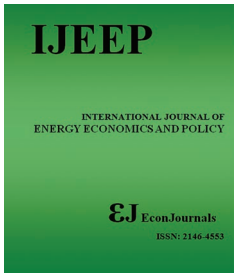


International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(5), 347-355.

Has Real Time Spot Electricity Market in India Impacted Day-Ahead Spot Electricity Market?

Rashmita Saran[1], Bharath Supra[2], G. P. Girish[1]*, Sweta Singh[1]

[1]ICFAI Business School, The ICFAI Foundation for Higher Education (A Deemed-to-be-University under Section 3 of UGC Act 1956), Hyderabad, Telangana, India, [2]School of Business Management, NMIMS University (A Deemed-to-be-University under Section 3 of UGC Act 1956), Mumbai, Maharashtra, India. *Email: gpgirish.ibs@gmail.com

Received: 06 May 2024 **Accepted:** 03 August 2024 **DOI:** https://doi.org/10.32479/ijeep.16984

ABSTRACT

Introduction of Real-Time Market (RTM) on June 1st, 2020, marked pivotal advancement in electricity trading in India featuring bi-hourly auctions and power transmission based on temporal blocks. Adherence to operational protocols outlined in Procedure for Scheduling Collective Transactions in RTM along with statutory directives like CERC Power Market Regulations 2010 ensures efficient market operation. Notable features include 15-min contract trading, clandestine bidding and authorization from SLDC. Day-Ahead Market (DAM) facilitates electricity exchange through double-sided closed auctions ensuring compliance with regulatory protocols. In this study we explore whether Real Time Spot Electricity Market in India has impacted Day-Ahead Spot Electricity Market. Findings of the study provide crucial insights for market participants, stakeholders, open access consumers and electric utilities is India.

Keywords: Electricity Market, Spot Electricity, Real Time Market, India, Day Ahead Market
JEL Classifications: Q40, Q41, Q48, Q49

1. INTRODUCTION

The inception of Real-Time Market (RTM) on June 1st, 2020 heralded sophisticated venue for electricity trading characterized by bi-hourly auction sessions. Power transmission is contingent upon lapse of four temporal blocks or an hour post-closure of auction's gate. Operational protocols adhere closely to directives delineated in Procedure for Scheduling Collective Transactions in Real Time Market as promulgated by the Power System Operation Corporation Ltd in conjunction with salient statutes such as CERC Power Market Regulations of 2010. It employs bifurcated closed auction bidding mechanism to ascertain price and volume of electricity transactions (CERC, 2024). Noteworthy attributes encompass trading of 15-min contracts, clandestine bidding and prerequisite for both buyers and sellers to procure authorization from SLDC predicated upon network accessibility and Availability Based Tariff (ABT). The exchange disseminates Area Clearing Price (ACP) and Area Clearing Volume (ACV) whilst mitigating risks via sundry strategies inclusive of bank balance and mandatory margin (IEX, 2024).

Day-Ahead Market (DAM) serves as conduit for physical exchange of electricity enabling transactions within various 15-min intervals throughout ensuing 24-h period commencing at midnight. This market modality operates via double-sided closed auction bidding mechanism wherein pricing and volume of electricity are ascertained. Compliance with regulatory protocols notably Procedure for scheduling of collective transactions stipulated by Central Transmission Utility (PGCIL), CERC (Open Access in Inter-State Transmission) Regulations of 2008 and governing Bye-Laws, Rules and Business Rules of Exchange is rigorously observed (Girish, 2016). Prominent attributes encompass trading

This Journal is licensed under a Creative Commons Attribution 4.0 International License

of 15-min contractual arrangements, anonymity within the bidding process, validation from State Load Dispatch Centers (SLDC) contingent upon network accessibility and deployment of ABT meters, congestion mitigation via market segmentation and establishment of ACP tailored to specific regions. Risk mitigation is effectuated through mandated margins inclusive of any supplementary provisions earmarked for distinct trading sectors or contractual modalities (Girish et. al., 2014; CERC, 2024; IEX, 2024; Agrawal and Tripathi, 2019).

Table 1 presents India's gross electricity generation in billion units spanning decade and a half delineating outputs from various sources of generating electricity such as thermal, hydro, nuclear, renewable energy sources (RES) and imports from Bhutan. Over this temporal expanse discernible upward trajectory in total energy output is apparent largely propelled by substantive contributions from thermal and hydroelectric sources (CEA, 2024). While thermal energy remains preeminent in energy amalgam a conspicuous surge in renewable energy sources is observable signaling transition towards cleaner energy modalities. Persistent role of Bhutanese imports in energy supply continuum is notable. Steady amplification in nuclear energy production is discernible. There is dynamic metamorphosis in India's energy landscape exemplifying diversification of energy sources (Girish et al., 2018).

Figure 1 delineates total installed generating capacity source-wise in India as of March 31st, 2024. Coal emerges as predominant source constituting 47.7% of total with Renewable energy sources trailing at 32.5%. The utilization of diesel (0.133%) and Gas (5.66%) for electricity generation remains marginal reserved primarily for periods of peak demand or energy shortfall. Despite their cost-intensive nature gas and diesel play crucial role in meeting peak electricity demand and are typically transacted within Real-Time Market (RTM) alongside Day-Ahead Market (DAM). (Agrawal, 2022; Ministry of Power, 2003).

