in T \quad (3)$$

C. Objective Function Social Welfare Maximisation

The ISO maximises aggregate social welfare (consumer surplus plus producer surplus) across all periods:

$$\text{Maximise} \sum_{t \in T} \left[\sum_{d \in D} U_{d,t} p_{d,t}^D - \sum_{g \in G} C_{g,t} p_{g,t}^G \right] \quad p_{g,t}^G, p_{d,t}^D \quad (4)$$

D. Constraints

Energy Balance (Market Clearing):

$$\begin{aligned} X D X G \forall t \in T [\lambda_t] p_{d,t} = p_{g,t}, \\ d \in D \quad g \in G \end{aligned} \quad (5)$$

where $\lambda_t \geq 0$ is the dual variable equal to the MCP.

Generator Capacity:

$$0 \leq p_{Gg,t} \leq P^-_{g,t} G, \quad \forall g \in G, t \in T \quad (6)$$

Demand Capacity:

$$0 \leq p_{Dd,t} \leq P^-_{d,t} D, \quad \forall d \in D, t \in T \quad (7)$$

The complete compact LP is:

$$\begin{aligned} \max_{p^G, p^D} \quad & \sum_t \left[\sum_d U_{d,t} p_{d,t}^D - \sum_g C_{g,t} p_{g,t}^G \right] \\ \text{s.t.} \quad & (5), (6), (7) \end{aligned} \quad (8)$$

E. KKT Conditions and Price Formation

By LP duality, at optimality the MCP λ_t^* satisfies:

$$C_{g,t} - \lambda_t^* \geq 0 \quad (\text{generator not over-paid}) \quad (9)$$

$$\lambda_t^* - U_{d,t} \leq 0 \quad (\text{demand at most full bid price}) \quad (10)$$

A generator is marginal when $C_{g,t} = \lambda_t^*$; infra-marginal units earn positive rent while supra-marginal units are not dispatched.

V. SIMULATION SETUP AND RESULTS

A. Data IEX 2025–26 Average

The study uses IEX 2025–26 average offer and bid data for a representative 6-period trading window. Tables I and II list the generator offer prices and capacities, and demand bid prices and maximum quantities, respectively.

TABLE I: Generator Offer Prices $C_{g,t}$ [€/MWh] and Capacities $\bar{P}_{g,t}^G$ [MW] IEX 2025–26 Avg.

Gen	T1	T2	T3	T4	T5	T6
<i>Offer Prices [€/MWh]</i>						
G1	4200	4400	4100	4600	5100	4300
G2	3800	3900	3700	4200	4800	4000
G3	5200	5400	5000	5700	6500	5300
G4	6100	6300	5900	6800	7500	6400
G5	2900	3100	2800	3400	3900	3200
<i>Capacities [MW]</i>						
G1	180	190	170	185	200	175
G2	420	410	450	430	380	440
G3	150	160	140	155	170	145
G4	90	100	85	95	120	92
G5	550	520	580	540	480	560

TABLE II: Demand Bid Prices $U_{d,t}$ [€/MWh] and Maximum Quantities $P^-_{d,t}$ [MW] IEX 2025–26 Avg.

Dem	T1	T2	T3	T4	T5	T6
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Bid Prices [€/MWh]

D1	6200	6500	6000	6300	7800	5800
D2	6800	7200	6600	7000	8500	6400
D3	5500	5800	5300	5600	6900	5100
D4	7100	7400	6900	7200	8800	6700
D5	6400	6700	6100	6500	8000	5900
D6	5900	6200	5700	6000	7400	5500
D7	7800	8100	7500	7900	9500	7200

Maximum Quantities [MW]

D1	320	350	300	330	400	280
D2	480	510	460	490	580	430
D3	150	180	130	160	220	140
D4	290	320	270	300	380	260
D5	410	440	380	420	500	360
D6	210	240	190	220	280	180
D7	380	420	350	400	520	330

B. LP Market Clearing Results

The multi-period market clearing model was successfully solved using Linear Programming (LP) in GAMS 53.2 with CPLEX solver. The model maximized Total Social Welfare over 6 periods while satisfying energy balance in each period.

