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A PROPOSED MODEL FOR OPTIMIZING PRICING AND GRID STABILITY IN A DEREGULATED POWER MARKET: INDIAN REGULATORY ABT FRAMEWORK ANALYSIS

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Abstract: - The deregulation of the electric power industry has shifted market transactions from cost-based operations to price-driven mechanisms, creating a pressing need for efficient tools to ensure grid stability and economic optimization. This study evaluates the role of Unscheduled Interchange (UI) charges and the Deviation Settlement Mechanism (DSM) in managing frequency deviations and reactive power (Q) adjustments under CERC regulations based on Availability-Based Tariff (ABT). Using real-time operational data and adaptive pricing models, the research compares static and adaptive Q management strategies. MATLAB simulations demonstrate that adaptive approaches outperform static methods, with adaptive Q reaching 5080.7 compared to 4542.9 in static models, reflecting reduced variability and improved stability. Dynamic pricing strategies, incorporating real-time impacts of 0.05, ensured the grid could respond effectively to fluctuations. Penalty multipliers of 1.5 during peak hours versus 1.0 in off-peak periods further encouraged grid discipline and economic efficiency. The findings underscore the superiority of adaptive regulatory mechanisms, showing that real-time integration of pricing and operational strategies not only minimizes economic losses but also enhances reliability in competitive power markets.
Keywords: PV, WECS, Battery, ANN, ESS, standalone hybrid system.

1. INTRODUCTION

The availability-based tariff (ABT) mechanism, which determines bulk power pricing, was first introduced for India by the Central Electricity Regulatory Commission (CERC) in 2002. ABT is a three-part tariffs framework introduced to ensure grid discipline by ensuring frequency stability. ABT consists of three parts: capacity charge, energy charge and unscheduled interchange charge [3]. Implementation of Real Time Market (RTM) from 1st June'2020 has given the required boost to the power markets in India coexistence of these markets has also influenced the operational strategy and load management decision of the utilities [8]. It provides the distribution companies (DISCOMs) and industrial open access customers an opportunity to optimize their demand and power purchase policy. The capacity charge, which is paid to the GENCOs for the availability of their generating units on a given day. This charge, referred to as energy charge, is a payment for the cost of fuel required in producing the electricity scheduled to be generated even though actual generation may differ from the scheduled output. The unscheduled interchange charge is charged when there is a deviation from the scheduled power exchange, which is the last component of ABT [6]. AIM to penalize GENCOs/DISCOMs contributing for frequency dip and rewarding them for supporting the system during contingencies [3] in this research using MATLAB Scripted Programming real time data collected and find Reward and Penalty of particular solar plant with the help of Proposed Model and optimize Pricing of power Market.

As deregulation in the electric industry is becoming a reality, some questions related to the ability of deregulated power pools to conduce the system to maximum efficiency operation require urgent answers. In a fully competitive environment, more efficient power producers and distributors will maximize their revenues, while those offering higher prices may have to improve their capabilities in order to lower the cost of power production and or deliver [1]. efficient operation. In a perfect competition market, more efficient generators and potential suppliers will optimize profitabilities and second-best would have an incentive (if any) to invest with a view to reducing the cost of power production and or delivery. Dynamic pricing is a promising answer to this problem, providing variable real-time electricity prices that fluctuate with the grid status, demand, and energy supply. Presently there are three functional power exchanges in India viz. Indian Energy Exchange Ltd. (IEX), Power Exchange India Ltd. (PXIL) & Hindustan power exchange (HPX). They provide an electronic platform for bidding and extend clearing and settlement services to the market players. Since IEX is the larger exchange with more than 80% market share, input data for our analysis has been taken from the website of IEX [17].

1.1 ABT

The primary goals of the ABT mechanism have been:

- Encouraging grid discipline [2].
- Promoting trading in energy
- Facilitating economic load Providing
- Encouraging higher generation availability

1.2 The Origin of ABT

The idea of ABT was first mentioned in 1993-94. The purpose of the investigation was to study some global regimes for the pricing of energy and management of the grid, and to propose a possible Indian solution (Ferrero and R.W, 1997) [1].