Figure 2 expounds upon intricacies concerning Consumption of Electricity generated in India across various sectors during 2020-21 as per report from Central Electricity Authority (CEA). In Indian context electricity finds primary application in industrial endeavors characterized by high voltage succeeded by domestic utilization and subsequently by agricultural pursuits. A nominal fraction of electricity is allocated towards commercial endeavors, industrial operations involving low and medium voltage, public illumination, traction, public water supply infrastructure and sewage pumping systems among others (CEA, 2024). Comprehending this facet facilitates acknowledgment of functions fulfilled by Day-Ahead Market (DAM) and Real-Time Market (RTM) within Indian electricity marketplace. The subsequent sections of paper are organized as follows: Section 2 provides an in-depth exploration of Indian electricity market, power exchanges and spot electricity market. Section 3 elucidates the roles undertaken by DAM and RTM in India culminating in conclusion of our study in Section 4.

2. INDIAN ELECTRICITY MARKET

The Indian electricity market is complex ecosystem encompassing generation, distribution, transmission and commercial dealings of electrical energy within the country by engaging diverse stakeholders and entities such as electricity producers, transmission entities, distribution enterprises, regulatory authorities and electricity trading platforms collaboratively striving to uphold dependable provision and effective allocation of electricity to consumers spanning various industries. (Girish et al., 2023; Girish et al., 2015) Table 2 intricately delineates hierarchical framework of India's power industry expounding upon multifaceted roles and obligations of various entities operating at central, state and regional/private echelons. It vividly portrays partitioned jurisdiction regarding formulation of policies, strategic planning, regulatory oversight, power generation, operational management, transmission, distribution, trading and the redressal mechanisms. At central level Ministry of Power exercises dominion over policy matters while regional administrations and private entities partake in execution and regulatory governance at localized levels. Central Electricity Authority (CEA) spearheads planning endeavors whereas Central Electricity Regulatory Commission (CERC) and Central Government Appointed Committee (CAC) administer regulatory affairs centrally. Analogously state electricity regulatory commissions (SERC) and state-appointed committees (SAC) preside over regulatory mandates at state

Table 1: Gross electricity generation from 2008-2009 to 2022-2023 in India (BU)

Year	Thermal	Hydro	Nuclear	Renewable energy sources	Bhutan import	Total
2008-2009	588.28	110.10	14.93	27.86	5.90	747.07
2009-2010	640.21	104.06	18.64	36.95	5.40	805.26
2010-2011	665.00	114.30	26.30	41.15	5.60	852.35
2011-2012	708.43	130.51	32.29	51.23	5.30	927.76
2012-2013	760.45	113.72	32.87	57.45	4.80	969.29
2013-2014	792.05	134.85	34.23	59.62	5.60	1026.35
2014-2015	877.94	129.24	36.10	61.79	5.00	1110.07
2015-2016	943.01	121.38	37.41	65.78	5.20	1172.78
2016-2017	994.22	122.31	37.66	81.87	5.64	1241.70
2017-2018	1037.06	126.12	38.35	101.84	4.78	1308.15
2018-2019	1072.00	135.00	37.70	126.76	4.40	1375.86
2019-2020	1044.45	155.67	46.38	138.32	5.81	1390.63
2020-2021	1032.51	150.30	43.03	147.25	8.77	1381.86
2021-2022	1114.71	151.63	47.11	170.90	7.49	1491.85
2022-2023	1206.21	162.10	45.86	203.55	6.74	1624.47

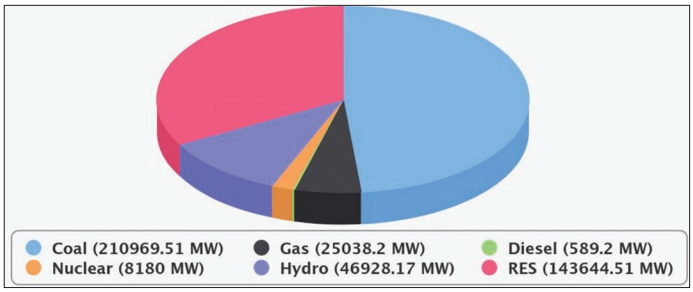
Source: Central electricity authority (CEA)

Table 2: Structure of power industry in India

Segment/Component	Centre	State/private	Private licensees
Policy	Ministry of power	State Government	
Plan	CEA		
Regulations	CERC and CAC	SERC and SAC	
Generation	CGS and Mega Power Projects	Generation Companies (Gencos) and IPP	Private Licensees in Ahmedabad, Kolkata, Delhi, Mumbai, Noida and Surat
System Operations	NLDC and RLDC	SLDC	
Transmission	CTU and Transmission licensees	STU and Transmission licensees	
Distribution	Distribution Licensees		
Trading	Power Exchanges (i.e. IEX and PXIL) and Trading Licensees	Trading Licensees	
Appeal	Appellate tribunal		

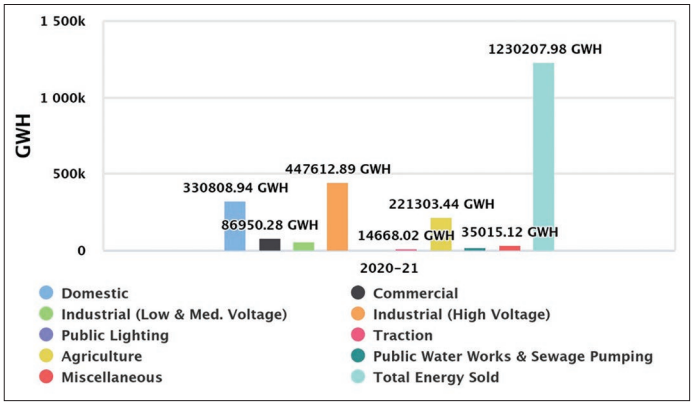
CEA: Central electricity authority, CERC: Central electricity regulatory commission, CAC: Central government appointed committee, SERC: State electricity regulatory commission, SAC: State government appointed committee, CGS: Central generating stations, IPP: Independent power producers, NLDC: National load dispatch centre, RLDC: Regional load dispatch centre, SLDC: State load dispatch centre, CTU: Central transmission utilities, STU: State transmission utilities, IEX: Indian energy exchange, PXIL: Power exchange India limited
Source: Girish et al. (2013); Girish et al. (2014); Ministry of Power (2003)