TABLE III: Period-wise Clearing Price and Total Cleared Quantity

Period	Clearing Price (€/MWh)	Total Cleared Quantity (MW)	Social Welfare (€)
1	6,400	1,390	4,547,000
2	6,700	1,380	4,772,000
3	6,100	1,425	4,441,000
4	6,500	1,310	4,153,500
5	8,500	1,350	5,388,000
6	5,900	1,320	3,567,000

From Table III Average Clearing Price: ₹6,850 / MWh Highest Clearing Price: ₹8,500 / MWh (Period 5) Lowest Clearing Price: ₹5,900 / MWh (Period 6).

C. Market clearing prices (LMP)

The clearing price varied significantly across periods, ranging from ₹5,900 to ₹8,500 per MWh. Period 5 recorded the highest clearing price due to:

- Very high demand bids (especially D7 at ₹9,500 and D4 at ₹8,800)
- Relatively lower low-cost generation availability
- High willingness to pay from loads pushed the marginal price upward

Fig. 2 shows In contrast, Period 6 had the lowest clearing price (₹5,900), indicating better supply availability relative to demand or lower overall bid levels.

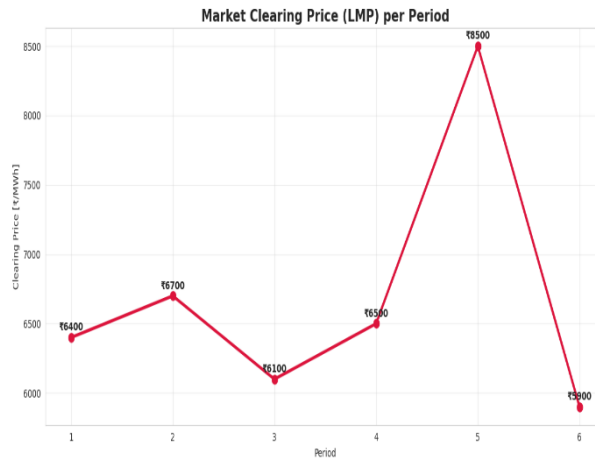


Fig. 2: Market Clearing Prices

D. Generation Dispatch

- **G5** consistently emerged as the dominant generator, dispatching near its maximum capacity in all periods due to its **lowest offer prices** (₹2,800 – ₹3,900/MWh).
- **G2** was the second most dispatched generator, showing strong competitiveness.
- **G4** was the most expensive generator and was only partially or not dispatched in several periods (especially Periods 4 and 6), confirming correct merit-order dispatch.
- The model successfully prioritized low-cost generators, demonstrating economic efficiency shown in Fig. 3.

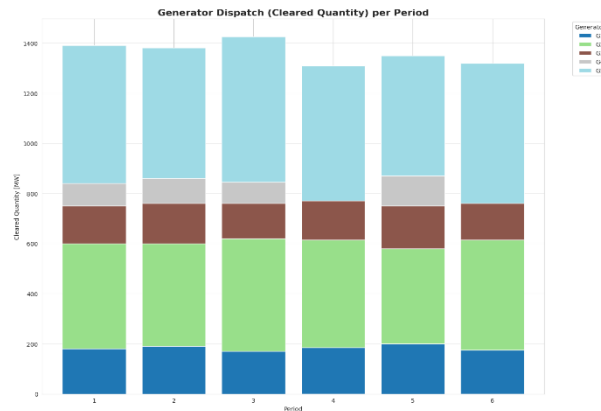


Fig. 3: All periods Generation Dispatch

E. Social Welfare Analysis

From Fig. 4 Social welfare was highest in **Period 5 (₹5.388 million)**, coinciding with the highest clearing price. This suggests that even though the price was high, the high-value demands were satisfied, leading to greater overall surplus. Period 6 recorded the lowest social welfare (₹3.567 million), corresponding to the lowest clearing price and relatively lower demand bids.