Though balancing market was envisaged as the preferred contract, the unique characteristics of Indian grid – significant high frequency variations, unscheduled overdraws and under drawal – made it necessary to adopt a novel frequency-linked pricing model. Therefore, ABT was conceived to be a custom-made solution for India's grid management issues [3].

1.3 ABT Mechanism

The availability-based-tariff structure of the bilk power has three components. These are (1) capacity charge, (2) energy charge and the (3) unscheduled interchange charge.

1.4 The Capacity Charge

A permanent charge on generation capacity designed to cover fixed costs of power plant equipment, and the engineering, procurement, and construction (EPC) cost of new capacity, promoting availability of generation capacity from its owner to the grid regardless of the dispatched status of the generator. Offsets infrastructure investment, and keeps plants turned on and ready to supply power States must pay this fee regardless of how much power they pull from a plant – it's a sunk cost. Forces fair sharing of costs and reduces bickering between parties [3].

1.5 The Energy Charge

Electricity rates on the basis of actual energy produced which can then be compiled with the fuel cost of the power plant That are indicative of the production cost of the electricity. Keeping the plants running We manage the capacity on a daily basis. x e the plants' efficiency factors the variable cost (x) depends on the type of plant's energy source (fuel) Efficient use of generation resources by selecting first the plants with lower fuel cost Ranks plants using a merit order dispatch, i.e., use the lowest cost energy source first [3].

1.6 The unscheduled interchange charge

The third one is the newest component of this three-part tariff which depends on the deviation of the generation from the scheduled one. Penalty for deviating from the scheduled generation or drawl by an entity in the power system found necessary by the electricity regulatory body and the unscheduled interchange (UI) has been made payable in the situation when a generator output is not matched with the declared capacity, the frequency of the grid deviates i.e. it rises or falls. Similarly, if the power consumers draw the power other than the scheduled consumption then also the grid frequency decreases or increases. Now whether the penalty would be imposed or not that depends on the grid condition at that moment. If the grid indiscipline in terms of frequency deviation increases then the imposed penalty amount also increases. The ABT is implemented in phased manner. The 15minute blocks i.e. 96 blocks in a day are being scheduled for generation and drawl. If the generators or the consumers fail to meet the schedule, then rescheduling is done through proper communication and coordination [3].

2. DIFFERENT METHODOLOGY

Here are the related methods and techniques discussed in the context of deregulated power systems, Availability Based Tariff (ABT), and their implementation challenges.

2.1 Unscheduled Interchange (UI) Mechanism

Purpose: Penalize deviations from scheduled generation and reward actions that stabilize the system Components: Capacity Charge: Based on availability, Energy Charge: Covers fuel costs. and UI Charge: Applies penalties/rewards for schedule deviations. Implementation: Requires precise frequency monitoring and timely penalty or reward application [3].

2.2 Advanced Metering and Communication Mechanisms

Its Purpose: Facilitate accurate data collection and communication for ABT implementation, Techniques: Use Integration of communication mechanisms to transmit data in real time [13].

2.3 Deviation settlement Mechanism (DSM)

Purpose: a commercial mechanism, that grid users do not deviate from and adhere to their schedule of drawal and injection of electricity in the interest of security and stability of the grid. The Role of DSM is becoming More Important with the Increase in Distributed Generation such as Wind/Solar [17].
In all Method Deviation Settlement Mechanism Currently use in CERC Regulation of Different Generating Station Structure of DSM the calculation of Over Injection case is below [16].

Calculation of Over Injection Case 1

Table 1: Calculation of Over Injection Case 1

Freq. (Hz)	Schedule (MWh)	Actual (MWh)	Deviati-on (MWh)	Normal Rate (Rs. /MWh)	PPA Rate (Rs. /MWh)	Wt. Avg. ACP DAM Rate (Rs./MWh)	Reward	Penalty
49.91	14.28	16.4695	2.1895	5432	2510	3601	5495.65	0

Schedule = 14.28 MWh
Actual = 16.4695 MWh
Deviation = 16.4695-14.28= 2.1895 MWh
Frequency = 49.91 Hz, Normal Rate =5432 Rs. /MWh, PPA Rate=2510 Rs. /MWh
WACP Rate=3601 Rs. /MWh
DC Penalty = Rs. 0/-
DC Reward = Rs. 5495.65/- (Deviation*PPA Rate=2.1895*2510=5495.65/- Rs

2.4 Penalty

This is a price signal for errors between scheduled and actual generation. In this instance, the Penalty is 0 Rs This indicates that no penalty was incurred for this particular deviation, which may be that the deviation does not generate any imbalance in the grid (e.g. the frequency is within desired limits).