Figure 1: Total installed generating capacity source-wise in India (as on March 31st, 2024)



Source: Central Electricity Authority (CEA)

Figure 2: Consumption of electricity produced in India by different segments in 2022



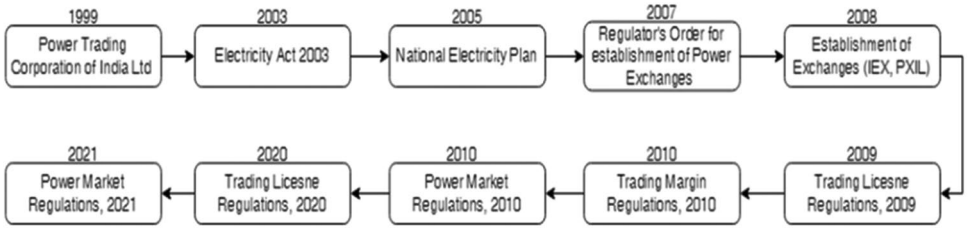
Source: Central Electricity Authority (CEA)

level. Generation endeavors are orchestrated by central generating stations (CGS), mega power projects, generation companies (Gencos) and independent power producers (IPP) encompassing private licensure in specific urban centers. System operations are meticulously overseen by National Load Dispatch Centre (NLDC) and Regional Load Dispatch Centre (RLDC) nationally along with state load dispatch centers (SLDC) provincially. Transmission activities are managed by central transmission utilities (CTU), transmission licensees, state transmission utilities (STU) and transmission licensees. Distribution primarily engages distribution licensees. Trading pursuits are facilitated through power exchanges like Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL) alongside trading licensees. Recourse mechanisms are available through the appellate tribunal for dispute resolution. Evolution of power sector reforms with introduction of policies and their timelines is presented in Figure 3 as compiled by Agrawal (2022).

The Indian Energy Exchange (IEX) serves as preeminent energy marketplace in India employing automated trading mechanisms for physical delivery of electricity, renewables and certificates on nationwide scale. IEX has pioneered cross-border electricity transactions expanding its operational scope beyond national borders to establish integrated South Asian Power Market. Driven by state-of-the-art technology, IEX places premium on customer-centric strategies ensuring efficient discovery of price points and seamless facilitation of power procurement procedures. Boasting expansive ecosystem comprising more than 7600 stakeholders across 28 states and 8 union territories including various distribution utilities both conventional and renewable energy producers as well as mandated entities IEX commands formidable presence within market landscape. IEX clientele encompasses over 4,800 commercial and industrial entities spanning diverse array of sectors such as manufacturing, information technology, institutional and commercial domains. Subject to regulation by the Central Electricity Regulatory Commission since its inception in June 2008, IEX achieved status of publicly listed entity on National Stock Exchange (NSE) and Bombay Stock Exchange (BSE) in October 2017. Offering spectrum of trading avenues including the Electricity Market (comprising the Day Ahead Market, Term Ahead Market, Real Time Market and Cross Border Electricity Trade), the Green Market (encompassing the Green Term Ahead Market and Green Day-Ahead Market) and Certificates Market (featuring Renewable Energy Certificates and Energy Saving Certificates), IEX presents array of opportunities for market participants to engage in energy exchange endeavors and champion sustainability initiatives (CERC, 2024; IEX; 2024). Figure 4 elucidates evolution of Indian Energy Exchange.