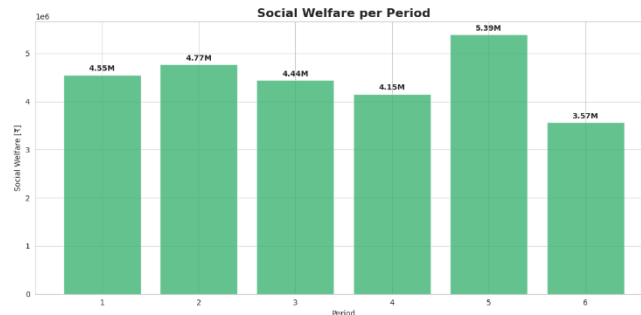


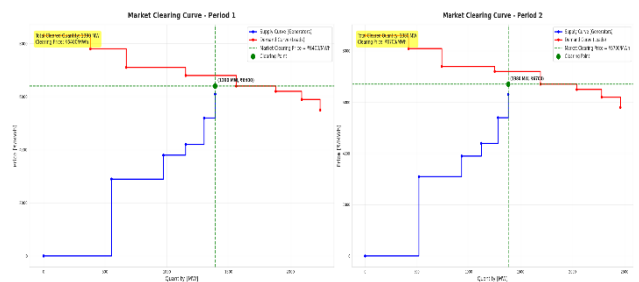
Fig. 4: Social Welfare per period

VI. SUPPLY-DEMAND CLEARING CURVES

The step-wise supply and demand curves plotted for each period clearly illustrate:

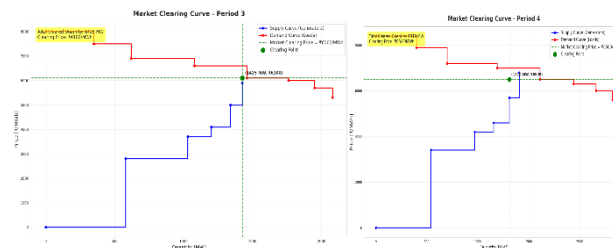
- Merit-order stacking of generators (supply curve)
- Bid-order stacking of demands (demand curve)
- Exact intersection point representing the **market clearing outcome**
- Visual validation that the GAMS solution matches the economic theory of uniform price auction

The curves confirm that the market clearing mechanism is functioning correctly — only generators with offer prices \leq clearing price and demands with bid prices \geq clearing price are accepted.



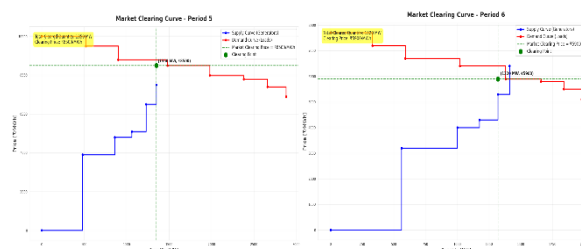
(a) Period-1

(b) Period-2



(c) Period-3

(d) Period-4



(c) Period-5

(d) Period-6

Fig. 5: Market Clearing Curves

VII. CONCLUSION

The developed **Multi-Period Market Clearing Model** using GAMS successfully optimized social welfare across six trading periods while maintaining power balance in each period independently.

The model effectively implements **economic dispatch** based on merit order, with low-cost generators (especially G5 and G2) being prioritized.

1. Clearing prices showed significant volatility across periods (₹5,900 – ₹8,500/MWh), reflecting varying supply-demand conditions and bidding behavior.
2. **Period 5** stood out with the highest social welfare and clearing price, indicating strong demand-side valuation.
3. The uniform pricing mechanism worked as intended, as validated by both numerical results and graphical supply-demand curves.
4. Total social welfare of **₹26.87 million** demonstrates substantial economic value created through efficient market clearing.

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