2.5 Reward

For the case where the seller over-generates, i.e. a positive deviation, the right side of the expression for Deviation Charge Reward is the reward that the seller receives for over-generating beyond the scheduled generation level.

Reward = Deviation ×PPARate = 2.1895 MWh × 2510 p/MWh = 5495.68 Rs

So, seller gets Rs 5495.68 reward for deviating.

Calculation of Under Injection case 2 [16].

Table 2: Calculation of Under Injection Case 2

Freq. (Hz)	Schedule (MWh)	Actual (MWh)	Deviation (MWh)	Normal Rate (Rs./MWh)	PPA Rate (Rs./MWh)	Wt. Avg. ACP DAM Rate (Rs./MWh)	Reward	Penalty
50.01	15.35	8.35	-7.00	4120	2510	3101	0	28840

Schedule = 15.35 MWh
Actual = 8.35 MWh
Deviation = 8.35-15.35= -7.00 MWh
Frequency = 50.01 Hz, Normal Rate =4120 Rs. /MWh, PPA Rate=2510 Rs. /MWh,
WACP Rate=3101 Rs. /MWh
DC Penalty = Rs. 28840/- (Deviation*Normal Rate=7.00*4120=28840/-)
DC Reward = Rs. 0/-

3. DSM MECHANISM 2024 UNDER CERC

The Commission received representations from the stakeholder's seeking clarity on the treatment of deviation for infirm power and in respect of certain other provisions in the Regulations such as Available Capacity, Contract Rate in case of third-party sale under open access etc The Commission extended the implementation of Regulations 8 (8) of Principle DSM Regulations, 2024 regarding the treatment of deviation for infirm power more than twice, in view of the communications received from various RE developers on the possibility of delay in receiving certificates for successful completion of trial run and clarity on deviation charges for infirm power without schedule. Further, the Commission also floated the draft amendment not only to bring further clarity on the provisions regarding infirm power but also to provide an opportunity to the stakeholders to understand the

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technical aspects, if any, associated with the delay in trial runs in case of wind and solar based power projects [9]. In above DSM Mechanism Solar Plant Over injection and Under injection Calculation based on the data and some important note that the in over Injection We get reward and under Injection Case We get Penalty so Important of the case is plant get maximize Reward and Minimize Penalty Using Our New Proposed Model they are explained Below with the Flow Chart and Calculation Using MATLAB Script Code Programming.