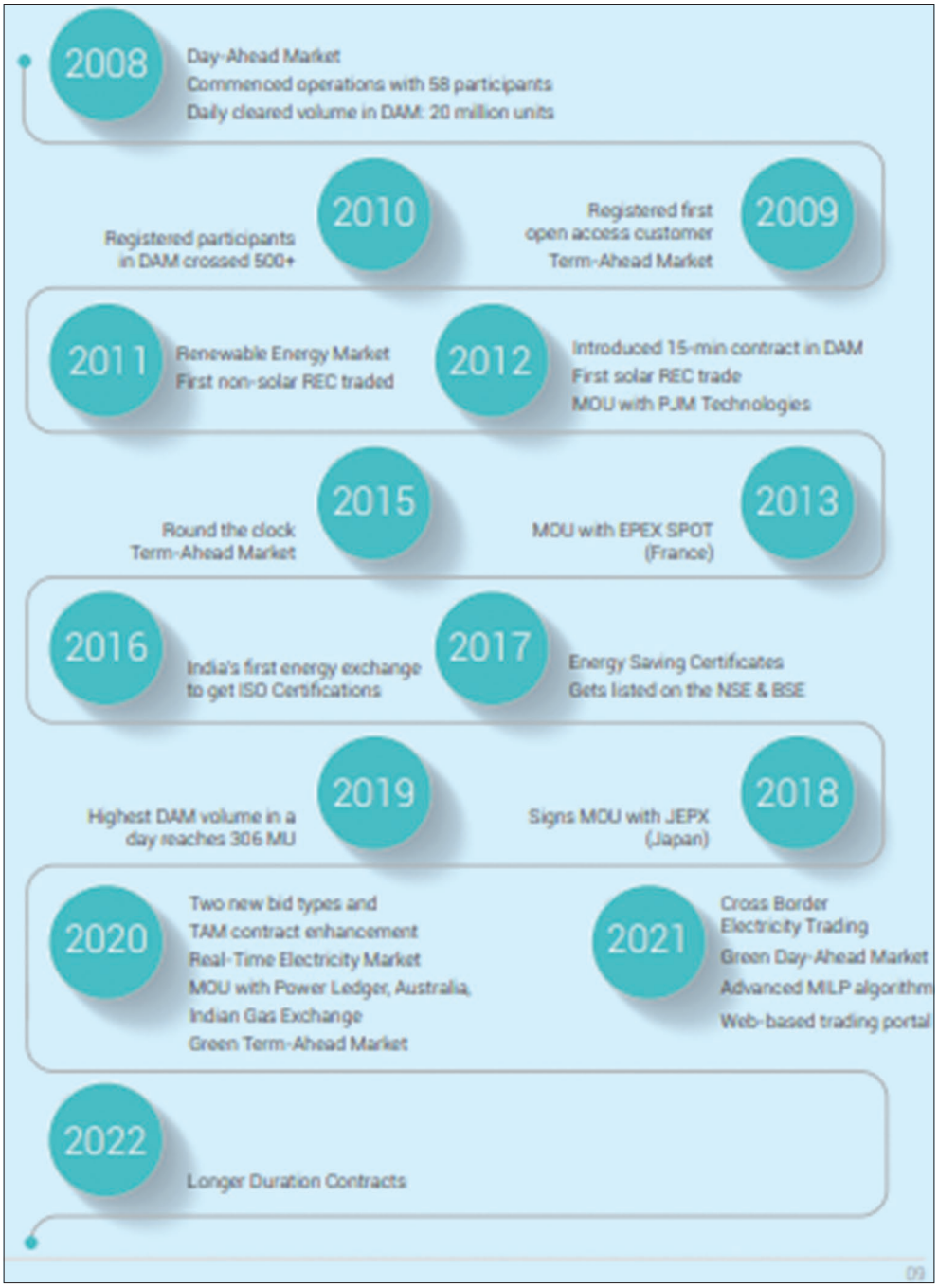
Figure 5 elucidates volume of various kinds of electricity transactions in total electricity generation in India (February 2024). Of the overall electricity generation, 85.63% was through long term power purchasing agreements. 14.37% was conducted

Figure 3: Evolution of power sector reforms in India



Source: Agrawal (2022)

Figure 4: Evolution of Indian energy exchange



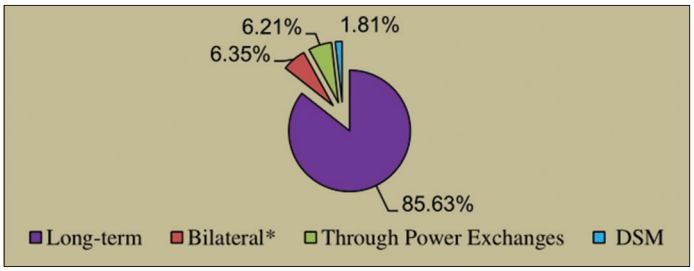
Source: Indian Energy Exchange (IEX)

through short-term agreements and Deviation Settlement Mechanisms (DSM). Within this 6.35% was facilitated through bilateral transactions involving trade intermediaries like traders, term-ahead contracts processed on power exchanges and direct

negotiations among distribution companies. 6.21% of electricity generation was directed through power exchanges encompassing both Day Ahead Market (DAM) and Real-Time Market (RTM) while 1.81% was overseen through DSM initiatives (CERC, 2024).

Table 3 elucidates India's power distribution dynamics spanning from 2008-2009 to 2022-2023 encompassing metrics such as energy requisites, availability, deficits (expressed as percentages) as well as peak energy demands and their corresponding availability and deficits (also represented as percentages). Over the years there has been consistent upward trajectory in energy demands reflective of nation's burgeoning appetite for electrical power. Accessibility of energy exhibits parallel ascent albeit at times falling short of meeting escalating demand. Despite concerted endeavors to narrow disparity deficits persist with some variability. There is general downward trend in deficits both in energy output and peak power, over the years indicative of enhancements in infrastructure and managerial practices. Persistent challenges endure particularly during certain periods where deficits surpass 10% mark underscoring imperative for sustained investment and refinement in power domain to secure dependable and sustainable energy provisioning aligning with nation's expanding energy requisites. This serves as testimony to the significant role that Day Ahead Market (DAM) and Real-Time Market (RTM) will play in years and decades ahead (CEA, 2024).

Figure 5: Volume of various kinds of electricity transactions in total electricity generation in India (February 2024)



Source: Central Electricity Regulatory Commission (CERC)

3. REAL TIME MARKET (RTM) AND DAY AHEAD SPOT ELECTRICITY MARKET IN INDIA (DAM)

Real-Time-Market (RTM) heralds nascent market segment commencing its trading endeavors on 1st of June, 2020. This market enclave orchestrates novel auction ritual unfolding every 30 min wherein dispensation of power occurs either post four temporal blocks or an hour subsequent to closure of auction gateway. Determinants of electricity's price and magnitude in this realm are discerned through bilateral closed auction marked by its duality in nature. Operations adhere meticulously to Protocol for Orchestrating Collective Transactions within Real-Time Market as promulgated by esteemed Power System Operation Corporation Ltd; alongside statutory directives of CERC Power Market Regulations of 2010, CERC Open Access in Inter-State Transmission Regulations of 2008, CERC Indian Electricity Grid Code Regulations of 2010 subject to amendments therein and ordinances, regulations and operational tenets delineated within the Bye-Laws, Rules and Business Rules of Exchange (CERC, 2024; IEX, 2024).

Timeline for Real-Time Market (RTM) operates as follows as elucidated in Figure 6: Participants can place bids and offers on Power Exchanges for power purchase and sale after revision period ends for specified half-hour period. Trading for day opens from 22:45 to 23:00 of previous day for first 2 time blocks of day repeating every half-hour thereafter. NLDC determines and communicates transmission corridor margins before RTM trading closure with allocation between exchanges based on their market share or a Commission-determined methodology. Post-auction power exchange optimizes and clears market by 23:15, communicating cleared transactions to NLDC for schedule incorporation into RLDCs/SLDCs which further inform generators and distribution companies. Cleared bids are binding both financially and physically for delivery period (CERC, 2024).

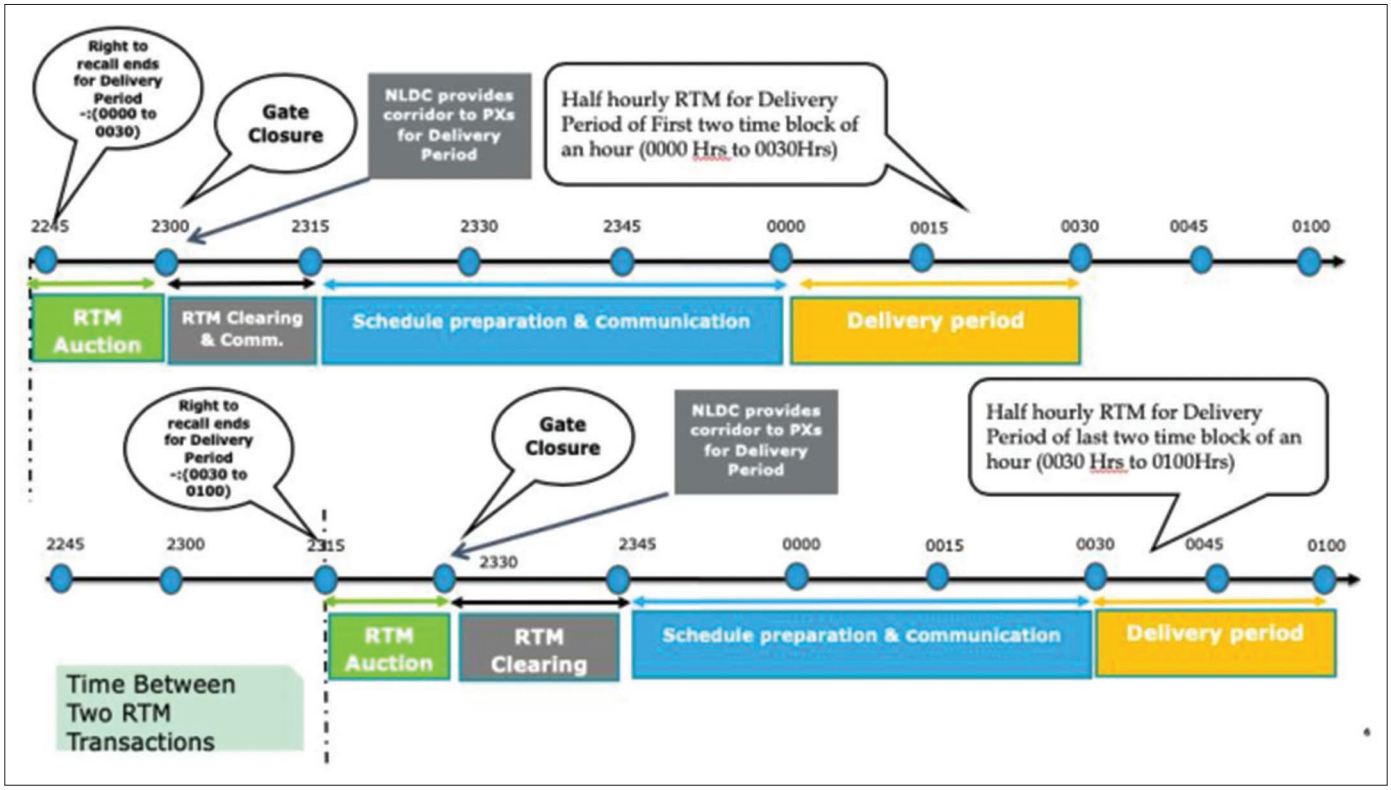
Agrawal and Kothari (2019) elucidated Indian power sector's transition from vertically integrated monopoly to wholesale