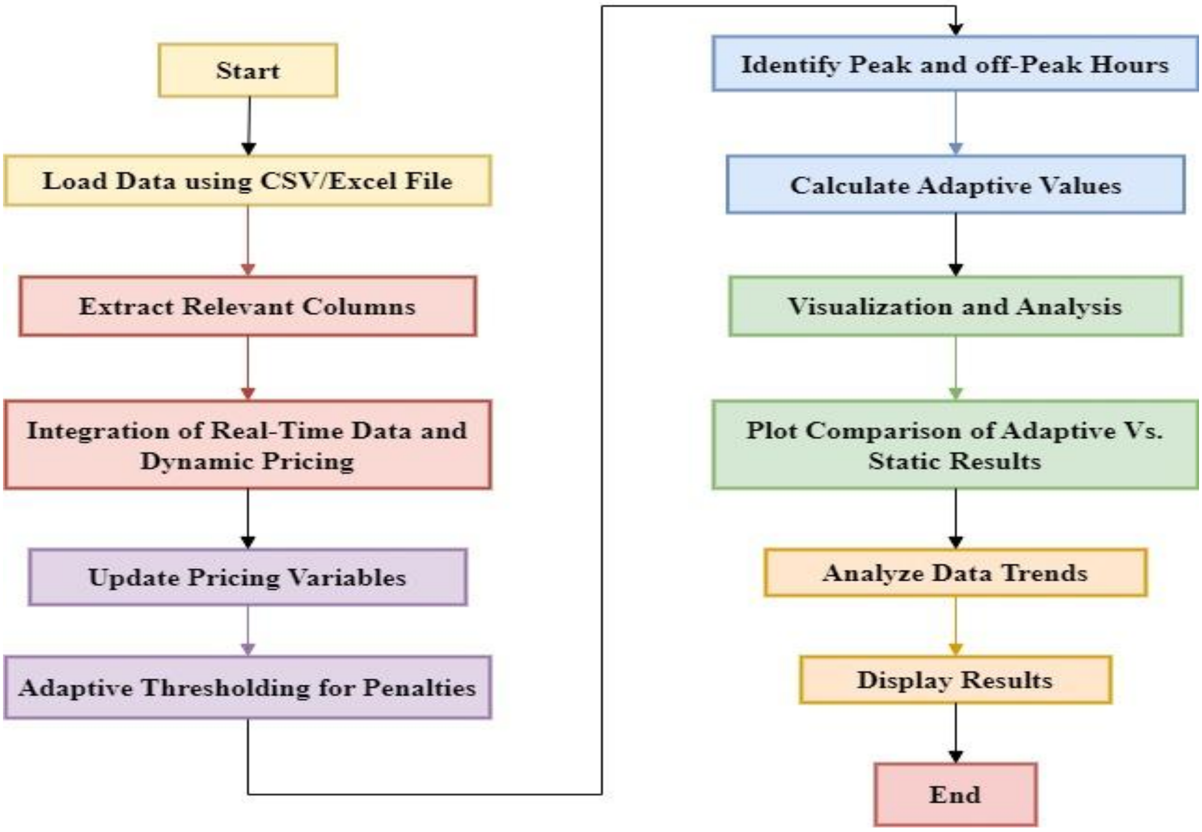

Fig. 3.1 Flow Chart of Proposed Model

The process begins with loading data from a CSV or Excel file, which contains relevant energy and demand-side management (DSM) data. Once the data is loaded, the next step is to extract the necessary columns that will be used for analysis and calculations. These extracted columns may include energy consumption, pricing, and penalty-related information. Following data extraction, the integration of real-time data and dynamic pricing takes place. This involves simulating real-time variations in pricing to reflect actual market conditions. As part of this step, the pricing variables are updated dynamically to adjust to fluctuations in demand and supply, ensuring an accurate representation of cost variations over time. the process moves to adaptive thresholding for penalties, where real-time data is analysed to identify peak and off-peak hours (Subrata Mukhopadhyay 2022).

A penalty multiplier is applied based on this identification, with higher penalties during peak hours and lower penalties during off-peak hours to encourage demand-side energy management. Once the penalty thresholds are set, the system proceeds to calculate adaptive values. These calculations take into account real-time pricing, penalty multipliers, and deviation values to compute adaptive costs and potential savings. This step ensures that financial impacts are considered while maintaining the integrity of the pricing model. The next phase involves visualization and analysis, where the computed adaptive values are graphically represented.

A comparison between adaptive and static results is plotted to highlight the effectiveness of dynamic pricing in optimizing costs. Additionally, the trends in data are analysed to identify patterns, fluctuations, and the overall impact of the adaptive model. the results are displayed, allowing for a comprehensive preview of the updated dataset. The process concludes by ensuring that the calculated data, visualization insights, and analysis outcomes are correctly presented for decision-making and further refinement of the pricing model.

This structured workflow ensures that real-time energy pricing and demand-side management strategies are efficiently implemented, promoting optimized pricing while maintaining security, adaptability, and financial feasibility.

Adaptive Q Calculation

$$Q = (H + P + W) * (A - M) + (D * (R - C)) \quad [4]$$

Where,

H = HPDAM rate p/kWh,

P = Normal Rate p/kWh,
W = Wt. Avg. Rate in p/kWh,
A = Actual in MWh,
M = Schedule in MWh,
D = Deviation in MWh,
R = DSM Reward in Rs,
C = DSM Penalty in Rs.

- Rate Aggregates (through (H + P + W)), which determine the cost of deviation.
- Deviation in Energy (through (A - M) and D), which captures how much the actual values differ from expected values.
- Settlement Reward/Penalty (through (R - C)), which captures the monetary impact of deviations.