Table 3: Power supply position in India from 2008-2009 to 2022-2023

Year	Energy (BU)			Peak (GW)		
	Requirement	Availability	Deficit (%)	Requirement	Availability	Deficit (%)
2008-2009	777.04	691.04	11.1	109.81	96.79	11.9
2009-2010	830.59	746.64	10.1	119.17	104.01	12.7
2010-2011	861.59	788.36	8.5	122.29	110.26	9.8
2011-2012	937.20	857.89	8.5	130.01	116.19	10.6
2012-2013	995.56	908.65	8.7	135.45	123.29	9.0
2013-2014	1002.26	959.83	4.2	135.92	129.82	4.5
2014-2015	1068.92	1030.79	3.6	148.17	141.16	4.7
2015-2016	1114.41	1090.85	2.1	153.37	148.46	3.2
2016-2017	1142.93	1135.33	0.7	159.54	156.93	1.6
2017-2018	1213.33	1204.70	0.7	164.07	160.75	2.0
2018-2019	1274.60	1267.53	0.6	177.02	175.53	0.8
2019-2020	1291.01	1284.44	0.5	183.80	182.53	0.7
2020-2021	1275.53	1270.66	0.4	190.20	189.40	0.4
2021-2022	1379.81	1374.02	0.4	203.01	200.54	1.2
2022-2023	1511.85	1504.26	0.5	215.89	207.23	4.0

Source: Central electricity authority (CEA)

Figure 6: Timeline for Real-Time Market (RTM)



Source: CERC and Powerline (2020)

competition model mandated by Electricity Act 2003 highlighting persisting inefficiencies. Bharath Kumar and Singh (2021) study explored ancillary services' significance in Indian power system's security proposing roadmap for market development amidst renewable energy integration. Ahmad and Alam (2019) in their study discussed improved liquidity in Power Exchanges (PX) since 2008, assessment of renewable energy contributions, unmet RPO targets and risk management measures. Kaur et al., (2024) scrutinized asymmetrical dynamics characterizing enduring correlation between wholesale electricity prices in India's day-ahead market and determinants encompassing fossil fuel prices, exchange rates and economic policy uncertainty appraising repercussions stemming from introduction of Real-Time Market and unfolding Russia-Ukraine conflict. Roumkos et al. (2022) in their study exhaustively examine fully unified energy marketplace within EU's electricity target paradigm with emphasis on amalgamating balancing markets spanning European control domains delineating regulatory structure, aligning design parameters, elucidating existing market modalities, showcasing numerical instances and elucidating ongoing deployment initiatives. Jones (2021) explored prognostic potential of wholesale electricity basis within MISO exchange elucidating its impact on spot pricing while contesting projected variability in forward premiums diverging from prior theoretical frameworks. Amidst burgeoning intricacies of worldwide energy milieu and ascendance of renewable energy reservoirs prognosticating forthcoming power market dynamics assumes paramount importance yet endeavor to forecast singular bids within spot electricity markets evinces hopeful prospect albeit stymied by constraints inherent in prevailing optimization models accentuating exigency for an innovative adaptable framework amalgamating sophisticated machine learning methodologies as corroborated by Tang et al., (2024) in their empirical scrutiny of data from Australian national electricity market affirming its viability and efficacy. Tanrisever et al. (2015) investigated intricacies of Dutch electricity market.

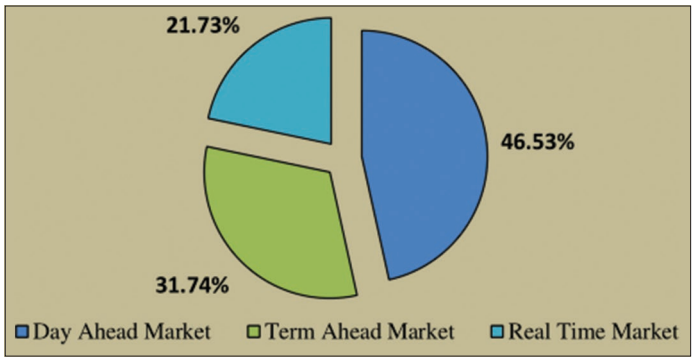
Marcjasz et al., (2023) study unveiled probabilistic electricity price prediction utilizing distributional neural networks for German market underscoring importance of incorporating higher-order statistical moments in volatile electricity price modeling. Nowotarski and Weron (2018) study analyzed probabilistic electricity price forecasting (EPF) underscoring importance in energy systems' strategizing and implementation owing to mounting ambiguity surrounding supply, demand, pricing delving into wider dimensions beyond conventional singular projections. Weron (2014) undertook thorough analysis of multifaceted methodologies devised for electricity price forecasting (EPF) scrutinizing their effectiveness, constraints and prospective ramifications whilst endorsing necessity of uniform comparative investigations employing homogeneous datasets, resilient error assessment protocols and statistical analyses to gauge consequential distinctions in model performance furnishing profound insights and recommendations to steer future course of EPF. Krizanic and Oplotnik (2017) analyzed electric power market across five EU countries post-financial crisis revealing increase in electricity consumption prompt corresponding hikes in industrial and household power prices influenced significantly by German market where tax hikes lead to reductions in electricity prices compounded by substantial subsidies for renewable energy resulting in supply increases and sporadic insights into production

Table 4: Volume of short-term transactions of electricity and deviation settlement mechanisms (all India) in February 2024

Transaction	Volume (MU)
Short-term transactions	
Bilateral*	7516.89
Through power exchanges	7348.86
(i) IEX	
(a) DAM	4741.75
(b) RTM	2339.92
(c) GDAM	262.84
(d) HP-DAM	0.00
(ii) PXIL	
(a) DAM	3.72
(b) RTM	0.00
(c) GDAM	0.00
(d) HP-DAM	0.00
(iii) HPX	
(a) DAM	0.64
(b) RTM	0.00
(c) GDAM	0.00
(d) HP-DAM	0.00
Through DSM	2135.74
Total Short-term transactions and DSM	17,001.49
Total generation	118,322.61