3.1 Power Market Related to Dynamic Pricing

Dynamic Pricing means prices are charges of electricity with specific time interval in power exchange in a day or year is called Dynamic pricing (Kian, A 2001). In present in our country there are three power market are available 1) IEX Means Indian Energy Exchange was started in 2008 dealing in short term transactions in power market 2) PXIL Means Power Exchange India Limited was started in 2008 dealing in long-term transactions in power market 3) HPX Means Hindustan Power Exchange Limited dealing in renewable energy transactions that follow open access guidelines for collective transactions and act as an intermediary between Seller and Buyer, the Following Trades are contained. DAM-Day-Ahead Mark, RTM-Real time Market, G-DAM-Green Day Ahead Market, TAM-Term-Ahead Market etc. [17]

4. CASE STUDY OF DIFFERENT SOLAR PLANT

In This research work we justify for using Adaptive Q Model of three Different Solar plant and find out How Adaptive Q Model Work and find out Some Important Factor Considering In Formula to Minimize Penalty Given By LDC In Deviation Settlement Mechanism Under CERC and also Simulation of Data and Getting Result of Q Vs. Deviation [MWh], Q Vs. Deviation [MWh], Rupees[INR] Vs. Number of samples and Main Result of Comparison of UI/DSM/Q In Particular Power Plant.

4.1 Gujarat State Electricity Corporation Limited (GSECL)

In our analysis, GSECL solar plant is in the same location as TPREL and GIPCL has a capacity of 100 MW (achieved in operational November 2021). GIPCL has been imposed a penalty of Rs. 2,58,946.87/- and a reward of Rs. 7,50,021.05/- GSECL plant has lower rate of penalty compare to TPREL and GIPCL Plant [16].

GSECL Plant Detail

Table-4.1 GSECL Solar Plant Real Data of Week 13-01-2025 to 19-01-2025 of SLDC Gujarat WRPC Web Portal [16]

Location	Village Radhanesda, Ta : Vav, District: Banas kantha
Capacity	100 MW
Date of commissioning	November-2021
PPA Rate of Unit	2510 p/MWH
Penalty	Rs. 2,58,946.87/- (Week 13-01-2025 to 19-01-2025)
Reward	Rs.7,50,021.05/- (Week 13-01-2025 to 19-01-2025)
No. of 15 Minute time block of Weekly	672
Average Frequency	49.99 Hz
Static Q Average	4542.9
Adaptive Q Average	5280.7

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4.2 Simulation and Result GSECL Plant of Q Vs. Deviation [MWh]

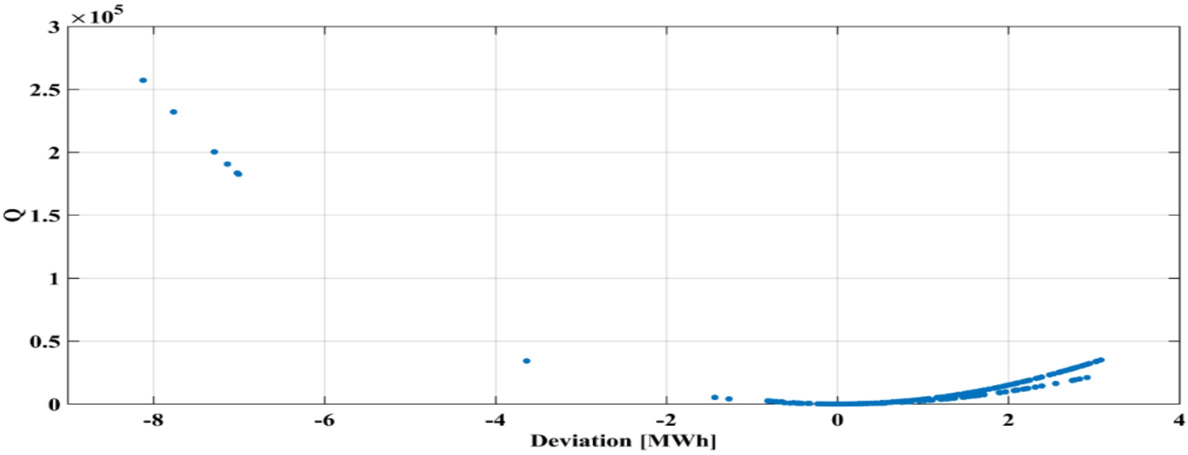

Fig. 4.1 Q Versus Deviation [MWh]

4.3 Simulation and Result of Q Vs. Weighted average ACP [Paise/kWh]

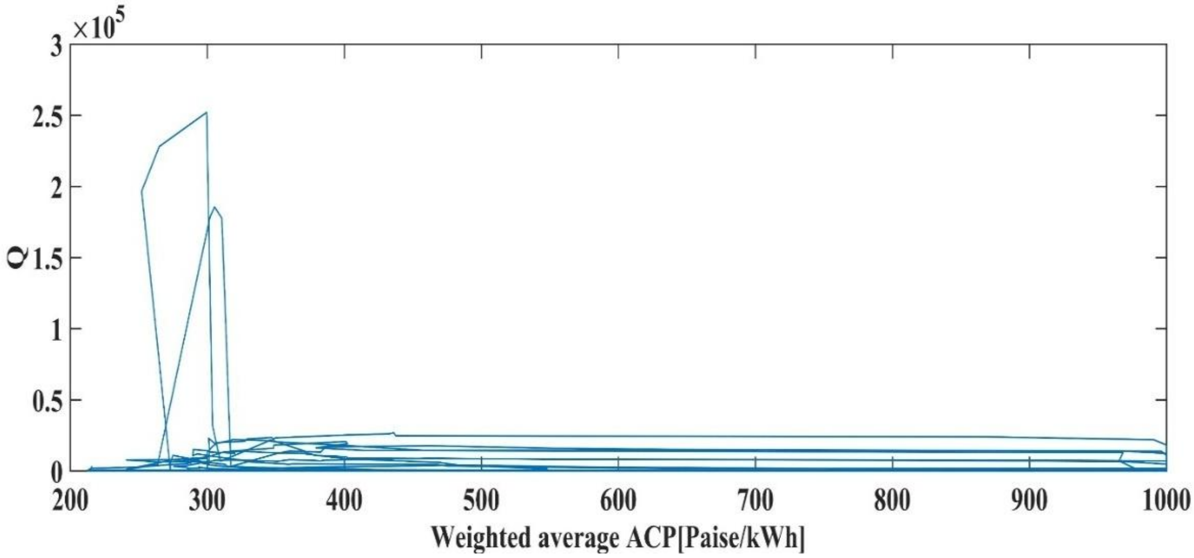

Fig. 4.2 Q Versus Deviation [MWh]