Source: Central electricity regulatory commission (CERC). IEX: Indian energy exchange, PXIL: Power exchange india limited, HPX: Hindustan power exchange, DAM: Day-ahead market, RTM: Real-Time Market, DSM: Deviation settlement mechanisms

Figure 7: Volume of Electricity transacted in different markets segments on Power Exchanges in February 2024



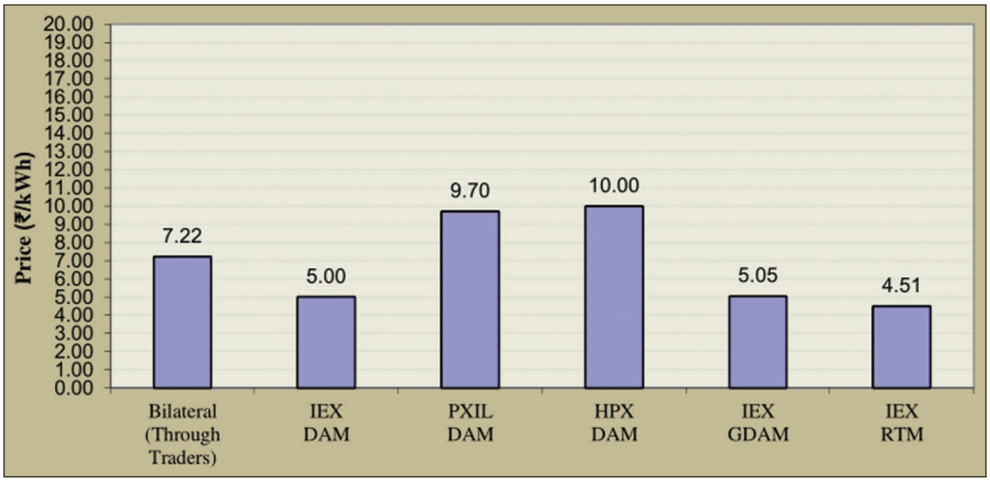
Source: Central Electricity Regulatory Commission (CERC)

costs coinciding with notable decline in power prices on German energy exchange.

Among myriad inquiries into various electricity markets predominant attention has been devoted to scrutinizing day-ahead spot electricity market and forecasting short-term electricity prices with scant literature delving into realm of real-time markets. The advent of real-time market in India assumes paramount importance due to nation's consequential energy deficit status. Table 4 presents volume of short-term transactions of electricity and DSM (all India) in February 2024. Quantum of transient electricity transactions and DSM underscored pivotal roles assumed by both Day-Ahead Market (DAM) and Real-Time Market (RTM). Substantial segment totaling 7,481.67 MU was orchestrated through bilateral arrangements accentuating intrinsic value of direct accords between procurers and suppliers. Transactions brokered via Power Exchanges amounted to 7,348.86 MU with Indian Energy Exchange (IEX) emerging as principal conduit. Within purview of IEX DAM commanded formidable share of 4,745.11 MU signifying pre-emptive settlement of transactions. RTM segment within IEX contributed 2,339.92 MU emblematic of its burgeoning efficacy in ameliorating real-time discrepancies between supply and demand. Whilst DAM transactions maintain preponderance inclusion of RTM transactions underscores market's acumen in swiftly addressing unforeseen demand vicissitudes and imperative for more dynamic pricing mechanisms. These short-term transactions and DSM aggregating to 17,001.49 MU vis-à-vis total generation of 118,322.61 MU accentuating their indispensable role in fostering resilient and efficacious electricity market landscape (CERC, 2024).

Figure 7 delineates dispersion of electricity transactions across assorted market segments within Power Exchanges framework for February 2024. 31.74% of aggregate electricity volume was transacted via term-ahead market emblematic of contractual agreements geared towards future electricity delivery. Day-ahead market seized substantial proportion amounting to 46.53% of transactions wherein electricity exchanges hands for imminent delivery slated for following day. Real-time market (RTM) staked its claim at 21.73% of overall transactions indicative of its

Figure 8: Weighted average price of short-term transactions of electricity in India (February 2024)



Source: Central Electricity Regulatory Commission (CERC)

burgeoning significance within Indian electricity market landscape stark contrast to its negligible presence in 2020. This data furnishes insights into proclivities and intricacies underpinning electricity trading dynamics across these discrete market segments (CERC, 2024).

Figure 8 presents Weighted Average Price of Short-term Transactions of Electricity in India for February 2024. The comparison between weighted average prices of electricity transactions in Day-Ahead Market (DAM) and Real-Time Market (RTM) at IEX illuminates divergent pricing dynamics inherent in these distinct market segments. In Day-Ahead Market prices ranged from ₹2.09/kWh to ₹10.00/kWh reflecting wide spectrum possibly influenced by fluctuating market conditions or strategic maneuvers by participants resulting weighted average price of ₹5.00/kWh serving as central measure providing insight into the collective transactional value over specified period. Real-Time Market exhibited narrower price range spanning from ₹0.99/kWh to ₹10.00/kWh with weighted average price of ₹4.51/kWh suggesting discernible pricing trend indicative of rapid, dynamic nature inherent in real-time electricity trading. This underscores nuanced distinctions in pricing behaviors between Day-Ahead and Real-Time Markets underscoring impact of temporal dynamics, market mechanisms and participant strategies within IEX and thereby indicating that real time spot electricity market in India definitely changed dynamics of day-ahead spot electricity market (CERC, 2024).