4.4 Simulation and Result GSECL Plant of Rupees [INR] Vs. Number of Samples

No. of samples = 96 (block/day) × 7 (days) = 672

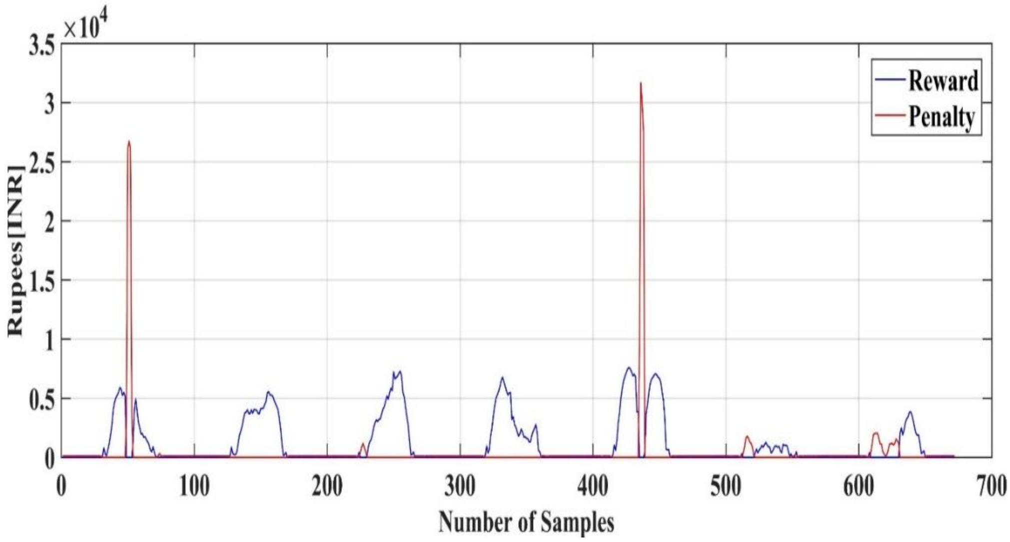

Fig. 4.3 Rupees [INR] Versus Number of Samples

4.5 Simulation and Result GIPCL Plant of Comparison of UI/DSM/Q

No. of samples = 96 (block/day) × 7 (days) = 672

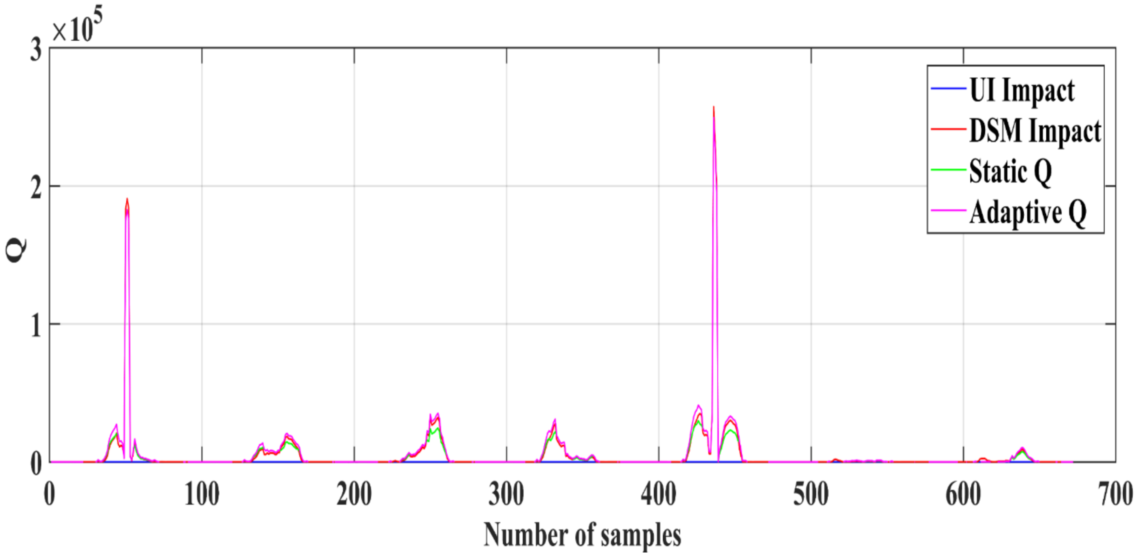

Fig. 4.4 Q Versus Number of Samples

5. RESULT ANALYSIS

By adding Adaptive Q to the DSM framework, the model facilitates grid optimal operation, as it changes real-time prices based on supply/demand. This flexibility will ensure higher revenues in peak hours, and savings in off-peak hours. The study proves that dynamic pricing, such as those who have adaptivity Q – with its dynamic adaptation rate, offer more effective energy management than the static ones. It also provides a more stable, efficient, and economically rewarding energy pricing framework and therefore beats traditional ways such as Static Q in UI devices.

In terms of the Penalty and Reward values, the GSECL Solar plant has the lowest value of Penalty as well as that a reward in Solar plant.

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CONCLUSION

With the DSM framework it is demonstrated that by incorporating adaptive Q, the FIM responds on a supply and demand basis and thus optimises grid operation. It is this flexibility that allows for higher revenues during peak demand times with cost reductions during off-Peak times. The study sheds a light that Real-time Dynamic techniques of adaptive Q yield a better observer-based energy management compared to Static approaches. It Provides a more stable, effective, and profitable way for charging electricity, so it is better than traditional way such as the static Q in UI.

Thus, the DS mechanism is clearly more efficient and secure compared to the UI mechanism, as it not only optimizes grid stability and frequency but also considers real-time adjustments to maximize earnings and minimize penalties through Adaptive Q calculations. The ability to adjust Q based on real-time data and penalties makes DSM a superior mechanism for managing grid operations under the ABT framework.

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