4. CONCLUSION

The inception of Real-Time Market (RTM) in June 2020 marked significant milestone in electricity trading landscape introducing dynamic auction system every 30 min for power distribution. Operating under strict adherence to operational protocols and statutory directives RTM ensures efficient market operation as outlined by Power System Operation Corporation Ltd and regulatory bodies such as CERC. The comprehensive analysis of short-term transactions highlights critical roles played by both Day-Ahead Market (DAM) and RTM in meeting fluctuating demand. With DAM accounting for a substantial share of transactions and RTM emerging as a crucial player market demonstrates its adaptability to address real-time discrepancies. Pricing dynamics between DAM and RTM emphasize rapid and dynamic nature of real-time electricity trading. Introduction of RTM has significantly impacted electricity market ushering in more resilient and efficient trading landscape as evidenced by shifting transaction volumes and pricing trends. This is crucial insight for market participants, stakeholders, open access consumers and electric utilities is India helping them strategize their plan of action in years and decades to come.

Further study can explore whether RTM prices can be forecasted using time-series econometric models (or) AI-ML models so that market participants can participate effectively. Studies in future can explore role played by Renewable Energy Certificate market and its impact on DAM and RTM prices and forecasting in India.

REFERENCES

Agrawal, A. (2022), Real time market (RTM) at Indian power exchanges: Need, short term assessment and opportunities. Energy Policy, 162, 112810.

Agrawal, A., Kothari, D.P. (2019), A conceptual lens for introducing retail competition in Indian power sector. Journal of Resources, Energy and Development, 16(2), 67-74.

Agrawal, A., Tripathi, G.C. (2019), Amendments in electricity act 2003: Where the gap lies? Energy Policy, 132, 797-802.

Ahmad, F., Alam, M.S. (2019), Assessment of power exchange based electricity market in India. Energy Strategy Reviews, 23, 163-177.

Bharath Kumar, T., Singh, A. (2021), Ancillary services in the Indian power sector - A look at recent developments and prospects. Energy Policy, 149, 112020.

Central Electricity Authority. (2024). Available from: https://cea.nic.in/?lang=en

Central Electricity Regulatory Commission. (2024), The Gazette of India. Available from: https://cercind.gov.in

Girish, G.P. (2016), Spot electricity price forecasting in Indian electricity market using autoregressive GARCH models. Energy Strategy Reviews, 11-12, 52-57.

Girish, G.P., Bhagat, R., Preeti, S.H., Singh, S. (2023), AI models for spot electricity price forecasting-a review. In: Vasant, P., Arefin, M.S., Panchenko, V., Thomas, J.J., Munapo, E., Weber, G.W., Rodriguez-Aguilar, R., editors. Intelligent Computing and Optimization. ICO 2023. Lecture Notes in Networks and Systems. Vol. 852. Cham: Springer.

Girish, G.P., Panda, A.K., Rath, B.N. (2013), Indian electricity market. Global Business and Economics Anthology, 1, 180-191.

Girish, G.P., Rath, B.N., Akram, V. (2018), Spot electricity price discovery in Indian electricity market. Renewable and Sustainable Energy Reviews, 82, 73-79.

Girish, G.P., Sashikala, P., Supra, B., Acharya, A. (2015), Renewable energy certificate trading through power exchanges in India. International Journal of Energy Economics and Policy, 5(3), 805-808.

Girish, G.P., Vijayalakshmi, S., Panda, A.K., Rath, B.N. (2014), Forecasting electricity prices in deregulated wholesale spot electricity market - a review. International Journal of Energy Economics and Policy, 4(1), 32-42.

Indian Energy Exchange. (2024). Available from: https://www.iexindia.com

Jones, K. (2021), Spot prices and forward premia on the MISO exchange. Energy Studies Review, 25(1), 1-17.

Kaur, C., Siddiki, J., Singh, P. (2024), The asymmetric impact of input prices, the Russia-Ukraine war and domestic policy changes on wholesale electricity prices in India: A quantile autoregressive distributed lag analysis. Energy Economics, 132, 107428.

Krizanic, F., Oplotnik, Z.J. (2017), Factors of electricity prices in selected EU member states after the financial crisis and during significant market distortions. International Journal of Energy Economics and Policy, 7(2), 250-254.

Marcjasz, G., Narajewski, M., Weron, R., Ziel, F. (2023), Distributional neural networks for electricity price forecasting. Energy Economics, 125, 106843.

Ministry of Power (Government of India). (2003). Available from https://powermin.gov.in

Nowotarski, J., Weron, R. (2018), Recent advances in electricity price forecasting: A review of probabilistic forecasting. Renewable and Sustainable Energy Reviews, 81(1), 1548-1568.

PowerLine. (2020), Moving to Real Time - RTM to Bring in Flexibility

in Electricity Market. PowerLine Magazine. New Delhi: India Infrastructure Publishing Company Ltd.

Roumkos, C., Biskas, P.N., Marneris, I.G. (2022), Integration of European electricity balancing markets. Energies, 15(6), 2240.

Tang, Q., Guo, H., Zheng, K., Chen, Q. (2024), Forecasting individual bids in real electricity markets through machine learning framework. Applied Energy, 363, 123053.

Tanrisever, F., Derinkuyu, K., Jongen, G. (2015), Organization and functioning of liberalized electricity markets: An overview of the Dutch market. Renewable and Sustainable Energy Reviews, 51, 1363-1374.

Weron, R. (2014), Electricity price forecasting: A review of the state-of-the-art with a look into the future. International Journal of Forecasting, 30(4), 1030-1081.